TRACTEBEL Engineering
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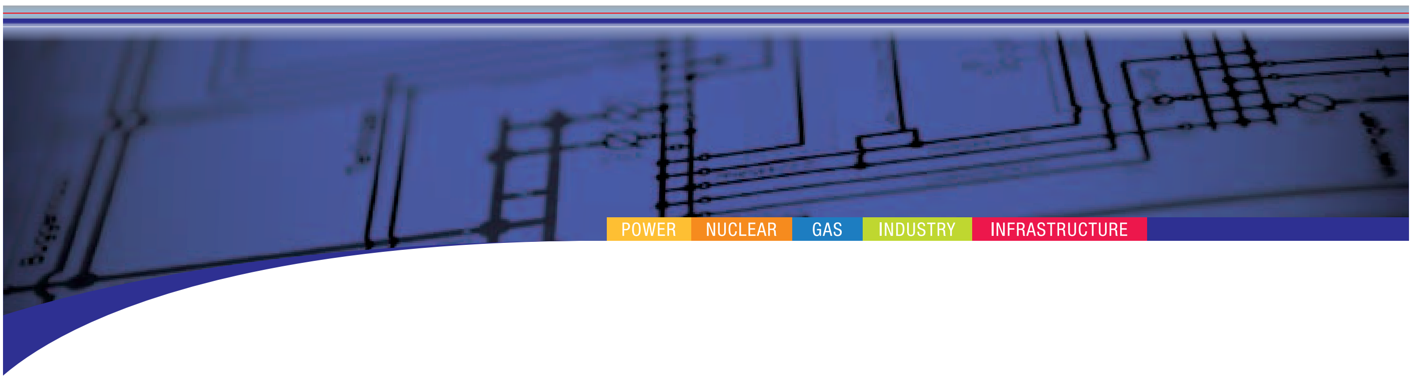
UPDATE OF THE ECOWAS REVISED MASTER PLAN FOR THE GENERATION AND TRANSMISSION OF ELECTRICAL ENERGY

Final Report Volume 2 : Optimal development plan and analysis of transmission network performance and stability

Economic Community
Of West African States

Communauté Economique
Des Etats de l'Afrique de l'Ouest

General Secretariat / Secrétariat Général



WEST AFRICAN POWER POOL (WAPP)

October 2011

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1. INTRODUCTION

The present report constitutes the Volume 2 of the Final Report of the 'Update of the ECOWAS Revised Master Plan for the generation and transmission of electrical energy'.

The Final Report includes the following volumes:

Volume 1: Study Data

Volume 2: Optimal development plan and analysis of transmission network performance and stability

Volume 3: Investment program development and priority project implementation strategy

Volume 4: Executive summary

1.1. Context

The system of the West African Power Pool (WAPP), a specialized institution of ECOWAS, constitutes the institutional framework of the regional electric system. The WAPP's strategic objective is based on a dynamic vision of the integration of the operation of the national electrical networks in a unified regional market. This unified regional market has to ensure in the medium and long term an optimal and reliable electricity supply at an accessible cost for the population of the different Member States.

The objective is to aim at the common economic good, thanks to a long-term co-operation in the energy sector and with the development of transborder exchanges of electricity.

The purpose of the present study is to update the regional plan of production and transport for submission to the General Secretary of the WAPP and the whole of the electric sectors of the Member States.

The aim of the study is, considering the context, to allow the various actors of the electricity sector to have a clear, total and coherent vision of the future development of the infrastructures of electricity production and transmission in the area and a rational base of decision making for their implementation.

This update of the master plan aims at integrating the ongoing developments in a medium and long term strategy of expansion of the regional infrastructures of production and transport, while keeping it coherent with the WAPP's vision.

1.2. Structure of Volume 2 of the Final Report

This Volume 2 of the Final Report describes the second phase of the study dedicated to the optimal development plan and to the analysis of transmission network performance and stability.

This report includes the following parts:

Chapter 2: presents the methodology, the data and the results of the economic study. The purpose of this study is to calculate a first optimal investment plan of production and transport and to draw up a first list of priority projects,

Chapter 3: presents the results of the network performance calculations and the stability analysis of the interconnected system. This part highlights the modifications to bring to the first list of priority projects for technical reasons.

The detailed data gathered during the data collection phase were presented in the first intermediate report of the study published in April 2011.

These data were discussed with the representatives of the WAPP and the representatives of the ministries and the electrical companies of the 14 Member States, during the workshop organized in Cotonou on May 5th, 6th and 7th 2011.

Please note that in this report the syntheses of the data used for the economic study and the performance and stability studies of the network are included respectively in chapters 2 and 3.

These syntheses take into account the comments and modifications which were provided by the Member States and the WAPP during the presentation of the first intermediate report, during the first presentation of the Optimal development plan which took place on July 15th and 16th 2011 in Cotonou and during the meeting held in Cotonou on August.27th 2011 for presenting the priority list of investments.

The list of regional priority interconnection projects presented in this report will be re-examined in the following phase of the study to take into account the additional impacts of the environmental, financial and institutional constraints.

2. ECONOMIC ANALYSIS

2.1. General methodology

2.1.1. Methodological principles

The objective of the economic analysis is to work out a first priority investment plan based on technico-economic simulation of the electric systems in all the West African countries. This priority investment plan will distinguish:

- national projects of production, projects of production supported by regional entities (OMVS, OMVG) and regional projects of production,
- regional projects of interconnection.

The list of priority investments is based, first, only on the economic analysis. Then, the system analysis of the power flows, will make it possible to better adapt this list to the technical constraints of network operation.

Please note that in a later phase of the study, the environmental, financial and institutional impacts will also be studied and the list of priority investments will be adapted consequently.

The economic analysis detailed hereafter includes the following stages:

- Setting up a scenario proposing the evolution until 2025 of the national parks of production as proposed in the national master plans without development of new interconnections (scenario1);
- Setting up a scenario which proposes an optimal development of the park of production at the regional level by supposing that no limit of **power transit** applies between the countries of the area. This theoretical scenario highlights the most interesting regional production projects. The comparison between this second scenario and the first one makes it possible to obtain the maximum profit that can be expected from the regional production projects. (scenario 2);
- Setting up a reference scenario of development obtained by optimizing the production and transport at regional level, while taking into account the limits of transit related to the projects of interconnection. (scenario 3).
- Carrying out sensitivity studies to certain key parameters in order to identify the long-term impact of these parameters on the list of priority projects released by scenario 3 (reference). This study meets in particular the needs expressed by the European Investment Bank (EIB) and by the WAPP. The various scenarios of the sensitivity analysis are established based on scenario 3 as reference and are to be compared with the latter.

The sensitivity studies carried out correspond to the setting up of the following scenarios:

- A development scenario corresponding to the assumption that the regional planned transport projects as well as the OMVG projects are postponed by two years (scenario 4),
- A development scenario corresponding to the realization of the scenario of low growth of the electric demand (scenario 5),

- A development scenario corresponding to the voluntary assumption of investment into renewable energy so that the quota of renewable energy in the entire installed power of the area reached the goal of 10% between now and 2020. (scenario 6),
- A development scenario corresponding to the assumption of a drop in fuel prices (75 USD/bbl for crude oil) (scenario 7),
- A development scenario corresponding to the assumption of a rise of fuel prices (125 USD/bbl for crude oil) (scenario 8),
- A development scenario corresponding to an actualization rate of 8% (scenario 9),
- A development scenario corresponding to an actualization rate of 12% (scenario 10),
- A development scenario corresponding to the assumption of a limitation of the total hydroelectric capacity that can be installed in Guinea during the study period (scenario 11).

The costs and benefits of regional interconnection projects suggested as a priority and added to the already decided and planned projects will also be examined by comparing the scenarios where these projects are and are not implemented.

The economic study thus described will allow defining the first lists of the national and regional priority investments in production. It will also make it possible to define a first list of regional priority investments in transmission and interconnection. It will highlight in particular the optimal capacities of the installations (production and interconnection capacities).

As mentioned here before, the lists of national and regional priority investments deduced from the economic analysis will be then re-examined by taking into account the results of the technical analysis of the operation and the study of stability of the inter connected networks. This technical analysis of the networks includes:

- Static and dynamic studies for the 2015 peak load and for two representative situations (interconnections of the countries and limitation of the development of the interconnections),
- Static and dynamic studies for the 2015 off-peak load and for two representative situations (interconnections of the countries and limitation of the development of the interconnections),
- Static studies for the peak load in 2020 and 2025.

The technical analysis of the networks will permit to release the possible modifications to bring to the priority investments list to ensure the feasibility of the operation of the electrical networks.

2.1.2. Techniques of simulation and optimization

These optimizations are based on the tool PRELE, developed by the Consultant and especially envisaged for this purpose. The model PRELE is designed to represent in the same modeling the production parks and the grid systems of all the countries with their interconnections. It optimizes the operation and if necessary the investment decisions of the system on the whole study period by minimizing the actualized total costs of the system and by respecting the imposed planning criteria. Moreover it takes into account real constraints such as the construction delays of the various power plants, hydrology (dry and wet years), the availabilities in terms of fuel per country (Gas, HFO, Diesel, LCO…), etc

The outputs of this modeling thus indicate the optimum between the use of the existing power plants (utilization periods, costs of maintenance and fuel) and the development of new hydraulic, thermal and renewable plants (types of power plants and capacities by country, years of commissioning). They propose moreover optimum flows of capacity between the countries.

The development plan optimized using the tool PRELE takes into account the types of units necessary to cover the demand while respecting various constraints such as the variability of the load diagram (peak and off-peak load), the variability of primary energies (dry year, wet year, dry season, wet season, availability of gas,…), but also the constraints related to the units operation (technical minimum, must runs, etc). In particular, it takes account of the minimum of thermal plants to install to face the driest years. It also takes into account the necessary construction delays, which supports the thermal units during the first years.

2.1.3. Taking into account the impact of the hydrological conditions

It is not useful to develop in the sensitivity study one or more additional scenarios corresponding to hydrological conditions of dry year. Indeed, the risk due to the uncertainty of the hydrological conditions of the hydroelectric projects is already taken into account directly while modeling in PRELE. In this modeling one indeed introduced various states of the system related to situations of dry years, of years of normal rainfall, dry season, wet season and combinations of these parameters. Each state is characterized by its probability of occurrence. Productible energies by each hydroelectric project in these various states take account of the statistics of hydrology gathered during the data collection. The optimization of the electric system takes directly into account the impact of the various hydrological conditions with their probability of occurrence.

2.1.4. Current operational difficulties in the electrical networks of the WAPP

The data collection phase in the various Member States clarified many current operational difficulties in the electrical networks of the Member States.

These difficulties are due to various causes such as the lack of available fuel related to financing problems (Senegal) and the run-down state and the lack of maintenance of the existing equipment (in the majority of the countries). As a consequence, a significant part of the installed capacity in production units in the area is currently unavailable. This raises the question of the `unserved demand. Technical measures must be implemented to gradually reduce this unserved demand, such as the implementation of appropriate maintenance policies, the accelerated rehabilitation of some existing production units, etc. It is supposed in the source data that `the unserved demand' will be gradually eliminated after a 6 years period. Even if this assumption can appear optimistic in the current context of the electric sector in the area, it was however kept because the long-term tendencies that one seeks in this study must remain coherent with the natural growth of the load and the length of the study does not exceed 15 years. Moreover, the sensitivity study on the load growth must make permit to evaluate the impact of lower load levels in the future.

Another difficulty which arises in certain countries results from 'non technical' losses (frauds) and the non-payment of the bills. To solve this last problem, certain countries systematically introduced prepaid tariffs.

With regard to the exploitation of the current interconnections, it is necessary to announce the following problems:

- Currently, in the group of interconnected countries composed of Ivory Coast, Burkina Faso, Ghana, Togo and Benin the short-term power reserve in operation is definitely insufficient and even nearly non-existent because of the under equipment of the various countries. Only Ghana can align a certain operational reserve thanks to the units of Akosombo. As a consequence, in the event of an incident in a country, the interconnections cannot fully ensure their role of help due to the lack of operational reserve in the neighboring countries. It is thus urgent to implement in the very short term in these countries adequate units and/or to release the required funds to develop a reserve at least equal to the largest production unit of these countries (in particular in Ivory Coast and in Burkina Faso).
- There is currently already a risk of slow oscillations between the parks of the countries mentioned above in case of loss of a large unit. Suitable measures must be implemented (installation and/or adjustment of PSS).
- Currently, the interconnection between Benin and Nigeria remains open because of adjustment problems of power-frequency in Nigeria. Nigeria announced measures which should make it possible to stabilize the network of the country in the near future. Meanwhile, Benin has to modify daily its exploitation scheme and the localization of the opening points of the Ghana-Togo-Benin block with the part of the Beninese network that remains connected to the Nigerian network. This is carried out in order to permanently keep an importation of 150 MW from Nigeria towards Benin (importation contract). In the near future, Nigeria must thus succeed in taking the appropriate measures and making the required investments to close this Benin-Nigeria interconnection.

2.2. Data

This chapter describes the data used within the framework of the economic study. These data relate to the fuel (cost and availability), the load forecast and the production and transmission projects.

2.2.1. General data

The actualization rate proposed is 10%.

The foreign exchange rates considered in the study are:

- 1€ =1.35 US$
- 1€=650FCFA

2.2.2. Fuels

Currently in West Africa, a broad variety of fuels are used such as, diesel oil (DDO), light crude oil (LCO), heavy fuel oil (HFO), natural gas (NG) and to a lesser extent coal. Among the planned units, apart from the hydroelectrical units, the majority of them will use NG for the countries of zone A and HFO or DDO for the countries of zone B. Several studies also propose the use of coal.

The natural gas used by the countries of zone A comes either from local gas resources or from imported through the West African Gas Pipeline (WAGP). The liquid fuels come mainly from Nigeria.

For the sake of a diversification of energy mix, of reducing the dependence to liquid fuel and reducing the fuel cost, other fuels will be considered for the electrical production within the framework of the master plan, in particular coal.

2.2.2.1. PRICE OF FUEL

The crude oil prices (thus also the price of its derivatives) and of natural gas are closely dependant. Coal as a primary energy source for the electrical production, is also related to the crude oil price. Nevertheless, the correlation between the prices of coal and crude oil is less important than the one linking the derivatives of oil, natural gas and crude oil.

In this study, it was agreed that the international fuel prices will be used. In this way, opportunity costs of locally available fuel will be taken into account and it prevents the local market of electricity of being skewed by "subsidized" fuels. In case of power exchange between countries, it is then avoided that a country subsidizes another country by selling electricity for a lower price than the real one (or market price).

In this study, a great attention is paid to the relative difference between fuels prices and not on their absolute level. For this reason, the crude oil price is considered constant during all the study.

However, several scenarios are studied according to the standard price of crude oil. Indeed, the crude oil price was extremely volatile during the last years with a strong increase until August 2008, then a strong reduction until the end of 2008, followed by a low rate of recovery. Recently, the events in the Arab world and in Japan caused a big and rapid raise of the oil prices. As it is impossible to draw a long-term tendency on which all the experts agree, various crude oil prices are studied:

- Low scenario: 75 USD/bbl;
- Base scenario (corresponding to the current location): 100 USD/bbl;
- High scenario: 125 USD/bbl.

The fuel prices in West Africa are presented for two specific conditions, delivered to the coast or to the continent. The "coastal" price corresponds to the fuel delivery for all the coastal countries from Senegal to Nigeria while the "continental" price corresponds to the delivery for Mali, Burkina Faso and Niger. For each delivery, average fuel costs exempted from taxes and subsidies are presented.

The fuel prices at the borders of an exporting country are estimated based on a correlation study. It is thus necessary to add the prices of maritime transport to have the coastal price and the prices of surface transport for the continental price.

The transport costs are estimated based on the experience of the Consultant and the publications of the IEA in the following way:

- The maritime liquid fuel transport costs per tanker of 30 000 tons are estimated to 5.9 USD/kton/mile;
- The maritime transport costs of coal between South Africa or Colombia and West Africa are estimated to 20 USD/ton for a ship of 40 000 tons;
- The terrestrial transport costs of liquid fuel by tanker are estimated to 0.11USD/ton/km;
- Regarding the cost of transport of natural gas, three different prices are to be considered according to the source:
  - WAGP (WAGP): 2 USD/MMBTU;
  - Native gas: about 0.1 USD/MMBTU;
  - LNG: Liquefaction: 0.9 - 1.3 USD/MMBTU; transport: 0.4 - 1.1 USD/MMBTU; Gasification & Storage: 0.3 - 0.5 USD/MMBTU.

Taking into account these costs of transport and the relations rising from the correlation study, it is possible to consider averages for coastal and continental prices for various fuels (taxes and subsidies exempted):

COST OF LIQUID FUELS "DELIVERED TO THE COAST"						
OPEC	HFO - 3.5%		DDO		LCO	
[USD/bbl]	[USD/bbl]	[USD/GJ]	[USD/bbl]	[USD/GJ]	[USD/bbl]	[USD/GJ]
75	58.8	9.7	92.6	16.2	75.9	13.3
100	78.2	12.9	125.1	21.9	101.2	17.8
125	97.6	16.0	157.7	27.6	126.5	22.3

Table 1 - Price of liquid fuels – coastal

COST OF LIQUID FUELS "DELIVERED TO THE CONTINENT"						
OPEC	HFO - 3.5%		DDO		LCO	
[USD/bbl]	[USD/bbl]	[USD/GJ]	[USD/bbl]	[USD/GJ]	[USD/bbl]	[USD/GJ]
75	79.7	13.1	111.1	19.5	92.3	15.1
100	99.1	16.3	143.6	25.2	115.8	18.9
125	118.5	19.5	176.2	30.9	139.3	22.8

Table 2 - Price of liquid fuels – continental

COST OF NATURAL GAS "DELIVERED TO THE COAST"						
OPEC	WAGP		Local Gas		LNG	
[USD/bbl]	[USD/MMBTU]	[USD/GJ]	[USD/MMBTU]	[USD/GJ]	[USD/MMBTU]	[USD/GJ]
75	8.6	8.2	6.7	6.4	9.4	8.9
100	10.9	10.3	8.9	8.5	11.6	11.0
125	13.1	12.4	11.2	10.6	13.8	13.1

Table 3 - Price of natural gas - coastal

COST OF COAL "DELIVERED TO THE COAST"		
OPEC [USD/bbl]	[USD/ton]	[USD/GJ]
75	86.3	3.8
100	105.4	4.6
125	124.5	5.4

Table 4 - Price of coal - coastal

2.2.2.2. AVAILABILITY OF FUELS

2.2.2.2.1. Availability of natural gas

This chapter presents the various possibilities of natural gas supply for the different countries of the ECOWAS. Three sources are currently possible: the Nigerian gas transported by the West African Gas Pipeline (WAGP), the indigenous resources of certain countries and, in the long term, the LNG.

West African Gas Pipeline

Three countries are currently served by the West African Gas Pipeline: Benin, Togo and Ghana. This gas pipeline transporting the Nigerian gas on a distance of 678 km is used commercially since the beginning of 2011. In March 2011, the first compressor plant of Lagos was commissioned allowing a gas provisioning under pressure.

In the years to come, additional investments are going to be carried out in the compressor plants and the gas production. These investments will make it possible to increase the quantity of gas available in the gas pipeline. The figure below shows the expected steps.

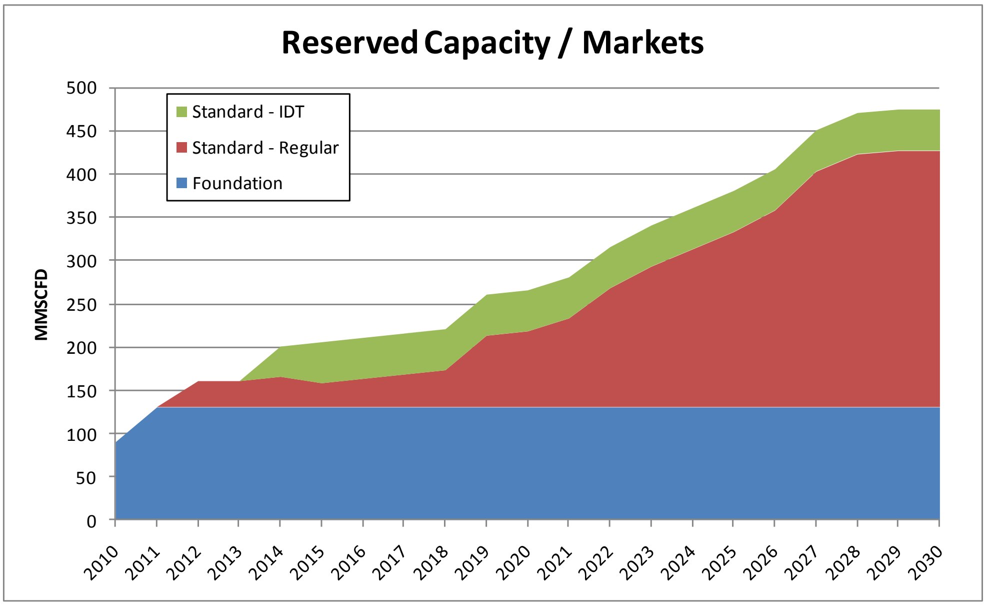


Figure 1 - Gas available - WAGP

Currently, only Ghana is supplied by Nigeria according to a contract of 120 MPC/D. As founding members, Togo and Benin can also claim a supply (5 MPC/D per country). However, technical problems in Nigeria limit the available gas and at the beginning of 2011, only 90 MPC/D towards Ghana were available.

The consultant supposes that the situation will be restored before the end of 2011 and that the investment plan announced by the WAGP will be respected, allowing to increase the available gas.

In addition to the quantities of gas reserved to the founding members, respectively 120, 5 and 5 MPC/D for Ghana, Togo and Benin, the additional quantities will be available for sale on an open market. The Consultant proposes to distribute the available quantities according to the capacity of the stations of the concerned countries: Ghana (234MPC/D + 130 MPC/D), Benin (100 MPC/D) and Togo (100 MPC/D).

This distribution is illustrated in the graph below.

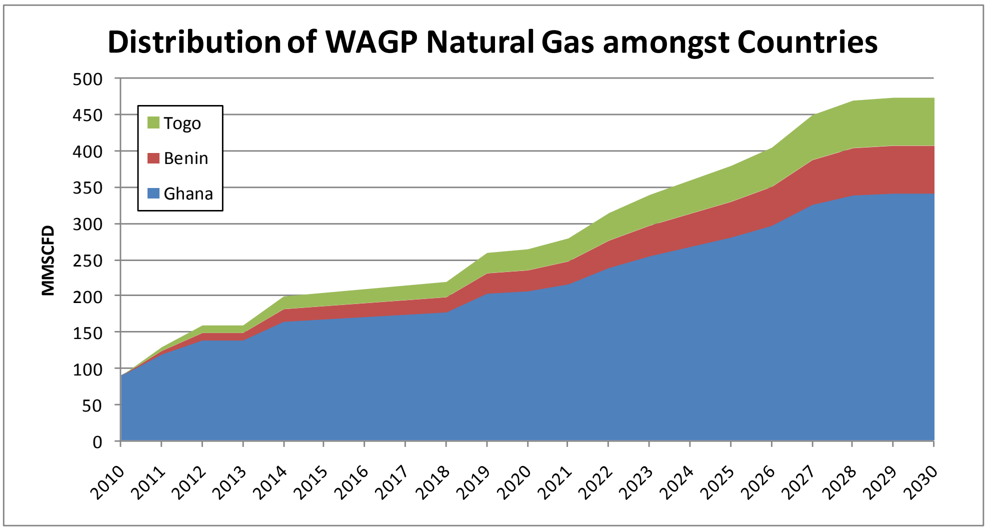


Figure 2 - Distribution of WAGP gas among the founding countries

Local gas

Another source of gas considered in the master plan corresponds to the local reserves of the producer countries. Nigeria, Ivory Coast and Ghana have offshore reserves. Senegal has small one shore reserves.

Nigeria is by far the country which has the greatest gas reserves in West Africa. The figure below shows the forecasts of gas production and the gas distribution by use.

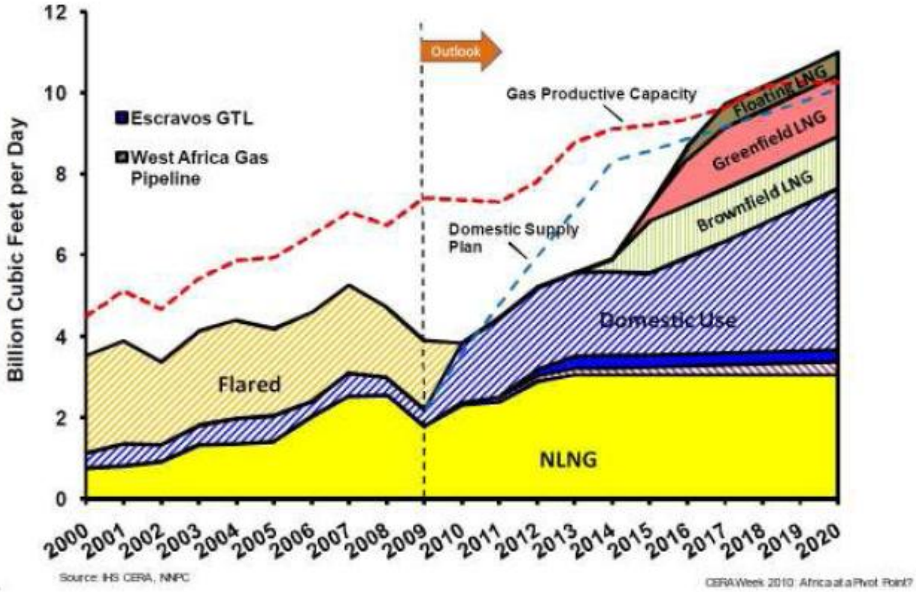


Figure 3 - Forecast of production and consumption of the Nigerian gas by use

Ghana recently put in production its first offshore oil field (Jubilee Field) which produces associated gas. This associated gas will be available at the coast in the surroundings of Domini at the end of 2011. Following the discovery of important oil and gas layers during the last years, the oil company of Ghana, GNPC, envisages a big raise of gas production in the years to come going from 80 MPC/D in 2011 to 300 to 500 MPC/D in 2026.

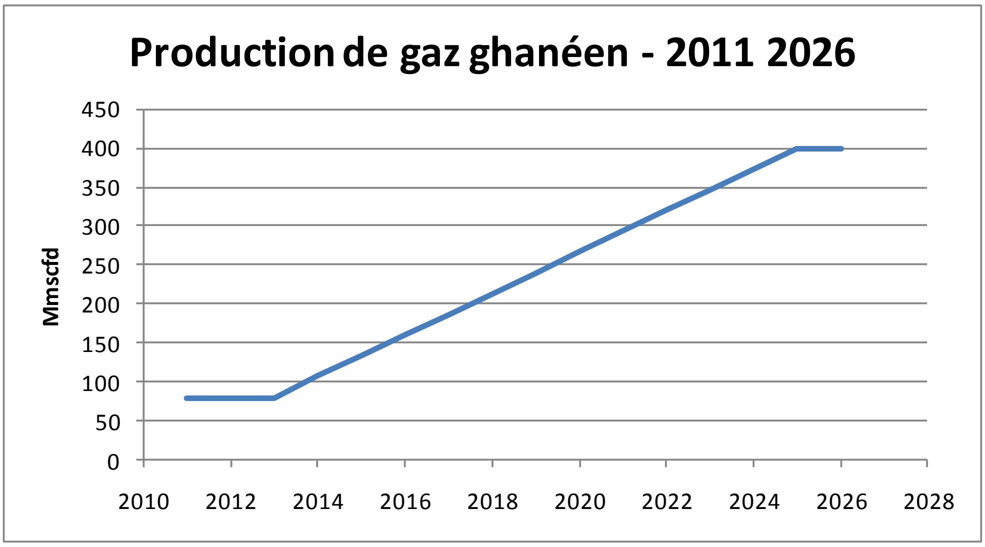


Figure 4 - Production of local gas in Ghana - 2011-2026

For 2011, gas production capacities in Ivory Coast are estimated to 205 Mpc/d. Three oil fields provide this production namely: CNR (40 Mpc/d), FOCTROT (130 Mpc/d) and AFREN (35 Mpc/d). In addition, the restitutions of the Mines and Energy seminar organized in Yamoussoukro in June 10th and 11th 2011 give a report on 750 Billion pc of residual reserve of gas and 1500 Billion pc of proven reserve in Ivory Coast.

In a conservative way, the consultant supposed that a quantity of 1000 billion pc could be consumed by Ivory Coast at the horizon of the study, among which 90% by the electric production. This estimate takes into account the need to invest in the increase of the gas production capacity, which could be a brake for the natural gas supply of Ivory Coast

The quantities of gas produced in Senegal are relatively marginal today and will remain marginal in the years to come.

LNG

Certain countries such as Ghana consider in the long term a provisioning of LNG in their energy mix.

No limitation applies to the quantities of LNG available for the African market; the main limitation is the non-existence of infrastructures for LNG regasification. There exists thus an important entry cost to allow a provisioning of LNG.

Between now and 2025, the commissioning of the LNG infrastructure is nevertheless not justified from a purely economic point of view for the supply of the power plants of the area taking into account the limited gas quantities to export on relatively short distances.

2.2.2.2.2. Availability of coal

No important coal center is currently exploited in West Africa.

During the optimization of the production plan, a series of coal centres are regarded as investment option in the countries where this technology is considered in the national plans of development, namely Senegal and Niger. These two countries have as a common point few hydroelectric and gas resources. Moreover, Niger has coal mines.

2.2.2.2.3. Solar potential

West Africa has particularly favourable areas for the development of solar technologies. The chart hereafter shows the potential of the countries. If it were decided to invest in renewable technologies in West Africa, Burkina Faso, Mali and Niger would be good candidates for CSP solar energy.

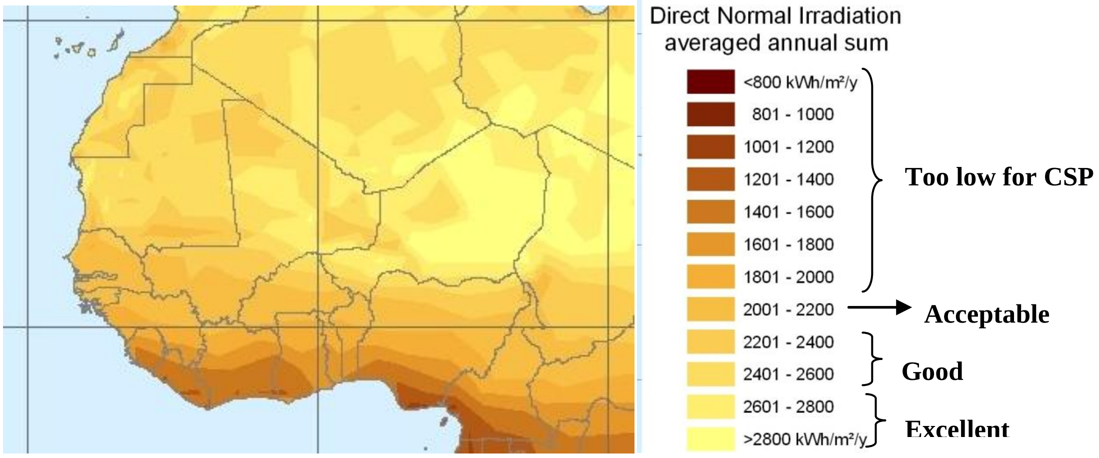


Figure 5 - DNI and the latitude of the area of interest (www.dlr.de)

2.2.2.2.4. Wind potential

The Consultant used the wind cartography software INTERFACES VORTEX recognized internationally by the wind sector. This software makes it possible to model the winds in various parts of the world with the objective of leading orientation studies.

The model was used for each one of the 14 countries of the WAPP in order to identify in each country the areas having a wind potential. The table below represents the mean potential production for the best sites of each country.

Wind resources of best identified sites (see maps in appendix)			
Country	**Average wind speed (m/s)**	**Generation (MWh/an/MW)**	**Comment**
Senegal	6	2588	
Gambie	6	2588	
Guinea-Bissau	5	1717	This generation level is usually considered to low for investment
Guinea	8	4051	
Sierra Leone	too low	x	No feasable wind project
Liberia	too low	x	No feasable wind project
Mali	7.2	3531	
Ivory Coast	4.8	1565	This generation level is usually considered to low for investment
Ghana	6	2588	
Burkina Faso	6.5	2999	
Togo	5.8	2451	
Benin	6.5	3006	
Nigeria	7.8	3933	
Niger	8	4051	

Table 5 - Wind potential by country (best identified sites)

2.2.3. Load forecast

The first part of the load forecast study consists in estimating, in collaboration with the local companies of electricity, the served and not served demand. This estimate is done based on historical data of loads, on shedding statistics and on average time of load supply.

The second part consists in analyzing the demand forecasts, in the short and medium term, worked out by the companies of electricity of each country and/or of the scenarios established by independent consultants during former studies.

The third part of the demand forecast consists, based on macro-economic parameters (GDP, Population) and existing programs of resorption of the not served demand, in establishing three scenarios framing the probable evolution of the demand for each country. This phase is based on a causal forecast of the electricity demand establishing correlations between the histories of electricity demand and macro-economic indicators. Two complementary approaches are considered: comprehensive approach and semi-comprehensive approach. The comprehensive approach analyzes the correlations between the national demand for a country and global macro-economic parameters (GDP, population, rate of electrification…) while the semi-total approach breaks up the demand into branches of industry and/or geographical areas.

In addition, the load estimated in the various scenarios and for the various countries is the load of the complete system including the internal consumptions and the losses.

A base scenario of the load forecast was established. It is used as reference scenario. In addition, a lower growth scenario is also presented and will be exploited in an alternative of the reference scenario.

Senegal

Between 2000 and 2010 the annual growth rate of the population in Senegal was estimated to 2.4% by the International Monetary Fund. The population of Senegal is estimated today at 13.4 million persons.

The GDP of Senegal (at constant price) grew on average of 4% per year over the last 10 years according to the International Monetary Fund. In the future, the annual GDP growth should reach 4.5% to 5%.

These two parameters must be weighed against in order to take into account the various types of consumers (domestic, industrial, tertiary, tourism…)

In addition, it is important to announce and take into account the efforts made by Senegal in terms of load management. Senegal took important actions in this field and in particular the systematic replacement of the incandescent lamps by low energy lamps. 550 000 lamps were replaced in 2010 (profit of 9MW estimated and confirmed by measurements). The plan in the long term considers (at the end of 2012) the replacement of 3.5 billion lamps which should lead to a load reduction of 70 MW.

Finally, the load forecast is carried out by considering two aspects:

- the load increase in the existing interconnected network (correlation study);
- the connection of isolated centers and rural electrification (cfr study SNC Lavalin).

	Base scenario [GWh]	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	2654	2561	456	440
2012	2991	2845	510	485
2013	3147	2966	532	502
2014	3319	3098	557	520
2015	3744	3428	629	575
2016	4311	3879	724	651
2017	4536	4050	761	680
2018	4774	4229	801	710
2019	5026	4417	844	741
2020	5306	4623	891	776
2021	5624	4853	944	815
2022	5933	5074	996	852
2023	6261	5306	1051	891
2024	6611	5549	1110	932
2025	6983	5806	1172	975

Table 6 - Forecast of the consumption of the interconnected network in Senegal in agreement with the SNC Lavalin study of 2010

The Gambia

The population growth in The Gambia is evaluated by the International Monetary Fund to 2.6% per year. The population of The Gambia is estimated to 1.7 millions in 2011.

Between 2000 and 2005, the GDP growth of The Gambia was fluctuating a lot from one year to the other (between -3% and +7% of annual growth according to the International Monetary Fund). Since 2006, the GDP growth was stabilized around 5.4%, a growth which is considered constant for the future by this Fund.

In The Gambia, the load growth is limited by the availability of supply. For this reason, it is difficult to establish a correlation between the growth of socio-economic parameters and the demand growth.

The revision of the forecast contains a plan of resorption of the not served demand during 5 years. In addition, the electrification of the isolated centers is taken into account.

	Base scenario [GWh]	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	239	219	50	46
2012	337	268	61	49
2013	414	317	70	54
2014	496	385	79	62
2015	586	414	94	66
2016	747	455	119	73
2017	771	496	123	79
2018	796	609	127	97
2019	821	658	131	105
2020	847	703	135	112
2021	879	722	141	115
2022	912	742	146	119
2023	945	763	151	122
2024	980	784	157	125
2025	1.017	806	163	129

Table 7 - Load forecast in The Gambia

Guinea Bissau

The population growth in Guinea Bissau is evaluated by the International Monetary Fund to 2.4% per year during the last 10 years and is forecasted to be of 2.9% per year for the coming years. The population of Guinea Bissau is estimated to 1.7 millions in 2011.

Since 2001, the annual GDP growth in Guinea Bissau is around 3% except for the year 2003 when a negative growth was observed according to the IMF. This growth should continue in the future.

Nevertheless, the load growth is limited by the degradation of quality of service. For this reason, it is difficult to establish a correlation between the growth of socio-economic parameters and the load growth.

Within the framework of the update of the master plan of the West African area, it is important to consider not only the customers currently connected to the network but also the potential customers. Consequently, the load forecast in Bissau, the connection of new customers and the connection of isolated centers are taken into account in the load forecast. Lastly, the mining demand is considered.

	Base scenario [GWh]	*Low scenario [GWh]*	*Mines [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*	*Mines [MW]*
2011	141	141		29	29	
2012	149	147		32	31	
2013	157	153		34	32	
2014	167	160		36	33	
2015	176	167		38	35	
2016	187	174	351	40	36	50
2017	233	182	351	50	38	50
2018	281	221	351	60	46	50
2019	332	263	351	71	54	50
2020	385	306	701	83	64	100
2021	441	352	701	95	73	100
2022	465	399	701	100	83	100
2023	491	418	701	106	87	100
2024	517	438	701	111	91	100
2025	545	458	701	117	95	100

Table 8 - Load forecast in Guinea Bissau

Guinea

Between 2000 and 2010, the annual growth rate of the population in Guinea did not stop increasing. This rate was estimated by the International Monetary Fund to 1.9% per year in the beginning of the year 2000 and to 2.5% in 2010. Today, the population of Guinea is estimated to 10.6 millions.

The GDP of Guinea (at constant price) grew on average of 2.95% per year over the last 10 years according to the International Monetary Fund.

Nevertheless, the load growth is limited by the degradation of quality of service. For this reason, it is difficult to establish a correlation between the growth of socio-economic parameters and the load growth.

The load forecast in Guinea is thus established by taking into account various aspects:

- Resorption of the unserved demand over a 6 years period;
- The connection of isolated centers:
  - The center of Nzerekoré should be connected to the interconnected network thanks to the CLSG line and the Guinea-Mali line;
  - The center of Kankan will be connected to the interconnected network with the commissioning of the Guinea-Mali interconnection;
  - The center of Faranah is located near the routing of the Linsan-Fomi line.
- The mining sector.

	Base scenario [GWh]	Low scenario [GWh]	Mines [GWh]	Base scenario [GWh]	Low scenario [GWh]	Mines
2011	608	608		139	139	
2012	760	687		164	148	
2013	934	760		190	155	
2014	1102	934		221	181	
2015	1563	1131		287	216	
2016	1718	1406	2643	302	247	377
2017	1766	1622	2682	311	286	383
2018	1819	1666	2723	321	293	389
2019	1875	1712	4864	330	302	694
2020	1937	1763	4936	340	309	704
2021	2032	1842	5011	357	324	715
2022	2101	1899	5086	369	334	726
2023	2170	1955	5162	381	343	737
2024	2238	2012	5239	393	353	748
2025	2308	2067	5318	405	363	759

Table 9 - Load forecast in Guinea

Sierra Leone

Between 2000 and 2005, the population growth in Sierra Leone was estimated by the International Monetary Fund to 3.7% per year. Today the population growth is rather estimated to 2.6% per year. The population of Sierra Leone is estimated to 6 millions in 2011.

The GDP of Sierra Leone (at constant price) has risen in a spectacular way these last 10 years (more than 9% per year on average according to the International Monetary Fund).

The majority of electrical installations were destroyed during the civil war in Sierra Leone. The rebuilding is underway but the majority of the areas located inside the country do not have access to electricity.

Today, the demand is primarily urban (residential and tertiary). Consumption follows the availability of the production.

Consequently, the load forecast in Sierra Leone takes 3 aspects into account:

- The load growth in the already interconnected areas;
- the rural electrification;
- the mining load (considered with a load factor of 80%).

	Base scenario [GWh]	*Low scenario [GWh]*	*Mines [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	202	162	350	38	30
2012	267	214	350	50	40
2013	363	291	631	68	54
2014	486	389	911	91	73
2015	587	470	911	110	88
2016	715	572	1612	134	107
2017	789	631	2313	148	118
2018	828	663	3013	155	124
2019	868	694	4135	162	130
2020	907	726	5256	170	136
2021	957	766	5256	179	143
2022	1007	806	5256	188	151
2023	1057	846	5256	198	158
2024	1107	886	5256	207	166
2025	1157	926	5256	217	173

Table 10 -Load forecast in Sierra Leone

Liberia

Today the annual GDP growth is very high in Liberia. It is between 5 and 12% per year according to the IMF.

The population growth in Liberia is estimated between 3 and 4% by the IMF depending on the years. Today, there are little less than 4.5 millions inhabitants in Liberia.

Nevertheless, very few customers are connected to the electrical network. In 2009, 1645 consumers were connected to 4 isolated sub-networks. The growth forecast of the load is very high for the first years. It is not a matter of natural growth of consumption but well of an increase in the number of customers connected to the network. Later on, the rural electrification and the expected increase in the macro-economic parameters are the key factors of the load growth.

Finally, two types of customers must be considered:

- The customers of Monrovia who are primarily residential and commercial and for which the load profile is equivalent to the already connected customers;
- The mining consumers who will connect themselves to the network in the future and who have an important load factor.

	Base scenario [GWh]	*Low scenario [GWh]*	*Mines [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*	*Mines [MW]*
2011	47	34		9	6	
2012	105	57	33	20	11	5
2013	163	90	131	31	17	20
2014	226	125	657	43	24	100
2015	263	180	1.183	50	34	180
2016	279	226	1.840	53	43	280
2017	296	263	1.840	56	50	280
2018	314	275	1.840	60	53	280
2019	334	288	1.840	63	54	280
2020	355	301	1.840	68	58	280
2021	378	316	1.840	72	60	280
2022	402	332	1.840	77	64	280
2023	428	349	1.840	82	67	280
2024	455	367	1.840	87	70	280
2025	484	387	1.840	93	74	280

Table 11 - Forecast of the demand in Liberia

Mali

Between 2000 and 2010, the population growth in Mali was estimated by the International Monetary Fund to 2.3% per year, while the administrative census with vocation of civil registery (RAVEC) of Mali estimates the growth to 3.6% per year. Today, the population of Mali is estimated to 14.5 millions.

The GDP of Mali (at constant price) grew on average of 5% per year during the last 10 years according to the International Monetary Fund.

The population growth is the main motor of the residential and tertiary growth of electricity consumption and the load forecast is consequently correlated to the evolution of the population.

In addition, the current growth of consumption on the electrified network contains rural electrification. For the future, the growth rate of rural electrification is supposed to be identical to the one of today.

Finally, the isolated centers must be considered because part of these centers will be connected to the interconnected network in a near future. Moreover, self-producers Malian Company for the Development of Textile Fibers (CMDT) and the gold mines are interested by a connection of their load to the interconnected network.

	Base scenario [GWh]	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	1.136	1.098	199	192
2012	1.232	1.174	216	206
2013	1.382	1.233	240	216
2014	2.111	1.294	346	227
2015	2.226	1.434	366	249
2016	2.896	2.144	464	352
2017	2.997	2.239	482	368
2018	3.153	2.930	509	470
2019	3.248	2.999	525	482
2020	3.398	3.085	550	497
2021	3.567	3.155	577	509
2022	3.740	3.279	605	529
2023	3.916	3.405	634	549
2024	4.097	3.534	663	570
2025	4.282	3.665	693	591

Table 12 -Load forecast in Mali

Ivory Coast

Between 2000 and 2010, the growth rate of the population in Ivory Coast was estimated to nearly 3% per year by the International Monetary Fund. Today the population of Ivory Coast is estimated to 22.7 millions.

The GDP of Ivory Coast (at constant price) has suffered a period of stagnation and even of decrease in the beginning of the year 2000. Today, it is believed to be of approximately 3% per year according to the International Monetary Fund.

According to the bulletin of annual statistics of the ICE, nearly 55% of the produced energy is consumed by the residential sector. The rest is consumed by the private and public services (15%) and industries (30%). Consequently, in Ivory Coast, the increase in population and the increase in the GDP must be weighed against in order to take into account the various types of consumers.

Lastly, the electric sector undertook several projects for the electrification and connection to the interconnected network of the isolated centers. The increase in the level of service by means of the progressive connection of isolated centers with the interconnected network should result in stabilization, or at least to a fall of the production in the isolated centers.

	Base scenario [GWh]	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	6.005	5.859	968	945
2012	6.390	6.131	1.030	989
2013	6.799	6.410	1.096	1.034
2014	7.245	6.696	1.168	1.080
2015	7.731	6.990	1.247	1.127
2016	8.197	7.291	1.322	1.176
2017	8.680	7.600	1.400	1.225
2018	9.182	7.917	1.480	1.276
2019	9.703	8.241	1.564	1.329
2020	10.244	8.574	1.652	1.382
2021	10.807	8.915	1.742	1.437
2022	11.391	9.265	1.837	1.494
2023	11.998	9.624	1.934	1.552
2024	12.628	9.992	2.036	1.611
2025	13.284	10.369	2.142	1.672

Table 13 - Load forecast in Ivory Coast

Ghana

Between 2000 and 2010, the population growth in Ghana was estimated by the International Monetary Fund to 2.5% per year. Today, the population of Ghana is estimated to 24 millions.

The GDP of Ghana (at constant price) grew on average of 5% per year over the last 10 years according to the International Monetary Fund.

Given the importance of the industrial customer VALCO, the Consultant proposes to consider separately the domestic load and VALCO.

The historical data used in the study of correlation of the load of the country are the population, the GDP, the GDP per capita, the produced energy, the consumed energy of the country and the total consumed energy. The GDP per capita was used to approach the income per capita that was not available.

The forecast of the industrial load for the base case is based on the assumption that two production lines would be exploited at VALCO in 2011. VALCO would also be able to bring into service three lines in 2013. For the low scenario, the assumption has been made that a production line would be exploited at VALCO in 2011. VALCO would also be able to bring two lines into service in 2013.

	Base scenario		*Low scenario*		*Base scenario*		*Low scenario*	
	Domestic consumption [GWh]	VALCO [GWh]	Domestic consumption [GWh]	VALCO [GWh]	Domestic consumption [MW]	VALCO [MW]	Domestic consumption [MW]	VALCO [MW]
2011	9.793	1.314	9.239	657	1.479	150	1.395	75
2012	10.421	1.314	9.652	657	1.573	150	1.457	75
2013	11.093	1.971	10.096	1.314	1.675	225	1.524	150
2014	11.764	1.971	10.522	1.314	1.780	225	1.590	150
2015	12.484	1.971	10.971	1.314	1.888	225	1.657	150
2016	13.252	1.971	11.440	1.314	2.007	225	1.730	150
2017	14.070	1.971	11.932	1.314	2.130	225	1.804	150
2018	14.941	1.971	12.446	1.314	2.262	225	1.881	150
2019	15.869	1.971	12.984	1.314	2.401	225	1.962	150
2020	16.857	1.971	13.547	1.314	2.550	225	2.047	150
2021	17.908	1.971	14.135	1.314	2.708	225	2.136	150
2022	19.027	1.971	14.750	1.314	2.877	225	2.228	150
2023	20.218	1.971	15.393	1.314	3.056	225	2.325	150
2024	21.485	1.971	16.065	1.314	3.247	225	2.426	150
2025	22.832	1.971	16.768	1.314	3.450	225	2.532	150

Table 14 - Forecast of the load demand in Ghana

Togo-Benin

In Benin, the GDP growth was relatively constant these ten last years with an annual growth rate between 3% and 5% according to the IMF.

The growth of the population of Benin reached 3.3% per year until 2005 and 2.8% per year since 2006. The population of Benin is of nearly 10 millions inhabitants.

In Togo, the GDP growth was negative in the beginning of the year 2000. Since 2003, the GDP grows on average of 2.5% per year.

In Togo, the annual population growth is of nearly 2.5%. There are currently a little more than 7 millions inhabitants in Togo according to the estimates of the IMF.

The electricity sector in Togo and Benin is governed by the International Agreement and Benino-Togolese Code for electricity signed between the two states in 1968 and creating a community of interest between the two countries in the field of electrical energy.

This code gave to the Electric Community of Benin the monopoly of the production, transport and the imports/exports of electrical energy on the whole territory of the two states.

Nevertheless, the International Agreement and Benino-Togolese Code signed in 1968 were revised in 2003. The clauses of the new agreement and Code of 2003 are hence now on in force. In accordance with the clauses of this new agreement and revised Benino-Togolese Code of 2003, the CEB does not have the monopoly of the electrical production anymore. The segment of the electrical production is opened to independent producers but the CEB remains the single purchaser of their production everywhere where their network is present.

For this reason, the energy data are available for both states together and not for each one independently from the other. The study of the demand relates hence to the Togo-Benin community based on information from the CEB.

The five main customers of the CEB are:

- In Togo:
  - CEET: Electrical Energy Company of Togo, national company of distribution of electricity;
  - WACEM: West African Cement, producer of cement;
  - SNPT: New Company of Phosphates of Togo, phosphate producer.
- In Benin:
  - SBEE: Beninese company of Electrical energy, national company of distribution of electricity;
  - SCB - Lafarge: Cement producer.

The main industrial customers account for approximately 15% of the demand for electricity. The rest of the demand is transferred to the Togolese and Beninese supply firms that act partially as self-producers since they have their own means of production. The demand of these customers is primarily residential and tertiary.

In the north of Benin, the SBEE works in collaboration with the Beninese Agency for Rural electrification and Energy Control (ABERME) to develop the 33kV network between localities and to try to connect the new loads and the isolated places. Thus, in the short term, Togo and Benin (to a lesser extent) envisage a considerable growth of the number of customers connected to the interconnected network. This tendency results in a strong growth of the load which started in 2009 and which should continue until 2012 according to the document “Load forecasts horizon 2020”.

Currently, Benin consumes more than half of the demand for electricity of the community. Nevertheless, for several years a more important increase in the load in Togo than Benin has been observed. The increase in the number of customers connected to the interconnected network of the CEET should confirm the tendency and Togo should occupy an increasingly important place in the consumption of electricity of the community.

Taking into account all these aspects, the load forecast for Togo and Benin are presented hereafter.

	Togo				Benin			
	Base scenario [GWh]	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*	*Base scenario [GWh]*	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	1042	1035	170	169	1341	1333	219	217
2012	1294	1286	211	210	1469	1460	240	238
2013	1440	1405	235	229	1564	1526	255	249
2014	1571	1503	256	245	1697	1624	277	265
2015	1712	1608	279	262	1835	1723	299	281
2016	1873	1728	305	282	1968	1816	321	296
2017	2046	1856	334	303	2105	1910	343	311
2018	2230	1990	364	325	2248	2006	366	327
2019	2426	2131	395	348	2396	2105	391	343
2020	2609	2257	426	368	2576	2229	420	364
2021	2801	2387	457	389	2766	2358	451	385
2022	3004	2523	490	412	2967	2492	484	407
2023	3217	2664	525	435	3178	2632	518	429
2024	3442	2812	561	458	3400	2777	555	453
2025	3680	2965	600	484	3634	2928	593	477

Table 15 - Load forecast in Togo and Benin

Burkina Faso

At the beginning of the year 2000, the annual growth of the population in Burkina Faso was higher than 3%. Since 2005, the growth slowed down to 2.3% per year according to the International Monetary Fund. Today, the population of Burkina Faso is estimated to 15 millions.

The GDP in Burkina Faso (at constant price) grew on average of 5% per year during the last 10 years according to the International Monetary Fund.

Until 2009, Burkina Faso had two networks independent from each other. Since 2009, these two networks are interconnected (Interconnected National Network: RNI).

In Burkina Faso, the demand growth is strongly related to the electrification rate. This electrification rate is correlated to the wealth of the country. For this reason, the principal macro-economic parameter which guides the evolution of the yearly consumption of electricity is the GDP.

The energy not served in the areas connected to the interconnected networks was very low until a few years ago. Nevertheless, it increased in a considerable way these last years. The main causes for load sheddings are:

- An important increase in demand and a massive connection of new customers to the CRCO interconnected network not compensated by an increase in the means of production;
- An increased unavailability of the interconnection with Ivory Coast.

In addition, rural electrification is a major concern for the SONABEL. The electrification of the new centers includes a part of construction of the local network and the construction of a connection line to the nearest electrical center. The aim is to achieve a goal of electrification of 60% in 2015. The current growth of consumption on the electrified network takes into account rural electrification. For the future, the rate of increase in rural electrification is supposed to be identical to today.

Finally, an ambitious program of connection of the isolated centers is envisaged in the short and medium term.

Taking into account these aspects leads to the following forecast:

	Base scenario [GWh]	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	873	873	178	178
2012	934	929	190	189
2013	1.006	987	205	201
2014	1.087	1.048	222	214
2015	1.173	1.112	239	227
2016	1.265	1.179	258	240
2017	1.362	1.250	278	255
2018	1.466	1.324	299	270
2019	1.576	1.402	321	286
2020	1.694	1.484	345	303
2021	1.820	1.570	371	320
2022	1.953	1.661	398	338
2023	2.095	1.755	427	358
2024	2.247	1.855	458	378
2025	2.408	1.959	491	399

Table 16 - Load forecast in Burkina Faso

Niger

The historical analysis of the demographical and economical data and of electricity consumptions is the preliminary stage to the projections of demand.

Between 2000 and 2010 the population growth in Niger was estimated by the International Monetary Fund to 3.1% per year. Today, the population of Niger is estamated to 15.2 million (source: INS-Niger).

The GDP of Niger (at constant price) grew on average of 4.8% per year over the last 10 years according to the International Monetary Fund.

There are 4 zones in Niger:

- The River area, around Niamey, supplied by Birnin Kebbi in Nigeria;
- The Center-East area, supplied by Katsina in Nigeria;
- The East area: 33 kV zone, supplied by Nigeria in 33 kV;
- The Northern area, close to Agadez.

The three first are supplied by Nigeria and are synchronous. There are emergency power plants (cold reserve). The fourth one is supplied by a coal plant.

In Niger, the demand is primarily residential and industrial. The residential sector accounts for 47% of electric consumption, while services account for 13% of this consumption. In addition, industries account for 39% of the load, according to the 2007 annual report of the Energy Information System of Niger (EIS).

In addition, in Niger, the connection of new customers following the implementation of the special program of the President of the Republic and the execution of the Development project of the interconnected electrical network of Niger DREIN made it possible to electrify several rural localities. The consumption of electricity in the interconnected network consequently grew steadily these last years. A rise of 88% of the demand in terms of "demanded energy" (524 GWh in 2008) has been recorded between years 2000 and 2008.

Finally, the connection of a cement factory of 20MW is considered in the Center-East area as from 2015

	Base scenario					*Low scenario*				
	River	**Center East**	**East**	**North**	**Total**	**River**	**Center East**	**East**	**North**	**Total**
	[GWh]	**[GWh]**	**[GWh]**	**[GWh]**	**[GWh]**	**[GWh]**	**[GWh]**	**[GWh]**	**[GWh]**	**[GWh]**
2011	429	249	62	109	849	422	245	61	107	835
2012	461	267	67	117	912	446	258	65	113	882
2013	494	286	72	125	977	470	273	68	119	931
2014	528	306	76	134	1.044	496	287	72	126	980
2015	535	433	132	136	1.235	494	409	126	125	1.154
2016	569	452	141	144	1.306	518	423	133	131	1.205
2017	604	473	149	153	1.379	544	438	139	138	1.258
2018	640	493	158	162	1.454	570	453	146	144	1.312
2019	677	515	167	172	1.530	596	468	152	151	1.368
2020	715	537	177	181	1.609	623	484	159	158	1.424
2021	754	559	187	191	1.691	651	500	166	165	1.482
2022	794	583	197	201	1.774	679	516	174	172	1.541
2023	835	607	207	212	1.860	707	533	181	179	1.601
2024	877	631	217	223	1.948	737	550	188	187	1.662
2025	921	656	228	234	2.039	767	567	196	194	1.725

	Base scenario					*Low scenario*				
	River	**Center East**	**East**	**North**	**Total**	**River**	**Center East**	**East**	**North**	**Total**
	[MW]	**[MW]**	**[MW]**	**[MW]**	**[MW]**	**[MW]**	**[MW]**	**[MW]**	**[MW]**	**[MW]**
2011	86	22	3	38	149	85	21	3	37	146
2012	93	23	4	41	160	90	22	4	39	154
2013	99	25	4	43	171	94	24	4	41	163
2014	106	26	4	46	183	99	25	4	44	172
2015	113	48	5	49	215	105	46	4	46	181
2016	120	51	5	53	229	110	48	4	48	190
2017	127	54	5	56	243	115	51	5	50	199
2018	135	58	5	59	257	121	53	5	53	208
2019	143	61	6	63	272	126	56	5	55	218
2020	151	64	6	66	287	132	58	5	58	228
2021	159	68	6	70	303	138	61	6	60	238
2022	168	72	7	73	319	144	63	6	63	248
2023	176	75	7	77	336	150	66	6	66	259
2024	185	79	7	81	353	156	69	6	68	270
2025	195	83	8	85	370	163	72	7	71	280

Table 17 - Load forecast in Niger

Nigeria

The population growth in Nigeria is evaluated by the International Monetary Fund to 2.7% per year. The population of Nigeria reached 160 millions in 2011.

Since 2001, the annual GDP growth in Nigeria varied between 5% and 10% except for the year 2002 when an exceptional growth of 21% was observed according to the IMF.

Given the quantity of energy not served in Nigeria, it is difficult to draw up a correlation study between the demand and the macro-economic parameters over the last 10 years.

The park of production has not been reinforced in Nigeria since 2006. The resorption of the demand could consequently not start. On the contrary, not served energy did nothing but increase given the constant decrease of the energy produced since 2006.

PHCN (Power Holding Company of Nigeria) estimates the demand to be supplied in Nigeria in 2011 to 9 GW. Nevertheless, PHCN has very ambitious development plans of production park in the short-term which will allow, if they are carried out, to reabsorb the unserved demand very quickly.

Taking into account the investment plans in means of production in the short-term in order to estimate the resorption of the load, the forecast of the served demand should follow the following tendency, if referred to the vision of PHCN.

	Base scenario [GWh]	*Low scenario [GWh]*	*Base scenario [MW]*	*Low scenario [MW]*
2011	39.102	25.524	6.376	4.162
2012	58.069	34.570	9.471	5.638
2013	61.321	43.624	10.000	7.114
2014	64.964	56.272	10.595	9.177
2015	68.830	65.178	11.225	10.629
2016	72.926	69.058	11.892	11.261
2017	77.258	72.339	12.599	11.797
2018	81.856	75.784	13.348	12.358
2019	86.717	79.383	14.142	12.946
2020	91.873	83.159	14.983	13.562
2021	98.732	88.365	15.874	14.207
2022	104.604	92.569	16.818	14.883
2023	110.821	96.969	17.818	15.591
2024	117.412	101.584	18.877	16.333
2025	124.393	106.415	20.000	17.110

Table 18 - Load forecast in Nigeria

2.2.4. Generation data

2.2.4.1. CHARACTERISTICS AND COSTS OF NEW TECHNOLOGIES

Gas Turbines and Combined Cycles

Several countries of the ECOWAS currently have gas turbines (GT) and combined cycles (CC) running either on natural gas (Ivory Coast, Ghana, Nigeria) or on liquid fuel (Togo, Ghana, Ivory Coast, Senegal…). The majority of these GT and CC are dual fuel allowing burning either gas or liquid fuels. Various manufacturers are represented on the continent (GE, Siemens, Alstom…) and different sizes of gas turbines are installed from 7.9 MW to 150 MW. In the same way, different CC are installed presenting powers varying from 50 MW (Senegal) to 450 MW (Nigeria).

During the optimization of the production plan a series of GT and CC known as standard are regarded as investment option. This serie of GT and CC is proposed in order to cover a broad range of size and technology.

The sizes suggested for the combined cycles are 60 MW, 300 MW and 450 MW. These sizes correspond to the orders of magnitude of the standards used in certain countries of the ECOWAS like Senegal (50MW), Ghana (90MW and 300 MW) and Nigeria or Ivory Coast (project) (450 MW). No size higher than 450 MW was proposed for systemic considerations. Indeed, a CC of 450 MW presents a dimensioning incident of 225 MW (1 GT and ½ ST) which is consequent considering the size of the West African networks.

The sizes suggested for the GT correspond to the GT of the combined cycles suggested namely: 45 MW, 100 MW and 150 MW.

In terms of technology, the selection of the GT and CC were made in order to facilitate maintenance and to minimize the capital costs rather than to maximize the output. It would be possible to reach one or two additional points of output but at a very high cost.

For the CC, two cooling methods are proposed, by cooling tower and by direct oulet. The direct outlet makes it possible to increase by one to two points the total output.

The Consultant used the Thermoflow software to estimate the investments and the operation costs of the different configurations. This software simulates the thermodynamic cycle of the power plant based on selected components. It informs of the net expected efficiency and thus of the specific consumption. The principal assumptions are summarized hereafter:

- Room temperature of 33°C;
- All the GT and CC are dual fuel;
- All the CC have a by-pass chimney to allow running the GT while the ST are unavailable;
- Planned and unplanned unavailabilities were adapted to the local conditions.

The fuels modeled in Thermoflow are on the one hand the natural gas and on the other hand the distillate #2. This distillate permits to represent the performances of the power plant burning diesel or LCO.

The table below presents the investment data of GT and CC technologies.

		THERMOFLOW CASES								
		1	2	3	4	5	6	7	8	9
Plant characteristics	**Unit**	**CCGT (300MW) 2GT + 1ST**	**CCGT (300MW) 2GT + 1ST**	**CCGT (450MW) 2GT+1ST**	**CCGT (450MW) 2GT+1ST**	**CCGT (60MW) 1GT+1ST**	**CCGT (60MW) 1GT+1ST**	**OCGT (45MW)**	**OCGT (100MW)**	**OCGT (150MW)**
Cooling method		**Air cool**	**Direct Water cool**	**Air cool**	**Direct Water cool**	**Air cool**	**Direct Water cool**			
GT Manufacturer + Model	-	GE 9E	GE 9E	Siemens SGT5-2000E	Siemens SGT5-2000E	Siemens SGT800	Siemens SGT800	ALSTOM GT8C2	Alstom GT11N2	Siemens SGT5-2000E
Alternative GT Manufacturer + Model	-	Alstom GT11N2	Alstom GT11N2	Ansaldo AE94.2 GE 9C	Ansaldo AE94.2 GE 9C	ALSTOM GT8C2	ALSTOM GT8C2		GE 9E	
Gross GT Power (Site condition)	MW	110	110	145	145	39/38	39/38	49	101	146
Number of GT	-	2	2	2	2	1	1	1	1	1
ST Manufacturer + Model	-	Siemens SST-900	Siemens SST-900	Siemens SST-900	Siemens SST-900	SST-300	SST-300	NA	NA	NA
Number of ST	-	1	1	1	1	1	1	NA	NA	NA
Gross ST power (Site condition)	MW	123	138	155	173	15	18	NA	NA	NA
Total Nominal (Gross) Power NG/ Oil	MW	342/-	357/ -	445	463	54/53	57/55	49/47	101	146
Total Nominal (net) Power NG/Oil	MW	332/ -	348/	432	452	53/51	55/54	48/46,5	100	144
Net Efficiency	%	49,1	51,5	49,3	51,6	47.9	50.2	32,1	31,6	33,1
Total investment cost	MUSD	334	320	404	386	73	72	41	69	88
Total investment cost / kW	USD/kw	977	896	908	834	1352	1263	837	683	603
Schedule of investment payment				16/34/50	16/34/50	20/50/30	20/50/30	50/50	50/50	50/50
(from EPC or EPC(M) contract signature)	%/year	16/34/50	16/34/50	over 3 years	over 3 years	over 2,5 years	over 2,5 years	over 2 years	over 2 years	over 2 years
Life duration	years	25	25	25	25	25	25	25	25	25
Fixed O&M cost	USD/kW	34	31	32	29	38	37	8.4	7	6
Variable O&M Cost (excl fuel)	USD/MWh	1.83	1.68	1.71	1.57	2.03	2.00	2.51	2.05	1.81
Fuel 1		Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas	Natural Gas
LHV net heat rate - Fuel 1	kJ/kWh	7331	6996	7247	6930	7522	7169	11225	11404	10869
Fuel 2		Distillate #2	Distillate #2	Distillate #2	Distillate#2	Distillate #2	Distillate #2	Distillate #2	Distillate #2	Distillate #2
LHV net heat rate - Fuel 2	kJ/kWh	7379	7039	7293	6970	7601	7240	11435	11620	11014
emission level CO2	T/h	134	134	173	173	22	29	30	62	86
emission level S02 (Distillate Oil)	T/h	0 563	0 563	0,727	0,727	0.92	0.92	0,125	0/0.263	0/0.362
emission level Nox (Without SCR)	ppmV (dry)	15	15	25/?	25/?	15/42	15/42	25/?	25/42 (wet)	25/?
emission level Nox with SCR	ppmV (dry)	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A.	N.A.
Planned availability (maintenance)	pu	7%	7%	7%	7%	7%	7%	7%	7%	7%
Unplanned availability (forced outage)	pu	8%	8%	8%	8%	8%	8%	8%	8%	8%

Figure 19 - GT and CC – investment data

Coal

The investments decided, planned and under consideration in Niger and Senegal concern small units (125MW in Senegal and 4*50 MW in Niger).

In the absence of concrete data on the technology used, standard investment data were proposed. The units were selected in order to facilitate maintenance and to minimize the capital costs rather than to maximize the output. It would be possible to reach one or two additional points of output but at a very high cost.

In a general way, two technologies would be considered:

- "Circulating Fluidized Bed" (CFB) Technology;
- "Pulverized Coal" (PC) Technology.

The Consultant used the Thermo flow software to estimate the investments and the operation costs of the various configurations. This software simulates the thermodynamic cycle of the power plant based on selected component of the power plant. It informs of the net efficiency expected and thus of the specific consumption. The principal assumptions are summarized hereafter:

- Room temperature of 33°C;
- Planned and unplanned unavailabilities were adapted to the local conditions.

The table below presents the investment data of coal technologies. Being given the size of the investments suggested for Senegal and Niger, it is the CFB technology that has been selected.

		Thermoflow Cases	
		10	11
Plant characteristics	**Unit**	**Coal (125MW) Type: CFB**	**Coal (250MW) Type: PC**
Number of ST	-	1	1
Gross ST power (Site condition)	MW	125	250
Total Nominal (Gross) Power NG/ Oil	MW	125	250
Total Nominal (net) Power NG/Oil	MW	116	230
Net Efficiency	%	37.6	39
Total investment cost	MUSD	314	540
Total investment cost / kW	USD/kw	2512	2160
Schedule of investment payment (from EPC or EPC(M) contract signature)	%/year	16/32/32/20 over 3,3 years	16/32/32/20 over 3,3 years
Life duration	years	35	35
Fixed O&M cost	USD/kW	75	65
Variable O&M Cost (excl fuel)	USD/MWh	3.14	2.7
Fuel 1		Coal	Coal
LHV net heat rate - Fuel 1	kJ/kWh	9574	9231
Fuel 2		Oil, biomass	Oil, biomass
LHV net heat rate - Fuel 2	kJ/kWh		
emission level CO2	T/h	106	206
emission level S02 (Distillate Oil)	T/h	0,053	0,103
emission level Nox (Without SCR)	ppmV (dry)	N.A	N.A
emission level Nox with SCR	ppmV (dry)	97 (SNCR)	96 (SNCR)
Planned availability (maintenance)	pu	7%	7%
Unplanned availability (forced outage)	pu	8%	8%

Table 20 - Coal center – Investment data

High speed and medium-speed diesel

A vast majority of the ECOWAS countries uses high-speed or medium-speed diesel groups running on diesel (DDO) or heavy fuel oil (HFO). These groups present powers varying from less than 1 MW to approximately 20 MW.

The advantages of these diesel groups are their relatively low capital cost, the construction speed and the facility of storage and supply of fuels. Their big disadvantages are the high fuels costs, their relatively high specific consumption and expensive maintenance.

During the optimization of the production plan a series of high-speed and medium-speed diesels groups known as standard are regarded as an investment option. This series of diesels groups is proposed in order to cover a broad range in terms of size and technology.

The table below presents the investment data for diesel technologies.

Plant characteristics	Unit	HFO 10MW	HFO 20MW	DDO 10MW
Total Nominal (net) Power	MW	10	20	10
Net Efficiency	%	40%	40%	36%
Total investment cost	MUSD	14.5	27	10.7
Total investment cost / kW	USD/kw	1450	1350	1070
Schedule of investment payment		50%/50%	50%/50%	50%/50%
(from EPC or EPC(M) contract signature)	%/year	over 2 years	over 2 years	over 2 years
Life duration	year	20	20	20
Fixed O&M cost	USD/kW	16.8	16.8	8.4
Variable O&M Cost (excl fuel)	USD/MWh	7.1	7.1	10.1
Fuel 1		HFO	HFO	DDO
LHV net heat rate - Fuel 1	kJ/kWh	9000	9000	10000
emission level CO2	kg/MWh	712.8	712.8	741
emission level S02 (Distillate Oil)	kg/MWh	4.1	4.1	0.9
Planned availability (maintenance)	pu	7%	7%	7%
Unplanned availability (forced outage)	pu	10%	10%	10%

Table 21 - Diesel - Investment data

Biomass

Some countries such as Senegal, Liberia and Sierra Leone consider biomass in their energy mix.

In the absence of concrete data on the technology used, standard investment data were proposed. The units were selected in order to facilitate maintenance and to minimize the capital costs rather than to maximize the output. It would be possible to reach one or two additional points of output but at a very high cost.

The table below presents the investment data of technologies using biomass. Given the size of the investments suggested for Senegal, Liberia and Sierra Leone, it is the CFB technology thta has been selected. According to the size of the projects, the data are variable.

Type of equipment	Unit	Large Biomass Plant (100MWe)	Medium Biomass Plant (40MWe)	Small Biomass Plant (5MWe)
Manufacturer + Model	-	CFB Boiler	CFB Boiler	Grate Furnace
Number of ST	-	1	1	1
nominal capacity of ST at site condition (32°)	MW	100	40	5
Total Nominal Power	MW	100	40	5
Total investment cost	MUSD	324	136	34
Schedule of investment payment	%/year	Y0-3: 45% Y0-2: 25% Y0-1: 10% Y0 : 20%	Y0-3: 45% Y0-2: 25% Y0-1: 10% Y0 : 20%	Y0-1: 55% Y0 : 45%
Total investment / kW	USD/kW	3240	3400	6800
Life duration	years	30	30	30
Discount rate	%	12	12	12
Fixed O&M cost (OPEX)	USD/kW/y	130	136	272
Variable O&M Cost (excl fuel)	USD/MWh	included	included	included
Fuel 1		Wood Chips	Wood Chips	Wood Chips
LHV net heat rate (32°) - Fuel 1	kJ/kWh	9600	9600	15000
emission level CO2	mg/Nm3	0	0	0
emission level S02	mg/Nm3	-	-	-
emission level Nox without DeNox	mg/Nm3	250	250	250
emission level Nox with DeNox (SNCR)	mg/Nm3	125	125	125
Planned availability (maintenance)	pu	7%	7%	7%
Unplanned availability (forced outage)	pu	8%	8%	8%
Pecularities				
- Average Available Energy	GWh	745	300	37
- Fuel consumption	t/year	510 000	204 000	40 000
- Fuel cost in Africa if available on site	USD/GJ	3.6	3.6	3.6
- Fuel cost in Africa if transport needed	USD/GJ	5.1	5.1	5.1

Table 22 - Biomass Production unit - Investment data

Hydroelectricity

One of the objectives of this master plan and of the national Master plans of the majority of West African countries is the development of the not yet exploited hydroelectric resources. These resources are very abundant and are mainly distributed in the basins of the Senegal, Niger, The Gambia and Konkouré Rivers.

These projects are taken into account as investment options during the optimization of the production plan and are thus put in competition with the other technologies presented in this chapter.

Nevertheless, it should be noted that the projects suggested in the countries of zone B can not reasonably be all set up by 2025 even if many of them are profitable from an economic point of view. Indeed, the financial limits of the countries, the environmental impacts, and the difficulties of accessibility are as many brakes to the massive development of the hydroelectricity. Moreover, a certain number of these projects could be dedicated to the local supply of the mining sector.

In the first two scenarios (without limits of interconnection and national development), no constraint was forced on the model in order to take these aspects into account.

Nevertheless, in order to obtain a reference case which can be used as a basis for the development of a list of priority investments, some constraints were forced based on the limits evoked herebefore and limiting the disproportionate investments in the countries having many hydroelectric resources.

The characteristics of the projects were determined based on the last available study for each work. When certain data such as the capital cost or the annual potential production were not available, the Consultant proposed values based on the site location, the type of installation and the power of the groups. These values are showed in italic.

Node	Name Power Plant	Status	Installed capacity	Total costs	Spec. Invest. costs	Average energy	Guaranteed energy
			[MW]	[M$]	[$/kW]	[GWh/an]	[GWh/an]
Burkina Faso	Bougouriba	Candidate	12	122	10125	30	*22.8*
Burkina Faso	Bagre Downstream		14	106	7536	36	*27.36*
Ivory Coast	Soubré	Candidate	270	620	2296	1116	*848*
Ivory Coast	Gribo Popoli	Candidate	112	364	3249	515	*391*
Ivory Coast	Boutoubre	Candidate	156	*401*	*2570*	785	*597*
Ivory Coast	Louga	Candidate	280	1330	4751	1330	*1011*
Ivory Coast	Tiassale	Candidate	51	*207*	*4068*	215	*163*
Ivory Coast	Aboisso Comoe	Candidate	90	*248*	*2756*	392	*298*
Ghana	Juale	Candidate	87	372	4276	405	*308*
Ghana	Pwalugu	Candidate	48	209	4361	184	*140*
Ghana	Daboya	Candidate	43	241	5611	194	*147*
Ghana	Hemang	Candidate	93	304	3270	340	*258*
Ghana	Kulpawn	Candidate	36	345	9587	166	*126*
Guinea	Amaria	Candidate	300	377	1256	1435	1057
Guinea	Bonkon Diaria	Candidate	174	211	1213	451	315
Guinea	Diaraguela	Candidate	72	178	2472	400	298
Guinea	Fetore	Candidate	124	160	1290	322	232
Guinea	Fomi	Candidate	90	156	1728	374	320
Guinea	Frankonedou	Candidate	36	83	2306	173	140
Guinea	Gozoguezia	Candidate	48	110	2292	259	200
Guinea	Grand Kinkon	Candidate	291	298	1024	720	618
Guinea	Kaleta	Decided	240	267	1114	946	228
Guinea	KassaB	Candidate	135	214	1585	528	467
Guinea	Kogbedou	Candidate	14	71	5083	111	99
Guinea	Kouravel	Candidate	135	185	1370	350	240
Guinea	Kouya	Candidate	86	156	1814	334	315
Guinea	Lafou	Candidate	98	128	1306	255	210
Guinea	Morisakano	Candidate	100	260	2600	523	438
Guinea	Nzebela	Candidate	48	94	1958	225	210
Guinea	Poudalde	Candidate	90	150	1667	342	319
Guinea	Souapiti	Candidate	515	692	1344	2518	2403
Guinea	Tiopo	Candidate	120	295	2458	590	480
Liberia	MtCoffee (+via)	Decided	66	383	5803	435	344
Liberia	St Paul 1B	Candidate	78	*244*	*3123*	*512*	*389*
Liberia	St Paul 2	Candidate	120	*375*	*3123*	*788*	*599*
Liberia	St Paul V1	Candidate	132	*412*	*3123*	*569*	*433*
Liberia	Mount Coffee (+V1)	Candidate	66	*234*	*3546*	*285*	*216*
Liberia	St Paul 1B (+V1)	Candidate	65	*203*	*3123*	*280*	*213*
Liberia	St Paul 2 (+ V1)	Candidate	100	*312*	*3123*	*431*	*328*
Liberia	Lofa To rivet	Candidate	29	*141*	*4861*	*125*	*95*
Liberia	St John To rivet	Candidate	67	*287*	*4280*	*289*	*220*
Liberia	CestosRiver	Candidate	41	*234*	*5707*	*177*	*480*

Table 23 - Hydroelectric projects Investment data (1/2)

Node	Name Power Plant	Status	Installed capacity	Total costs	Spec. Invest. costs	Average energy	Guaranteed energy
			[MW]	[M$]	[$/kW]	[GWh]	[GWh]
Mali	Kénié	Candidate	34.4	126	3671	199	163
Mali	Taoussa	Candidate	25	209	8340	*108*	*82*
Mali	Sotuba 2	Candidate	6	48	7943	39	37
Mali	Markala	Candidate	10	40	4025	53	*40*
Niger	Kandadji	Candidate	130	405	3115	629	478
Niger	Gambou	Candidate	122.5	*577*	*4712*	*528*	*402*
Niger	Dyodyonga	Candidate	26	*60*	*2293*	*112*	*85*
Nigeria	Mambilla	Candidate	2600	4000	1538	*11214*	*8522*
Nigeria	Zungeru	Candidate	700	*1077*	*1538*	*3019*	*2295*
Sierra Leone	Bumbuna II	Decided	40	*78*	*1950*	220	237
Sierra Leone	Bumbuna III	Candidate	90	176	1950	396	317
Sierra Leone	Bumbuna IV V	Candidate	95	*185*	*1950*	494	463
Sierra Leone	Gummed II	Candidate	6	*40*	*6709*	*31*	*1*
Sierra Leone	Benkongor	Candidate	200	*490*	*2447*	1164	959
Sierra Leone	Kuse II	Candidate	91.8	*235*	*2561*	680	549
Sierra Leone	Kambatibo	Candidate	52.5	*164*	*3120*	269	212
Sierra Leone	Bitmai I	Candidate	52.5	*164*	*3120*	268	212
Sierra Leone	Bitmai II	Candidate	36.6	*130*	*3543*	250	211
Togo	Adjarala	Decided	147	333	2265	366	237
Togo	Tététou	Candidate	50	*159*	*3174*	148	*112*
Benin	Kétou	Candidate	160	*337*	*2105*	490	*372*
Burkina /Ghana	Noumbiel	Candidate	60	286	4767	203	*154*
C Iv /Liberia	Tiboto	Candidate	225	*578*	*2570*	1200	*912*
Liberia/S.L	ManoRiver	Candidate	180	473	2625	795	612
OMVG Guinea	Digan	Candidate	93.3	112	1200	243	24
OMVG Guinea	FelloSounga	Candidate	82	285	3474	333	286
OMVG Senegal	Sambangalou	Decided	128	433	3386	402	208
OMVG G. Bissau	Saltinho	Candidate	20	83	4273	82	24
OMVS Guinea	Balassa	Candidate	181	171	945	470	401
OMVS Guinea	Boureya	Candidate	160	373	2331	717	455
OMVS Guinea	Diaoya	Candidate	149	332	2228	581	389
OMVS Guinea	Koukoutamba	Candidate	281	404	1438	858	507
OMVS Guinea	Tene I	Candidate	76.4	122	1597	199	129
OMVS Mali	Felou	Decided	60	170	2828	350	320
OMVS Mali	Gouina	Decided	140	328	2343	565	227
OMVS Mali	Gourbassi	Candidate	21	*91*	*4311*	104	*79*
OMVS Mali	Badoumbe	Candidate	70	*197*	*2818*	410	*312*
OMVS Mali	Bindougou	Candidate	49.5	*158*	*3185*	289	*220*
OMVS Mali	Moussala	Candidate	30	*114*	*3801*	175	*133*

Table 24 - Hydroelectric projects Investment data (2/2)

Characteristics of the power plants	Units	Hydropower
Life duration	year	50
Variable O&M Cost (excl fuel)	USD/MWh	2
Fixed O&M cost	%.	Included in variable
Planned unavailability (maintenance)	pu	4%
Unplanned unavailability	pu	2%

Table 25 - Hydroelectric projects standard Parameters

Solar energy

For CSP technologies, the normal direct irradiation (NDI in kWh/m ² /y) is an essential criterion to define the potential of the sites. Consequently, in the area of interest, 4 ranges of DNI were defined:

- Nonsuitable < 2.000 kWh/m2/a
- Acceptable 2.001 - 2.200 kWh/m2/a
- Good 2.201 - 2.600 kWh/m2/a
- Excellent >2.600 kWh/m2/a

This scale is specific to the area and is defined based on DNI data available for the area.

Another key parameter is the latitude which influences the unit losses. The latitudes considered are of 15°, 20° and 25°. The latitudes of less than 10° are not considered because they are classified as "nonsuitable" in the DNI scale.

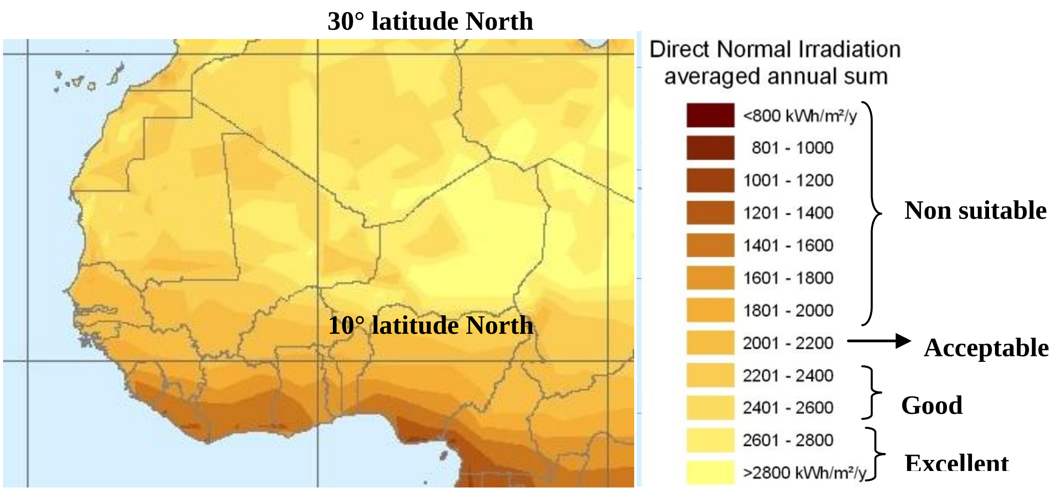


Figure 6 - DNI and the latitude of the area of interest (www.dlr.de)

By using Andasol3 as typical unit (50 MW with 7.5h of storage in Spain), we obtain the data of Table 26 for a DNI of 2400 kWh/m2/a and a latitude of 20 ° North. The costs considered in Table 26 are the costs for 2009/2010.

Characteristics of the power plants	*Units*	*Solar thermics (CSP)*
Nominal output (local conditions)	MW	50
Average available energy available	GWh	206
Bill book of payment	%/year	70% Y0-1 30% Y0
Capital cost	MUSD	507
Capital cost/kW	USD/kW	10138
lifespan	year	25
Operation cost and maintenance - fixed	USD/kW/year	254
Operation cost and maintenance - variable	USD/MWh	-
Output	%	17%
Planned unavailability (maintenance)	pu	2%
Unplanned unavailability	pu	-
Characteristics		
- storage	H	7.5
- DNI	kWh/m ² /y	2400
- No. of loops	-	152
- Surface of the mirrors	m ²	497000

Table 26 - Solar production unit CSP- Given of investment

Traditional investment data for a photovoltaic installation in Europe with an operating time ratio adapted to the area are presented in Table 27. The costs considered in Table 27 are costs for 2010/2011.

Characteristics of the power plants	*Units*	*Solar PV*
Nominal nominal output (local conditions)	MW	1
Energy available average	GWh	2
Bill book of payment	%/year	100% Y0
Capital cost	MUSD	3.66
Capital cost/kW	USD/kW	3660
lifespan	year	20
Operation cost and maintenance - fixed	USD/kW/year	20
Operation cost and maintenance - variable	USD/MWh	-
Output	%	15%
Planned unavailability (maintenance)	pu	0.50%
Unplanned unavailability	pu	0.75%
Characteristics		
- storage	H	
- DNI	kWh/m ² /y	
- No. of loops	-	
- Surface of the mirrors	m ²	

Table 27 - Solar production PV unit - Investment data

Wind energy

Two wind technologies are proposed as an investment option for the master plan. The first technology corresponds to the current state of art in terms of wind turbines. It is a turbine of approximately 2 MW proposed by all the manufacturers (GE, REPower, Vestas, Gamesa, Siemens, Nordex, Enercon…). This technology is currently the most widespread.

The second technology suggested consists of a smaller structure, more flexible which can be installed more easily in distant areas where the traditional wind turbines are difficult to install. Typically, this technology is proposed by the Vergnet Company.

Type of equipment	Unit	Wind turbine (25x2MW)	Wind turbine (50x1MW)
Total Nominal Power	MW	50	50
Average available Energy (2000 hours)	GWh	100	100
Total investment cost	MUSD	69	81
Schedule of investment payment	%/year	70% Y0-1 30% Y0	70% Y0-1 30% Y0
Total investment cost / kW	USD/kW	1485	1750
Life duration	years	20	20
Discount rate	%	12	12
Fixed O&M cost	USD/kW/y	17	17
Variable O&M Cost	USD/MWh	9.5	9.5
Planned availability (maintenance)	pu	1%	1%
Unplanned availability (forced outage)	pu	4%	4%

Table 28 - Wind - Investment data

2.2.4.2. DEVELOPMENT PLANS OF THE PARK OF PRODUCTION

For each country, the development plans of the national park of production discussed at the time of data collection missions and the big international projects are considered.

For each Member State, a list of electric production units was drawn up, distinguishing the existing units from the future units (decided or candidates):

- Existing units: production units having been commissioned before March 2011;
- Decided units: units whose construction is undergoing or was decided for an exact date of commissioning (study finished and guaranteed financing);
- Candidates units: units for which the studies are not finished yet or for which the financing was not found yet.

Among the projects suggested by the countries, those which are decided are not questionable in the production master plan. On the other hand, the candidate projects belong to the investment options optimized by the software.

In addition to the projects under consideration by the countries, a series of “standard” investments are also proposed as investment option. The standard gas turbines and the combined cycles proposed permit to cover a broad range in terms of size and technology.

Senegal

- Decided projects:
  - The hydroelectric plant of Félou within the framework of the OMVS. It is a power plant of 60 MW and, according to the agreements with the OMVS, Senegal will have 25% of the power. That will ensure 15 MW additional as from 2013 on the condition that the network of the OMVS allows the transfer of this additional capacity;
  - Within the framework of the OMVS also, the power plant of Guinea, for 140 MW is planned in 2017. The share of Senegal is 25% or 35 MW;
  - Through the OMVG, Senegal should benefit from 40% of production of the hydroelectric plant of Sambangalou in 2017, or 51MW;
  - A coal plant on the site of Sendou (total of 875 MW divided in 7 phases) as of 2016;

- The hiring of a 50 MW diesel unit in 2011 for a one year duration, with possibility of renting an additional 100MW;
- The rehabilitation of the C3 and C4 groups of Bel Air (+30MW in 2011 and 25MW in 2012);
- Extension of the C6 group of Bel-Air: 2 x 15 MW in 2012;
- The commissioning of Koudi II (2 x 15 MW) in 2012;
- A Biomass unit of 2 x 15 MW with Ross Bethio in 2014. Produced energy estimated per year: 236 GWh.

• Candidates projects:
- The installation of mobile units on HFO of 40 MW in Tobin (with option for an extra 30MW) and 70MW in the harbour of Bel-Air (one second barge of 70MW is considered) in 2012;
- The following units are planned for the isolated centers:
  - 2012:2 x 5 MW HFO in Ziguinchor which will make it possible to stop the hirings of power in this area;
  - 2012:2 x 4 MW HFO in Tambacounda.
- A wind site of 125 MW from 2014 onwards;
- A solar park of 7.5 MW in Ziguinchor;
- Several diesel units of 30 or 60 MW could be built by independent producers.

The Gambia

• Decided projects:
- Complete commissioning of the units of Kotu;
- The rehabilitation of the unit G6 of Kotu in 2011;
- The rehabilitation of the unit G2 (HFO) in Kotu (3 MW) in 2012;
- The installation of 2 new diesel units of 6.5 MW running on HFO, at the power plant of Brikama at the end of 2011;
- The installation of an extra 9 MW in Brikama running on HFO also at the end of 2011;
- 4 units of 2 MW running on HFO for the isolated centers;
- Construction of a wind farm of 1 MW in Tanji in 2012.

Area	Current load	New Units	Connection to Banjul
Farafenni & Mansa Konko	1.8 MW	2 MW in 2013	2013
Bansang	0.6 MW	2 MW in 2013	2014
EASSAN/Barria	0.46 MW		OMVG
KEREWAN	0.22 MW	2 MW in 2013	
LOW	1.8 MW	2 MW in 2013	2014
KANIR	0.18 MW		

• Candidates projects:
- Extension of the power plant of Brikama to 2 x 10 MW in 2013;
- A project of an additional 4MW of wind in 2014;
- Through the OMVG, The Gambia should profit from 12% of the power of the hydroelectric plans of Sambangalou in 2017, that is 15 MW;
- A solar project of 10MW;

- Extension of the wind farm of 6 MW;
- A combined cycle of 60MW after 2014;
- The second phase of the projects of the OMVG.

Guinea Bissau

- Decided projects:
  - The installed capacity at this moment is of approximately 5.6 MW. But the capacity available uninterrupted is of 5 MW (2.5 MW EAGB and 2.5 MW of hiring);
  - 2 groups of 2.5MW financed by the World Bank and installed in 2012. Regarding the commissioning of these units, the leasing agreements of 2.5MW will be broken;
  - Financing of 15 MW HFO for the town of Bissau supported by the UEMOA and the BOAD. Envisaged in several stages of 5 MW between 2012 and 2014;
  - Rehabilitation of the power plant of EAGB in Bissau (2MW);
  - Rehabilitation of the power plant of Bafatà (5MW);
  - Commissioning of the power plant of Buba (5MW);
  - Through the OMVG, Guinea Bissau should benefit from 8% of power from the hydroelectric plant of Sambangalou in 2017, that is 10 MW;
  - It is supposed that when the means of production become sufficient, the self-producers will stop using their own means of production.
- Candidates projects
  - Power plant HFO of 55MW;
  - Saltinho, OMVG phase 2: 20MW.

Guinea

- Decided projects:
  - 106 MW with the project of thermal plant of Manéah running on HFO. The commissioning is supposed to happen in 2014 and 2015;
  - Commissioning of additional 100MW at Tombo plant;
  - The hydroelectric run-of-river plant of Kaléta which will include three units of 80 MW and will produce on average 946 GWh per year.
  - The rehabilitation of the thermal and hydroelectric units of Guinea;
  - Through the OMVG, Guinea should benefit from 40% of power from the hydroelectric plant of Sambangalou in 2017, i.e. 51 MW.
- Candidates projects:
  - In addition to the second phases of the OMVS and OMVG projects, the sites mentioned below are also considered in Guinea.
    - The site of Souapiti presents an installable power of 515 MW and is planned for 2018. It could be associated with a project of aluminum foundry that would not leave power for other uses. If the aluminum factory is not built, it will be useful for the supply of the mines and export;
    - The site of Kassa B (135MW) is planned for 2021;
    - The site of Poudaldé on the Cogan River close to Tiopo is under feasibility study. It is planned for 2017. Its installed capacity is of 90 MW for a producible of 350 GWh.
    - Finally, the Grand-Kinkon project has an installed capacity of 291 MW for an annual producible of 735 GWh and an estimated cost of 298M$

The list of projects is presented hereafter:

Site	***Localization***	***Capacity [MW]***	***Annual Producible [GWh]***
Souapiti	Maritime Guinea	515	2518
Amaria		300	1435
Poudadlé		90	350
Tiopo		120	590
Grand Kinkon		291	735
Kassa B	Mid-Guinea	135	528
Kouya		86	334
Bonkon-Diaria		174	451
Fetore		124	322
Lafou		98	255
Kouravel		135	350
Fomi	Upper Guinea	90	374
Diareguela		72	400
Frankonédou		36	173
Kogbédou		14	96
Morisanako		100	523
Nzébéla	Forested Guinea	48	225
Gozoguézia		48	259

Table 29 - Hydroelectric sites under consideration in Guinea except OMVS/OMVG

- In addition, the connection of the production units of the isolated centers from Nzerekore (3MW), Kankan (3MW) and Faranah (1.5 MW) is planned for 2016 with the interconnection projects of CLSG and Guinea-Mali.

Sierra Leone

- Candidates projects:
  - Extension of the Bumbuna dam by phase 2:
    - Addition of 350 MW thanks to the Yiben dam, envisaged upstream in 2017;
  - The addition of a new dam upstream of the current dam of Goma and the installation of additional turbines for a total of 6 MW envisaged in 2015;
  - New hydroelectric dam of Benkongor with 3 possible phases:
    - Phase 1:34.8 MW;
    - Phase 2:80 MW;
    - Phase 3:85.5 MW.
  - A project of power plant of 100 MW using the biomass as fuel;
  - A sugar project which could produce 15 MW starting of bagasse;
  - A project of solar power plant of 5 MW;
  - The hydroelectric installations mentioned in the following table are also considered in Sierra Leone.

Site	Capacity [MW]	Annual producible [GWh]
Kuse 2	91.8	679.7
Kambatibo	52.5	268.5
Bitmai 1	52.5	268
Bitmai 2	36.6	249.5
Mano To rivet	180	795

Table 30 - Hydroelectric sites under consideration in Sierra Leone

For the site located on the Mano River on the border with Liberia, an equal division of the power and the producible between the two countries is planned. The total necessary investment is estimated to 473 M$.

Liberia

- Decided projects:
  - 10 MW of high-speed diesel groups (10 x 1MW) running on DDO on the site of Bushrod. The commissioning is envisaged in 2011;
  - 10 MW of medium-speed diesel groups (2 x 5MW) running on HFO on the site of Bushrod. The commissioning is envisaged in 2013;
  - The rehabilitation of the hydroelectric installation of Mount Coffee (66 MW could be available in 2014).
- Candidates projects:
  - The Buchanan project of 35 MW (2 x 17.5 MW) located in Kakata. The commissioning is envisaged in 2013;
  - 30 MW of medium-speed diesel groups (6 x 5MW) running on HFO on the site of Bushrod. The commissioning is envisaged in 2015;
  - The development of the St Paul River with the creation of the SPRA (Saint Paul River Authority) with the hydroelectric sites of
    - Saint Paul - 1B: 78 MW and 512 GWh of annual producible;
    - Saint Paul - 2:120 MW and 788 GWh of annual producible.

    These sites could be commissioned by 2018;
  - The construction of an additional tank ("Ultimate" Via Storage) on the Saint Paul River upstream of the above mentioned sites. 132 MW could be produced locally by the V-1 power plant thanks to this tank. Moreover, the construction of a channel connecting it with the tank Via of Mount Coffee would make it possible to increase the capacities of the hydroelectric plants located downstream in the following proportions:
    - Mount Coffee: possible addition of 66 MW;
    - Saint Paul - 1B: possible addition of 65 MW;
    - Saint Paul - 2: possible addition of 100 MW.
  - A hydroelectric dam of 180 MW on the Mano River on the border with Sierra Leone with a Annual producible of 795 GWh. This site would be divided for a total value of 50% for each country. The necessary total investment is estimated to 473 M$;

- A hydroelectric dam of 225 MW on the Cavally River at the border with Ivory Coast with an annual producible of 1200 GWh. This site would also be shared for a total value of 50% per country;
- Hydroelectric sites identified on the rivers Lofa (total of 29 MW), Holy John (total of 67 MW) and Cestos (total of 41 MW).

Mali

- Decided projects:
  - 60 MW of the BID project (6 diesel groups of 10 MW each) running on HFO in Balingué. 40 MW have already been commissioned in 2010. The commissioning of the 20 MW remaining is envisaged in 2011;
  - 92 MW through the IP Albatross thanks to diesels groups running on HFO in the mining zone of Kayes. The commissioning is envisaged in 2012;
  - A combined cycle of 30 MW of the BOOT project on the site of Noumoubougou (15MW guaranteed - commissioning in 2012);
  - The hydroelectric project of installation of Félou carried out within the framework of the OMVS. The share allocated to Mali is of 45%, or 27MW. Construction is undergoing and the commissioning is envisaged in 2013;
  - The hydroelectric project of Gouina carried out within the framework of the OMVS. The share allocated to Mali is 45%, or 63MW. The commissioning is planned for 2017;
  - Connection with the interconnected network of isolated diesel groups for a total of 30.4 MW in the horizon of the study;
  - A 10 MW solar project in Mopti is installed in 2012 and connected to the interconnected network in 2019.
  - A project of combined cycle of 400 MW envisaged with Aboadze (Ghana) by the Emergency and security supply plan of Electric Energy of the WAPP. A part of its energy should be importe by Mali.
- Candidates projects:
  - The hydroelectric project of installation to the Sotuba 2 (6 MW). The commissioning is envisaged in 2014;
  - The agro-industrial project of the sugar company of Markala (SoSumar) will contain a power plant of cogeneration from which 3MW will be extra and transferred to the interconnected network. The commissioning is envisaged in 2014;
  - The project of a small hybrid power plant for a total of 0.75MW (0.25 solar + 0.5 diesel) with Ouelessebougou in 2016;
  - The hydroelectric project of installation to the current of Kenié (42 MW). The commissioning is envisaged in 2015;
  - A combined cycle of 150 MW is planned by the Emergency and Security Supply Plan in electrical energy of the ECOWAS;
  - Extension of the PV solar Mopti of 50 MW which will be connected to the interconnected network;
  - A PV solar project of 20 MW to be installed as from 2013;
  - The hydraulic project of Taoussa on the Niger River close to WAGP, mainly dedicated to agriculture with a supplement of hydroelectricity of 25 MW;
  - The project of hydroelectric plant of 10 MW (3 Kaplan turbines) in Markala on the Niger river with an annual producible of 53 GWh;

- Within the framework of the projects of the OMVS, Mali should benefit from part of the production of the Guinean sites of Koukoutamba (281MW, 858 GWh), Boureya (160 MW, 717 GWh) and Balassa (181 MW, 470 GWh) all three located on the Bafing;
- In a more remote horizon, the OMVS projects of Gourbassi (21 MW, 104 GWh) and Badoumbe (70 MW, 410 GWh), then of Bindougou (50 MW, 289 GWh) and Moussala (30MW, 175GWh) could also be implemented in Mali.

Ivory Coast

- Decided projects:
  - Addition of 222 MW on the site of independent producer CIPREL which will form a combined cycle with the gas turbine of 111 MW commissioned in 2010. The commissioning of the new gas turbine is envisaged in July 2012 and that of the steam turbine in July 2013;
  - Emergency addition of an extra 250 MW (total= 450MW) on the site of CIPREL or Vridi thanks to a new gas turbine and a new steam turbine in 2012;
  - A combined cycle of 450 MW (2 gas turbines and a steam turbine of 150 MW each) on the site of Abbata. The commissionings are envisaged in 2014 (1st gas turbine), 2015 (2nd gas turbine) and 2016 (steam turbine);
  - A project of combined cycle of 400 MW envisaged with Aboadze (Ghana) by the Emergency and security supply plan of Electric Energy of the WAPP. A part of its energy should be imported by Ivory Coast.
- Candidates projects:
  - The project of 270 MW of the Soubré dam. The commissioning is envisaged in 2018;
  - A combined cycle of 450 MW (2 gas turbines and a steam turbine of 150 MW each one) on the site of Bassam which will constitute the 5th thermal plant of Abidjan. The commissionings would be envisaged in 2020 (1st gas turbine), 2023 (2nd gas turbine) and 2025 (steam turbine);
  - The capacities of the hydroelectric sites are indexed in the table below:

Basins	***Sites***	***Capacity [MW]***	***Annual producible [GWh]***
SASSANDRA	Louga	280	1.330
	Gribo Popoli	112	515
	Boutoubre	156	785
BANDAMAN	Tiassalé	51	215
CAVALLY	Tiboto	225	1.200
COMOE	Aboisso-Comoé	90	392

Table 31 - Hydroelectric installations under consideration in Ivory Coast

For the site of Tiboto a distribution of 50% for the Ivory Coast and 50% for Liberia can be assumed within sight of the more or less equal distribution of the basin of the Cavally river between the two countries.

Ghana

- Decided projects:
  - Phase 1 of power plant T3 of Aboadze (in construction), which will consist of a combined cycle of 120 MW. Its commissioning is planned for 2012;
  - A second gas turbine of 110MW on the site of Tema T1 with commissioning envisaged in 2012. The addition of a steam turbine of 110 MW is envisaged in 2015 to create a combined cycle of a total of 330 MW;
  - Hydroelectric dam of 400 MW in Bui on the Black Volta with an annual producible of 1000 GWh. The commissioning is planned for mid 2013;
  - Two gas turbines of 110 MW each one envisaged in Domini by BTPP (central Domini T1) in order to benefit from the offshore gas resources discovered. Their commissioning is envisaged in 2013;
  - Addition of a steam turbine of 110 MW on the power plant of Aboadze T2 to pass to a combined cycle of 330 MW in total. The commissioning is envisaged in 2014;
  - A project of combined cycle of 400 MW envisaged with Aboadze (T4) by the Emergency and security supply plan of Electric Energy of the WAPP.
  - 2x5MW solar PV in 2012 and 2013;
  - Wind: 50 MW in 2014 and 100 MW in 2015;
  - A project of combined cycle of 450 MW (2 gas turbines of 150 MW each one and a steam turbine of 150 MW) on the site of Maria Gléta in Benin decided by the Emergency and Security supply plan of Electric Energy supply of the WAPP. A part should be dedicated to the Ghana.
- Candidates projects:
  - Phase 2 of the power plant of Aboadze T3 with similar characteristics to phase 1 described previously. The commissioning is envisaged in 2016;
  - GT on barge: 2x50 MW;
  - SAP project of CC 2x163.6 MW;
  - The power plant of Cempower on the Tema T2 site initially made up of 2 gas turbines of 110 MW to which a steam turbine of 110 MW will be added to create a combined cycle of 330 MW;
  - Addition of a steam turbine of 110 MW to the power plant of Domini T1 by BTPP to create a combined cycle of a total of 330 MW;
  - 5 hydroelectric sites at the stage of feasibility studies, led by the VRA (Juale, Pwalugu, Kulpawn, Daboya) and the ministry for energy (Hemang):

Site	*Capacity [MW]*	*Annual producible [GWh]*
Juale	87	405
Pwalugu	48	184
Kulpawn	36	166
Daboya	43	194
Hemang	93	340

Table 32 - Hydroelectric sites under consideration in Ghana

There also is a project of dam with hydroelectric plant of 60 MW (3 Kaplan turbines of 20MW) at the border with Burkina Faso on the site of Noumbiel (also called Koulbi in Ghana) on the Black Volta. The total annual producible is estimated to 203 GWh with a distribution of 80% of the energy produced for Burkina and 20% for Ghana.

Togo

The sector of electricity in Togo and Benin is governed by the International agreement and Benino-Togolese Codes electricity signed between the 2 states in 1968 and creating a community of interest between the 2 countries in the field of electrical energy.

This code conferred to the Electric Community of Benin the monopoly of the production, transport and the imports/exports of electrical energy on the entire territory of the two states.

Nevertheless, the International Agreement and Benino-Togolese Code signed in 1968 were revised in 2003. It is hence the clauses of the new agreement and Code of 2003 that are now in force. According to the clauses of this new agreement and revised Benino-Togolese Code of 2003, the CEB does not have the monopoly of the electrical production anymore. The segment of the electrical production is opened to the independent producers but the CEB remains the single purchaser of their production everywhere where their network is present.

- Decided projects:
  - The project of 147 MW Adjarala dam with an annual producible of 366 GWh. The commissioning is envisaged in 2017 by the CEB.
  - A project of combined cycle of 450 MW (2 gas turbines of 150 MW each one and a steam turbine of 150 MW) on the site of Maria Gléta in Benin decided by the Emergency and Security supply plan of Electric Energy supply of the WAPP. A part should be dedicated to the Togo.
- Candidates projects:
  - A wind project of 20 MW to be set up with a guaranteed annual energy of 40 GWh whose commissioning is envisaged in 2013;
  - 100 MW of thermal production with a guaranteed annual energy of 350 GWh in 2013 (commissioning) and of 700 GWh as from 2014;
  - A solar project of 5 MW of the CEB with a guaranteed annual energy of 10 GWh whose commissioning is envisaged in 2015;

- A project of dam with hydroelectric plant of 50 MW in Tététou on the Mono River which would be located between the Nangbeto and Adjarala dams with an annual producible of 148 GWh. A feasibility study was carried out in 1984.

Benin

- Decided projects:
  - The project of 147 MW Adjarala dam (Togo) with an annual producible of 366 GWh that should be shared between Togo and Benin.
  - 80 MW on the site of Maria Gleta in Cotonou. The commissioning is envisaged in 2011;
  - A project of combined cycle of 450 MW (2 gas turbines of 150 MW each one and a steam turbine of 150 MW) on the site of Maria Gléta in Cotonou decided by the Emergency and Security supply plan of Electric Energy supply of the WAPP. The power plant should be operational in 2014.
- Candidates projects:
  - A 20 MW solar project to be set up with a guaranteed annual energy of 40 GWh whose commissioning is envisaged in 2012;
  - A 5 MW solar project of the CEB with a guaranteed annual energy of 10 GWh whose commissioning is envisaged in 2015;
  - A solar project of 5 MW financed by the AFD in the North-East of Benin. (commissioning supposed: 2014);
  - A project of dam with hydroelectric plant of 160 MW in Kétou on the Ouémé River with an annual producible estimated to 490 GWh. A feasibility study was carried out in 1992.

Burkina Faso

- Decided projects:
  - 18 MW running on HFO and forming the first phase of the power plant of Komsilga. The commissioning is envisaged in 2011;
  - 37.5 MW (3 diesel groups of 12.5 MW running on HFO and forming the 2nd phase of the power plant of Komsilga. The commissioning is envisaged in 2011;
  - 36 MW (2 diesel groups of 18 MW) running on HFO which will form the 3rd phase of the power plant of Komsilga (total 90MW). The commissioning is envisaged in 2013;
  - 20 MW (2 diesel groups of 10 MW running on HFO and forming the 2nd phase of the power plant of Sore 2. The commissioning is envisaged in 2012.
  - A project of combined cycle of 400 MW envisaged with Aboadze (Ghana) by the Emergency and security supply plan of Electric Energy of the WAPP. A part of its energy should be imported by Burkina Faso.
- Candidates projects:
  - A solar project of 20 MW of which 16 MW would be dedicated to the mining company Semafo. The commissioning is envisaged in 2012;
  - A photovoltaic solar project of 1.5MW (extensible with 3MW) in Ouagadougou. The commissioning is supposed to take place in 2012 (already committed financing);
  - A photovoltaic solar project of 20MW (extensible with 40MW) in Ouagadougou. The commissioning is supposed to intervene in 2014;
  - The connection of isolated centers between 2011 and 2013 for a total of 13.5 MW installed and 9.5 MW available;

- A project of dam with hydroelectric plant of 60 MW (3 Kaplan turbines of 20 MW) at the border with Ghana on the site of Noumbiel (called Koulbi in Ghana) on the river Mouhoun (Black Volta). The total annual producible estimated to 203 GWh with a distribution of 80% of the energy produced for Burkina and 20% for Ghana;
- A project of dam with hydroelectric plant of 12 MW (3 turbines of 4MW) in Bougouriba with producible of 30 GWh;
- A project of dam with hydroelectric plant of 14 MW (2 Kaplan turbines of 7MW) to Bagré-downstream with an average annual producible of 37.3 GWh.

Niger

- Decided projects:
  - In 2011, seven 2.2 MW diesel units each will be installed with the power plant of Niamey 2, to replace the old diesel units;
  - In 2012,2 units of 2MW each will be installed in Maradi and 2 others of 2 MW will be installed in Zinder, in Centre-East Niger area;
  - In the river area, an additional diesel power of 70MW will be installed in Niamey in 2013.
  - In the River area, the Kandadji dam will be completed by 2015. This 130 MW dam should bring 629 GWh annually to Niger;
- Candidates projects:
  - The coal center of Salkadamna would add up 200 MW. This power plant would be localized between the River, Centre-East and Northern areas, close to a coal deposit and would be built by sections of 50MW between 2015 and 2016;
  - In the River area, a 30 MW wind farm is planned in 2014. The site has still to be defined;
  - In the River area, a thermal solar power plant of 50 MW is planned for 2014. The site still has to be defined;
  - In the Centre-East area, Zinder, a combined cycle of 60 MW is expected in 2013;
  - Other hydro units are mentioned in the River area:
    - Gambou for 122.5 MW;
    - Dyodonga for 26 MW.

Nigeria

- Decided projects:
  - A project of combined cycle of 450 MW (2 gas turbines of 150 MW each one and a steam turbine of 150 MW) on the site of Maria Gléta in Benin decided by the Emergency and Security supply plan of Electric Energy supply of the WAPP. A part should be dedicated to Nigeria.
  - FGN phase 1:1408 MW of which 1055 MW were commissioned in 2007. There remain 353 MW planned for 2011;
  - NIPP: 2599 MW planned for 2011;
  - FGN phase 2:2148 MW envisaged including 696 MW for 2012 and 1452 MW for 2013.

For all that, the oil companies envisaged the following investments:

- The power plant of Afam 6, by Shell: 5 units of 150 MW in 2012;
- The power plant of Bonny, by Mobil: 3 units of 130 MW in 2012;
- The Chevron Texaco power plant with 3 units of 250 MW by 2012;
- The power plant of TotalFinaElf with 4 units of 125 MW by 2012.

Moreover, some IPP are expected:

- Alscon with 6 units of 90 MW by 2012;
- Power plant IBOM Power 2 with 500 MW in 2012.

- Candidates projects:
  Important hydroelectric projects are considered in Nigeria:

  - The rehabilitation of Kainji;
  - The project of Zungeru (700MW);
  - The project of Mambilla (8x325MW).

  Some IPP are also expected of which

  - ICS Power: 6 units of 100 MW in 2015;
  - WESTCOM power plant of 500 MW in 2015;
  - The Farm Electric power plant of 150 MW in 2015;
  - The Supertek power plant of 1000 MW in 2017;
  - The Ethiope power plant of 2800 MW in 2017.

Comments concerning the OMVS

The OMVS is an organization having for purpose to organize the actions of four countries for the development of the Senegal River and its basin. Its members are Guinea, Mali, Mauritania and Senegal.

The first realization of the OMVS is the Manantali dam located in Mali on the Bafing (affluent of Senegal) whose construction was completed in 1988. A hydroelectric plant of 205MW (4 groups of 41 MW) was installed offering an annual producible of 800GWh. The production of the site was made available for 3 of the countries of the OMVS thanks to a 225 kV interconnection line from Bamako to Dakar along the border of Senegal with Mauritania.

The OMVS considers many projects with horizons going from short to the long term. They are summarized in the following table:

River	*Site*	*Country*	*Capacity* *[MW]*	*Annual producible* *[GWh]*	*Estimated cost* *[M$]*	*Status*	*Commissioning supposed*
Senegal	Félou	Mali	60	350	170	EC.	2013
	Gouina	Mali	140	589	329	APD	2017
Bafing	Koukoutamba	Guinea	281	858	440	APD	CT
	Boureya	Guinea	160	717	373	APS	CT
	Balassa	Guinea	181	470	171	F	CT
	Bindougou	Mali	50	289		PF	MT
	Diaoya	Guinea	149	581	332	PF	LT
Falémé	Gourbassi	Mali Senegal	21	104		F	MT
	Moussala	Mali	30	175		PF	MT
Bakoye	Badoumbe	Mali	70	410		F	MT
Tene	Tene I	Guinea	76	199	122	PF	LT

Table 33 - hydroelectric Projects of the OMVS

EC.: In construction; APD: Detailed preliminary draft; APS: Summary preliminary draft; F: Feasibility; PF: Pre-feasibility; CT/MT/LT: short/middle to long term.

Comments concerning the OMVG

The OMVG is an organization which aims at coordinating the actions of the four countries concerned with the basin of The Gambia River: Senegal, Guinea, The Gambia and Guinea Bissau. By extension, other rivers of the area are concerned by this organization.

Up to now, the OMVG has two big projects.

The first big project is composed of two parts and is planned for 2016:

- The hydroelectric plant of Sambangalou which will include 4 units of 32 MW and will produce on average 402 GWh per year.
- A 225 kV interconnection which will cross 1677 km to connect 15 sub-stations, for an investment of 576.5 million dollars. It will allow the evacuation of the energy of Guinea, and the interconnection of the 4 countries of the OMVG.

The second big project is composed of four parts and is envisaged later on:

- The run-of-river power plant of Saltinho in Guinea Bissau. Of a power of 20 MW (3 units of 6.5 MW), it will have an average producible estimated to 82 GWh.
- The run-of-river power plant of Digan in Guinea. With a power of 93.3 MW, will have an average producible of 242.5 GWh.
- Fello-Sounga dam, in Guinea, with its two units of 41 MW. It will ensure the annual production of 333 GWh.
- Reinforcement of the 225 kV interconnection line built at the time of the first project. 500 new kilometers of line should be built. There will be 4 new sub-stations. That will cost 145.4 million dollars.

2.2.5. Transmission data

The purpose of this chapter is to synthesize the data of transport which were introduced into the optimization tool PRELE.

The decided projects have a set commissioning date. The planned projects are not questioned but the possibility of a delay of 2 years is considered. Finally, the projects considered are left free with optimization. In addition, investments other than the big projects of interconnections are proposed to the optimization tool.

2.2.5.1. DECIDED PROJECTS

This section shows the decided projects for which the studies are finished and for which the financing was or is about to be obtained.

"330kV Coastal Backbone" project

The project consists of a 330 kV axis along the coast interconnecting Ivory Coast (Riviera), Ghana (Prestea and Volta), Togo (Lome C), Benin (Sakété) and Nigeria (Ikeja West). 2 sections are planned to complete the 2 already existing sections

- The Volta (Ghana) - Sakété (Benin) section passing by Lome which should be commissioned in 2013;
- The Riviera (Ivory Coast) - Ghana (Prestea) section. It should be commissioned by 2017.

OMVG project

The OMVG project includes a 225 kV interconnection simple line simple circuit crossing Guinea, Senegal, Guinea-Bissau and The Gambia to share the hydroelectric production of the Guinean sites. The commissioning is envisaged in 2017 but the first phase (Linsan-Labé-Mali and Linsan-Kaolack-Tambacounda) could be finished sooner (2015).

CLSG project (Ivory Coast - Liberia - Sierra Leone - Guinea)

A single circuit 225 kV interconnection line is envisaged between the stations Man (Ivory Coast) - Yekepa (Liberia) - Nzérékoré (Guinea) - Buchanan (Liberia) - Monrovia (Liberia) - Bumbuna (Sierra Leone) - Linsan (Guinea). Its commissioning is envisaged in 2015. In the short-term, only a single circuit line will be installed. Nevertheless, the pylons are designed to accommodate a second circuit in a longer-term.

Interconnection Mali - Ivory Coast

This 225 kV interconnection will connect the stations of Ferkéssédougou (Ivory Coast) - Sikasso (Mali) - Koutiala (Mali) and Ségou (Mali). It is under development and 64% are already built. The commissioning is expected during 2012.

Please note that the 225 kV single circuit line internal to Ivory Coast which is planned between Laboa and Ferkéssédougou supplements this project while making it possible to close the 225 kV loop inside Ivory Coast and to secure the interconnections towards the North.

Interconnection Ghana-Burkina Faso.

A 225 kV interconnection line between Bolgatanga (Ghana) and Ouagadougou (Burkina Faso) will be commissioned in 2013.

Interconnection Ghana - Burkina Faso-Mali

This interconnection 225 kV envisages to connect the Bolgantaga (Ghana) - Bobo Dioulasso (Burkina Faso) - Sikasso (Mali) - Bamako (Mali) substations by 2015. It is envisaged in double circuit on the Bamako-Sikasso section. In Sikasso, a circuit goes towards Ferkessedougou and a second continues towards Bobo Dioulasso.

2.2.5.2. PLANNED PROJECTS

This section shows projects already quite detailed and having been subject of feasibility studies but for which complementary studies are still to be done and/or for which part of the financing still remains to be found.

Interconnection Guinea - Mali

The project of Guinea-Mali interconnection is registered among the priority projects identified by the Revised Master plan of the ECOWAS. It is conceived to evacuate the production of the future hydroelectric plant of 90MW of Fomi (Guinea). The project includes the construction of a 225 kV line between Fomi (Guinea) and Nzérékoré (Guinea) then between Fomi (Guinea) and Bamako (Mali) and between Fomi (Guinea) and Linsan (Guinea). It is planned for 2016.

These transmission lines will not only allow the interconnection of Guinea and Mali, but also the interconnection between the Member States of the OMVS and with the future line of interconnection of Ivory Coast - Liberia - Sierra Leone - Guinea (CLSG).

Project “North-core”

The project uses again a 330 kV interconnection line between Birnin Kebbi (Nigeria) - Bembéréké (Benin) - Niamey (Niger) - Ouagadougou (Burkina Faso). Several variants are considered in terms of number of circuits (1 or 2) by section. The commissioning of this line is planned in 2016.

330 kV North-South axis in Ghana

This project, although inside the network of Ghana, is an important link of the framework of the WAPP interconnected network strongly improving the capacities of export towards Burkina Faso. This 330 kV interconnection line connects the station of Domini (at the border with the Ivory Coast) to the station of Bolgatanga at the border with Burkina Faso. The commissioning of this axis is planned for 2015.
Reinforcement project of the Nigeria-Benin interconnection

This project of a double circuit line between Sakété (Benin) and Omotosho is planned (commissioning date considered: 2016).

2.2.5.3. PROJECTS CONSIDERED

This section shows various projects which are evoked in the collected documents or during the discussions carried out during the data collection missions in the various countries. The studies of prefeasibility of these projects were not started yet or are in hand.

Median backbone project

This project is considered by the CEB in its priority development projects. This interconnection would connect Yendi (Ghana) - Kara (Togo) - Bembereke (Benin) and Kaindji (Nigeria). It would be expected by 2020. This project could be justified to reinforce and evacuate the power produced by the site of Kaindji towards the northern zones of these countries.

Nevertheless this project requires to be further specified and studied in details in particular on the following points:

- The station of Yendi in Ghana is rather remote with a relatively low load and there is no project of extension of the 330 kV network of Ghana to connect this 161 kV sub-station. It would be more logical to extend this line to the 330 kV axis crossing Ghana from North to South;
- The other variant is to carry out the median backbone in 161kV, except for the Kainji-Bembereke section, which would be in 330 kV.

Interconnections Liberia – Ivory Coast

A coastal interconnection between Monrovia in Liberia and San Pedro in Ivory Coast is evoked by the concerned countries. This project would allow in particular the evacuation of the hydroelectric project of Tiboto (Cavally), at the border between the two countries.

OMVS interconnections

Regarding the commissioning of the hydraulic site of Gouina (decided project, commissioning estimated in 2017), it will possibly be necessary to reinforce the 225kV network towards Dakar. A loop by the interior of the country is considered via Tambacounda which would also allow a connection with the OMVG network.

A Linsan-Manantali link is also considered to interconnect the dams in project on the territory of Guinea: Boureya and Koukoutamba.

2.2.5.4. OTHER INVESTMENT OPTIONS

In addition to the projects under consideration by previous studies, new projects are left for the PRELE optimization from 2018 on.

- A new interconnection between **Guinea** and the **north of Ivory Coast** (Fomi-Odienne-Boundiali-Ferkessedougou) is proposed. Such an axis would make it possible to directly evacuate the hydroelectric energy produced in Guinea towards the northern areas having few means of production with low operation costs. The layout of this line will be discussed in order to limit its environmental impact.
- In the same optic, a variant of this layout would consist of a line connecting **Guinea** to the area of **Sikasso in Mali**.
- The various installations under consideration for the **median backbone** are proposed as an investment option
- Finally, the reinforcement of the existing decided or planned axes is also considered.

2.2.6. Presentation of the results

The determination of the production and transmission master plan made it possible to find the optimal combination between the development of production parks at regional level and the development of the regional network system to supply the electricity demand at a minimal cost.

In this master plan, the candidate production projects were proposed as investment options whereas the commissioning of the decided units was regarded as acquired.

As mentioned in the methodology, scenario 1 (national Master plans without developing new interconnections) and scenario 2 (optimal regional development without limits of transit between the countries) are initially presented hereafter.

Then, scenario 3, the reference scenario (optimal regional development taking into account the limits of transit between the countries), is described, imposing the decided and planned transmission project and the decided production projects and optimizing the other projects in order to minimize the cost of the objective function.

2.3. Scenario without development of new interconnections

This scenario proposes the evolution until 2025 of the national parks of production as proposed in the national master plans without development of new interconnections.

In order to take into account all the problem aspects, an alternative was considered making it possible to study the impact of the mining projects in the energy balance of the area of West Africa.

2.3.1. Energy mix

In terms of energy mix, the results presented hereafter are those which were obtained in the absence of massive mining projects in Guinea, Guinea Bissau, Sierra Leone and Liberia.

Nevertheless, the principal impacts of a massive mining consumption are also examined.

2.3.1.1. INSTALLED CAPACITY

In terms of investment options, the optimization carried out using the tool PRELE shows that the hydroelectric projects are massively selected based on purely economic criterion in spite of their particularly important capital cost because their operation cost is extremely low. Nevertheless, the number of invested projects is limited by the load in the area considered and the limited possibilities of exports.

If the mining projects were implemented, the number of selected hydroelectric projects would be more important, increasing by as much the ratio of hydroelectric energy in the energy mix.

About thermal projects, the combined cycles are largely promoted, mainly when they are fed with natural gas. Indeed, these units have a very low operation cost due to the combined effect of a very good efficiency and a fuel at low prices.

The coal projects are also selected massively based on their economic performance in order to cover the local loads.

Nevertheless, it is important to note that few projects using renewable sources are selected among the investment options. Indeed, these projects are in general expensive to install and relatively not very effective because intermittent. Other criteria such as the profit in CO2 emissions are however favorable. The environmental and financial aspects will be considered in a forthcoming part of the study. Let us note however that in the countries where the gas and hydroelectric resources are non-existent, the wind projects become competitive. It is the case in particular of Senegal and The Gambia.

Figure 7, hereafter, presents the evolution of the regional energy mix in terms of installed capacity working on the assumption of scenario 1 without development of new interconnections, and in the absence of massive mining projects.

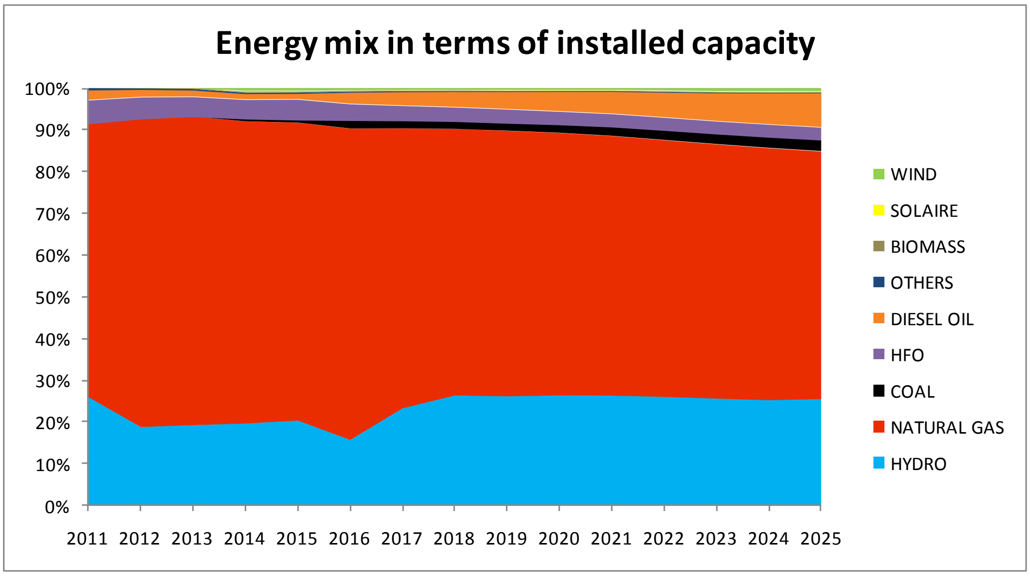


Figure 7 - Installed capacity by type of fuel in the scenario without development of new interconnections

2.3.1.2. PRODUCED ENERGY

The economic stacking of the units wants that the least expensive units to operate run at maximum during all the year. Thus the hydroelectric units produce the maximum of energy which they are able to provide according to the climatic conditions and of the local load conditions. In the same way, the combined cycles burning natural gas are operated in base production.

In addition, the gas turbines have a low efficiency and run, in an optimum production plan, only as peak units, even if they burn natural gas.

A fortiori, the gas turbines and diesel groups burning other fuels form the marginal units, operated only as a last resort when the other possibilities (of production and importation) reached their limit.

The coal projects and biomass are also used as base units.

Intermittent renewable energies as for them are used as soon as the conditions allow it.

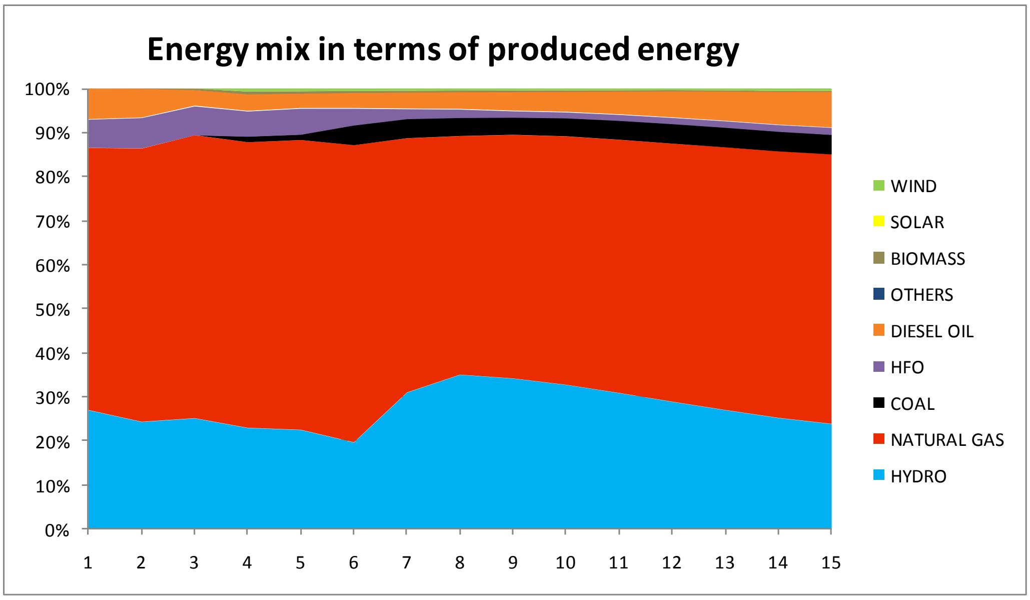


Figure 8 - Energy produced by type of fuel in the scenario without development of new interconnections

2.3.2. Average Marginal costs

In order to identify the areas which would need to be more strongly interconnected with their neighbours in order to decrease their production costs, the average marginal costs per year and per area inside the countries were calculated.

In the short term, the marginal cost is very high in certain areas because of the lack of production means.

In the medium term, the development of the optimal production park by country will help reducing the marginal cost in a substantial way by considering nevertheless that the exchanges between the countries are strongly limited.

Lastly, in the long term, the most competitive projects will already have been built, such that projects with higher production costs would have to be commissioned, yielding an increase of the marginal cost in the majority of the areas.

The figure hereafter represents the marginal costs in the various areas of the 14 countries of West Africa by 2020 in the scenario without new interconnections.

One finds in red the areas where the marginal cost is the highest. Without surprise, the areas with the most expensive energy are located inside the continent; they do not have gas infrastructures or hydroelectric projects. In this case, the marginal units are regularly diesel units at the interior-continent price. For these areas the marginal cost is higher than 100 USD/MWh.

The units with a marginal cost slightly lower than the maximum are tagged in yellow. The marginal units in these areas are regularly less expensive units like coal (Senegal-Dakar and Niger-Salkadamna) or for which the importation from better located areas is regularly sufficient. They have a marginal cost between 90 and 100 USD/MWh.

Then there are the areas where the marginal unit is a gas turbine running on natural gas. This case is valid for all the southern part of West Africa (in green on the chart) where the marginal cost is between 80 and 90 USD/MWh.

Lastly, the areas where there are such hydroelectric possibilities that these units are often marginal are indicated in blue. For these sites, the marginal cost is lower than 80 USD/MWh.

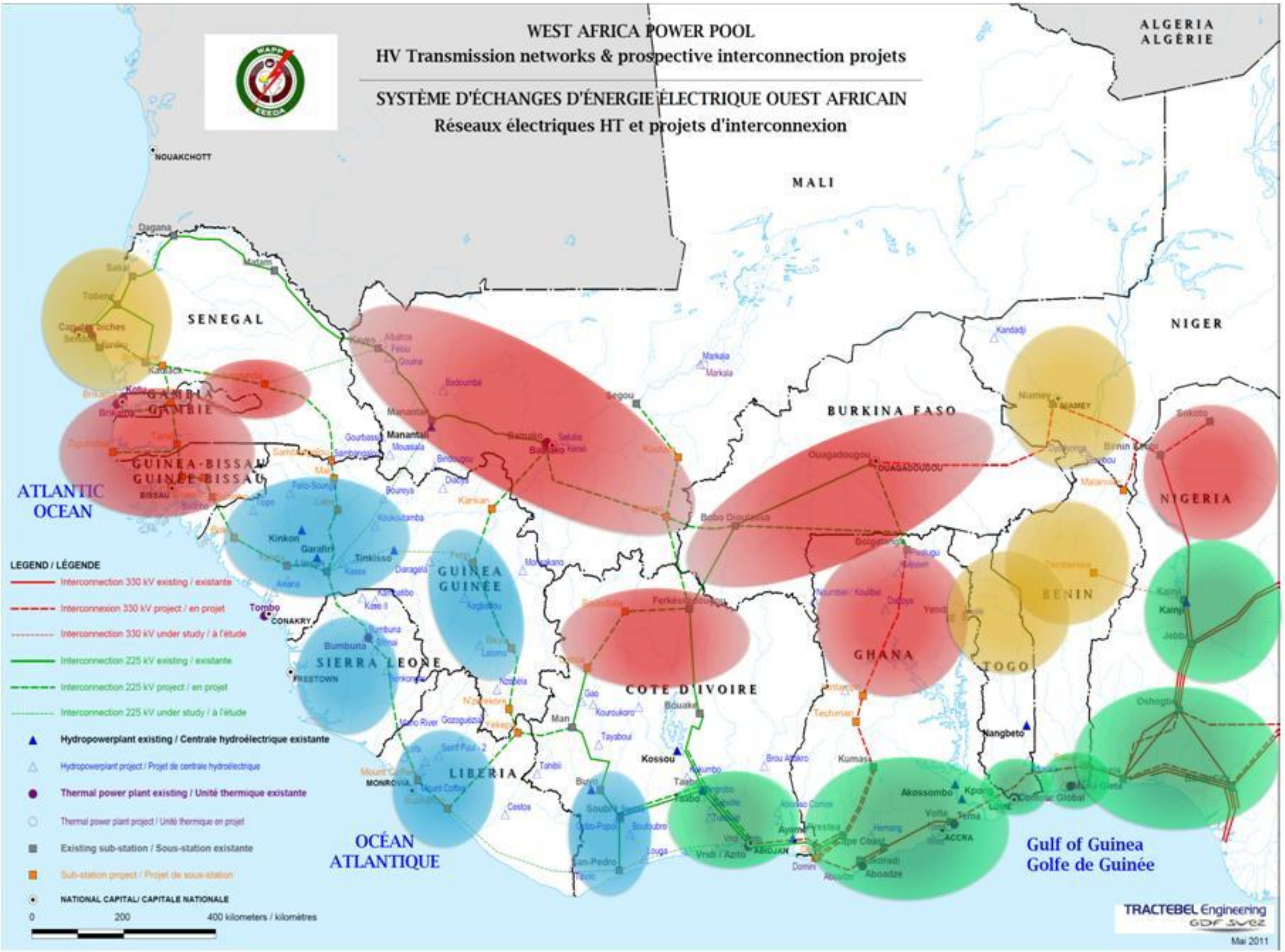


Figure 9 - Marginal cost by area in West Africa

2.4. Scenario without transit limits

This second scenario proposes an optimal development of the production park on the scale of the area by supposing that no limit of power transit applies between the countries all over the study period.

In order to take into account all the aspects of the problem, an alternative was considered making it possible to study the impact of the mining projects in the energy balance of the area of West Africa.

2.4.1. Energy mix

In terms of energy mix, the results presented hereafter are those in the absence of massive mining projects in Guinea, Guinea Bissau, Sierra Leone and Liberia.

2.4.1.1. INSTALLED CAPACITY

In terms of investment options, the observations made within the framework of the case without development of the interconnections remain applicable in this scenario.

The optimization carried out using the tool PRELE shows that the hydroelectric projects are massively selected based on purely economic criterion in spite of their particularly important capital cost because their operation cost is extremely low.

About thermal projects, the combined cycles are largely supported, mainly when they are fed with natural gas. Indeed, these units have a very low operation cost due to the combined effect of a very good efficiency and a low price fuel.

It is important to note that few projects using renewable sources are selected among the options investment. Only some wind projects are selected. Indeed, these projects are in general expensive to install and relatively not very effective because intermittent (solar and wind). Other criteria such as the profit in CO2 emissions are however favorable. The environmental and financial aspects will be considered in a forthcoming part of the study.

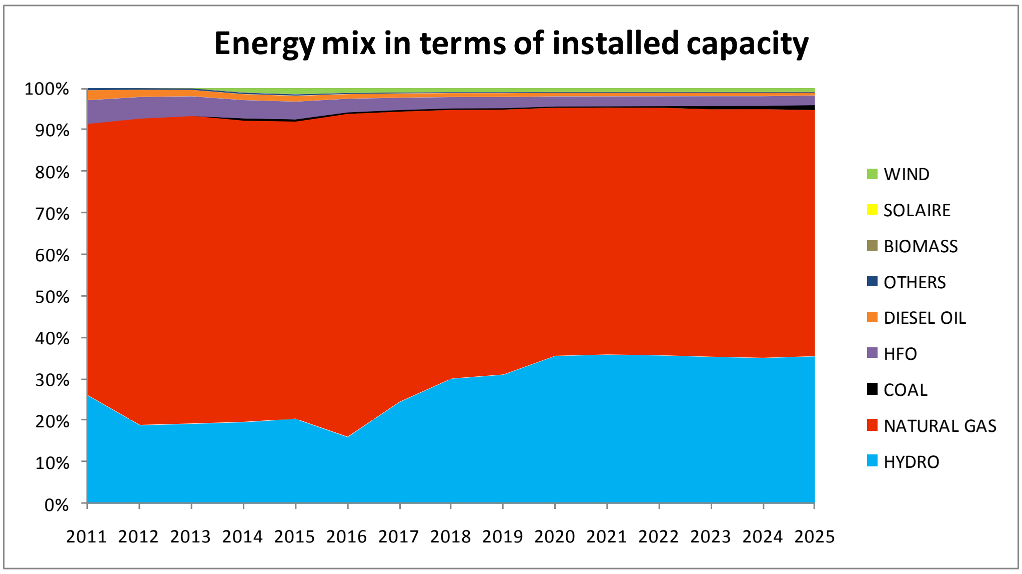


Figure 10 - Installed capacity by type of fuel in the scenario without transit limits

2.4.1.2. PRODUCED ENERGY

As in scenario 1, the economic stacking of the units wants that the least expensive units to operate run at maximum during all the year. Thus the hydroelectric units produce the maximum of energy which they are able to provide according to the climatic conditions. In the same way, the combined cycles burning natural gas function in base.

Nevertheless, the units burning other fuels are definitely exploited. In addition, the gas turbines have a low efficiency and run, in an optimum plan of production, only as peak units, even if they burn natural gas.

The coal and biomass projects are also used as base unit.

Intermittent renewable energies as for them are used as soon as the conditions allow it.

Lastly, while comparing with the case without development of new interconnections, it appears that the production of hydroelectricity is supported by the possibilities of exchanges between the countries and that the use of very expensive fossil fuels such as diesel decreases very appreciably.

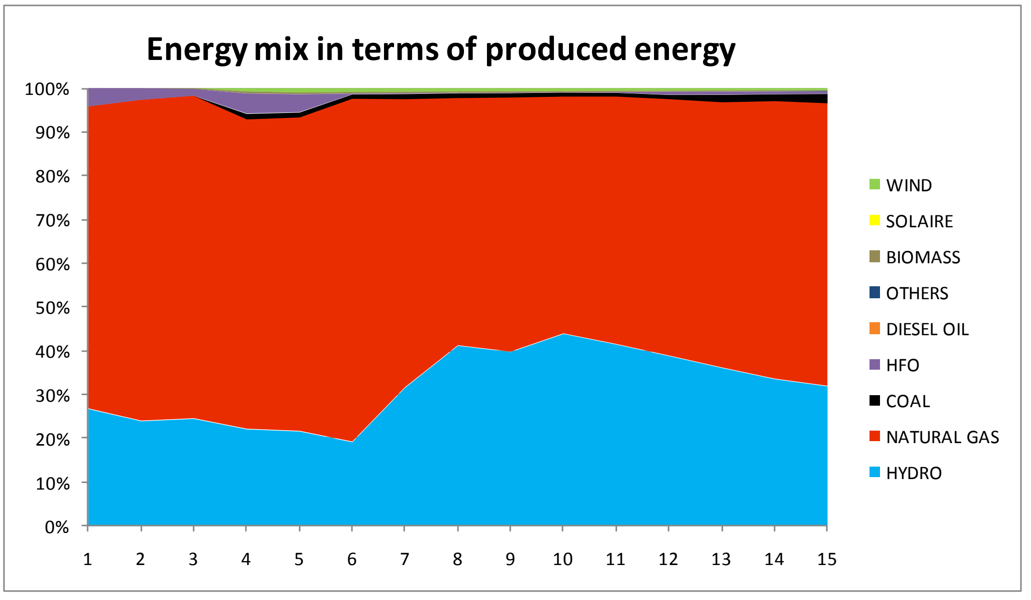


Figure 11 - Energy produced by type of fuel in the scenario without transit limits

2.4.2. Transit on the interconnection lines

In the long term, the hydroelectric projects should become the key of the energy production in West Africa. Guinea having an immense tank is brought to become strongly exporting in the next decades.

The other countries with a strong hydroelectric potential (in particular Sierra Leone with Bumbuna, Liberia with the St Paul project, Ivory Coast with the Soubre project) should also contribute in an important way to the electrical production in the area.

The countries having natural gas will also have a big role to play in terms of electrical production.

On the contrary, the countries having no important hydroelectric resources and no sources of natural gas supply (as Burkina Faso for example) will naturally import electricity in a market based exclusively on the economic criteria and without transit constraints.

Consequently, the interconnection projects of Guinea with its neighbors should be capital to allow the optimal exploitation of the hydroelectric potential in the area. Let us note consequently the interest of the projects Guinea - Mali, CLSG and OMVG.

Moreover, the axes feeding the importing areas of electricity (Burkina Faso and North of Ghana) will have also a considerable role to play. Thus the axis Mali - Burkina Faso - Ghana will be a very important section for supplying the electricity demand of the Center-North of the WAPP area.

2.4.3. Scenario with mining sector

In the various countries of the zone B, many projects are considered by 2020:

- Guinea Bissau: 100 MW
- Guinea: 700 MW
- Sierra Leone: 750 MW
- Liberia: 280 MW

These mining loads, if they were connected to the network, would considerably change the supply/demand balance for these countries.

Thus, the load of Sierra Leone would be multiplied by four and the country, initially exporting electricity thanks to the national hydroelectric projects, would become importer. Hydroelectric energy could not be any more evacuated towards the areas of the North-East because it would be consumed locally.

Consequently, additional production means will have to be implemented.

The electricity supply of the importing areas will be done primarily thanks to the coal projects in Senegal and Niger and thanks to the export from countries with natural gas reserves (Ghana). In this configuration, the priority projects will be those permitting to feed the Center-North of the WAPP area, in particular the South-North axis of Ghana.

2.5. Reference scenario

In this chapter, the reference scenario is presented.

For this scenario, the decided and planned transmission projects are commissioned at fixed date. An alternative will be carried out in order to analyze the impact of a delay on the planned projects.

The projects considered are regarded as investment options from 2018 on as well as the reinforcement of already existing axes or axes with fixed commissioning date.

In addition, a certain number of projects other than those already considered are proposed as investment options from 2018 on.

For production, the decided projects are commissioned at fixed date while the candidate projects are regarded as investment options from 2015 on for the thermal projects and from 2018 on for the hydroelectric projects.

Nevertheless, it should be noted that the hydroelectric projects proposed in the countries of the zone B could not reasonably be all set up by 2025 though many appear profitable from an economic point of view. Indeed, the financial limits of the countries, the environmental impacts, and the difficulties of accessibility will prevent the massive development of the hydroelectricity. Moreover, numerous projects could be entirely dedicated to the supply of the mining sector.

Consequently, in order to obtain a reference case which can be used as a basis for the development of a list of priority investments, some constraints were imposed according to the limits evoked here before and limiting the disproportionate investments in the countries having many hydroelectric resources.

The results of this optimization are presented hereafter.

- At first, the principal results in terms about the implemented production are presented;
- The interest of the national production projects is then discussed on basis of the results of the reference scenario;
- Among the projects which arise from the economic optimization, the projects answering the criteria hereafter are highlighted like potential regional projects:
  - Projects whose capacity is higher than 150MW;
  - Projects belonging to no regional entity (OMVS, OMVG);
  - Projects located near interconnection lines in order to allow the division of the capacity;
  - Projects not being directly dedicated with local activities (mines).
- Finally the priority transmission projects for sharing resources between the countries are highlighted.

2.5.1. Implemented production means

The optimization carried out using the tool PRELE shows that the hydroelectric projects are massively selected based on purely economic criterion in spite of their particularly important capital cost because their operation cost is extremely low.

About thermal projects, the combined cycles are largely supported, mainly when they are fed with natural gas. Indeed, these units have a very low operation cost due to the combined effect of a very good efficiency and a fuel at low prices.

The coal projects are also selected based on their economic performance.

It is important to note that few projects using renewable sources are selected among the options investment. Indeed, these projects are in general expensive to install and relatively not very effective because intermittent (solar and wind).

Nevertheless, it is remarkable to note that wind projects are economically profitable in the absence of subsidies in areas where few hydroelectric or gas resources are available and where the marginal cost is high on the short term. These projects have two advantages: they can be set up quickly and they will propose, in the short term, a partial alternative to liquid fuels.

The figure hereafter presents the annual energy mix of the area of West Africa in terms of installed capacity.

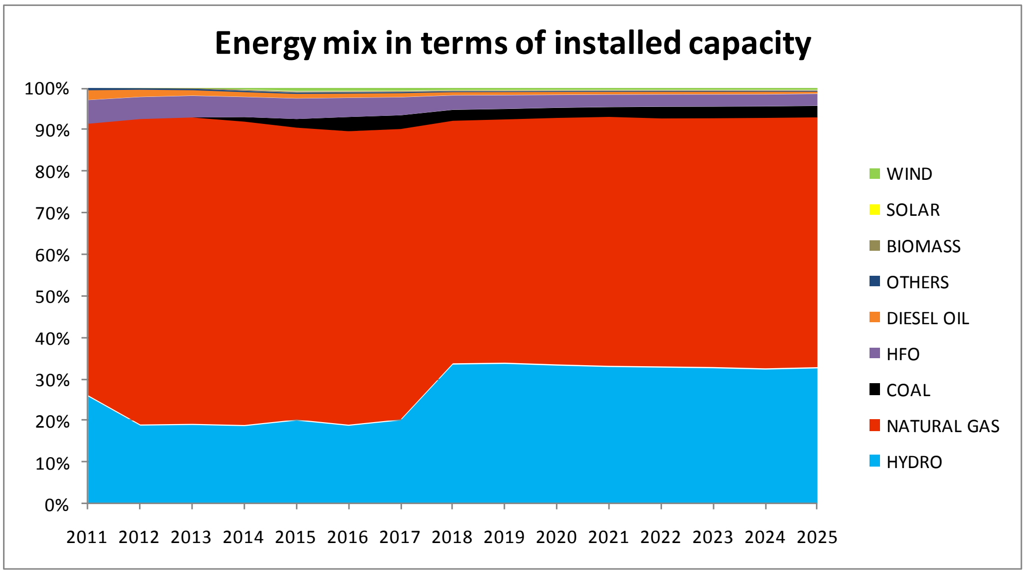


Figure 12 - Installed capacity by type of fuel in the reference scenario

In terms of produced GWh, the economic optimum wants that the least expensive units to operate run at maximum during all the year. Thus the hydroelectric units produce the maximum of energy which they are able to provide according to the climatic conditions (average energy or guarantee). In the same way, the combined cycles burning natural gas run in base production.

Intermittent renewable energies as for them are used as soon as the conditions allow it. And the coal and biomass projects are also used as base units.

Nevertheless, the units burning other fuels are definitely less operated. In addition, the gas turbines have a low efficiency and run, in an optimum production plan, only as peak units, even if they burn natural gas.

Lastly, while comparing with the case without development of new interconnections, it appears that the production of hydroelectricity is supported by the exchanges possibilities between countries and that the use of very expensive fossil fuels such as the diesel decreases very appreciably.

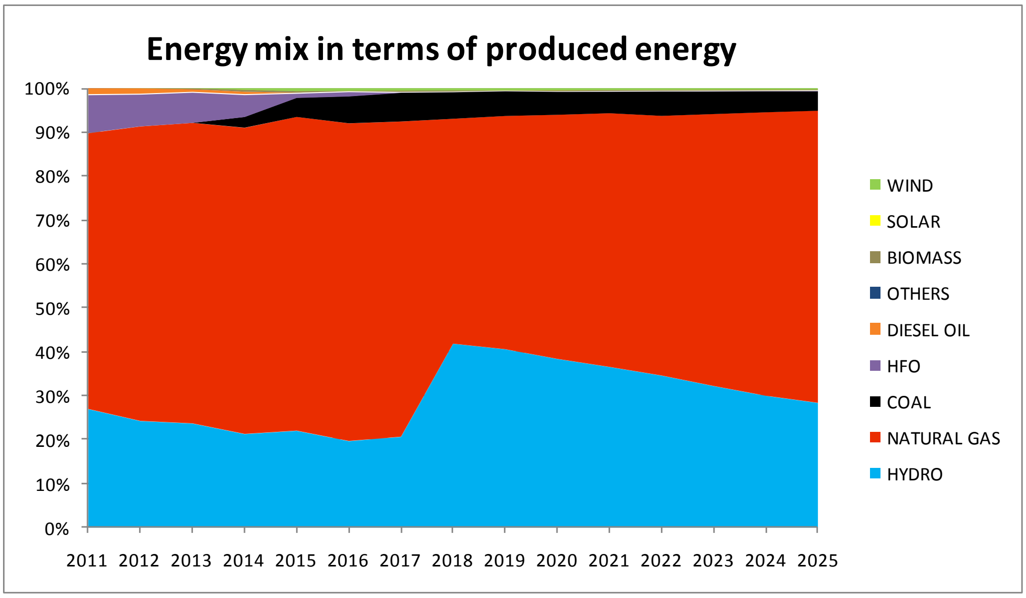


Figure 13 – Produced energy by type of fuel in the reference scenario

2.5.2. National production projects

2.5.2.1. SENEGAL

Supply-demand balance

The coal power plants decided for the Senegal strongly modify the energy mix of the country. Indeed, in the absence of significant gas and hydroelectric resources, Senegal used, until now, liquid fuels to feed the national load.

From a regional point of view, Senegal should export part of the electricity generated by coal plants to the neighbouring countries) as soon as these plants will be installed.

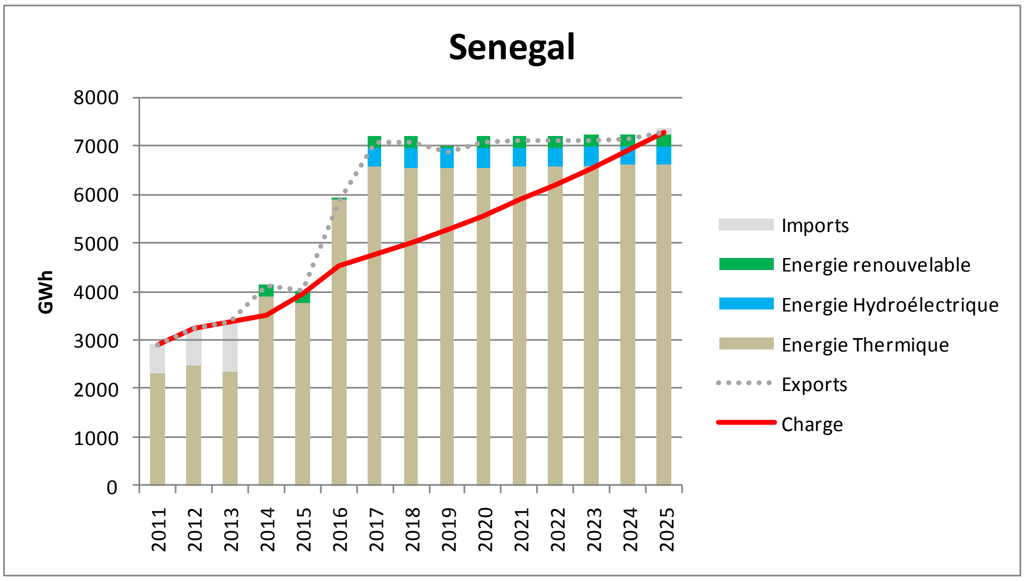


Figure 14 - Supply-demand balance in energy for Senegal

Marginal cost

The coal units allow a significant decrease of the marginal cost of Senegal.

If no new interconnection was built (national development scenario), the marginal cost in the long term would be identical to the reference scenario since Senegal does not count on the importation to reduce its marginal cost

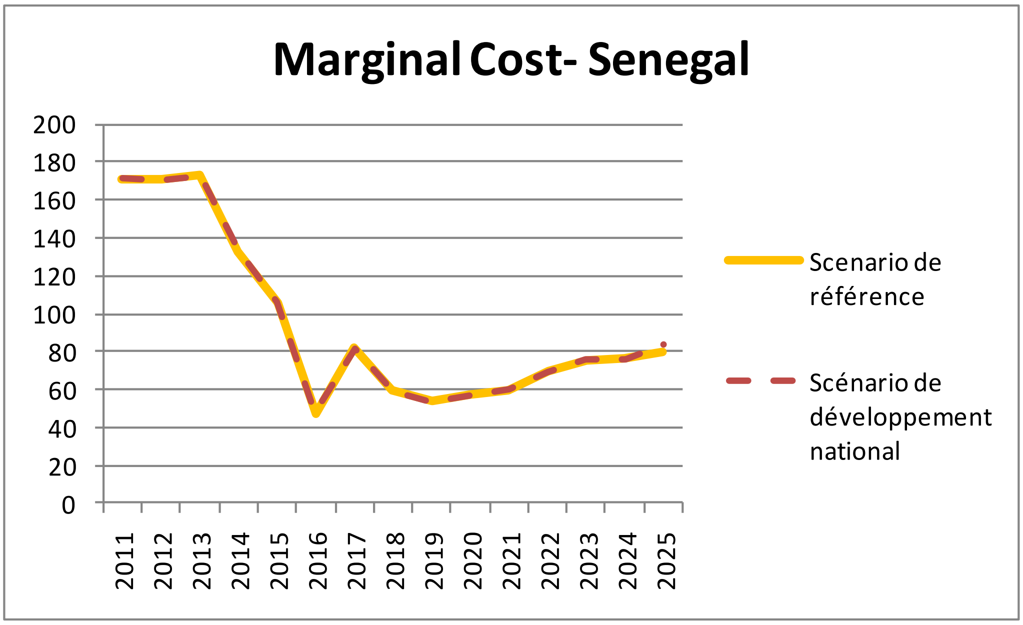


Figure 15 - Trend of marginal cost [$/MWh] in Senegal

National projects

In addition to the projects already decided for the country and to the regional projects, Senegal has a certain number of national projects which could help with the load supply at lower costs.

This section lists the candidate projects and presents their advantages within the framework of the optimal plan of regional development

1) **Installation of mobile HFO units in Tobin and in the harbour of Bel-Air**
   With the coal projects in the medium term in Senegal, the mobile HFO units are not selected by the optimization tool. However, if the coal projects were delayed, the HFO units would become an interesting alternative.

2) **Installation of HFO units in the isolated centers of Ziguinchor and Tambacounda**
   These units are important in the short term for the supply of these isolated centers but should not be used any more when the OMVG loop is commissioned. Indeed, the importation of energy from Guinea and the area of Dakar would permit to reduce the marginal cost of these centers.

3) Commissioning of a wind site of 125MW from 2014 on

From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area. Moreover, given that wind projects have the advantage of being set up quickly, they could be considered in case of delay in coal projects.

4) Solar park of 7.5MW in Ziguinchor

From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

5) Construction of several diesel units of 30 to 60MW

On the very short term, the existing and decided projects should be sufficient for supplying the load if fuels are available to feed the units. In the medium and long term, alternatives to liquid fuels should be installed. Consequently, the diesel units are not optimal from a purely economic point of view. Nevertheless being given their low investment costs and their fast installation, they could be planned to fill a possible delay in the other projects.

Conclusions

In conclusion, for Senegal, the development plan by 2025 should be based on the decided coal units, allowing bringing back the marginal cost of the country to a lower level.

In case of delay in these projects, it will be necessary to invest in units running on HFO and diesel or wind plants, with the advantage of fast installation and low capital cost. It is reminded however that the units using liquid fuels have a very high operation cost and that they should not be privileged by Senegal.

By 2020, Senegal should rely on the importation from the hydroelectric projects and in particular OMVS and OMVG projects, in addition to the national projects already set up.

After 2020, the coal option should be selected again as investment option because the hydroelectric projects could become insufficient for the supply of the national load.

The table below shows the principal national developments selected by the optimization tool among the candidate projects according to purely economic criteria and to the horizon of the study.

Name	***Technology***	***Fuel***	***Commissioning***	***Capacity***
Ziguinchor	Diesel	HFO	2012	2*5 MW
Tambacounda	Diesel	HFO	2012	2*4 MW

Table 34 - National projects for Senegal

2.5.2.2. THE GAMBIA

Supply-demand balance

From a regional point of view, The Gambia should import part of its electricity from the hydroelectric sites of neighbouring countries (in particular OMVG) as soon as it is interconnected.

In the short term, the wind potential of the country could be an interesting alternative to fossil fuels. This technology indeed has the advantage of being able to be setting-up quickly, by 2012-2014.

Let us note that in The Gambia, the marginal cost is very high in the short term. This configuration supports the development of wind energy.

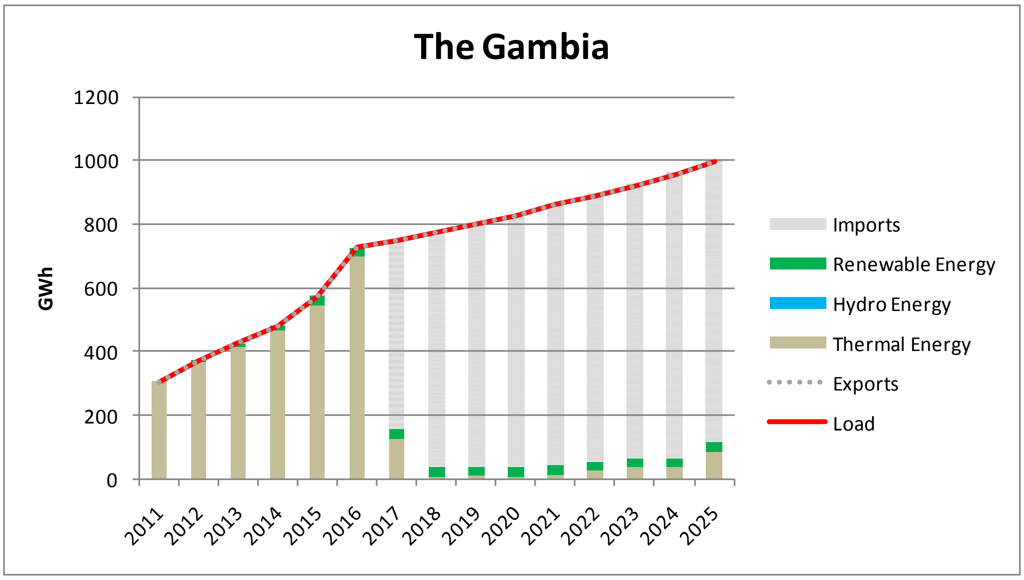


Figure 16 - Supply-demand balance in energy for The Gambia

Marginal cost

The marginal cost of The Gambia is very high in the short term. The investment in wind energy makes it possible to reduce this cost slightly but it is especially the importation which will allow The Gambia to feed the demand for electricity at lower costs.

If no new interconnection were built (national development scenario), The Gambia would not have any other possibility than investing in units burning liquid fuels.

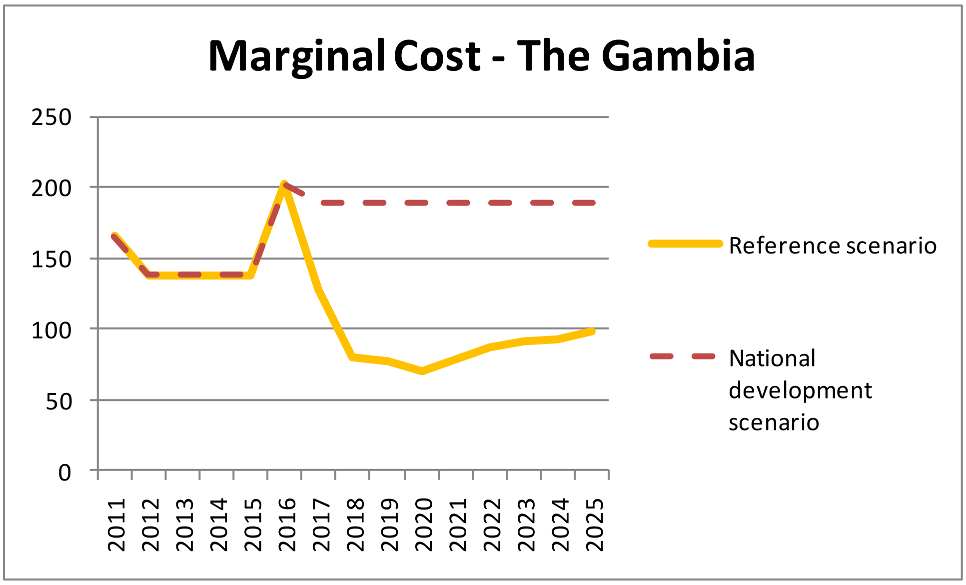


Figure 17 - Trend of marginal cost [$/MWh] in The Gambia

National projects

In addition to the projects already decided for the country and to the regional projects, The Gambia has a number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects their interest within the framework of the optimal plan of regional development.

1) Extension of the power plant of Brikama 2x10 MW in 2013

The extension of the power plant of Brikama is essential from 2015 on to secure the supply of the country until the interconnection of The Gambia with the neighbouring countries (thanks to the OMVG loop envisaged in 2017).

2) Wind project of 4MW in 2014 and its extension of 6MW after 2015

The wind projects are selected by the optimization tool because they are envisaged in the short term and that they will help reducing the marginal cost of The Gambia, currently very high.

3) Solar project of 10MW

From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

4) Combined cycle of 60MW after 2014

From a purely economic point of view, it is more interesting, in the medium term, to import electricity since countries having hydroelectric resources (in particular thanks to the OMVG) than producing locally with liquid fuels. Nevertheless, in case of delays in the hydroelectric projects or the construction of the regional transmission network, The Gambia could locally produce its electricity starting from a combined cycle running on HFO.

Conclusions

In conclusion, for The Gambia, the development plan by 2015 should be based on the decided and candidate thermal units and on a wind project making it possible to bring back the marginal cost of the country to a lower level.

By 2020 and later, The Gambia should rely on the importation from the hydroelectric projects and in particular OMVG projects in addition to the national projects already set up.

In case of delay in these projects, new thermal units should nevertheless be built in The Gambia, in particular a combined cycle running on HFO. Moreover, an important reserve in terms of thermal energy must be maintained in The Gambia in order to mitigate a possible shortage of hydroelectric electricity (dry year) or an unavailability of the grid.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study.

Name	***Technology***	***Fuel***	***Commissioning***	***Capacity***
Brikama Extension	Diesel	HFO	2015	2*10 MW
The Gambia Wind 1	Wind Turbine	WIND	2014	4 MW
The Gambia Wind 2	Wind Turbine	WIND	2015	6 MW

Table 35 - National projects for The Gambia

2.5.2.3. GUINEA BISSAU

Supply-demand balance

From a regional point of view, Guinea Bissau should import part of its electricity from the hydroelectric sites of neighbouring countries (in particular OMVG) as soon as it is interconnected.

In the short term, Guinea Bissau should supply its load with its thermal resources. Unfortunately, the projects in the short term are not sufficient to feed all the demand. This is why the marginal cost is very high during the first part of the study period. In practice, that means that part of the auto- producers will continue to feed the load which cannot be supplied by the network.

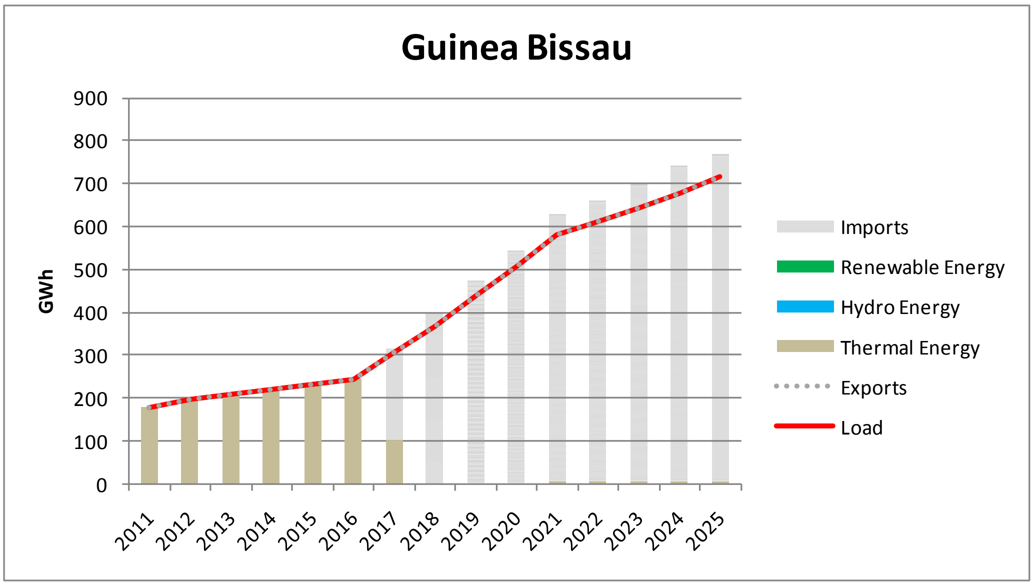


Figure 18 - Supply-demand balance in energy for Guinea Bissau

Marginal cost

The marginal cost of Guinea Bissau is very high in the short term because of the lack of production means, which is actually compensated by the auto-producers.

In the longer term, the hydroelectric projects of the OMVG in particular will help reducing strongly the marginal cost of the area.

If no new interconnection were built (national development scenario), new thermal units should be built to feed the load and the marginal cost would be much higher.

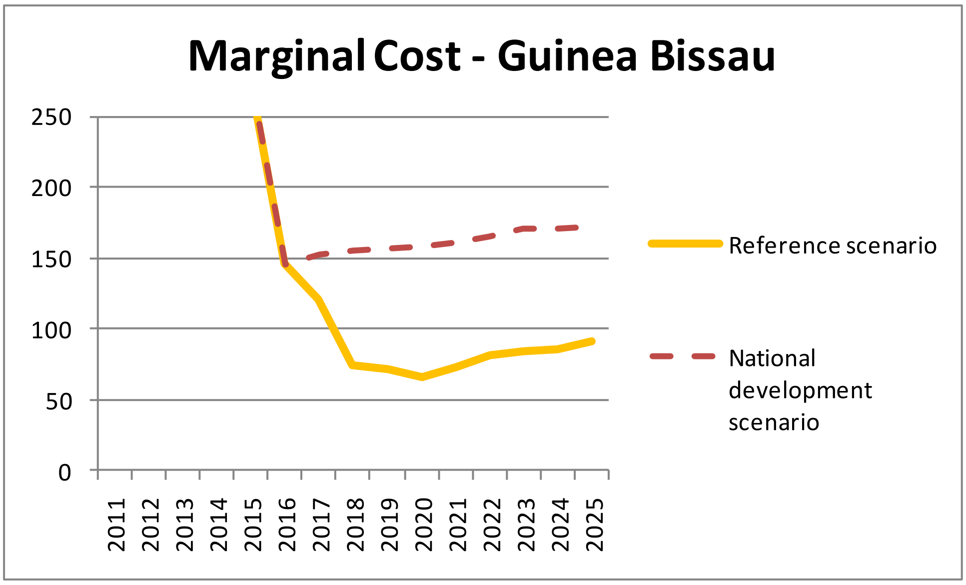


Figure 19 - Trend of marginal cost [$/MWh] in Guinea Bissau

National projects

In addition to the projects already decided for the country and to the regional projects, Guinea-Bissau has a number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) **Project of an HFO power plant of 55MW around Bissau**

   A new power plant running on HFO would be essential as early as possible to reabsorb the unserved demand. Nevertheless, considering that the feasibility studies must still be realized and that the 30kV loop around Bissau must be built to allow the supply of the load, the horizon 2015 seems reasonable for this power plant.

2) **Hydroelectric plant of Saltinho within the framework of the OMVG**

   The hydroelectric project of Saltinho is less competitive than the other hydroelectric projects. Consequently, based on purely economic criterion, this installation is not justified. Nevertheless, its development within the framework of the OMVG and its proximity with the axis of transport of the OMVG gives to this project an additional value. Moreover, it would help reducing the energy dependence of Guinea Bissau.

Conclusions

In conclusion, for Guinea Bissau, the development plan by 2015-2017 should be based on the decided and candidate thermal units in order to limit the quantity of unserved energy.

By 2020 and later, Guinea Bissau should rely on the importation since the hydroelectric projects and in particular on the OMVG projects in addition to the national projects already set up. Among the projects of the OMVG, the installation of Saltinho is less competitive from an economic point of view but could be justified for other reasons (political, technical, environmental and/or financial).

In case of delay in these projects, new thermal units should nevertheless be built in Guinea Bissau. Moreover, an important reserve in terms of thermal energy must be maintained in Guinea Bissau in order to mitigate a possible shortage of hydroelectric electricity (dry year) or an unavailability of the grid.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study.

Name	***Technology***	***Fuel***	***Commissioning***	***Capacity***
Bissau	Diesel	HFO	2015	55 MW

Table 36 - National projects for Guinea Bissau

2.5.2.4.

2.5.2.5. GUINEA

Supply-demand balance

From a regional point of view, Guinea should tend towards the export of the energy produced on its territory with its hydroelectric resources.

Nevertheless, the installation of hydroelectric projects is relatively long and in the short term, Guinea will have to use thermal production means to cover its load. In the absence of production means, part of the load will be not served.

Let us note that if the interconnection lines towards the countries of zone A, having gas resources, was suddenly commissioned before the hydroelectric projects are developed in Guinea, the country would be slightly importing (2015-2016).

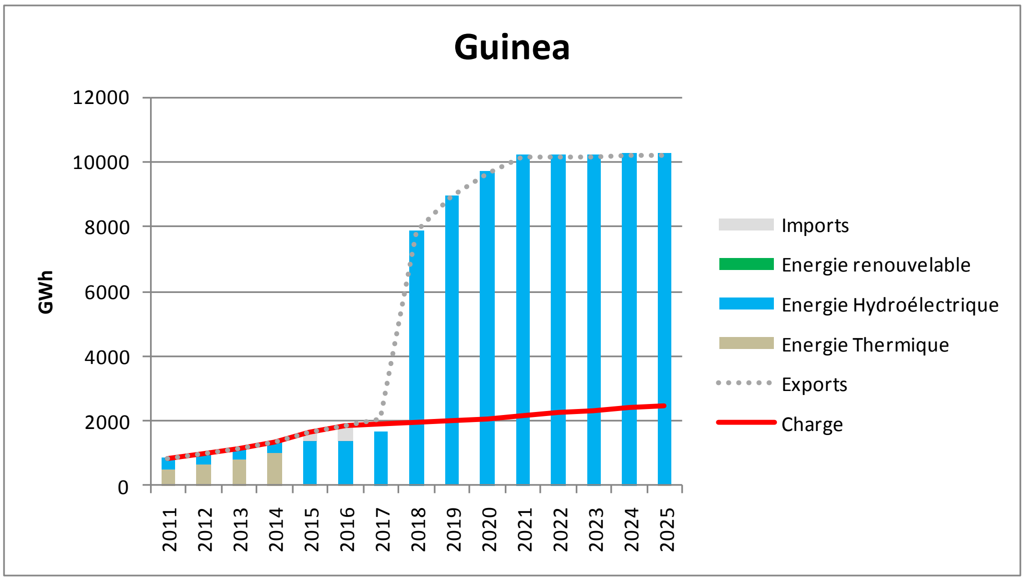


Figure 20 - Supply-demand balance in energy for Guinea

Marginal cost

The marginal cost of Guinea is very high in the short term because of the lack of production means.

In the longer term, the hydroelectric projects of the OMVG, OMVS and the national projects will help reducing strongly the marginal cost of the area.

If no new interconnection was built (national development scenario), the marginal cost in the long term would be identical to the reference scenario since Guinea does not count on the importation to reduce its marginal cost. Let us note however that during the period 2015-2017, the reference scenario shows that the economic optimum recommends that Guinea imports its energy from the countries with gas resources, which is not possible in the isolated case and what explains the delay in the resorption of unserved energy.

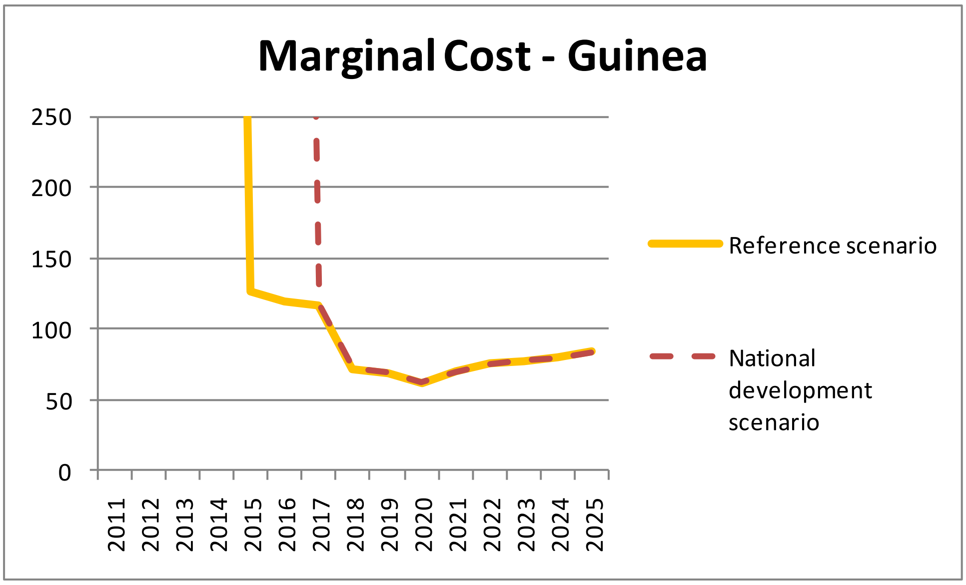


Figure 21 - Trend of marginal cost [$/MWh] in Guinea

National projects

Among the candidate projects for Guinea, many hydroelectric installations belong to the projects of the OMVG and the OMVS. These projects are presented in section 2.5.3.

In addition, based on criteria defined in section 2.5, five Guinean projects were adopted as regional projects: **Souapiti**, **Amaria**, **Bonkon Diara**, **Grand Kinkon** and **Kassa**. These projects are described more precisely in section 2.5.4.

Lastly, in addition to the projects already decided for the country and to the regional projects, Guinea has a several national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) National hydroelectric projects

In Guinea, the majority of the projects are justified from an economic point of view:

- The site of **Poudaldé** on the Cogan River close to Tiopo is planned for 2017. It presents a lower price than Tiopo and is very interesting for Guinea.
- The site of **Fomi** is also very interesting for its cost and its localization, near the town of Kankan and on the 225kV axis Guinea-Mali.
- Another projects in High-Guinea, namely **Kouravel** is also competitive. Moreover, its localization near the town of Labé and the main 225kV axes makes it interesting for the load supply in all the West circuit area of Guinea.

Conclusions

In conclusion, for Guinea, the development plan by 2015-2017 should be based on the decided and candidate thermal units in order to limit the quantity of not served energy.

As soon as possible, the local hydroelectric sites should nevertheless be invested in order to reduce the marginal cost in Guinea.

Let us note that the number of projects which are justified economically is particularly high in Guinea. They cover much more than the local load and the energy produced by these projects is partially intended for export in the reference scenario. It is obvious that all these projects could not be commissioned by 2025 even though it represents the economic optimum. Consequently, other aspects such as the environmental parameters, the accessibility of the sites and the possibilities of connection to the interconnected network will have to be taken into account in order to select the projects which should be highlighted by the local authorities.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study. The most economically interesting national hydroelectric projects should be commissioned with priority and their development is estimated for 2018-2019. The competitive but slightly more expensive projects have a commissioning date estimated at 2020.

Name	*Technology*	*Fuel*	*Commissioning*	*Capacity*
Poudalde	Hydro	HYDRO	2017	90 MW
Fomi	Hydro	HYDRO	2019	90 MW
Kouravel	Hydro	HYDRO	2021	135 MW

Table 37 - National projects for Guinea

2.5.2.6. SIERRA LEONE

Supply-demand balance

From a regional point of view, Sierra Leone should tend towards the export of the energy produced on its territory being given its many hydroelectric resources.

Nevertheless, the installation of hydroelectric projects is relatively long and, in the short term, Sierra Leone will have to use thermal production means in addition to the hydroelectric energy of Bumbuna I to cover its load.

Let us note that if the interconnection lines towards the countries of the zone A, having gas resources, had suddenly been commissioned before the hydroelectric projects are developed in Sierra Leone, the country would become slightly importer (2015-2016).

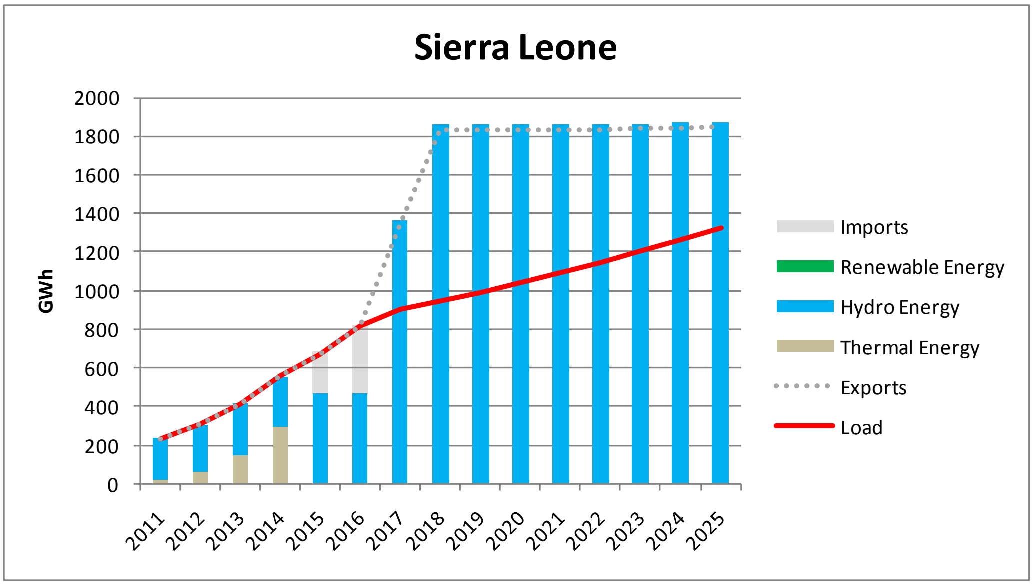


Figure 22 - Supply-demand balance in energy for Sierra Leone

Marginal cost

In the short term, the marginal cost of Sierra Leone should increase because the share of the electricity produced from cheap resources (Bumbuna I) will decrease.

In the longer term, the national hydroelectric projects will help reducing strongly the marginal cost of the country.

If no new interconnection were built (national development scenario), the marginal cost in the long term would be identical to the reference scenario since Sierra Leone does not count on the importation to reduce its marginal cost. Let us note however that during the period 2015-2017, the reference scenario shows that the economic optimum recommends thin Sierra Leone imports its energy from countries with gas resources, which is not possible in the isolated case. It explains why the marginal cost is higher during this period.

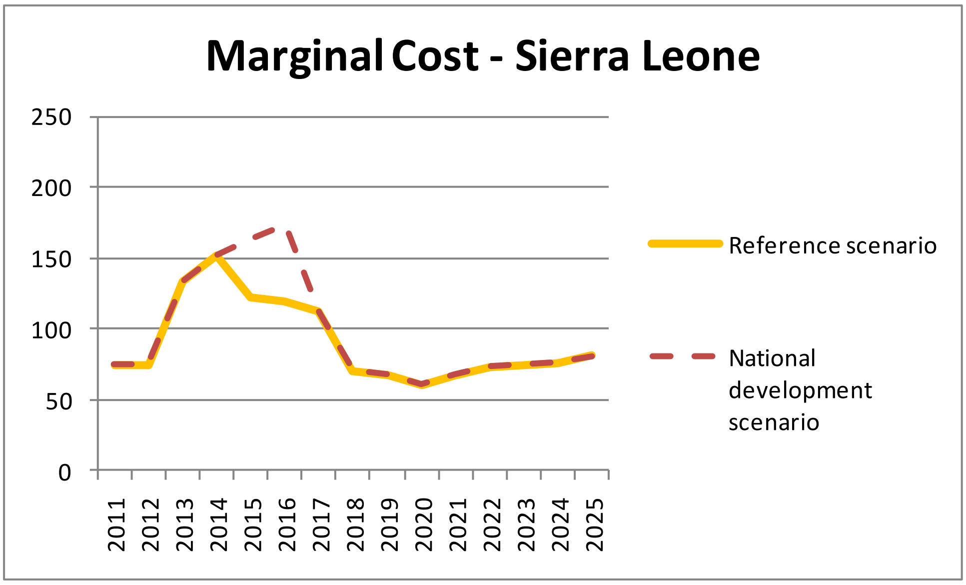


Figure 23 - Trend of marginal cost [$/MWh] in Sierra Leone

National projects

Based on criteria defined in section 2.5, the Bumbuna project and the Mano River project at the border of Sierra Leone and Liberia are adopted as regional project. These projects are described in section 2.5.4.1.

In addition to the projects already decided for the country and to the regional projects, Sierra Leone has a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) Hydroelectric projects

The installation of Benkongor is considered only in the long term, after the horizon of this study. Only phase III of Benkongor is considered in the medium term and this installation is justified economically

The other hydroelectric projects are considered in the longer term since no feasibility study exists. Moreover, they are not part of the development plans described by the Ministry of Energy in its document "Sierra Leone Energy Sector: Prospective customers & Challenges". Lastly, the projects of Kambatibo, Bitmai and Goma have a relatively high cost, making these projects less competitive.

2) Project of a 100 MW biomass power plant

From a purely economic point of view, the biomass projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

3) Sugar project which could produce 15MW from bagasse

From a purely economic point of view, the biomass projects are not justified in the area. However, coupled to an industrial activity, this project makes sense.

4) Project of solar power plant of 5 MW

From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

Conclusions

The development plans for Sierra Leone are of 2 types; hydroelectric and renewable (biomass and solar). In a purely economic scenario however, the renewable projects are not competitive. On the other hand, the hydroelectric resources of the country should be exploited as soon as possible, for the supply of the domestic load, the supply of the mining sector if this one suddenly develops in Sierra Leone or for exporting towards areas without hydroelectric resources.

On the very short term nevertheless, it will be necessary to invest in units burning liquid fuels to satisfy the electric demand, waiting for the deployment of the hydroelectric sites of Bumbuna and, in the longer term, of Benkongor.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study.

Name	***Technology***	***Fuel***	***Commissioning***	***Capacity***
BENKONGOR 3	Hydro	HYDRO	2018	85 MW

Table 38 - National projects for Sierra Leone

2.5.2.7. LIBERIA

Supply-demand balance

From a regional point of view, Liberia should tend towards the export of the energy produced on its territory with its hydroelectric resources.

Nevertheless, the commissioning of hydroelectric projects is relatively long and, in the short term, Liberia will have to use thermal production means to cover its load.

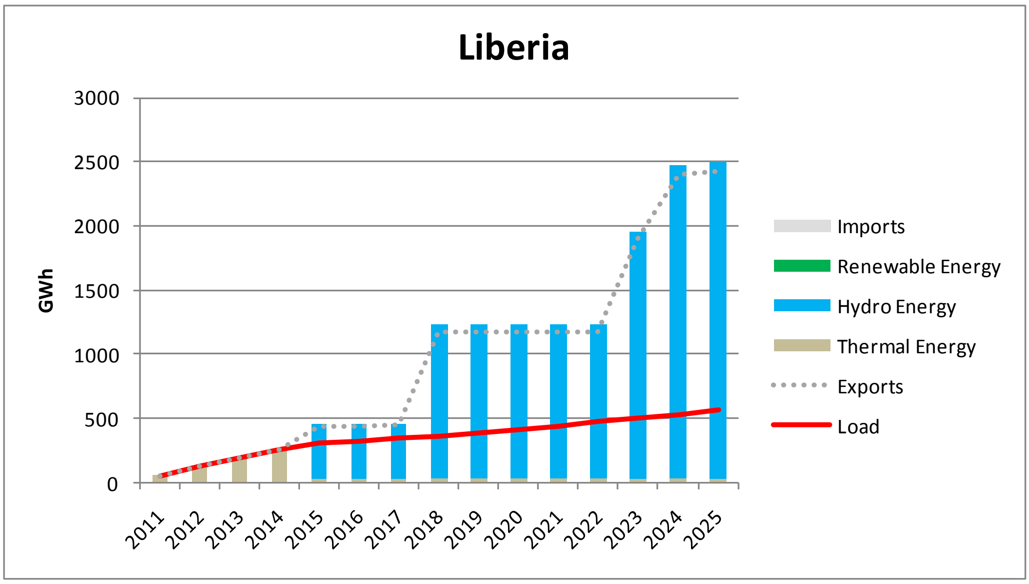


Figure 24 - Supply-demand balance in energy for Liberia

Marginal cost

In the short term, the marginal cost of Liberia is very high because electricity is produced from diesels group whose operation costs are very high.

In the longer term, the national hydroelectric projects will help reducing strongly the marginal cost of the country.

If no new interconnection were built (national development scenario), the marginal cost in the long term would be identical to the reference scenario since Liberia does not count on the importation to reduce its marginal cost.

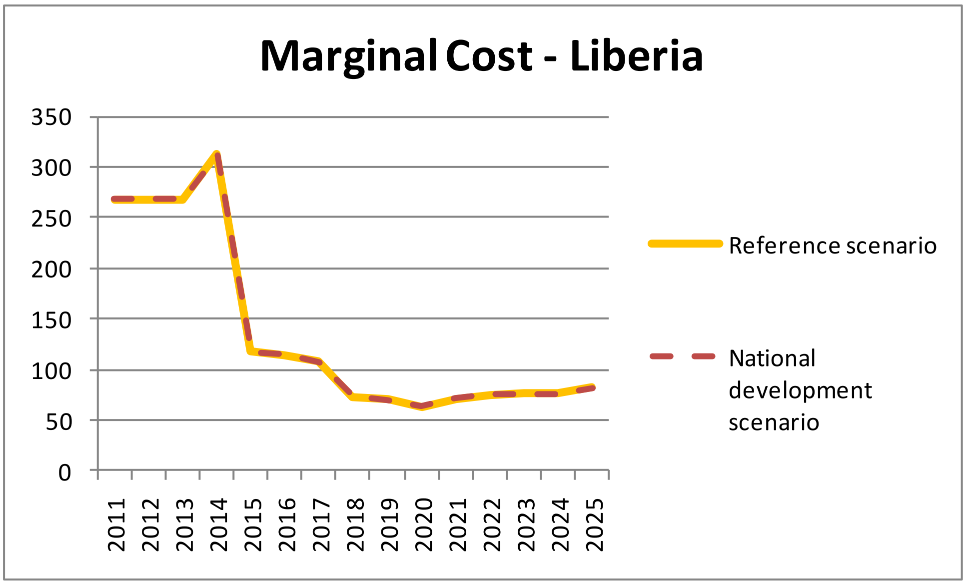


Figure 25 - Trend of marginal cost [$/MWh] in Liberia

National projects

Based on criteria defined in section 2.5, the Mano River project at the border of Sierra Leone and Liberia is adopted as regional project. In the same way, the Tiboto project at the border of Ivory Coast and Liberia is also highlighted at the regional level. These projects are described in section 2.5.4.1.

In addition to the projects already decided for the country and to the regional projects, Liberia has a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) **Buchanan project of 35 MW (2 X 17.5 MW) located at Kakata**

   This project, using shavings as combustible is not justified economically. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

2) **Hydroelectric projects**

   In Liberia, the most promising projects are those located on the **Saint-Paul River**. The first phase of the project with the sites from Saint-Paul 1B and 2 is fully justified on the economic plan. The second phase of Saint-Paul project consists in an additional tank (“Ultimate” Via Storage) and is however considered in the longer term. Moreover the impact of this tank for the environment could prove to be a critical element. Consequently, this extension is not considered to the horizon of the study

   The other hydroelectric sites identified on the Lofa (total of 29 MW), Holy John (total of 67 MW) and Cestos (total of 41 MW) rivers are as for them less competitive from an economic point of view. However, their small size could make the implementation of these projects easier.

3) **30 MW of semi-rapid diesel groups (6*5 MW) running on HFO on the site of Bushrod**

The commissioning of these groups is envisaged in the medium term and it will not be necessary if the hydroelectric projects are developed according to the program considered. Nevertheless, any delay in the hydroelectric projects will have to be compensated by thermal projects in order to secure the supply of electricity.

Conclusions

The development plans for Liberia are of 2 types; hydroelectric and renewable (biomass). In a purely economic scenario however, the renewable projects are not competitive. On the other hand, the hydroelectric resources of the country should be exploited as soon as possible, for the supply of the domestic load, the supply of the mining sector if this one suddenly develops in Liberia or for exporting towards areas without hydroelectric resources.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study.

Name	***Technology***	***Fuel***	***Commissioning***	***Capacity***
SAINT-PAUL 1B	Hydro	HYDRO	2020	78 MW
SAINT-PAUL 2	Hydro	HYDRO	2020	120 MW

Table 39 - National projects for Liberia

2.5.2.8. MALI

Supply-demand balance

From a regional point of view, Mali should import part of its electricity from the hydroelectric sites of neighbouring countries (in particular OMVS).

In complement, the own hydroelectric resources of the country are privileged by the optimization tool.

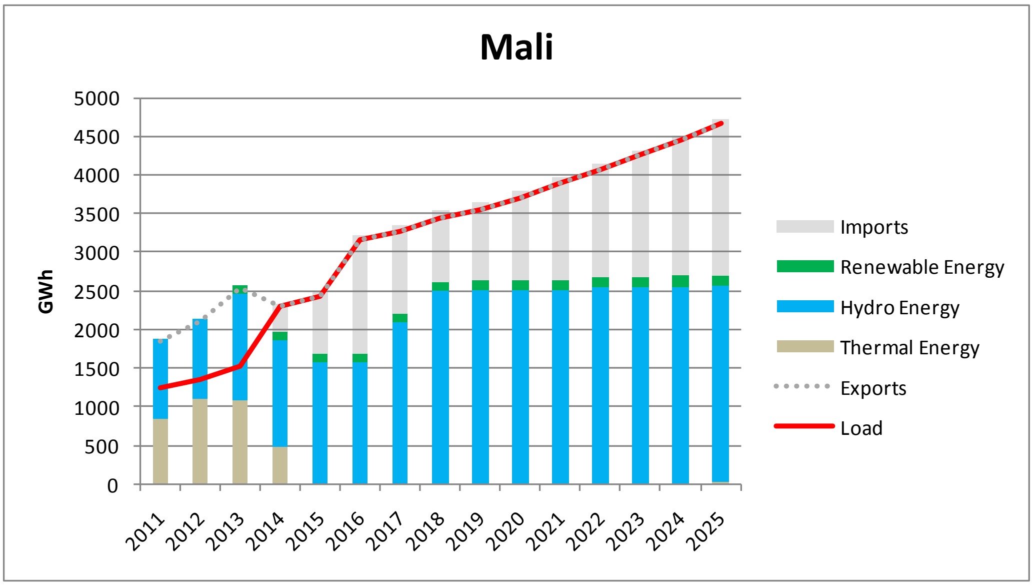


Figure 26 - Supply-demand balance in energy for Mali

Marginal cost

The energy mix of Mali, based on hydroelectric and thermal resources, helps the country to reach an average marginal cost in the short term, and lower than in the other countries of zone B.

In the longer term, the hydroelectric potential of the neighbouring countries would make it possible to reduce further this marginal cost.

If no new interconnection were built (national development scenario), the marginal cost in the long term would be higher than in the reference scenario because Mali should exploit thermal resources in complement of hydroelectric energy.

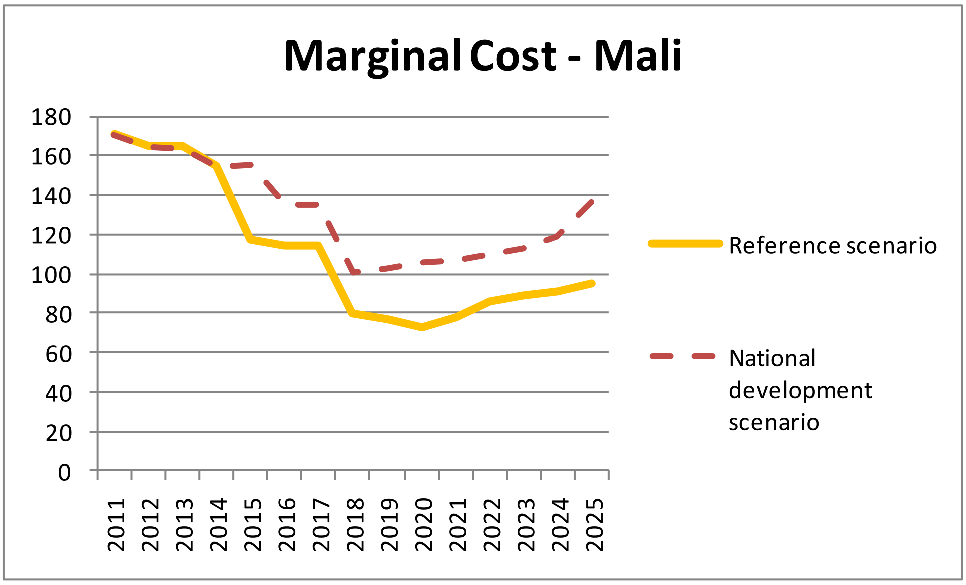


Figure 27 - Trend of marginal cost [$/MWh] in Mali

National projects

In addition to the projects already decided for the country and to the regional projects (projects OMVS presented in section 2.5.3), Mali has a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) **Hydroelectric projects**

The run-of-river hydroelectric project of **Kenié** is fully justified economically.

For the region, the other small projects (**Sotuba** 2, **Taoussa**, **Markala**) are less competitive than the great installations under consideration in the other countries of the zone. Nevertheless, from a national point of view, these projects are interesting because their financing will be easier than for the great projects. Moreover, they are important for the Malian population since they are partly dedicated to agriculture.

2) **The agro-industrial project of Markala**

From a purely economic point of view, the biomass projects are not justified in the area. However, coupled to an industrial activity, this project makes sense.

3) **Solar projects of Mopti and the project of a small hybrid power plant**

From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

4) **A combined cycle of 150MW**

This project envisaged by the Emergency plan and of Electric Safety of Energy supply of the EEEOA would not be justified if all the hydroelectric projects under consideration in the area were carried out in the intended deadlines. Nevertheless, any delay in the hydroelectric projects will have to be compensated by thermal energy.

Conclusions

In conclusion, for Mali, the development plan by 2015 should be based on the existing and decided hydroelectric and thermal units.

By 2020, Mali should rely on the regional (OMVS) and national hydroelectric projects (Kenié) in addition to the national projects already set up.

In case of delay in these projects, it will be necessary to invest in units running on HFO and diesel which have the advantage of being able to be commissioned more quickly and whose capital cost is lower. Let us recall however that these units have a higher operation cost and that they should not be privileged in Mali.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study.

Name	*Technology*	*Fuel*	*Commissioning*	*Capacity*
KENIE	Hydro	HYDRO	2016	42 MW

Table 40 - National projects for Mali

2.5.2.9. IVORY COAST

Supply-demand balance

From a regional point of view, Ivory Coast should tend towards the export of part of its electricity. Indeed, this country has at the same time important hydroelectric resources and a gas potential to exploit.

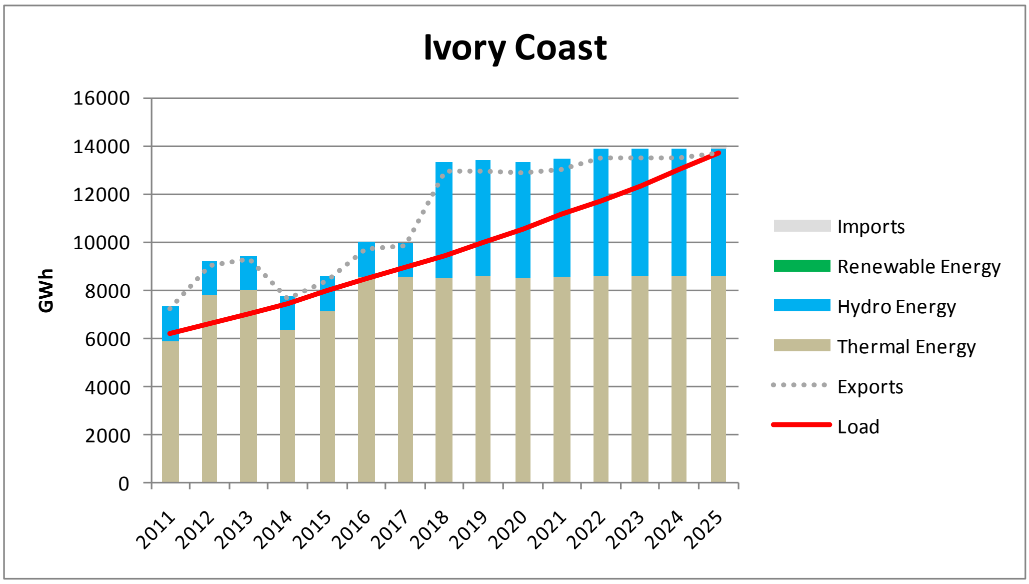


Figure 28 - Supply-demand balance in energy for Ivory Coast

Marginal cost

The energy mix of Ivory Coast, based on hydroelectric and thermal resources (gas), permits to reach a low marginal cost in the country in the short term.

In the longer term, its hydroelectric and gas potential should help reducing even further this marginal cost.

If no new interconnection were built (national development scenario), the marginal cost in the long term would be identical to the reference scenario since Ivory Coast does not count on the importation to reduce its marginal cost.

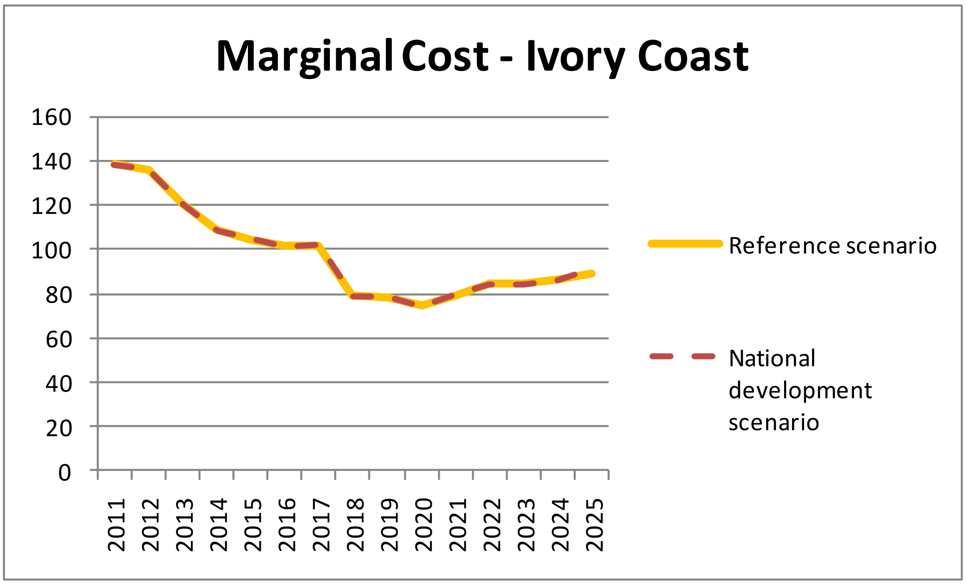


Figure 29 - Trend of marginal cost [$/MWh] in Ivory Coast

National projects

Based on criteria defined in section 2.5, the Tiboto project at the border between Ivory Coast and Liberia are highlighted at the regional level. In the same way, the projects of Soubré and Botoubré are projects which could be exploited at regional level. These projects are described in section 2.5.4.1.

In addition to the projects already decided for the country and to the regional projects, Ivory Coast has a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) **Hydroelectric projects**
   The hydroelectric projects of **Aboisso-Comoé** and **Gribo-Popoli** are competitive from an economic point of view.
   The project of **Louga** on the other hand is less competitive. It is thus not highlighted in the reference scenario based exclusively on economic criteria.
   The project of **Tiassale** is also less competitive. It has nevertheless the advantage of being smaller and the required funds with its construction could be easier to find.

2) **Combined cycle of Bassam (5th power plant of Bassam)**
   This combined cycle is expected to be commissioned only after the development of the hydroelectric potential of the country, meaning after the end of the study period.

Conclusions

In conclusion, for Ivory Coast, the development plan at the horizon of the study should rely on a mix of hydroelectric and thermal projects (gas). This potential should be exploited at national but also regional level thanks to resources sharing.

In case of delay in the hydroelectric projects or in case of difficulties to exploit the gas potential of the country, the exporting vocation of Ivory Coast would be reduced. On the contrary, exploiting more massively the gas reserves would make it possible for Ivory Coast to increase the quantity of exported electricity.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study.

Name	*Technology*	*Fuel*	*Commissioning*	*Capacity*
ABOISSO COMOE	Hydro	HYDRO	2018	90 MW
GRIBO POPOLI	Hydro	HYDRO	2020	112 MW

Table 41 - National projects for Ivory Coast

2.5.2.10. GHANA

Supply-demand balance

From a regional point of view, Ghana should tend towards the export of part of its electricity in the medium term. Indeed, at the same time the hydroelectric and gas potential of the country and the maturity of the decided and candidate projects are in favor of an opening towards the regional markets.

Later on however, if the projects develop massively in the countries at hydroelectric strong potential, Ghana could import part of its electricity.

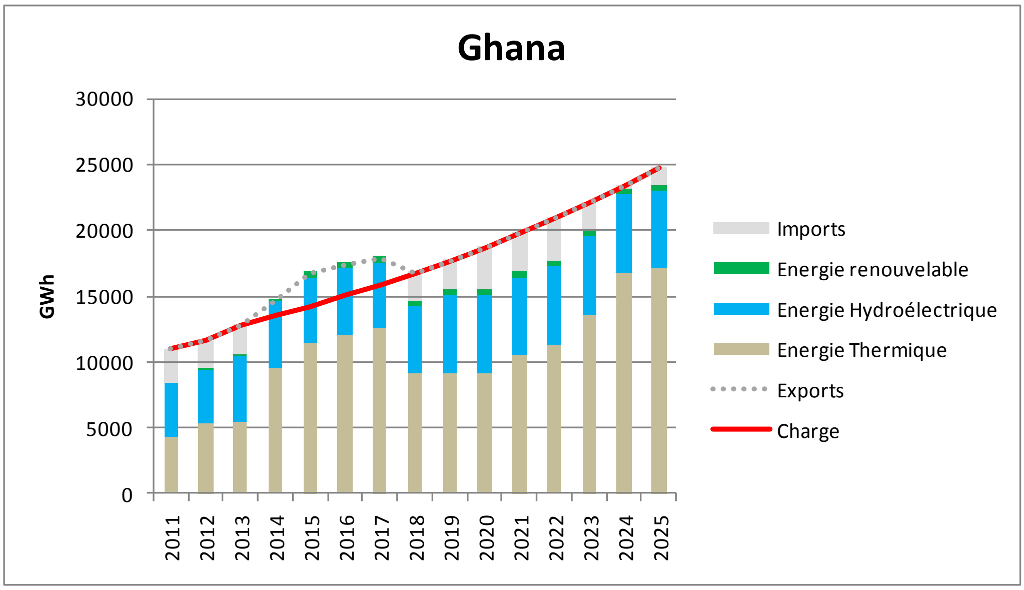


Figure 30 - Supply-demand balance in energy for Ghana

Marginal cost

The energy mix of Ghana, based on hydroelectric and thermal resources (gas), helps the country to lower its marginal cost in the short term.

Moreover, since the structure of the production park of Ivory Coast, Ghana, Togo, Benin and Nigeria are close (energy mix composed of hydroelectric and gas resources) and that these countries are interconnected in 330kV via the Coastal backbone, the trend of marginal costs in all these areas is similar.

In the longer term, it's hydroelectric and gas potential should make it possible to keep reducing this marginal cost.

If no new interconnection were built (national development scenario), the marginal cost in the long term would be identical to the reference scenario since Ghana does not count on the importation to reduce its marginal cost, except for the period 2019-2022 when little importation could decrease the marginal cost thanks to the hydroelectric resources of the countries of zone B.

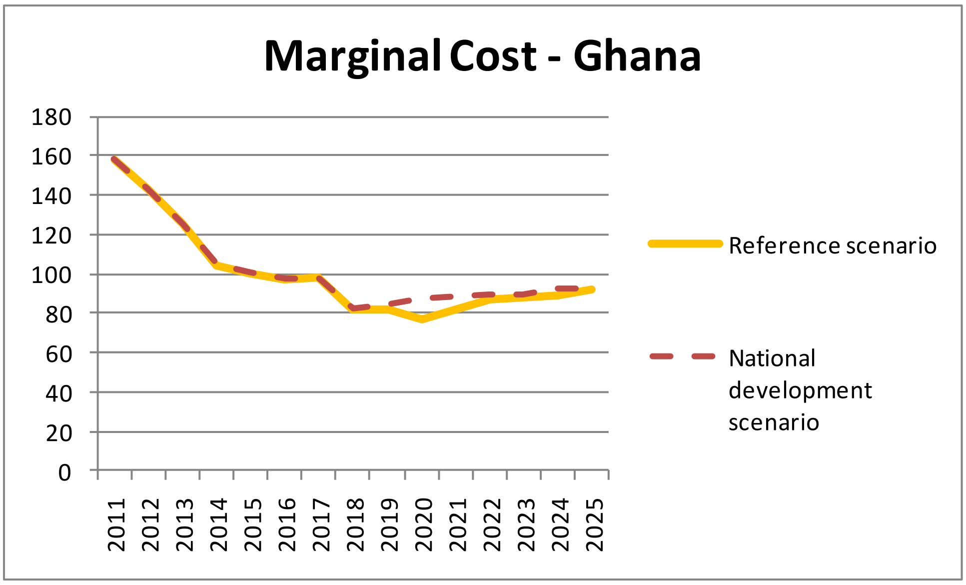


Figure 31 - Trend of marginal cost [$/MWh] in Ghana

National projects

In addition to the projects already decided for the country (among which the combined cycle of Aboadze decided by the WAPP) and of the regional great projects, Ghana has a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) Hydroelectric projects

Ghana wishes to develop a policy of renewable energy which is not based exclusively on wind power. To this purpose, five hydroelectric sites are envisaged in Ghana: Juale, Pwalugu, Kulpawn, Daboya and Hemang.

Among these sites, those with the lowest operation costs are Juale, Pwalugu and Hemang. These three sites associated with a wind development policy should permit to the country to develop renewable energy at lower costs.

2) Combined cycles projects running on gas

Ghana has its own gas resources in addition to a provisioning from Nigeria through the WAGP pipeline.

Given the volumes of gas available and the needs for Ghana in terms of production means, the most economic solution would consist in large combined cycles (450MW). If such projects could not be set up at short-term, the following projects could be realized:

- **The SAP Project** of CC 2x163.6 MW becomes economically interesting from 2014/2015 on.
- The combined cycle of **Cempower on the site of Tema II** should be commissioned in 2015/2016.
- **Phase II of the power plant of Aboadze T3** (120MW) whose commissioning is envisaged in 2016 is justified fully based on economic criterion after 2020.

- In the same way, the addition of a **steam turbine of 110 MW to the power plant of Domini T1** by BTPP to create a combined cycle of 330 MW is competitive from 2020 on.
- The project of **WP on barge** (2x50 MW) is not competitive based on economic criterion;

Conclusions

In conclusion, for Ghana the development plan at the horizon of the study should rely on a mix of hydroelectric and thermal projects (gas). Given the gas resources available to the country and the important requirements in terms of energy, the most economic solution would consist of the fast commissioning of large combined cycles (450MW). If these combined cycles could not be realized in the short term, the majority of the projects under consideration for Ghana should be commissioned during the study period.

The table below shows the principal national developments selected by the optimization tool according to purely economic criteria and to the horizon of the study.

Name	***Technology***	***Fuel***	***Commissioning***	***Capacity***
SAP (DC)	Combined Cycles	NAT GAS	2014/2015	2*163.6 MW
Domini T1 (ST)	Combined Cycles	NAT GAS	2015	110 MW
Aboadze T3 (DC)	Combined Cycles	NAT GAS	2016	120 MW
Pwalugu	Hydro	HYDRO	2019	48 MW
Juale	Hydro	HYDRO	2019	87 MW
Hemang	Hydro	HYDRO	2019	93 MW
Cempower (DC)	Combined Cycles	NAT GAS	2020	300 MW
Standard	Combined Cycles	NAT GAS	2020	300MW

Table 42 - National projects for Ghana

2.5.2.11. TOGO-BENIN

Supply-demand balance

From a regional point of view, the Togo-Benin community should be relatively autonomous in terms of electrical production with the arrival of Maria Gleta in 2014 thanks to an energy mix based on the hydroelectric potential and the gas resources coming from the WAGP pipeline.

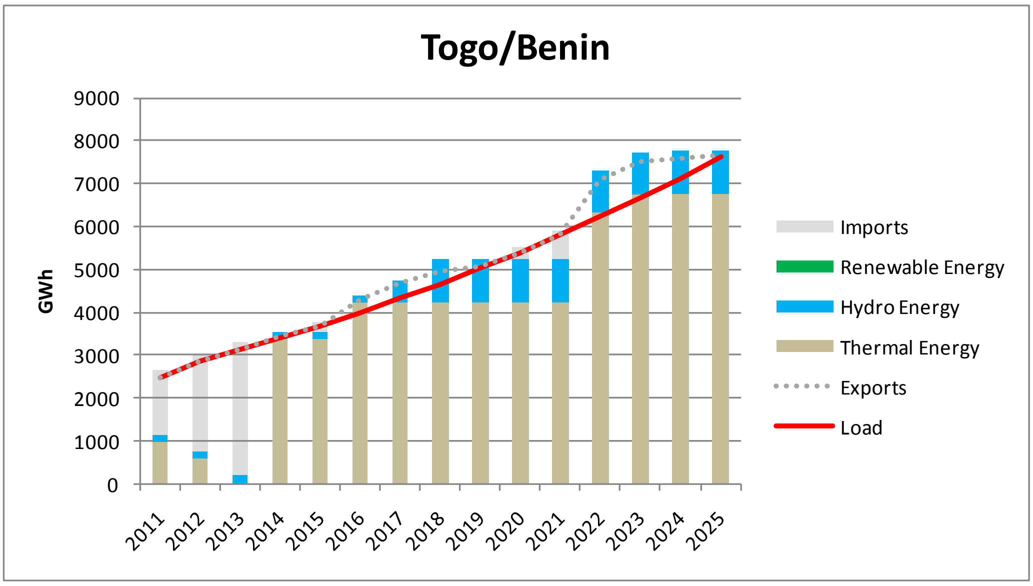


Figure 32 - Supply-demand balance in energy for the community Togo-Benin

Marginal cost

The interconnection of the Togo/Benin community with the neighbouring countries allows the country to have a relatively low marginal cost in the short term thanks to the thermal and hydroelectric resources of Nigeria and Ghana.

In the longer term, the hydroelectric and gas potential of the Togo/Benin community should permit to reduce further this marginal cost.

Moreover, since the structure of the park of production of Ivory Coast, Ghana, Togo, Benin and Nigeria are close (energy mix composed of hydroelectric and gas resources) and since these countries are interconnected in 330kV via the Coastal backbone, the trend of marginal costs in all these areas is similar.

If no new interconnection were built (national development scenario), the marginal cost in the long term would be very close to the reference scenario since the Togo-Benin community should be relatively autonomous in terms of electrical production in the medium and long term.

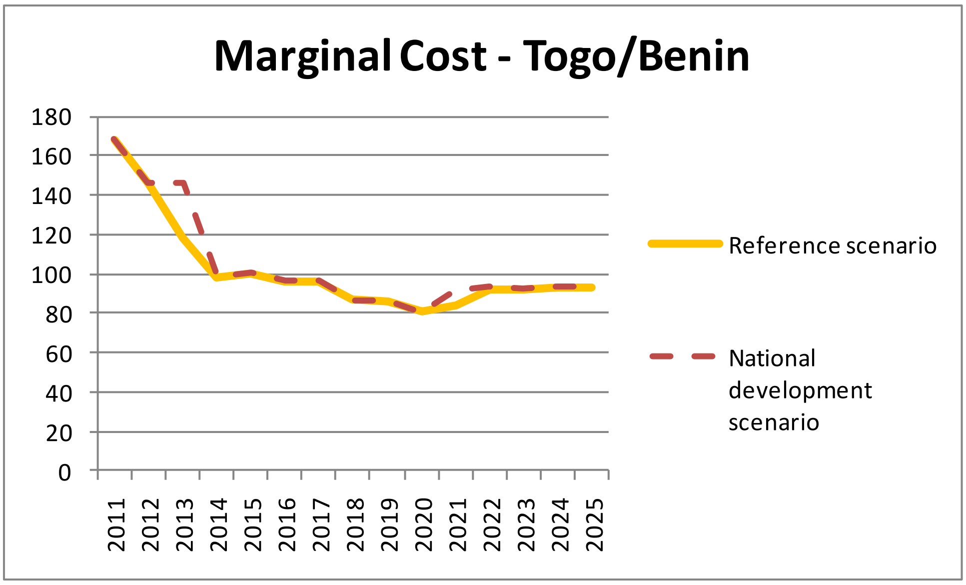


Figure 33 - Trend of marginal cost [$/MWh] in Togo/Benin

National projects

In addition to the projects already decided for the country (among which the combined cycle of Maria Gleta decided by the WAPP) and to the great regional projects (in particular a possible combined cycle of 450 MW with Togo - see section 2.5.4.2), Togo and Benin have a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects of **Togo** and their interest within the framework of the optimal plan of regional development.

1) **Wind project of 20MW and solar project of 5MW**

   From a purely economic point of view, the wind and solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

2) **Hydroelectric project of 50MW in Tététou**

   This small hydroelectric project has a relatively high capital cost, and is consequently less competitive, on a purely economic level, than other projects. Nevertheless, from a national point of view, this project is interesting because its financing will be easier to find than for the great projects.

3) **Thermal project of 100MW.**

   This project is interesting because it allows the use of natural gas dedicated to the country. Nevertheless, it should be under consideration in the form of a combined cycle of 450 MW. Moreover, with such a size, this project could be considered at the regional level (see section 2.5.4.2).

This section shows the candidate projects of **Benin**_and their interest within the framework of the optimal plan of regional development.

1) **Solar projects for a total power of 30 MW**

   From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

2) **Hydroelectric project of 160MW in Kétou**

The site is on the level of the Dogo forest near the village of Bernandingon, at approximately 150 km of Cotonou.

This project is fully justified on the economic plan and, from its size, it has a regional vocation. Nevertheless, the project as suggested in this study, namely 160MW and 490GWh could have a strong impact on the environmental level (strategic planning of the CEB 2007-2026).

This is why other versions are also considered with a limited installed capacity (108.8MW) but reducing the environmental impact. With a capacity of 108.8MW, the project would not really have of regional vocation any more.

Conclusions

In conclusion, for the Togo-Benin community, it is essential to exploit the gas resources available in the two countries thanks to the WAGP pipeline. The project of Maria-Gleta in Benin is a first stage but a second project of the same scale should be considered in Togo.

Moreover, the hydroelectric installation of Kétou in Benin is completely competitive from an economic point of view.

Let us note that given the size of the projects under consideration for these 2 countries, they could be included in a regional vision.

The table below shows the principal developments selected by the optimization tool, in addition to the projects decided based on purely economic criterion and at the horizon of the study.

Name	***Technology***	***Fuel***	***Commissioning***	***Capacity***
Kétou (Benin)	Hydro	HYDRO	2018	160 MW

Table 43 - National projects for Togo and Benin

2.5.2.12. BURKINA FASO

Supply-demand balance

From a regional point of view and based exclusively on economic criterion, Burkina Faso should be a net importer of electricity since it only has few hydroelectric resources and no access to gas.

Thus, the commissioning, in 2012, of gas projects in Ivory Coast and in the other southern countries and the medium-term development of hydroelectric energy in the countries of zone B should help Burkina Faso to cover its load at lower costs.

However, if the area wished to develop the renewable energy sources, Burkina Faso would be very a good candidate for solar energies (see section 2.7.3).

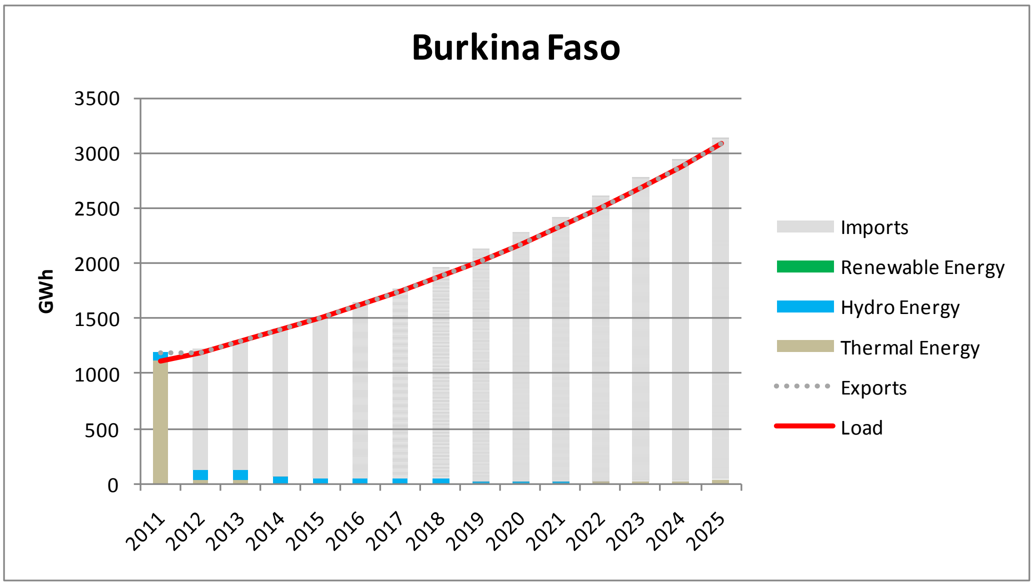


Figure 34 - Supply-demand balance in energy for Burkina Faso

Marginal cost

In the very short term, the marginal cost of Burkina Faso is very high because the country does not have any alternative to liquid fuels.

The interconnection of Burkina Faso with the neighbouring countries permits to the country to reduce its marginal cost thanks to the gas potential of the southern countries of zone A and the hydroelectric potential of country of zone B.

If no new interconnection were built (national development scenario), the marginal cost would remain very high during all the study period.

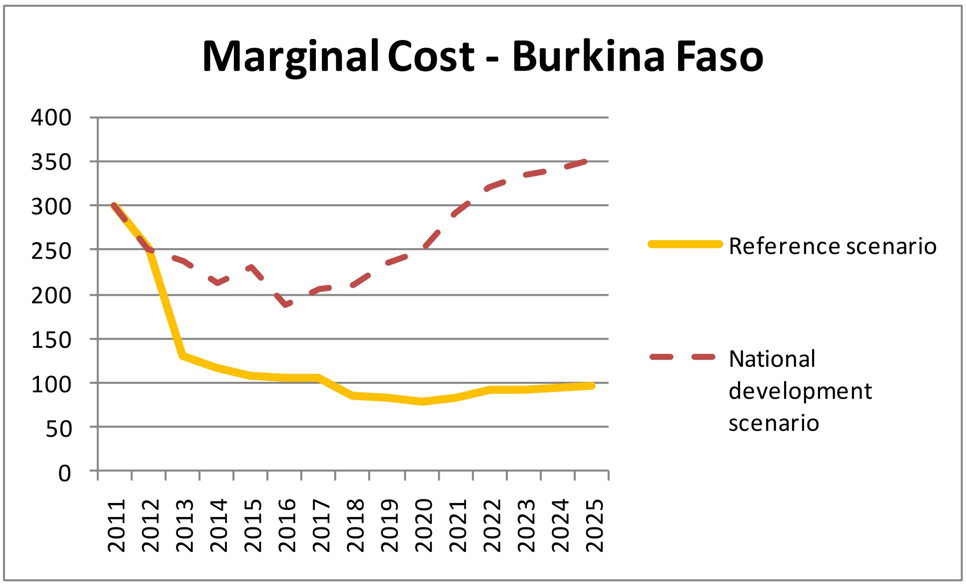


Figure 35 - Trend of marginal cost [$/MWh] in Burkina Faso

National projects

In addition to the projects already decided for Burkina Faso there are a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) **Solar projects**

   From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area. Accordingly, Burkina Faso is one of the countries having the greatest solar potential. Moreover, the coupling of the solar projects to industrial activities (mining companies in particular) ensures their financing.

2) **Hydroelectric projects**

   Three hydroelectric projects (**Noumbiel**, **Bougouriba**, **Bagré**) are considered in Burkina Faso. From a purely economic point of view and looking only at the electrical production, these 3 installations are less competitive than the other projects. Nevertheless, from a national point of view, these projects are interesting because their financing will be easier to gather than for the great projects considered elsewhere in the area. Moreover, their utility for other sectors should not be neglected.

Conclusions

In conclusion, Burkina Faso relies primarily on the importation to feed the national demand. This is why few projects are considered for this country.

Among the projects suggested, the solar projects are not economically competitive if no incentive for commissioning is considered. Nevertheless, if the financing can be assured, Burkina Faso is one of the countries in the area with the best potential.

At regional level, the hydroelectric projects considered are also less competitive. They could however be justified for other national aspects not taken into account in this study (utility for other sectors, capacity to finance the great projects,…).

Consequently, no candidate project is selected for Burkina Faso in addition to the decided projects.

2.5.2.13. NIGER

Supply-demand balance

From a regional point of view, Niger should be, in the short and medium term, an importing country since it has only few hydroelectric and gas resources.

But the commissioning of the coal projects in Salkadamna could reverse the tendency and transform Niger into an exporting country.

In addition to the importation and coal, Niger should rely on its hydroelectric resources to cover the load.

Lastly, the wind potential of the country could be a considerable asset in terms of electrical production. This project indeed has the advantage of a quick possible commissioning, by 2014.

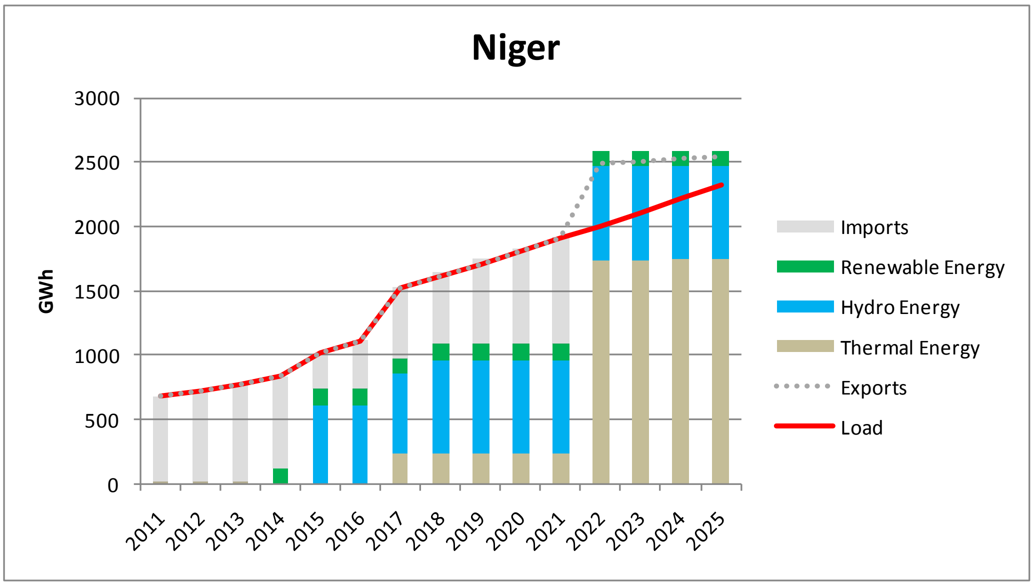


Figure 36 - Supply-demand balance in energy for Niger

Marginal cost

Thanks to its interconnections with Nigeria, Niger has a relatively low marginal cost.

If no new interconnection were built (national development scenario), the marginal cost would be extremely similar since the country is already interconnected with Nigeria.

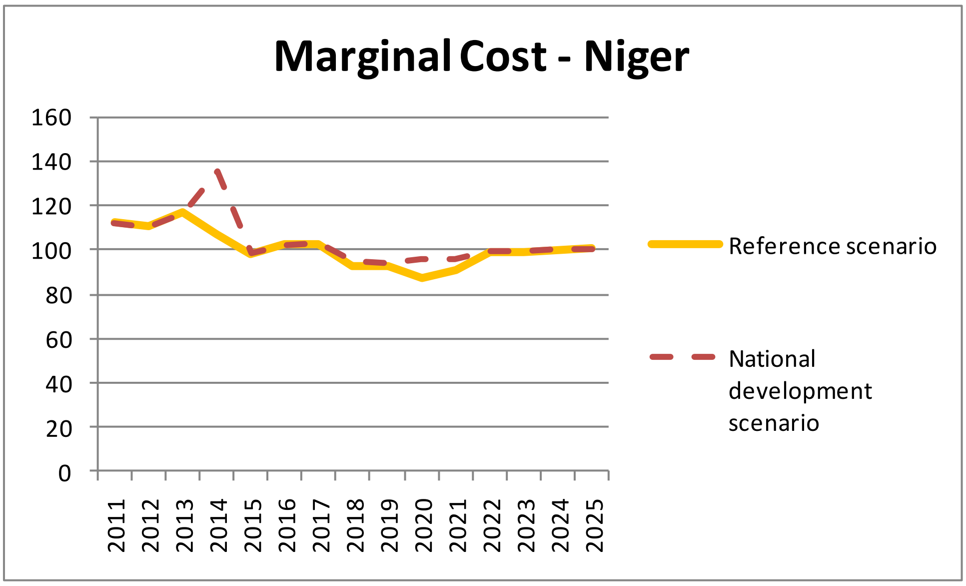


Figure 37 - Trend of marginal cost [$/MWh] in Niger

National projects

Based on criteria defined in section 2.5, the coal project of Salkadamna, whose economic interest is justified from 2022 on (even earlier if the hydroelectric projects were delayed) is highlighted at the regional level. This project is described I nsection 2.5.4.2.

In addition to the projects already decided for the country and to the regional projects, Niger has a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) **Wind farm of 30 MW**

   This project is selected by the optimization tool because it is envisaged in the short term and that it will help reducing the marginal cost of Niger.

2) **Thermal solar power plant of 50 MW**

   From a purely economic point of view, the solar projects are not justified in the area. Nevertheless, other factors are to be taken into account and in particular the energy policy of the area.

3) **Combined cycle of Zinder (60 MW)**

   In the medium and long term, alternatives to liquid fuels should be installed. Consequently, this combined cycle is not optimal from a purely economic point of view, especially when compared to the coal power plant project of Salkadamna.

4) **Hydroelectric projects**

   Other hydro units are mentioned in the River area. **The Gambou** project has a relatively high capital cost. It is consequently less competitive so that the installation of **Dyodonga** (26 MW) is preferred. Moreover, this second project is smaller and could be easier to finance.

Conclusions

In conclusion, in addition to the imports, Niger should rely in the medium term on its wind and hydroelectric resources to cover its load.

In the longer term, the country could become exporter thanks to the installation of the coal project.

The table below shows the principal national developments selected by the optimization tool based on purely economic criterion, in addition to the decided projects and the projects with regional vocation.

Name	*Technology*	*Fuel*	*Commissioning*	*Capacity*
River area	Wind	WIND	2014	30 MW
Dyodonga	Hydro	HYDRO	2018	26 MW

Table 44 - National projects for Niger

2.5.2.14. NIGERIA

Supply-demand balance

From a regional point of view and based on economic criteria, Nigeria should be an autonomous country in terms of electrical production.

Indeed, the country possesses important gas resources and a hydroelectric potential which enable him to produce electricity at lower costs but there is such a load in the country that all the investments that can be reasonably realized are intended for the cover of the local load.

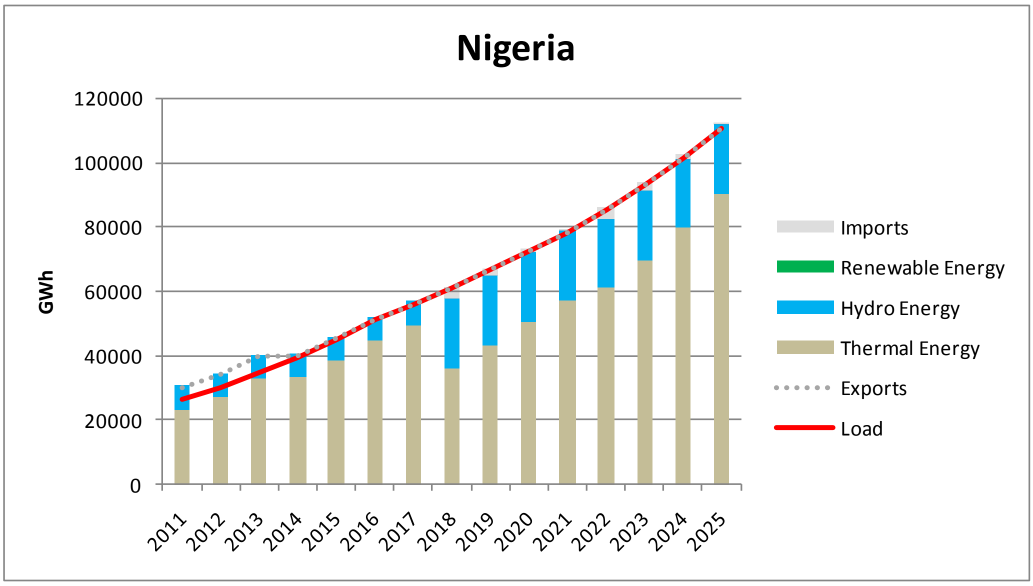


Figure 38 - Supply-demand balance in energy for Nigeria

Marginal cost

Thanks to its gas resources, Nigeria has a low marginal cost. Moreover, the investment in the 2 hydroelectric sites of Mambilla and Zungeru further reduce the marginal cost of the country.

If no new interconnection were built (national development scenario), the marginal cost would be extremely similar since the country does not count on the importation to reduce its marginal cost.

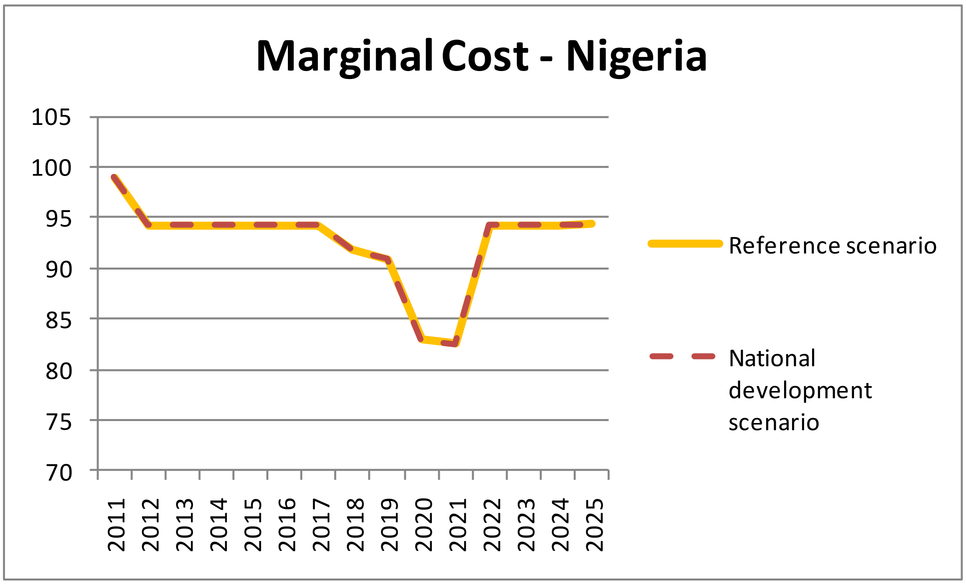


Figure 39 - Trend of marginal cost [$/MWh] in Nigeria

National projects

Based on criteria defined in section 2.5, the hydroelectric plants of Zungeru and Mambilla highlighted at the regional level. These projects are described in section 2.5.4.2.

In addition to the projects already decided for the country and to the regional projects, Nigeria has a certain number of national projects which could help supplying the load at lower costs.

This section shows the candidate projects and their interest within the framework of the optimal plan of regional development.

1) IPP - Gas turbines

In Nigeria, many projects of gas turbines are already decided.
It becomes nevertheless essential for Nigeria to invest in base units (combined cycles). The passage to combined cycles belongs to the economic optimum calculated by PRELE. Indeed, the kWh cost is lower for a combined cycle than for a gas turbine.

Conclusions

In conclusion, the economic optimum recommends that Nigeria exploits its hydroelectric resources and that it uses its gas resources as well as possible, in particular by developing combined cycles.

The needs for the country are very important. Consequently, the investments which will be carried out should be useful primarily, economically speaking, for the supply of the local load.

The table below shows the principal national developments selected by the optimization tool based on purely economic criterion, in addition to the decided projects and the projects with regional vocation.

Name	*Technology*	*Fuel*	*Commissioning*	*Capacity*
Standards	Combined cycles	NAT GAS	2016-2021	1000 MW/an

Table 45 - National projects for Nigeria

2.5.3. Production projects supported by regional entities

2.5.3.1. OMVS

OMVS is an organization dedicated to organize the actions of four countries for the development of the Senegal River and its basin. It gathers Guinea, Mali, Mauritania and Senegal. This organization considers many projects, in addition to those already carried out (Manantali) and the decided ones (Félou - Gouina).

Among the projects considered **Balassa** is the most interesting from an economic point of view. Moreover, its size and its location give to this project a regional character which deserves to be supported.

In the same way, the **Koukoutamba** and **Boureya** projects have a very interesting potential and are competitive from an economic point of view. Based on these criteria, they could be also justified at regional level. Let us note however that they are located on the axis Linsan-Manantali whose design could be modified because of environmental problems.

Badoumbé project considered in the medium term is more modest in terms of size which makes it less interesting at regional level, although it is competitive based on economic criterion.

Lastly, the projects for which the feasibility studies were not carried out yet are considered only in the longer term and are not considered at the horizon of the study.

Name	*Technology*	*Fuel*	*Commissioning*	*Capacity*
Balassa	Hydro	HYDRO	2018	181 MW
Koukoutamba	Hydro	HYDRO	2018	281 MW
Badoumbe	Hydro	HYDRO	2018	70 MW
Boureya	Hydro	HYDRO	2021	160 MW

Table 46 - Projects OMVS at the horizon of the study

2.5.3.2. OMVG

OMVG is an organization which aims at coordinating the actions of the four countries concerned with the basin of The Gambia River: Senegal, Guinea, The Gambia and Guinea Bissau. This organization considers many projects, in addition to those already decided (Sambangalou-Kaléta).

The projects (**Saltinho, Digan** and **Fello-Sounga**) have a small capacity. Moreover, if the project of Digan is strongly competitive, the 2 others are less attractive from a purely economic point of view.

Name	*Technology*	*Fuel*	*Commissioning*	*Capacity*
Digan	Hydro	HYDRO	2018	93.3 MW

Table 47 - Projects OMVS at the horizon of the study

2.5.4. Great regional production projects

The regional projects are adopted based on purely economic criteria and according to the reference scenario. The variants could emphasize other investments. In addition, the financial and environmental studies will have to confirm these projects.

2.5.4.1. REGIONAL HYDROELECTRIC PROJECTS

The table hereafter presents the hydroelectric projects which arise from the reference scenario to the regional level.

Site	*Country*	*Capacity [MW]*	*Energy [GWh]*	*Commissioning*
Souapiti	Guinée	515	2518	2018
Amaria		300	1435	2018
Grand Kinkon		291	720	2018
Kassa		135	528	2018
BonkonDiara		174	451	2020
Mano River	Liberia – Sierra Leone	180	795	2021
Bumbuna	Sierra Leone	350	1245	2018
Soubre	Côte d'Ivoire	270	1116	2018
Boutoubre		156	785	2018
Tiboto		225	1200	2018
Zungeru	Nigéria	700	3019	2018
Mambilla		2600	11 214	2018

Table 48 - Hydroelectric projects with regional vocation

Souapiti

The site of the hydroelectric Souapiti is located on the river Konkouré Its development will enable the construction of a dam in Roller Compacted Concrete (RCC) with a side retaining normal of 230 m, with a total capacity of the reservoir of 17,300 hm^3 , a design flow of 545m^3 /s and an installed capacity of 515 MW. 225 kV transmission network of OMVG offers opportunities to evacuate the energy of Souapiti to the countries of the region.

In addition, the dam would regulate the flow in any season for Kaleta

The dam was originally foreseen with an installed capacity of 750 MW. However, the environmental and the socio-economic issues needed the review of this project.

Amaria

The Site of Amaria is in Guinea Maritime downstream from the junction between Konkouré and Badi Rivers.

Three variants are considered. The table hereafter summarizes the parameters according to the reservoir height:

Reserve	*[m]*	*60*	*80*	*100*
Production (guaranteed energy)	[GWh/an]	440	1400	2450
Installed capacity	[MW]	120	300	665
Firm capacity	[MW]	50	160	280

Table 49 - Description of the Amaria project

The initial dam had a designed normal height of 93 m for an installed capacity of 665 MW. Nevertheless, the environmental aspect and the important socio-economic impacts required the revision of this project.

The alternative selected today consists of a dam with an installed capacity of 300MW and a guaranteed energy of 1435GWh.

The beneficiary countries of this project would be Guinea and the countries connected to the 225kV interconnection network. Indeed, the site of Amaria is ideally located on the layout of the OMVG line and near the evacuation axes of CLSG and Guinea-Mali (Linsan-Fomi section).

Grand Kinkon

The Grand Kinkon project has an installed capacity of 291 MW and is very economically interesting. With its size and its location (at only 7km of the OMVG network), it has a regional extent which should be encouraged.

Kassa

Although its capacity is lower than 150MW, the installation of Kassa reaches multiple goals and has consequently a true regional vocation.

Located on the Koba River at a few kilometers of the border between Guinea and Sierra Leone, it will allow the construction of a dam for an installed capacity of 135 MW. The production of electrical energy could be evacuated through the 225 kV line envisaged within the framework of the WAPP (line CLSG).

Bonkon-Diara

The Bonkon-Diara project offers an interesting potential of 174MW for 451GWh/an.

No feasibility study or of impact could be collected for this project.

Nevertheless, it is ideally located from an electric point of view, near the town of Labé and on the OMVG loop between Linsan and Tambacounda. It would permit to feed the town of Labé but also the isolated regions of Senegal, as well as Sambangalou.

Bumbuna

In Bumbuna, a 50 MW plant was commissioned in 2010 and allow the supply of the capital Freetown.

The extension of Bumbuna dam is considered. Moreover, the localization of the project along the CLSG line would make possible to share this resource in the region. This project is very interesting economically speaking.

Mano River

Located on the routing of the CLSG line, at the border between Sierra Leone and Liberia, the Mano River site is a very important regional project.

If countries develop their national hydroelectric resources (Saint-Paul in Liberia, and Bumbuna and Benkongor in Sierra Leone), this project will become interesting on a vaster level than these two countries and it will completely justify its regional status.

Soubré

Ivory Coast has a dense hydrographic network characterized by four large rivers which run from the North to the South. These rivers are from West to East:

- Cavally,
- Sassandra,
- Bandama,
- Comoé.

Among these four rivers, Sassandra has the most important annual inflows and experiences the least effect by climatic variations because of its situation in forest zone of its basin. The former studies showed that the recognized sites of the Sassandra basin represent a potential power of 1100 MW for an annual potential production of 5900 GWh. Among these sites, only Buyo dam with 165 MW of installed capacity and 850 GWh of annual production is in service since 1980. The Sassandra River is thus equipped to 15% of its potentiality. Thus, the realization of the hydroelectric dam of Soubré arises like a continuation of the progressive development of the Sassandra River.

Reserve	*[m]*	*RN 152*	*RN 157.5*	*RN 164*
Production (guaranteed energy)	[GWh/an]	1116	1300	1480
Installed capacity	[MW]	270	288	328
Firm capacity	[MW]	50	160	280
People to be moved		2955	6401	16285
Surface of reservoir	[km ²]	17.3	60	172

Table 50 - Description of the Soubré project

The former studies had retained as alternatives for the project the two dimensions 157.5 m IGCI and 164 m IGCI. Taking into account the worrying situation of the environmental impact of the project, the current project considers a dam with the dimension 152 m IGCI.

This project, located at the junction between the countries of zone B and the countries of zone A could be connected to an important network node allowing its evacuation towards the countries crossed by the CLSG line, towards the northern areas through the axis Soubré-Man-Ferkessedougou-Sikasso/Bobo Dioulasso, or finally towards the southern areas through the Coastal backbone.

Boutoubré

The site of Boutoubré located at 50 km from the town of Soubré downstream, and 80 km from the town of Sassandra could be equipped with a hydroelectric dam to increase the capacity of the electric production park of 156 MW and 785 GWh.

Just like the Soubré project, the Boutoubré project is located on the Sassandra River whose potential is still relatively unexploited.

Just like the Soubré project, the Boutoubré project is close to several evacuation axes towards the West (CLSG), the north (North-South axis Ivory Coast, Ivory Coast-Mali interconnection and Ivory Coast-Burkina Faso interconnection) and the south-east (Coastal backbone).

Tiboto

The site of Tiboto, on Cavally River, is an excellent regional project. Located at the border between Liberia and Ivory Coast, it is perfectly justified economically.

The feasibility studies are not yet available for this project but the points of attention will be the topographic, geological, geotechnics and hydrological aspects.

Zungeru

The project of hydroelectric plant of Zungeru is located on the Kaduna River in the state of Niger in Nigeria, downstream from the hydro power plant of Shiroro. With this project, Nigeria would reduce its dependence on gas for the electrical production. Lastly, it could be useful for the agricultural irrigation of the local communities. The alternative selected here mentions 700MW but the installed capacity could vary from 600MW to 950MW, with different impacts on the environment.

Moreover, coupled with the development of the Median backbone, this installation would also allow supplying the northern areas of the neighbouring countries (Benin, Togo and Ghana) at lower costs.

Mambilla

In addition to the project with regional vocation of Zungeru the **Mambilla** project (2600 MW) seems a very important project for the region.

Being given its localization in Nigeria, far from the borders with the other countries of West Africa, it could nevertheless be directly connected to the regional network through a 760kV transmission line.

2.5.4.2. REGIONAL THERMAL PROJECTS

The list of thermal projects economically competitive and answering the criteria fixed to be justified as regional projects is very limited and this for two reasons:

- Two regional projects were already decided by the WAPP in Ghana (Aboadze) and Benin (Maria-Gleta);
- Many combined cycles projects are already decided by the countries (coal-Senegal,…).

Consequently only 2 projects are adopted:

Site	*Country*	*Technology*	*Capacity [MW]*	*Commissioning*

Salkadamna	Niger	Coal	200	>2020
South	Togo	Combined Cycle	450	2020

Table 51 - Thermal projects with regional vocation

Coal project in Niger

The coal project in Niger is essential for the load supply in the north-east area of the WAPP. Indeed, in this area, the gas and hydroelectric resources are limited, which tends to strongly increase the marginal cost.

Let us note that on a purely economic level, this project would be justified only after 2020 but that implies that many hydroelectric projects are built in the countries of zone B and that no technical constraint is opposed to the export of this energy towards the northern areas of the WAPP. It is consequently probable that this project will be essential in a shorter term.

Moreover, the North-core transmission project will allow the division of this energy between Niger, Burkina Faso, Benin and the north of Nigeria.

Combined Cycle project in Togo

Among the countries crossed by the Coastal backbone, Togo is the only one without any combined cycle project (WAPP or national).

In the absence of such project, the country would become strongly importer and the gas coming from Nigeria would be unexploited.

Consequently, it is essential to consider a combined cycle project in this country in the long term.

2.5.5. Regional transmission projects

In the long term, the hydroelectric projects should become the key of the energy production in West Africa. Guinea having an immense tank is brought to become strongly exporting in the next decades. The other countries with a strong hydroelectric potential (in particular Liberia, Sierra Leone and Ivory Coast) should also contribute in an important way to the electrical production of the area.

Consequently, the interconnection projects of these countries with their neighbors should be capital to allow the optimal exploitation of the hydroelectric potential of the area. Let us note the interest of the already decided or planned projects: Guinea – Mali interconnection, Mali - Ivory Coast interconnection, CLSG interconnection and OMVG loop. Other projects could still appear to reinforce this area. These projects are discussed hereafter.

The countries having natural gas will also have a big role to play in terms of electrical production. The interconnection of Ivory Coast, Ghana, Togo, Benin and Nigeria between them and with the other countries will allow the optimal exploitation of this resource.

On the contrary, the countries without important hydroelectric resources and no natural gas supply (as Burkina Faso for example) will naturally become importers of electricity in a market based exclusively on the economic criteria and without constraints of transit.

Consequently, the axes permitting to feed the importing areas of electricity will also have a considerable role to play. The axis Mali - Burkina Faso - Ghana will be a very important section for the supply of the demand for electricity of the Center-North of the area.

2.5.5.1. PROJECTS CONSIDERED

Median backbone project

From a purely economic point of view, this interconnection is not a priority.

Indeed, with the production projects considered and suggested for Benin (combined cycle of Maria Gleta - 450 MW) and for Togo (standard combined cycle - 450 MW), the northern areas of these countries would be fed directly by the local production means.

Nevertheless, if Zungeru project were considered at regional level, it would be essential to build an axis allowing the evacuation of this energy towards the other countries of the area. Because of the localization of this hydroelectric project, the Median backbone would be an excellent mean to share the resources.

Lastly, let us remind that other aspects, and in particular the technical side could amend this project.

Interconnection Liberia - Ivory Coast

A coastal interconnection between Monrovia in Liberia and San Pedro in Guinea is evoked by the countries concerned. This project would allow in particular the evacuation of the hydroelectric project of Tiboto (Cavally), at the border between the two countries.

Since this production project belongs to the very competitive projects and that its characteristics justify its regional character, this axis should be built at the same time than the hydroelectric installation.

Let us note however that the utility of this project for the evacuation of the hydroelectric potential of Sierra Leone and Liberia does not arise from the economic study. Indeed, the installation of a second circuit on line CLSG is more profitable than the construction of the line San-Pedro – Monrovia.

Interconnections OMVS-OMVG

The first phase of the OMVS-OMVG interconnection relates to the **Kayes-Tambacounda** section. As of the commissioning of the hydraulic site of Gouina (decided project, commissioning estimated in 2017), it will indeed be necessary to reinforce the 225 kV network towards Dakar so that Senegal can profit from the shares of this project which return to him.

Based on purely economic consideration, the Senegalese load would be rather fed by local coal units whereas the hydroelectric potential of Mali would allow the supply of the northern zones of the WAPP. Therefore, the axis Kayes-Tambacounda does appear as a priority.

However taking the quotas of the countries into account in the OMVS projects, this line is important for Senegal even if it does not come out of the economic study.

The second phase of the OMVS interconnection relates to the **Linsan-Manantali** section to interconnect the dam projects on the Guinean territory: Boureya and Koukoutamba.

These two production projects are among the most interesting projects on the economic plan. Nevertheless, this layout connects two strongly producing zones of electricity and does not really allow the evacuation of the power towards importing zones. Moreover, the routing of this axis could be re-examined for environmental questions. Consequently, other alternatives should be under consideration for Boureya and Koukoutamba. Since the benefit of this routing on the economic optimum is to interconnect the hydroelectric projects of the area, the environmental aspects will be decisive to define the best routing for this interconnection.

2.5.5.2. OTHER INVESTMENT OPTIONS

In addition to the projects under consideration by previous studies, new projects are proposed for optimization in Prele.

Guinea (Fomi) - Ivory Coast (Boundiali) project

This project is very important to allow the evacuation of the hydroelectric power of Mali towards the northern areas having a very high marginal cost. In particular it could allow the evacuation from the great hydroelectric projects under consideration in Guinea like Amaria and Kassa and would help reducing the marginal cost in the North of Ivory Coast, in the area of Sikasso in Mali and Burkina Faso.

Moreover, the investment cost of this project should be relatively limited since it could join the axis Man-Laboa-Boundiali-Ferkessedougou with connection at Boundiali from Fomi. In this case, the length of the line to be built would be limited. The layout will have to be discussed with the environmental criteria.

The optimization tool brings this axis into service from 20180 on for an installed capacity estimated at 2*250MW. The economic optimum wants to strongly charge this axis with an average flow with 327MW in 2020.

Guinea - Mali (Sikasso) project

This project should have a capital cost higher than the Guinea- Ivory Coast (Northern) project evoked previously. Indeed, this axis Fomi-Sikasso is longer than the Fomi- Boundiali interconnection.

Consequently, for supplying the northern areas (north of Ivory Coast, area of Sikasso in Mali and Burkina Faso), the routing Guinea-Ivory Coast (Northern) is preferred to the routing Guinea-Mali (Sikasso).

Reinforcement of the decided or planned existing axes

In the long term, the optimization tool considers the doubling of certain sections already existing, decided or considered.

- The feeding of the Northern region (Mali, Burkina Faso) from hydro sites of Guinea requires the strengthening of several sections upstream and downstream of the proposed line Fomi-Boundiali. Thus, a second line may be needed on the axis **Linsan-Fomi** in order to evacuate the power produced around Linsan by the hydro plants of Souapiti, Amaria and Grand Kinkon. This reinforcement should be made upon arrival of the hydro or 2018.
- Similarly, the sections Boundiali-Ferkessedougou-Bobo and Bobo-Ouagadougou and should be reinforces to allow the supply of Burkina Faso since 2018.
- With the many hydroelectric projects under consideration in Sierra Leone and Liberia (Bumbuna, Benkongor, Mano River, Mount Coffee and Saint-Paul), the **doubling of the CLSG line** could become necessary after 2018. This line will be built to allow the commissioning of a second circuit. Consequently, the cost overrun which would be generated should be limited.
- In zone A, the thermal projects under consideration in the countries, and in particular the regional projects (combined cycle of Maria Gleta and standard combined cycle suggested in Togo after 2020) could require a **reinforcement of the Coastal backbone** in the long term. In particular the section between Togo (Lome) and Benin (Sakété) should be reinforced with the arrival of the regional production project (450 MW combined cycle) in Togo.
- The commissioning of **Salkadamna** power plant will require the construction of a 330 kV line connecting this plant to the North-core interconnection and allowing the evacuation of the power produced towards the north of Benin and Burkina Faso. Moreover, a 132 kV axis should be built between this power plant and the Center-East area in Niger to allow the supply of this area at a lower marginal cost.
- Lastly, in Nigeria, the North-South reinforcements under consideration in the national development plans should be sufficient to feed the northern areas of the WAPP.

2.5.5.3. SYNTHESIS OF THE REGIONAL TRANSMISSION PROJECTS

The table below shows the principal transmission developments selected by the optimization tool based on purely economic criteria, in addition to the decided and planned projects. Moreover, the lines justified by associated regional projects are indicated in italic.

Name	***Associated production project***	***Commissioning***	***Capacity***
Liberia (Monrovia) – Ivory Coast (San Pedro)	*Tiboto*	*2018*	*150 MW*
Interconnection OMVS (Linsan-Manantali)	*Koukoutamba, Boureya, Balassa, Badoumbé*	*2018*	250MW
Guinea(Fomi) – Ivory Coast (Boundiali) (two circuits)		2018	2x250 MW
Linsan – Fomi second line)	Souapiti	2018	250 MW
Boundiali-Ferke-Bobo (second line)		2018	250 MW
Bobo-Ouaga (second line)		2018	250 MW
CLSG line (second circuit)		>2020	250 MW
Coastal backbone section Lomé-Sakété (second circuit)		>2020	312 MW

Salkadamana - Niamey	*Salkadamna*	*>2020*	*200 MW*
Salkadamana – Center East	*Salkadamna*	*>2020*	*100 MW*
Median backbone		*>2020*	*300 MW*

Table 52 - Synthesis of the regional transmission projects (economic criteria)

2.5.5.4. AVERAGE FLOWS BY 2020

By 2020, the tendencies evoked here before, namely the exporting tendency of the countries having a strong hydroelectric potential should already be very marked. Thus, the axis Guinea - Mali - Burkina Faso, CLSG interconnection and OMVG loop but also a new line proposed connecting Guinea to the North of Ivory Coast are very strongly charged.

Moreover, the axes allowing the supply of the northern areas from the areas having hydroelectric or gas resources also experience an increase of average flow. One notes thus the axes Mali-Burkina Faso-Ghana and Ivory Coast-Burkina Faso.

The Coastal backbone is very charged by 2020. This tendency will be increasing after this period, requiring inter alia the reinforcement of the section between Togo and Benin.

Since Figure 40 represents average flows by 2020 in the reference scenario, the coal project of Niger is not brought yet into service. This is why the country imports its energy. After the commissioning of Salkadamna, flows will be reversed on the North-core interconnection.

Figure 40- Average flows on the interconnection lines in 2020 - reference scenario

2.6. Comparison of the scenarios

The comparison between the actualized total costs of

- The scenario presenting the optimization of the national production without increase of interconnections;
- The scenario without transit limits between countries;
- The reference scenario.

Gives the profit the area can hope for in terms of optimization of the production.

The actualized profit takes into account the reduction of unserved energy, but also the possibility of supplying the load with more competitive energy sources.

In this context, the maximum profit hoped for the area of West Africa was estimated at nearly 6 billion dollars, i.e. more than 10% of the discounted cost of the reference scenario. Let us remind however that this profit is hypothetical since it supposes that the lines are available as of today and with an infinite capacity. It corresponds to the difference between the costs of scenarios 1 and 2.

The reference scenario presents the optimal regional development of the electric system of production and transport by holding account limits of transit on the interconnections. In this case, the profit hoped compared to the situation without new interconnections was estimated at 3 billion dollars.

Summary of the costs (kUSD)	***Scenario 1***	***Scenario 2***	***Scenario 3***
	Without new interconnection	Without transit limits	Reference scenario
Investments costs			
Generation units	6 316.334	6 868.480	7 010. 508
Transmission lines			103.061
Fixed costs of the generation units	1 012.092	836.852	953.520
Variable costs of electricity (except natural gas)	11 517.466	4 125.571	8 360.262
Cost of natural gas	39 373.910	40 352.594	38 701.317
Total	58 219.802	52 183.497	55 128.668

Table 53 - costs of scenarios 1, 2 and 3

2.7. Studies of sensitivity

The objective of this chapter is to analyze various alternatives and compare them to the reference scenario, to emphasize the influence of certain key parameters on the optimization results.

These alternatives will analyze successively the impact:

- Of a delay of 2 years in the commissioning of the planned transmission projects;
- Of a lower demand growth in the various countries;
- Of a renewable constraint of 10% of production capacity (without hydro) from 2020 on;
- Of a low fuel cost (based on 75$/bbl instead of 100$/bbl);
- Of a high fuel cost (based on 125$/bbl instead of 100$/bbl);
- Of a low actualization rate (of 8% instead of 10%);
- Of a high actualization rate (of 12% instead of 10%);
- Of a reduction of the possible investments in the hydroelectric candidate projects in Guinea in order to take into account the technical constraints and especially the constraints of financing related to the mobilization of an enormous capital.

In order to analyze the impact of these alternatives, the discounted costs calculated will be compared with those calculated for the reference scenario (presented in the table below). Let us note that these costs do not include the capital costs of the imposed projects not impacting optimization, i.e. the decided and planned transmission projects as well as the decided production projects.

Summary of the costs (kUSD)	***Scenario 3***
	Reference scenario
Investments costs	
Generation units	7 010 508
Transmission lines	103 061
Fixed costs of the Generation units	953 520
Variable cost of electricity (except natural gas)	8 360 262
Cost of natural gas	38 701 317
Total	55 128 668

Table 54 - costs of the reference scenario

2.7.2. Alternative with delay of the transmission projects

This alternative consists in regarding a delay of two years for the commissioning of the planned transmission projects and for the OMVG project.

Since the OMVG project is thus delayed to 2019, this year was also selected (instead of 2018) as the earliest commissioning date for considered lines, reinforcements and new interconnections suggested by the Consultant.

Summary of the costs (kUSD)	Scenario 3	Scenario 4
	Reference scenario	Delay of the transmission projects
Total	55 128 668	55 374 609

Table 55 - Costs of the scenario with delay of the transmission projects

The principal change of this alternative compared to the reference scenario is the more important use in the short term of liquid fuels in local units for the electric production.

The important modifications concerning the investment decisions in production in this alternative are mentioned below:

- The delay of the OMVG loop makes the investments in candidate thermal units essential in The Gambia (combined cycle of 60 MW) like in Guinea Bissau (HFO plant of 55 MW). It also extends the use of HFO units in the isolated centers of Ziguinchor and Tambacounda in Senegal and new investments in heat capacities to feed these centers (approximately 28 MW and 30 MW additional capacities invested respectively in each one of them from 2017 on to compensate the deficit) become necessary. Let us note that before 2019, the marginal prices of electricity are naturally higher in this alternative than in the reference case for the above mentioned nodes.
- The connection delay between the nodes of Linsan and Fomi in Guinea (Guinea-Mali project delayed from 2016 to 2018) provokes a necessary investment of 10 MW in thermal capacities in to Fomi in the short-term before the appearance of the local hydroelectric projects.

Let us note that there is no major difference between this alternative and the reference scenario concerning the investments choices neither in considered lines nor in reinforcements and new lines proposed.

This alternative confirms the interest to develop the planned transmission projects as well as the OMVG project with the commissioning dates envisaged. If these projects were both delayed of two years, an additional discounted cost of approximately 246M$ should be supported by the countries of the area.

2.7.3. Alternative with a lower load growth

This alternative considers a scenario with a low growth of the electric demand, compared with the reference scenario. The electric demand taken into account (annual point and energy) corresponds to the low scenarios of section 2.2.3. Load forecast

Summary of the costs (kUSD)	Scenario 3	Scenario 5
	Reference scenario	Low demand growth
Total	55 128 668	49 337 339

£Table 56 - Costs of the scenario with low demand growth

Adopting the approach of a low demand growth allows reducing all costs at the horizon of the study. The discounted costs are reduced by 10.5% compared to the reference scenario.

The important modifications implied by this alternative as for the investment decisions in candidate production units are mentioned below:

- The commissioning of a certain number of hydraulic projects is delayed of approximately a year because of the lower demand. They are the projects of, Mano River between Sierra Leone and Liberia, and Gribo Popoli in Ivory Coast. In Liberia, only the site of St Paul 1B (78 MW) is justified at the horizon of the study and the site of St Paul 2 (120 MW) is not justified anymore.
- The commissioning steps for the Coal plant of Salkadamna in Niger are also shifted so that the whole 200 MW are only necessary two years later, compared to the reference scenario.
- Concerning the other thermal candidate units, it should be noted that there is, in this alternative, no more need for building combined cycles in The Gambia or Togo. In the same way, only the candidate project of a second combined cycle T3 (120 MW) is necessary in Ghana, with a deferred commissioning of 6 years compared to the reference scenario.

The principal changes concerning the investment decisions in the transmission lines (projects considered, reinforcements, and new lines suggested) are mentioned below:

- In this alternative, the Linsan-Manantali interconnection is also justified for the exchanges of power between Guinea and Mali
- Installation of a 2nd circuit on the CLSG interconnection for the section Monrovia (Liberia) - Man (Ivory Coast) is not justified economically any more because less hydroelectric projects are invested in these countries.
- The reinforcement of the Coastal backbone between Togo and Benin is not justified any more since the combined cycle of Togo is not selected any more among the investment options.

Let us note that the interconnection suggested between the substations of Fomi in Guinea and Boundiali in Ivory Coast remains interesting from 2020 on, even in this alternative with low demand growth.

This alternative tends to show that, even in the event of a lower load growth, the regional transmission projects to evacuate the power from Guinea remain of utmost importance for the area. On the other hand, the combined cycle project in Togo who has a regional vocation will be justified at the horizon of the study only if the load growth is considerable.

2.7.4. Renewable alternative

This alternative consists in adopting a voluntary approach of investment in renewable electric production capacities (except hydroelectricity) so that the quota of these capacities in the total power installed of the area reaches 10% as from 2020.

This constraint corresponds to a power of approximately 2500 MW of renewable generation having to be installed by 2020.

In order to avoid the massive commissioning of renewable capacities during the only year 2020, it was supposed that the objective would be achieved by stages of 500 MW from 2016 on.

Lastly, the quota of 10% of the yearly peak load was maintained until the end of the study period. Thus, renewable capacity imposed in 2025 reached more than 3500 MW.

The table below summarizes the minimum capacities constraints on renewable production imposed to the optimization for each year as previously explained.

Year	Imposed capacity of renewable generation (out hydro) [MW]
2016	500
2017	1000
2018	1500
2019	2000
2020	2500
2021	2700
2022	2900
2023	3150
2024	3400
2025	3650

Table 57 - Renewable capacity (without hydro) imposed per year for the scenario of voluntary investment into renewables

In order to achieve these goals, the renewable candidate projects already known in the countries of the area (presented in the section 2.2.4.2 “Development plans of the park of production”) were forced in the optimization.

In addition to these already known candidate projects and to the decided renewable projects, it was necessary to add additional investment options in the countries of the area, as presented in the table below.

Country	Technologies and renewable capacities envisaged for the decided and known candidates projects	Technologies and renewable capacities suggested for additional investments (as from 2016, 2021)
Senegal	biomass (30MW) wind (125MW) solar photovoltaic (7.5MW)	wind (100MW, 100MW) solar photovoltaic (100MW,100MW)
The Gambia	wind (11MW) solar photovoltaic (10MW)	wind (40MW, 40MW) solar photovoltaic (20MW, 20MW)
Guinea Bissau	no renewable candidate projects known	solar photovoltaic (20MW, 20MW)
Guinea	no renewable candidate projects known	no renewable technologies suggested because massive hydroelectric investments
Sierra Leone	biomass (115MW) solar photovoltaic (5MW)	biomass (125MW, 125MW)
Liberia	biomass (35MW)	biomass (35MW, 35MW) solar photovoltaic (20MW, 20MW)
Mali	biomass (18MW) solar photovoltaic (80MW)	solar photovoltaic (150MW, 150MW) solar thermal(50MW,50MW) biomass (20MW, 20MW)
Ivory Coast	no renewable candidate projects known	no renewable technologies suggested because massive thermal investments with local gas and little wind and solar resources
Ghana	wind (150MW) solar photovoltaic (10MW)	wind (100MW, 100MW) solar photovoltaic (100MW, 100MW)
Togo	wind (20MW) solar photovoltaic (5MW)	wind (50MW, 50MW) solar photovoltaic (25MW, 25MW)
Benin	solar photovoltaic (30MW)	solar photovoltaic (70MW, 70MW)
Burkina Faso	solar photovoltaic (43MW) solar thermal (4MW)	solar photovoltaic (150MW, 150MW) solar thermal (50MW, 50MW)
Niger	wind (30MW) solar thermal (50MW)	wind (30MW, 30MW) solar photovoltaic (20MW, 20MW)
Nigeria	no renewable candidate projects known	wind (300MW, 300MW) solar photovoltaic (250MW, 250MW) biomass (200MW, 200MW)

Table 58- Renewable capacity and technologies (without hydro) of the decided projects, known candidates and additional investment options suggested

The capacities and technologies suggested were selected to avoid a too significant part of intermittent production in the energy mix of each country and to try developing the technologies already existing or with high potentials within each country (based on the information of section 2.2.2.2 and on the document « Renewable Energies in West Africa, Regional Report on Potentials and Markets – 17 Country Analyses » published by the German Federal Ministry for Economic Cooperation and Development).

The distribution of the capacities suggested in the countries was selected in order to match the localization of the local renewable resources and to take into account the importance of the load. The data used about costs and availabilities of the renewable resources were presented in sections 2.2.2.2 and 2.2.4.1.

Summary of the costs (kUSD)	***Scenario 3***	***Scenario 6***
	Reference scenario	Voluntary renewable investment
Total	55 128 668	56 251 999

Table 59 - Costs of the scenario with voluntary renewable investments

Logically, the cost difference with the reference scenario appears mainly in higher capital costs (and fixed cost) for the generation units in the renewable alternative. This cost overrun is partly compensated by the reduction in the natural gas and liquid fuel consumption, so that the total discounted costs increase compared with the reference scenario globally reaches 1 123 M$, which corresponds, relatively, to an increase of 2%.

The results of the economic optimization for this alternative are presented in the graphs below. They show for 2020 and 2025 the total renewable capacities which will have to be installed by country and by technology to respect the renewable constraint of 10% of installed capacity in the area.

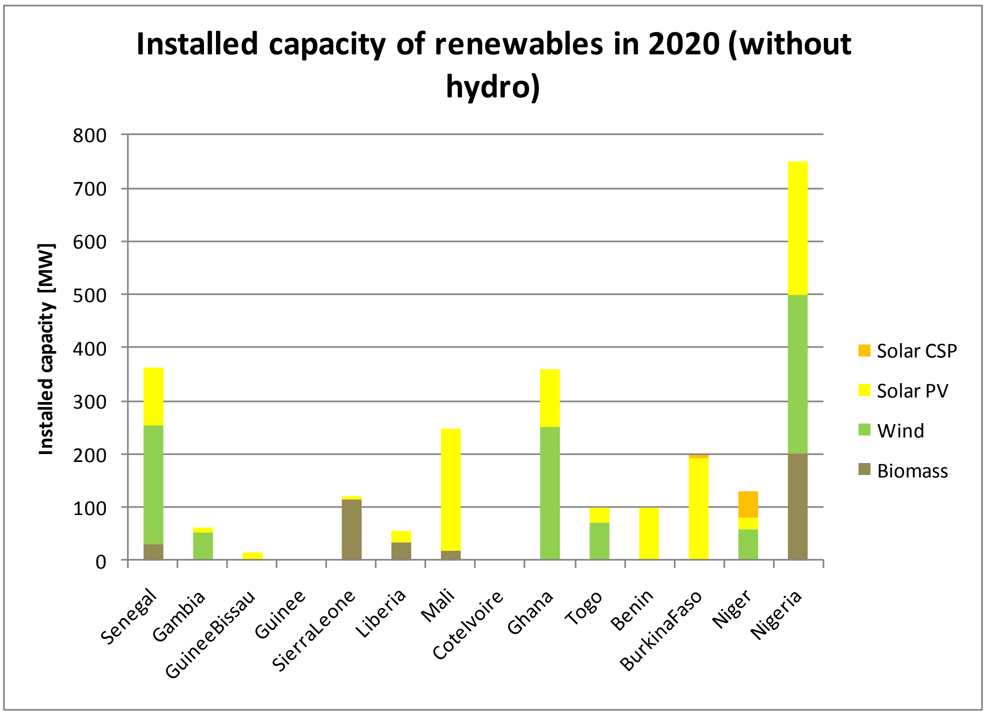


Figure 41 - Renewable installed capacity by country in 2020 (except hydro) for the voluntary scenario of renewable investment

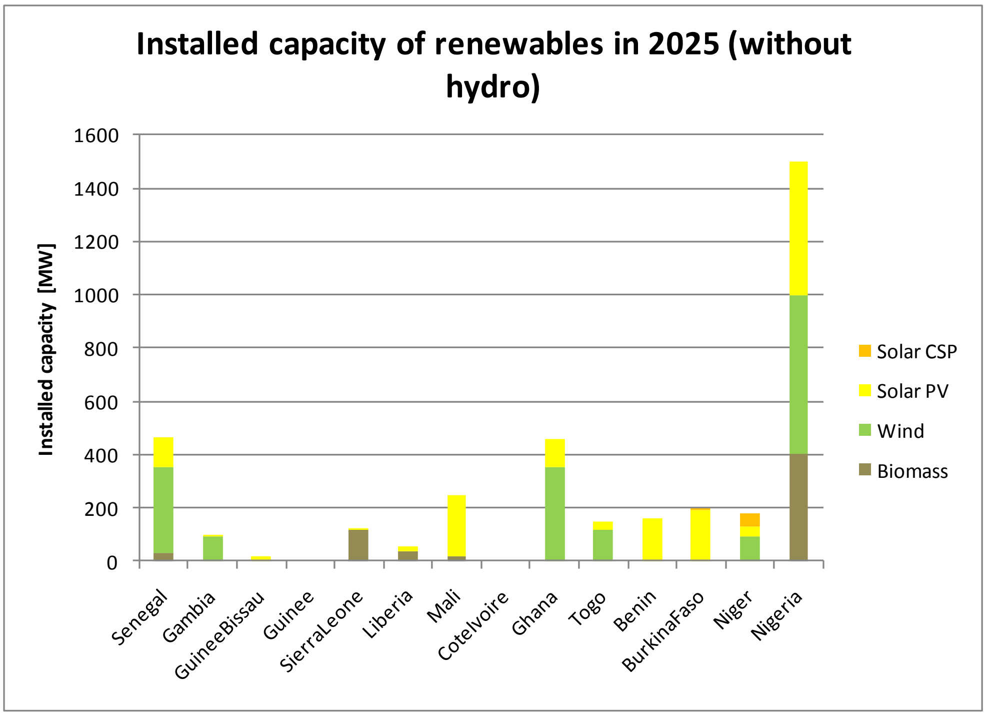


Figure 42 - Renewable installed capacity by country in 2025 (except hydro) for the voluntary scenario of renewable investment

Various comments can be done about these results:

- When it is proposed as candidate for a country, wind is the first technology to be retained, thanks to its low costs per kWh.
- The biomass is the second least expensive renewable technology. Nevertheless the additional investments suggested in this technology (compared to the known projects) are retained only in Nigeria. One of the reasons is for example the fact that Sierra Leone, albeit its high biomass potential, can develop less expensive hydroelectric resources for an exportation purpose.
- The additional investments suggested in photovoltaic technology are retained to complete the two previous technologies to satisfy the imposed constraint.
- Except the thermal solar projects (CSP) already known (and thus imposed in this alternative) in Mali and Niger, no new project arises from optimization, because of the high cost per kWh of this technology (primarily because of the capital costs and the fixed costs), much higher than for solar photovoltaic and other renewable technologies.

The important modifications concerning the investment decisions in thermal and hydroelectric production in this alternative are mentioned below:

- In Liberia, the St Paul projects (1B and 2) are not justified anymore at the horizon of the study. The commissioning of several hydroelectric projects is delayed: Digan (2 years), Boureya (1 year), Kouravel (1 year), Manor River (1 year) and Gribo Popoli (1 year).
- The complete commissioning of the 200 MW coal project in Salkadamna in Niger is delayed of one year.

- There is, in this alternative, no more need for building a combined cycle in The Gambia. The commissioning steps for the candidate combined cycles in Ghana are shifted in the future and approximately 200 MW less are invested in this type of units in Ghana by 2025 compared with the reference scenario. The combined cycle suggested in Togo remains interesting, but only in the long term, after 2022. 6000 MW of cycles combined with Nigeria remain also interesting and this in the short term.

The principal changes concerning the investment decisions in transmission lines (projects considered, reinforcements, and new lines suggested) are mentioned below:

- The Linsan-Manantali interconnection is not really justified any more.
- In Nigeria, a reduction of approximately 400 MW in transport capacity will be necessary between the south and the center of the country in 2025, compared with the reference scenario. This is due to the fact that wind and solar photovoltaic projects appear in the northern and center areas for this alternative.
- The interconnection suggested between the substations of Fomi in Guinea and Boundiali in Ivory Coast remains very important in this alternative.

In conclusion, it appears that the overall investment and operation costs of the production park and the grid do not increase in a considerable way with the implementation of a renewable policy. Moreover, such policy would make it possible to decrease the energy dependence of certain countries (Burkina Faso and The Gambia in particular) and to reduce the dependence on fossil fuels of countries very dependant on gas (Nigeria in particular).

Thus, it would be possible to support at regional level:

- A project of one or more **wind farms for an installed capacity of 200MW to distribute between Senegal and The Gambia.** These countries indeed have an interesting potential along the Atlantic coast. Moreover, Senegal and The Gambia already have projects at national level, showing the willingness of these countries to develop these resources.
- The construction of **wind farms for a total of 300 MW in Nigeria** to decrease the energy dependence of the north of Nigeria and to reduce the fossil fuel consumption in this country.
- The development of **solar photovoltaic projects for a total of 150 MW in Burkina Faso** (in addition to the projects already under consideration by the country and the local industries) in order to reduce the marginal cost of the country. The country has an interesting photovoltaic potential and shows its willingness to develop renewable energies on its territory.
- The development of **solar photovoltaic projects for a total of 150 MW in Mali** (in addition to the projects already under consideration by the country and the local industries) in order to reduce energy imports in this country and to foster the interesting PV potential on its territory.

2.7.5. Alternative low fuels cost

The purpose of this alternative is to analyze the effect of a decreased fuel cost compared to the reference scenario. With this intention, the fuel prices considered were aligned on a crude oil price of 75$/bbl instead of 100$/bbl in the reference scenario. The values of these lowered prices are included in section 2.2.2.1 "Price of fuels". Let us note that the prices considered for biomass fuels were not adapted because of their low sensitivity compared to the crude oil price.

Summary of the costs (kUSD)	***Scenario 3***	***Scenario 7***
	Reference scenario	Low fuels cost
Total	55 128 668	44 647 252

Table 60 - Costs of the scenario with low fuels cost

A considerable reduction of 19% of the actualized total costs is observable in this alternative compared with the reference scenario. This reduction is primarily due to the reduction of the natural gas cost which provokes a global reduction of about 15% in the total discounted costs.

The important modifications concerning the investment decisions in production for this alternative are mentioned below:

- The commissioning of a certain number of hydroelectric projects is delayed by the optimization because of the possibility of supplying the load with thermal units at low costs. The commissioning of Kétou in Benin is thus delayed of 5 years compared to the reference scenario; the sites of Mano River between Sierra Leone and Liberia and Gribo Popoli in Ivory Coast are delayed of 3 years; finally, the site of Aboisso Comoé in Ivory Coast is delayed of 2 years. In Liberia, the projects St Paul (1B and 2) are not justified any more at the horizon of the study.
- Concerning the coal candidate production units, it should be noted that the 200 MW project of Salkadamna in Niger is not justified any more here by economic optimization.
- In Ghana, the investment in combined cycles with gas is reinforced: 200 MW more are invested in these units by 2025 compared to the reference scenario.

Let us note that the 6000 MW investment in combined cycles in Nigeria which arose from the reference scenario is still justified in this alternative and this in spite of a lower gas cost which is consequently not low enough to justify the operation of open cycle gas turbines as base units.

Generally, let us also note that the proportion of electricity generated at the horizon of the study by the thermal units running with gas and liquid fuels increases in this alternative, with the detriment of the hydroelectric units.

The principal changes concerning the investment decisions in transmission lines (projects considered, reinforcements, and new lines suggested) for this alternative are mentioned below:

- In this alternative, the Linsan-Manantali interconnection is also justified for the power exchanges between Guinea and Mali.

- Installation of a 2nd circuit on the section Monrovia (Liberia) - Man (Ivory Coast) of the CLSG project is not justified economically any more.
- The interconnection suggested between the substations of Fomi in Guinea and Boundiali in Ivory Coast is slightly less charged in this alternative since less hydroelectric projects are selected by the economic optimum but it remains nevertheless competitive.

2.7.6. Alternative high fuels cost

The purpose of this alternative is to analyze the effect of an increased fuel cost compared to the reference scenario. With this intention, the fuel prices considered were aligned on a crude oil price of 125$/bbl instead of 100$/bbl in the reference scenario. The values of these increased prices are included in section 2.2.2.1 “Price of fuels”. Let us note that the prices considered for biomass fuels were not adapted because of their low sensitivity compared to the crude oil price.

Summary of the costs (kUSD)	***Scenario 3***	***Scenario 8***
	Reference scenario	High fuels costs
Total	55 128 668	65 374 071

Table 61 - Costs of the scenario with high fuels costs

A significant growth of 18.5% of the actualized total costs is observable in this alternative compared with the reference scenario. This growth is primarily due to the cost of the natural gas which alone increases the total discounted costs of about 15%.

- The important modifications concerning the investment decisions in production in this alternative are mentioned below:
- Certain hydroelectric projects which did not come out of the optimization in the reference scenario are now economically justified in this alternative for a commissioning between 2020 and 2025. They are the projects of Fello Sounga (OMVG) in Guinea, Tiassalé in Ivory Coast and Gambou in Niger.
- The commissioning of certain projects is also advanced compared to the reference scenario. It is e.g. the case for the Gribo Popoli project in Ivory Coast (4 years). In Liberia, the site of St Paul 1B (78 MW) is justified from 2018 on and of St Paul 2 (120 MW) from 2021 on instead of 2023 and 2024 respectively in the reference scenario.
- Concerning the coal projects, Salkadamna in Niger is, in this alternative, justified from 2015 on, i.e. 7 years in advance compared with the reference scenario.
- Two renewable projects (except hydro) which did not arise from the optimization in the reference scenario are justified economically in this alternative. They are the biomass project (bagasse) of Sosumar in Mali and the wind project of 20MW in Togo, which becomes interesting from 2013-2014 on.

Also, this alternative also confirms the interest of a combined cycle in south Togo which arose from the reference scenario.

In a general way, logically, the proportion of generated electricity in this alternative at the horizon of the study by the thermal units running with gas and liquid fuels (at high costs) decreases with the profit of the hydroelectric and coal units (whose cost increase does not appear penalizing).

The principal changes concerning the investment decisions in transmission lines (projects considered, reinforcements, and new lines suggested) for this alternative are mentioned below:

- The Linsan-Manantali interconnection is not justified any more except for connecting and sharing the hydroelectric resource of Boureya and Koukoutamba.
- The installation of a 2nd circuit on the section Monrovia (Liberia) - Man (Ivory Coast) of the CLSG project is economically justified in the shorter term that in the reference scenario.

2.7.7. Alternative with low actualization rate

The purpose of this alternative is to analyze the impact of a low actualization rate fixed at 8% instead of 10% in the reference scenario, to reflect a lower capital cost.

The important modifications concerning the investment decisions in production in this alternative are mentioned below:

- Certain hydroelectric projects which did not arise from the optimization in the reference scenario are now economically justified in this alternative for a commissioning between 2020 and 2025. They are the projects of Fello Sounga (OMVG) in Guinea, Tiassalé in Ivory Coast, Tététou in Togo, and Gambou in Niger.
- The commissioning of certain projects is also advanced compared to the reference scenario. It is e.g. the case of the Gribo Popoli project in Ivory Coast (4 years). In Liberia, the sites of St Paul 1B and St Paul 2 (120 MW) are justified both in 2018 compared with 2023 and 2024 respectively in the reference scenario.
- Concerning the coal projects, Salkadamna in Niger is, in this alternative, justified from 2015-2016 on, i.e. 7 years in advance compared with the reference scenario.
- The commissioning steps of the Ghanaian projects of combined cycles are slightly shifted in the future.

The principal changes concerning the investment decisions in transmission lines (projects considered, reinforcements, and new lines suggested) for this alternative are mentioned below:

- The Linsan-Manantali interconnection is not justified any more except for connecting and sharing the hydroelectric resource of Boureya and Koukoutamba.
- The installation of a 2nd circuit on the section Monrovia (Liberia) - Man (Ivory Coast) of the CLSG project is economically justified in a shorter term that in the reference scenario.
- An additional reinforcement of the axis between Abidjan and Soubré in Ivory Coast could in this alternative be justified, to allow a transit of 600 MW from 2020 on.
- The interconnection suggested between the sub stations of Fomi in Guinea and Boundiali is still very interesting in this scenario.

Let us note that these conclusions are very close to those which emanated from the alternative considering a high price of fuels. This is logical since a low actualization rate supports the investments (for example in hydroelectric production units or coal as in transmission lines) avoiding operation costs in the future (which, once actualized, are more expensive with a low actualization rate).

2.7.8. Alternative with high actualization rate

The purpose of this alternative is to analyze the impact of a high actualization rate fixed at 12% instead of 10% in the reference scenario, to reflect a higher capital cost.

The important modifications concerning the investment decisions in production in this alternative are mentioned below:

- The investment in a certain number of hydroelectric projects is delayed by the optimization in this alternative. They are the sites of Mano River between Sierra Leone and Liberia (4 years), Gribo Popoli (3ans) and Aboisso Comoé in Ivory Coast (3 years). In Liberia, the St Paul projects (1B and 2) are not economically justified any more at the horizon of the study.
- Concerning the candidate coal production units, it should be noted that the Salkadamna project in Niger is still justified but only for 100 MW in 2024-2025 (instead of 200 MW possible and invested in the reference scenario).
- In Ghana, the investment in combined cycles with gas is reinforced: 163 MW more are invested in these units by 2025 compared to the reference scenario.

Let us note that the investment in 6000 MW of combined cycles in Nigeria which arose from the reference scenario is still justified in this alternative, just as the investment in a combined cycle of 450 MW in Togo.

The principal changes concerning the investment decisions in transmission lines (projects considered, reinforcements, and new lines suggested) for this alternative are mentioned below:

- The installation of a 2nd circuit on the section Monrovia (Liberia) - Man (Ivory Coast) of the CLSG project is not economically justified any more.
- The interconnection suggested between the substations of Fomi in Guinea and Boundiali in Ivory Coast is in this alternative slightly less justified.

Just like the scenario with low actualization rate was very close to the scenario with high fuel prices, this alternative with a high actualization rate is relatively similar to the one with low fuel prices.

2.7.9. Alternative with reduction of the candidate hydroelectric projects in Guinea

The purpose of this alternative is to consider limited investment capacities in the hydroelectric projects that are candidates and located in Guinea compared with the reference scenario.

To this purpose, the less advanced projects on the plan of the studies or those located far from the 225 kV decided and planned network for Guinea were not considered.

Summary of the costs (kUSD)	***Scenario 3***	***Scenario 11***
	Reference scenario	Reduction of the candidate hydroelectric projects in Guinea
Total	55 128 668	55 303 181

Table 62 - Costs of the scenario with reduction of the candidate hydroelectric projects in Guinea

In terms of actualized total costs, this alternative corresponds to a moderate cost overrun of 175 M$ over the study period compared with the reference scenario, that is to say an increase 0.3%. The capital costs are lowered overall because there are fewer hydroelectric projects (expensive investment compared with the thermal solutions) as well as the reduced transmission capacity that is necessary to export the production of these hydro projects. The operation costs, and in particular the costs associated with the natural gas consumption, are increased, leading to the cost overrun mentioned.

Beside the reduction of hydroelectric production of Guinea, the important modifications arising from the economic optimization in this alternative are listed below:

- The commissioning of certain hydroelectric projects is advanced compared to the reference scenario, to compensate the energy deficit provoked by putting aside some projects in Guinea: Gribo-Popoli in Ivory Coast (advanced 3 years), Saint Paul 1B and Saint Paul 2 in Liberia (advanced 2 years)
- 180 MW of additional combined cycle are justified in Ghana at the horizon of the study in this alternative, to compensate the lack in hydroelectric energy importation.

The principal changes concerning the investment decisions in transmission lines (projects considered, reinforcements, and new lines suggested) for this alternative are presented below:

- The Linsan-Manantali interconnection is not justified anymore except for connecting and sharing the hydroelectric resource of Boureya and Koukoutamba.
- The installation of a second circuit on the CLSG interconnection between Monrovia (Liberia) and Man (Ivory Coast) is justified sooner than in the reference scenario to export more energy from the hydroelectric sites of Liberia and Sierra Leone.

The Interconnection suggested between the substations of Fomi in Guinea and Boundiali in Ivory Coast is less justified in this alternative since fewer hydroelectric projects are considered in Guinea.

2.7.10. Synthesis of the alternatives

The alternatives show that according to the evolution of the great macro-economic parameters that are the load growth, the actualization rate and the trend of the fuels prices, two completely different behaviors could occur.

On the one hand, if the actualization rate suddenly decreased or if the prices of fossil fuels increased, the hydroelectric projects would be largely favoured with the detriment of the thermal projects (natural gas and coal).

Oppositely, if the actualization rate had suddenly increased or if the prices of fossil fuels decreased, the hydroelectric projects would be largely underprivileged with the profit of the thermal projects.

Consequently, it is important to maintain a balanced energy mix between the various resources in order to ensure a reasonable discounted cost in all circumstances.

Lastly, if an energy policy based on renewable energies were implemented on the scale of West Africa, the discounted cost would only be fairly impacted (2%) and would allow to reduce the energy dependence of certain areas having only few hydroelectric or gas resources.

2.8. Conclusion: Provisional list of priority projects based on the economic criteria

The provisional list of priority projects presented hereafter and based on the economic study relates to transmission and production projects which are added to the transmission projects already decided and planned and to the decided production projects which cannot be questioned any more and are described in the data in sections 2.2.4 and 2.2.5.

2.8.1. Priority production projects

The optimal development plan of the West African area resulting of this study and based on an exclusively economic optimization model tends to show that it is essential to develop the **hydroelectric resources** in the countries of zone B, in Ivory Coast and in Nigeria.

The mountainous regions of Forest Guinea and Fouta Djalon are the source of many rivers which feed Guinea itself but also Liberia and Sierra Leone.

This is why regional entities (OMVS and OMVG) consider the development of the potential of Guinea, in particular through the projects **Grand Kinkon** *(OMVG),* **Boureya**, **Koukoutamba** *and* **Balassa** *(OMVS). These projects deserve to be supported in priority at regional level.*

In addition to these projects, many other installations are considered for Guinea. Nevertheless, for technical, environmental and financial reasons but also in order to ensure a reasonable development cost in all circumstances (and in particular if the cost of fuels dropped suddenly or if the actualization rate increased), it is not reasonable to consider the commissioning of as many hydroelectric plants. Among the great projects under consideration in the country, the project of ***Kassa B*** *is certainly one of the projects to be supported at the regional level, first of all because its cost by GWh is one of the lowest and secondly because it has a true regional vocation from its location at a few kilometers of the border between Guinea and Sierra Leone. Projects of* ***Grand Kinkon****,* ***Amaria*** *and* ***Souapiti*** *have also a high regional interest due to their economic competitiveness and their size. Particular attention should nevertheless be made to these projects on the environmental point of view.*

In Sierra Leone, the ***Bumbuna*** *project is totally justified economically and is ideally located along the CLSG line.*

Moreover, the project of ***Tiboto*** *located at the border between Liberia and Ivory Coast has a relatively competitive cost of GWh. Consequently, it could be retained as a priority project for the countries. Let us note however that this project can be evacuated only through one 225 kV line to build between Monrovia and San Pedro*

Among the internal projects in Ivory Coast, the project of ***Soubré*** *has a cost of GWh slightly more important than Boutoubré but the size of this project (270 MW) and the status of the preliminary studies are such that this project should be under consideration in priority.*

Finally, the project Zungeru (in the western part of Nigeria) and the project Mambilla (on the 760kV line that will cross Nigeria) could be under consideration at the regional level.

Within a regional framework where the macro-economic parameters could strongly influence the discounted cost, it is important to maintain a **balanced energy mix** between the various resources in order to ensure a reasonable development cost in all circumstances. This is why thermal projects must be regarded as priority projects.

Today two priority projects were already highlighted by the WAPP. They are the combined cycles of Aboadze in Ghana and Maria-Gleta in Benin.

In addition to these projects and to projects decided by the countries, two projects appear crucial at regional level.

The coal project in Niger *is essential for the load supply in the North-east area of the WAPP. Indeed, in this area, the gas and hydroelectric resources are limited, which tends to strongly increase the marginal cost. In the reference scenario, this project was considered only in the long term (after 2020) but the alternatives showed that this project could become crucial in a shorter term. The North-core transmission project will allow sharing this energy between Niger, Burkina Faso, Benin and the north of Nigeria.*

The ***combined cycle project in Togo*** *is important for the region. Indeed, among the countries crossed by the Coastal backbone, Togo is the only one to not count any combined cycle project (WAPP or national). In the absence of such a project, the country would become strongly importer and the gas coming from Nigeria would be unexploited. Let us note however that a high fuel cost and a low actualization rate are unfavourable to the thermal projects in general and to this project in particular.*

Lastly, the alternatives showed that if a voluntary development scenario of renewable energy were set up, on the scale of West Africa, the discounted cost would be only fairly impacted (1%) and would allow reducing the energy dependence of certain areas having only few hydroelectric or gas resources.

Thus, it would be important to support the following renewable projects first:

- *A construction project of one or more* ***wind farms for an installed capacity of 200MW*** *(in addition to the projects already under consideration by the countries) to distribute between* ***Senegal and The Gambia****. These countries indeed have an interesting potential along the Atlantic coast. Moreover, Senegal and The Gambia have already projects at national level, which shows the willingness of these countries to develop these resources.*
- *The construction of* ***wind farms for a total of 300 MW in Nigeria*** *to decrease the energy dependence of the north of Nigeria and to reduce the fossil fuel consumption in this country.*
- *The development of* ***solar photovoltaic projects for a total of 150 MW in Burkina Faso*** *(in addition to the projects already under consideration by the country and the local industries) in order to reduce the marginal cost of the country. The country has an interesting photovoltaic potential and shows its willingness to develop renewable energies on its territory.*
- *The development of* ***solar photovoltaic projects for a total of 150 MW in Mali*** *(in addition to the projects already under consideration by the country and the local industries) in order to reduce energy imports in this country and to foster the interesting PV potential on its territory.*

In conclusion the production projects considered to be priority based on economic criterion are the followings:

Name of the project	*Country*	*Technology*	*Commissioning*
Balassa, Boureya, Koukoutamba (OMVS)	Guinea	Hydro	2020
Grand Kinkon	Guinea	Hydro	2018
Kassa B	Guinea/Sierra Leone	Hydro	2018
Souapiti	Guinea	Hydro	2018
Amaria	Guinea	Hydro	2018
Bumbuna	Sierra Leone	Hydro	2018
Tiboto	Liberia/Ivory Coast	Hydro	2018
Soubré	Ivory Coast	Hydro	2018
Zungeru	Nigeria	Hydro	2018
Mambilla	Nigeria	Hydro	2018
Salkadamna	Niger	Coal	2020
Combined cycle	Togo	Nat. Gas	2020
200 MW park	Senegal/The Gambia	Wind	2016-2020
300 MW park	Nigeria	Wind	2016-2020
150 MW park	Burkina Faso	Solar photovoltaic	2016-2020
150 MW park	Mali	Solar photovoltaic	2016-2020

Table 63 - Priority production projects

2.8.2. Priority transmission projects

The development of the optimal development plan according to the macro-economic parameters showed the interest of massively developing the hydroelectric projects in West Africa but also to maintain a balanced energy mix in order to preserve a reasonable development cost in all circumstances.

Moreover, the low cost overrun generated by a voluntary policy as regards renewable energies could encourage the countries to invest in such resources.

It is consequently necessary to reinforce the grid system in order to allow the optimization of the exchanges between the areas having hydroelectric, gas and renewable resources.

Whatever the load, fuels price or actualization rates parameters considered, the study concludes that the ***Guinea (Fomi) - Ivory Coast (Boundiali)*** *project is always a very important project for the area. This project should be regarded as a priority project for 2018. In addition, upstream projects* ***(Linsan-Fomi)*** *and downstream* ***(Boundiali-Ferkessedougou- Bobo and Bobo- Ouagadougou)*** *should be reinforced.*

The reinforcement of the lines allowing the export of the energy produced in Guinea, in Sierra Leone and Liberia will be all the more important as many hydroelectric projects will be invested in these countries and that the neighbouring countries will develop less projects at national level. Thus, the reinforcement of the ***CLSG line*** *could become crucial in the long term (>2020).*

Moreover, considering the importance of also developing the gas resources in the countries in the South of zoneA, the ***Coastal backbone*** *will be a critical link which could require a reinforcement in the long term (>2020).*

Moreover, several transmission projects are directly associated with production projects considered to be priority based on economic criteria.

The Median backbone *would allow sharing the production of Zungeru between the different countries of the region.*

The ***Monrovia-San Pedro*** *interconnection allows sharing the energy produced by Tiboto between Ivory Coast and Liberia. This investment is more expensive than the construction of a second circuit on the CLSG line but if the Tiboto project is decided, this line will have to be built and it will be able to compensate the second circuit of the CLSG line.*

In the majority of the scenarios considered, the ***OMVS interconnection between Linsan and Manantali*** *is justified economically only by the presence of important hydroelectric sites (Balassa, Koukoutamba, Boureya) on its routing. Nevertheless, each one of these projects is so interesting that this line should be built in priority.*

At last, the coal plant of ***Salkadamna*** *being located relatively far from the network, a line will have to be built at the same time to connect the power plant to the interconnected network (North-core interconnection). Moreover, a second line could be built between Salkadamna and the Center-East area of the country.*

The table below shows the principal transmission developments selected by the optimization tool based on purely economic criteria, in addition to the decided and planned projects. Moreover, the lines which are justified by their associated regional projects are indicated in italic.

Name	***Associated production project***	***Commissioning***	***Capacity***
Median backbone	*Zungeru*	*>2020*	*300 MW*
Liberia (Monrovia) - Ivory Coast (San Pedro)	*Tiboto*	*2018*	*150 MW*
OMVS-OMVG interconnection (Tambacounda - Kayes)	*Gouina*	*2017*	250MW
OMVS-OMVG interconnection (Linsan – Manantali)	*Koukoutamba, Boureya, Balassa*	*2018*	250MW
Guinea(Fomi) – Ivory Coast (Boundiali)		2018	2x250 MW
Linsan-Fomi (second line)	Souapiti	2018	250 MW
Boundiali-Ferke – Bobo (second circuit)		2018	250 MW
Bobo – Ouaga (second line)		2018	250 MW
Ligne CLSG (second circuit)		>2020	250 MW
Coastal backbone section Lome-Sakété (second line)		>2020	312 MW
Salkadamana - Niamey	*Salkadamna*	*2020*	*200 MW*
Salkadamana - Center East	*Salkadamna*	*2020*	*100 MW*

Table 64 - Priority transmission projects

3. TRANSMISSION NETWORK PERFORMANCES AND STABILITY ANALYSIS

3.1. Introduction

The economic analysis aims at providing a list of priority investments. The objective of the stability study is to determine whether these investments will lead to a stable operation of the network or if additional measures have to be taken to stabilize it. If such measures are needed, their impact must be taken into account in the priority investment list.

To this purpose, a complete model of the WAPP's system for the years 2015, 2020 and 2025 was built and different scenarios were investigated. The examined system configurations varied on the availabilities of the interconnections between countries, leading to different production units' commitment and international exchanges.

On these scenarios, multiple simulations were carried out to test the system and assess its stability limits. The analysis covered static and dynamic aspects: security analysis, operation optimization, reactive compensation study, short-circuits study, small signal stability, transient stability and dynamic security assessment. All these simulations revealed the weaknesses of the system and permitted to conclude on how to extend its operation limits up to the desired level.

This chapter presents the results and conclusions of the transmission network performances and stability analysis. At first, the methodology used for modeling the network and performing the simulations is explained. Secondly, all details and assumptions done for modeling the WAPP's interconnected network are given. Then the different scenarios and the various simulations are presented. Finally, the analysis is concluded and the impact on the investment priorities is assessed.

3.2. Methodology

This section explains the methodology for all simulations performed later here below. The static analysis is depicted before the dynamic analysis.

3.2.1. Static analysis

3.2.1.1. OPTIMAL POWER FLOW AND REACTIVE COMPENSATION

This part of the study consists in optimizing the system operation, first by using its existing resources, and second by completing these resources with reactive compensation that could be needed.

3.2.1.1.1. Optimal power flow (OPF)

This first optimization is carried out using only the existing elements of the system. The objective of the optimization is twofold:

- Improving the initial state by reducing the number of nodes violating the normal voltage range. For this step, there is no objective function and the OPF is trying to respect all the grid constraints (this step is called “feasibility step”).
- Improving further the operation point by reducing reactive generation and increasing the reactive margin of generators. This operating point is then used to perform the different system analysis.

3.2.1.1.1.1. Definition of the optimization process

The optimization problem consists of three key features:

- The objective function which represents the operating performances of the power system;
- The set of variables: state ($\boldsymbol{x}$) and control ($\boldsymbol{u}$) variables;
- The set of equality and inequality constraints.

3.2.1.1.1.2. Objective function

The objective consists of the maximization of the individual reactive margin of each generator. This objective function characterizes the system security

$$\boldsymbol{f}(\boldsymbol{x},\boldsymbol{u}) = \sum_{\boldsymbol{i}\in\boldsymbol{G}} \frac{\left(\boldsymbol{Q}_{\boldsymbol{g},\boldsymbol{i}} - \boldsymbol{Q}_{\boldsymbol{g}0,\boldsymbol{i}}\right)^2}{\boldsymbol{Q}_{\boldsymbol{g}\max,\boldsymbol{i}} - \boldsymbol{Q}_{\boldsymbol{g}\min,\boldsymbol{i}}}$$

This objective function is aimed at meeting voltage security requirements. Simulations have shown that these requirements are adequately reflected when the individual reactive margin of each generating unit is maximized.

For closely located units, this objective function translates into similar reactive power loading with regards to their reactive power limits.

3.2.1.1.1.3. Variables

Variables are divided into two groups: state ($\boldsymbol{x}$) and control ($\boldsymbol{u}$) variables. The state variables correspond to all complex bus voltages. The control variables are related to quantities used to “manipulate” (or control) the state variables. They consist of:

- Reactive power generation (by controlling the voltage setpoint). This concerns active power generation units and SVC;
- Transformer’s tap positions. All transformers are supposed to be OLTC.
- Reactive power of shunt capacitor /inductors. All compensation means are assumed controllable.

3.2.1.1.1.4. Constraints

Equality constraints: Kirchhoff’s equations

Inequality constraints: include operational constraints. These constraints are:

- Limits on state variables: voltage magnitudes (in general +/- 5%) and thermal ratings of branches;
- Limits on control variables (Maximum and minimum reactive power of generators, transformers tap available range, available steps of compensation banks).

3.2.1.1.2. Reactive power compensation

This second optimization consists in completing the existing resources of the system with capacitor banks or reactor banks, to better manage the reactive power and the voltages in the system. The reasons invoked for such installations are usually all related:

- Compensating the load and improving the power factor;
- Unload a line or a transformer by decreasing the reactive power flowing through, leaving more capacity for transiting active power;
- Better controlling the voltages;
- Adjust the reactive power production of generating units.

3.2.1.2. SECURITY ANALYSIS

The objective of the security analysis is to estimate the ability of the network to operate in case of contingencies.

This static analysis covers the disconnection of all branches (lines and transformers) in the system. The loss of generating units will be analyzed dynamically as such contingency require the simulations of dynamic phenomena (frequency deviation, primary response of machine …).

For this analysis, the lines and transformers that are considered for contingency are all connected at high voltage, from 760 to 90 kV.

When a branch is lost, two types of problem can appear, caused by the new power flows in the network when it has reached its new steady state (dynamic behavior is not taken into account for the static security analysis): branch overloads and voltage variations (either under-voltage or over-voltage). The following criteria have been defined:

Branch overloads criteria

- Initial load flow, before contingency, shouldn’t show any branch overload
- After contingency, the following overloading are accepted :
  - Lines and cables : 110%
  - Transformers : 120%

Voltage variations criteria

- In the initial voltage profile, the voltage of every node in the network is between 0.95 pu and 1.05 pu
- After contingency, the range tolerated is 0.9 pu to 1.1 pu

3.2.1.3. SHORT-CIRCUIT ANALYSIS

The short-circuit computations have been performed with SHOCC, a software developed in-house by Tractebel Engineering. It uses IEC 60909 breaker standards.

The short-circuit computation is performed for a three phase fault for the 760 kV, 330 kV, 225 kV, 161 kV, 150 kV, 132 kV, 110 kV and 90 kV nodes.

The current measured must be less than the opening capability of the installed equipment. These capabilities were not available in the data collection and are consequently assumed to be:

- 31.5 kA for 161 kV, 225 kV, 330 kV and 760 kV breakers
- 25 kA for 90 kV, 110 kV, 132 kV and 150 kV breakers

The analysis is performed at peak load, and twice for each scenario: once with the generation units' commitment corresponding to the scenario and once with all generating units connected. This last configuration is the one providing the maximum values of short-circuit currents.

3.2.2. Dynamic analysis

3.2.2.1. SMALL SIGNAL STABILITY

The small signal stability assesses the damping level of the system oscillations. The goal is to detect the eventual poorly damped oscillations and to study how to improve the system behavior to such disturbances.

The future interconnected system of West Africa will be characterized by several blocks connected together by relatively long AC lines. This type of structure is likely to face problems of inter-area oscillations. This analysis will detect such inter-area oscillations modes which could appear between the various parts of the network.

3.2.2.1.1. Theoretical bases

3.2.2.1.1.1. Linear phenomena

Small signal stability concerns the study of the small fluctuations around an operating point. The small fluctuations are caused through the slight disturbances that occur at any time in a network (as a result of switching of loads, control actions …). These disturbances differ essentially from those considered in transient, voltage or frequency stability studies, since in the latter cases the disturbances have larger amplitudes.

This analysis of small fluctuations is performed by the linearization of the equations that describe the system. This approach is based on the assumption that the non-linear system can be accurately approximated by a linear system for small fluctuations.

Such analysis is mandatory following network modifications like interconnection or new units introduction susceptible of seriously affect the existing rate of damping.

It must be observed that small system stability is a necessary condition for the operation of a power system.

3.2.2.1.1.2. Absolute stability criterion

The study of linear systems supplies an absolute stability criterion: the eigenvalues are identified and verification is made that all their real parts are negative.

Indeed, in response to a disturbance, there is an exponential that relates to each eigenvalue. If the real part of one of these eigenvalue is positive, the exponential will be increasing and the system will be unstable.

3.2.2.1.1.3. Evaluation of damping

When the system is stable, the analysis of the eigenvalues indicates the degree of damping of the system. The requirement thereby is that the phenomena get damped rapidly enough.

Given the uncertainties regarding some parameters, the cases where the real part of an eigenvalue would be close to zero, either negative or positive, would be considered unacceptable, although purely mathematically the first would be stable while the second would not.

Generally, the system will be considered stable when there is a sufficient stability margin (the real part is sufficiently negative). In the present study, the steady state stability will be checked for various operating conditions.

3.2.2.1.1.4. Transfer functions and dominant modes

There are many eigenvalues in a large system. To each eigenvalue relates a degree of damping and an oscillation frequency. The whole forms a “specific operating mode”.

As a first approximation, the specific operating modes can be classified into four groups:

- the inter-area modes: their frequency is generally comprised between 0.1 and 1 Hz, they relate to the natural oscillations between set of units forming together coherent electrical areas;
- the electromechanical modes: their frequency is around 1 Hz and they relate to the natural oscillations of the generating units;
- the modes relating to the damper windings: they are highly damped;
- the modes relating to control systems (speed or voltage): these can be found within the entire frequency range, depending on the characteristics of the systems;
- the other modes: they cannot be related directly to any precise cause.

3.2.2.1.2. Methodology

HERCULES is a new software recently developed by TRACTEBEL ENGINEERING for the analysis of the system stability for small perturbation. This software, based on the method of Arnoldi, makes it possible to determine eigenvalues of a great system in a zone around the imaginary axis. For each mode of oscillations, the right and left eigenvectors are given thus making it possible to evaluate the coefficient of participation of each variable and its mode shape.

An automatic link exists between EUROSTAG and HERCULES to transfer the state matrix and the associated identification of each variable.

The study will be focused on the modes having a frequency equal or lower than 1.5 Hz that means the range of inter-area oscillations and electromechanical modes. The oscillation modes will be determined and their damping will be compared with the international standards applied in that field[1].

The "task force" CIGRE[1] about the oscillations in networks recommends a minimum damping of 5 %. This threshold of 5% for the damping will be considered in the following analysis as the minimum level to be respected.

3.2.2.1.3. Modal analysis

3.2.2.1.3.1. Eigenvalues computations

For each mode, the following parameters were evaluated:

- Oscillation frequency of the mode:

$$f = \frac{\omega}{2\pi}$$

- Its damping defined as follows :

$$\zeta = -\sigma / \sqrt{\sigma^2 + \omega^2}$$

where σ (resp. ω) is the real (resp. imaginary) part of the eigenvalues $\sigma \pm j\omega$ associated to that particular mode. The damping makes it possible to determine the number of cycle necessary to damp the related oscillations. One can show that a damping of 37% (1/e) is reached after $1/(2\pi\zeta)$ cycles;

- A classification of the generating units according to the module of the right eigenvector. They are thus classified according to their contribution to the mode of oscillation considered.

3.2.2.2. TRANSIENT STABILITY

Transient stability condition is ensured when the system is able to withstand the consequences of a severe disturbance and to return to stable steady state service (in other words, withstand the fault avoiding the loss of synchronism of one or more unit).

The transient stability analyses are performed through time domain dynamic simulations. The critical fault clearing time (CCT), always given for a specific location in the network, is defined as *the longest admissible fault at this location to avoid the loss of synchronism of one generator (or a whole power plant)* with respect to the system. It is what we define as the “classical” or “intrinsic” critical clearing time which means that they do not include the action of the protective systems.

The international practice is to evaluate the CCT’s following a three phase fault and compare them to base and backup protections operating times. The base clearing time is here assumed to be equal to 100 ms, while the backup operating time is assumed to be 300 ms.

[1] The study "Analysis and Control of Power System Oscillations", Task force 07, Study Committee 38, December 1996 will be used like reference in this field. The practice of various owners’ networks in the world is exposed there.

In terms of transient stability, the most severe fault is a 3-phase fault at the HV connection node without faulted line reclosing. Most critical locations are generally HV terminals of generating units as the units' acceleration is maximum during the fault. The residual voltage in case of 2-phase or 1-phase faults being much higher than the 3-phase fault, their related CCT's are higher than the ones computed by for a 3-phase fault.

In order to compute the CCT, the synchronism of the generating units is evaluated within a few seconds following the clearing of the fault. Stability on longer term is not taken into account to compute the Critical Clearing Time. This must be kept in mind because other phenomena such as the non-recovery of the voltage may induce, on longer term, changes in the machines speed.

It also has to be noticed that for operating conditions close to peak conditions, the system is usually facing voltage collapse before having loss of synchronism problems. This is due to the high proportion of induction motors (AC) in the load at peak conditions. To be focused on transient stability and risk of loss of synchronism, a standard impedant load model is used for the entire network.

The load model is written:

- $P_i(t) = P_0 \left(\frac{U}{U_0}\right)^2 \left(\frac{\omega}{\omega_0}\right)^\gamma$, where $\gamma = 0$
- $Q_i(t) = Q_0 \left(\frac{U}{U_0}\right)^2 \left(\frac{\omega}{\omega_0}\right)^\delta$, where $\delta = 0$

3.2.2.3. DYNAMIC SECURITY ASSESSMENT

The methodology used to carry out the dynamic security analysis consists in simulating different scenarios: short-circuit on lines, unit contingencies and power transfer between areas.

For these simulations, several criteria are checked to verify the ability of the system to withstand the transients and to recover to a stable steady-state:

- No machine loses synchronism
- No machine protection (under and over voltage, under and over frequency) is activated.
- For all nodes, all voltages recover above 0.7 pu. This helps checking no voltage collapse occurs anywhere in the network.
- At steady-state, the voltage recovers between 0.9 pu and 1.1 pu.
- The frequency of the system does not drop below 49.5 Hz, first stage of the UFLS as indicated in the WAPP Operation manual. At steady-state, the frequency recovers between 49.8 Hz and 50.2 Hz.

3.2.2.3.1. Three phase short-circuits

The three phase short-circuit cleared in base time is used as a dimensioning incident for network design and planning. It is therefore expected that the network can support a three-phase fault cleared in base time (100 ms) everywhere in the grid.

To check this, a three-phase fault with null impedance will be simulated on every 760, 330, 225, 161, 150, 132, 110 and 90 kV line, at 0.1 and 99.9% distance of the line.

Also, the interconnections are concerned by such simulations and it will be verified that the various parts of the system are able to support the transient and recover to a stable state.

3.2.2.3.2. Loss of generating units

A machine contingency is a likely incident that has to be supported by the system. To check this, for all operating areas, all machines contingencies were simulated: generators, and SVC.

The frequency deviation provoked by such contingencies is observed and recommendations, among others on the UFLS tuning, will be issued based on these observations.

3.2.2.3.3. Maximum transfer capacities

The maximum transfer capacities were determined for all interconnections between countries.

They concern only active power and they are based on dynamic stability criteria, not on static criteria, or ratings of equipments. The limit is reached when the system becomes unstable due to:

1) A frequency collapse
2) A voltage collapse and/or motor stalling
3) A loss of synchronism

Since the stability during and after a three phase fault is considered as a design and operation criterion, it is here checked that the system can support three phase faults at the interconnection extremities.

The transit on the interconnection lines is increased by turning on generators in one operating area and increasing the load in another operating area.

3.3. Assumptions and model construction

This section presents the construction of the PSA model of the WAPP's network.

First it is necessary here to emphasize that the objective of the study is to look at the West African network in case of interconnections and electricity exchanges. The study examines the system behavior and the interactions between its different parts at high voltage level. It does not look into details at low voltage levels inside the national networks. Solely the elements prone to have an interaction at high voltage levels were modeled.

This section starts by summarizing, for each country, the detail level and the elements that were modeled. Then, the second part of the section gives more details of the model.

3.3.1. Model description for each country

This section describes the simulation model as it was built for 2015. The reinforcements foreseen for 2020 and 2025 will be described in the concerned sections.

3.3.1.1. SENEGAL

Today Senegal's electrical system is linked to Mali through a 225 kV line connecting the substations Kayes (Mali) to Matam (Senegal). It operates its transmission network in 225 and 90 kV.

The OMVG project will interconnect Senegal to Gambia, Guinea and Guinea-Bissau by a 225 kV line. The goal is to share the energy produced by Kaleta and Sambangalou power plants. This project has 2 phases:

- Phase 1: Interconnection along the coast in 225 kV
- Phase 2: Interconnection through the middle of the country in 225 kV, making a loop with phase 1.

Senegal's model includes the 225 and 90 kV voltage levels. The line Tobene-Kounoune was considered operating in 225 kV in 2015 and the future loads were connected to the nearest 90 or 225 kV substation.

3.3.1.2. THE GAMBIA

The Gambia's network is presently isolated from the rest of the WAPP's network. They are foreseen to interconnect with the OMVG project.

Up to now, the highest voltage level in The Gambia is 33 kV. What occurs at this voltage level will have little influence on the WAPP's interconnected system.

As a conclusion, the transmission network model in The Gambia covered the 225 kV OMVG network and an equivalent network was implemented in Brikama to simulate the load and generation of the Greater Banjul Area.

3.3.1.3. GUINEA BISSAU

Guinea Bissau's network is presently isolated from the rest of the WAPP's network. They are foreseen to interconnect with the OMVG project.

Up to now, the highest voltage level in Guinea Bissau is 30 kV. What occurs at this voltage level will have little influence on the WAPP's interconnected system.

As a conclusion, the transmission network model in Guinea Bissau covered the 225 kV OMVG network and an equivalent network was implemented in Bissau to simulate the load and generation of the city of Bissau.

3.3.1.4. GUINEA

Guinea is presently isolated from the rest of the WAPP's network. It is foreseen to interconnect with the implementation of many projects: OMVG, CLSG and Guinea-Mali interconnections.

All these projects were modeled and Guinea was represented fully down to the 110 kV level, and partially at 60 kV level for the area of Conakry.

3.3.1.5. SIERRA LEONE

Presently, Sierra Leone's existing network is isolated from the rest of the WAPP's network. It is foreseen to interconnect with the 225 kV CLSG project at Bumbuna. From Bumbuna, an already existing 161 kV connection will link Freetown to the WAPP's network.

As a conclusion, Sierra Leone was modeled from 225 kV to 161 kV. An equivalent network was implemented to simulate the load and generation of Freetown.

3.3.1.6. LIBERIA

Presently, Liberia is isolated from the rest of the WAPP's network. It is foreseen to interconnect with the 225 kV CLSG project. The interconnection will permit to connect the capital city of Monrovia. Also the generation center of Buchanan will be connected.

As a conclusion, Liberia was modeled from 225 kV to 161 kV. An equivalent network was set up in Monrovia to simulate its load and generation.

3.3.1.7. MALI

Mali is currently interconnected to Senegal's network by a 225 kV line. Its transmission system is composed of 225 and 150 kV voltage levels. The distribution level of 30 kV has a loop. Its network is concentrated in the south-west of the country.

Three interconnections are foreseen and a fourth one is under study. Mali will be connected to Ghana and Burkina Faso by a 225 kV line from Bamako (Mali) to Bolgatanga (Ghana), passing through Sikasso (Mali) and Bobo Dioulasso (Burkina Faso). The second interconnection will be with Ivory Coast, from Segou (Mali) to Ferkessedougou (Ivory Coast) by a 225 kV line, connecting also Koutiala (Mali) and Sikasso(Mali). The third one will be between Bamako (Mali) and Fomi (Guinea), again through a 225 kV line. The interconnection under study is from Manantali (Mali) to Linsan (Guinea).

The model has the 225 and 150 kV voltage levels. The existing 30 kV loop was not modeled and its generation and load were equally split between Lafiabougou and Balingue substations.

3.3.1.8. IVORY COAST

The electrical system of Ivory Coast has one interconnection with Burkina Faso and one with Ghana (both operating in 225 kV). It operates its transmission network in 225 and 90 kV.

It is foreseen to reinforce the interconnection with Ghana from Riviera (Ivory Coast) to Prestea (Ghana) with a 330 kV line. Another new interconnection is foreseen with Mali from Ferkessedougou (Ivory Coast) to Segou (Mali), going through Sikasso and Koutiala (both in Mali), in 225 kV. Some internal reinforcements are also foreseen:

- New line in 225 kV between Laboa, Boundiali and Ferkessedougou
- Second line in 225 kV between Soubre, Taabo
- Third line in 225 kV between Taabo and Azito

The model was made from 330 kV down to 90 kV level. The 90 kV was reinforced in order to avoid lines and transformers overloads in the base case (the list of reinforcements for this voltage level was not provided).

3.3.1.9. GHANA

Ghana's network is one of the most important of the WAPP, being connected to Ivory Coast by a 225 kV line between Prestea (Ghana) and Azito (Ivory Coast) and connected to Togo/Benin by two 161 kV lines between Asiekpe (Ghana) and Lome Port (Togo). Although the generation is concentrated in the south, there are great loads in the north of the country.

The following projects are foreseen to reinforce the electrical system:

- Interconnection with Ivory Coast in 330 kV from Riviera (Ivory Coast) to Prestea (Ghana).
- Interconnection with Togo/Benin in 330 kV from Volta (Ghana) to Sakete (Benin), passing through Lome Port (Togo).
- Interconnection with Burkina Faso from Bolgatanga (Ghana) to Ouagadougou (Burkina Faso) in 225 kV.
- Interconnection between Ghana, Burkina Faso and Mali connecting Bolgatanga (Ghana), Bobo Dioulasso (Burkina Faso), Sikasso (Mali) and Bamako (Mali) substations in 225 kV.
- Interconnection with Togo (through the north) connecting Bawku (Ghana) and Dapaong (Togo) in 161 kV.
- Connection between south and north of Ghana in 330 kV level (from Kumasi to Bolgatanga substation).

The 330, 225 and 161 kV voltage levels were modeled. The reinforcement of the system in 161 kV up to 2020 was taken from Ghana's Transmission Master Plan study.

3.3.1.10. TOGO AND BENIN

Togo and Benin electrical system can be considered as one block interconnected at 161 kV. Due to the frequency problems in Nigeria, the eastern and western parts are disconnected. As in Ghana, the generation is concentrated in the south of both countries. But here the main part of the load can be found there also. Today, Togo is interconnected to Ghana by two 161 kV lines and Benin is connected to Nigeria by a 330 kV line.

The North-core project foresees the interconnection between Malanville (Benin), Dosso (Niger), Niamey (Niger) and Birnin Kebbi (Nigeria) at 330 kV. An interconnection between Sakete (Benin) – Lome Port (Togo) – Volta (Ghana) in 330 kV and one between Dapaong (Togo) and Bawku (Ghana) in 161 kV are also foreseen.

To reinforce the electrical system, the following lines are planned to be built:

- 161 kV line between Ketou and Parakou (Benin)
- 161 kV line connecting Bembereke and Malanville (Benin)
- 161 kV line between Kara and Dapaong (Togo)

The model includes the 330 and 161 kV levels. The Maria Gleta Power Plant (450 MW) was also considered.

3.3.1.11. BURKINA FASO

Burkina Faso's network is composed of long lines and several different voltage levels. The system is connected to Ivory Coast by a 225 kV line.

Three interconnections are foreseen:

- Bolgatanga (Ghana) – Ouagadougou (Burkina Faso) in 225 kV.
- Bolgatanga (Ghana) – Bobo Dioulasso (Burkina Faso) – Sikasso (Mali) – Bamako (Mali) in 225 kV.
- Ougagadougou (Burkina Faso) – Niamey (Niger) in 330 kV.

The system was modeled from 330 to 33 kV.

3.3.1.12. NIGER

Niger is currently interconnected with Nigeria only, at 132 kV level. It is foreseen to increase the interconnection capacity with the North Core project between Nigeria, Niger, Benin and Burkina Faso.

Moreover, Niger's grid is presently divided in four zones. In the planned projects, a coal production in Salkadamna is located in the middle of the River Area, the Centre-Eastern Area and the North Area. It is foreseen to accompany this Salkadamna project with interconnections between the River Area in 330 kV and the Centre-Eastern Area in 132 kV.

As a conclusion, Niger's network was modeled from 330 kV down to 132 kV. An equivalent network simulated the load and generation in Niamey.

3.3.1.13. NIGERIA

Nigeria is the biggest country in the WAPP area. It operates its transmission network in 330 and 132 kV, with 330 kV interconnections with Benin and 132 kV interconnection with Niger.

It is foreseen to start up a 760 kV super grid inside Nigeria, and reinforce the interconnections at 330 kV levels with the neighboring countries.

As a conclusion, Nigeria was fully modeled from 760 kV to 330 kV. The 132 kV level was not modeled because of the small impact it will have on the other countries. Only the 132 kV interconnections with Niger were taken into account.

3.3.1.14. MAURITANIA

Mauritania is presently connected to the WAPP area at 225 kV, with a line passing through Senegal to carry the electricity from Manantali dam. In a close future, increasing the exchanges between Mauritania and the WAPP is not a priority.

It was then considered here that Mauritania is a load of 48 MW, representing the import level contracted in the agreement around Manantali (40 MW) and Felou (18 MW).

3.3.2. Static model

This section provides the information needed for the static analysis.

3.3.2.1. LOAD

For each country, the data collected was used at best with the load forecast carried out in the inception report to spread the load among the different substations represented in the model.

The load levels considered correspond to peak load for 2015, 2020 and 2025. The final load repartition by country is given in Table .

Table and Table 1 give more details on the load per region in Niger and Nigeria respectively. This detail was done for Niger because there are four zones that are not connected. In Nigeria, the system is so big that it is worth splitting the information by zone.

The reactive power consumption was calculated so that all power factors are equal to 0.85 in 2015, and 0.9 in 2020 and 2025.

Finally, for off peak load situation, a ratio of 70% was used for all countries.

	2015	2020	2025
Country	Active power consumption	Active power consumption	Active power consumption
Name	MW	MW	MW
Senegal	629	891	1172
The Gambia	94	135	163
Guinea Bissau	38	83	117
Mali	366	550	693
Guinea	287	340	405
Sierra Leone	110	170	217
Liberia	50	68	93
Ivory Coast	1247	1652	2142
Burkina Faso	239	345	491
Ghana	2113	2775	3675
Togo	279	425	600
Benin	299	420	593
Niger	195	260	336
Nigeria	11225	14983	20000
Mauritania	48	48	48
Total	17219	23145	30745
Total WAPP area	17171	23097	30697

Table 65 – Load repartition by country for the peak load models

		2015	2020	2025
Country	Zone	Active power consumption	Active power consumption	Active power consumption
Name	Name	MW	MW	MW
Niger	River	113	151	195
Niger	Centre-East	28	38	49
Niger	East	5	6	8
Niger	North	49	66	85
Total Niger		195	261	337

Table 66 – Load repartition by zone in Niger for the peak load models

		2015	2020	2025
Country	Zone	Active power consumption	Active power consumption	Active power consumption
Name	Name	MW	MW	MW
Nigeria	Lagos	5224	6956	9282
Nigeria	Benin	804	1086	1452
Nigeria	Enugu	1954	2613	3489
Nigeria	Bauchi	760	1014	1353
Nigeria	Kaduna	1193	1593	2126
Nigeria	Shiroro	1290	1721	2298
Total Nigeria		11225	14983	20000

Table 17 – Load repartition by zone in Nigeria for the peak load models

3.3.2.2. GENERATION

Based on the inception report lists and the results of the economic study, all existing generators and future generators projected for 2015, 2020 and 2025 were included in the model. In case of power limitation and/or rehabilitation, the accurate level of available power was taken into account.

3.3.2.3. TRANSPORT

The grid was modeled fully from 760 to 90 kV, except for Nigeria where the 132 kV voltage level was only partially modeled (for the interconnections with Niger) given its low influence on the rest of the WAPP area. At lower voltage levels, an equivalent of the system was built.

The information collected from each country was used at best to reproduce the existing system and complete it with future projects.

For 2015, two scenarios were studies. The first one, referred as the Base case, considers the future projects limited to the expectations for 2015, with two exceptions; the North Core interconnection and the OMVG phase 1 interconnection. Such exceptions were made because of the interest they represent, for connecting a country (The Gambia and Guinea Bissau for the OMVG interconnection), for exporting the power of an important power plant (Kaleta for the OMVG interconnection) or improving the transfer capacity and the stability (for the North Core interconnection). Then a second scenario examines what the situation would be in 2015 if the system's interconnections were limited to the most fragile situation. These two scenarios will be further described below.

For 2020 and 2025, the future projects modeled correspond to the results of the economic study.

3.3.3. Dynamic model

This section provides the information needed for building a dynamic model complementary to the static model described here above.

3.3.3.1. LOAD

3.3.3.1.1. Dynamic load model

The distribution by substation and the amount of load used for dynamics simulations are identical to the static model. Nevertheless, in order to obtain more realistic results, the distribution character of the load was taken into account in the dynamic model. The dynamic load structure is as the figure below.

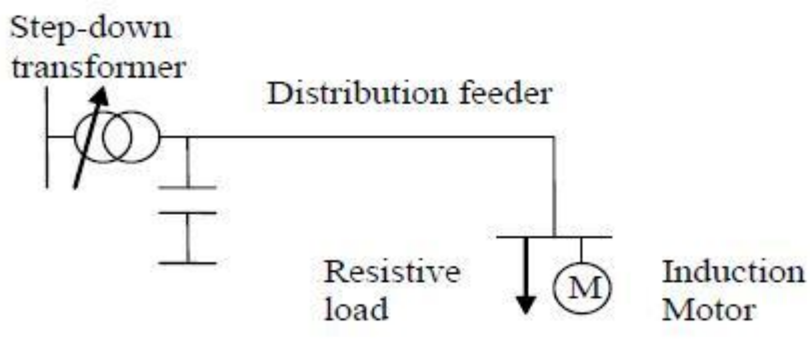


Figure 43 – Dynamic Load Model

This model represents a load characterized by a significant proportion of induction motors connected downstream a step-down transformer and a distribution feeder. The model includes:

- A step down transformer equipped with a continuously regulating under load tap changer;
- A distribution feeder modeled by an impedance;
- A shunt compensation connected at the secondary of the transformer;
- A generic induction motor connected downstream the distribution feeder;
- A resistive load connected downstream the distribution feeder.

The shunt compensation device connected to the transformer secondary is adjusted to match the reactive power absorbed by the load model with the load flow one and the distribution feeder is modeled as an impedance.

It was used standard values for the model characteristics since no information was provided. These are shown in Table .

Transformer	
Min. Ratio (pu)	0.9
Max. Ratio (pu)	1.21
Time Cons. (s)	20
Loading (%)	60
Uref (pu)	1.03
Resistance (pu)	0.005
Leakage (pu)	0.035
Feeder	
Voltage Drop (pu)	0.01
Ratio (X/R)	0.5
Load Mix	
Motor Loading (%)	100
Rotating Load Prop. (%)	40
Inertia (MW s/MVA)	0.5
Efficiency	0.95
Rated Mech. Power (pu)	0.87
Starting Torque Cd (pu)	0.77
Maximal Torque (pu)	2.3
Nominal Speed (rpm)	2959
Starting Current Id (pu)	5.6

Table 68 – Load model characteristics

A key factor of the load model is the proportion of AC motors. No information has been communicated about the composition of the load. Thus, for the dynamic study, it will be considered that the proportion of induction motors is 40% at peak load and off peak load conditions.

3.3.3.1.2. Defense schemes

The dynamic load modeling covers also the defense schemes like Under Frequency Load Shedding (UFLs) and Under Voltage Load Shedding (UVLS).

As no information was given about UFLS and UVLS by the different countries, it was not modeled.

About UFLS, the information of the WAPP Operation Manual states that:

- 10% of the load must be shed when the frequency drops down to 49.5 Hz
- 20% of the load must be shed when the frequency drops down to 49.2 Hz

The compliance of these settings with the dynamic behavior of the system will be reviewed in the dynamic studies.

3.3.3.2. GENERATION

For generation units, accurate information was rarely collected. Usually, either this information is very difficult to obtain, or it is inexistent (for future units for example) or incomplete. For many countries, the information provided corresponds to the assumptions done in previous studies.

As a matter of fact, a lot of assumptions were necessary to complete the dynamic model. At first, it was tried to copy the information from existing generators whose data were available. As a second choice, the Consultant assumed values based on good practices and experience.

Given the size of the system and the dynamic influence of small units, units below 5 MW were not modeled dynamically. Their production behaves as a negative load.

Synchronous machines are represented by full models including saturation. Wind farm are modeled by converters. The network counts five SVC (three for the CLSG project and two in Ghana).

3.3.3.2.1. Dynamic parameters and controllers

Dynamic parameters of all machines were taken from available information when there was any. Otherwise, they were copied from similar existing units, or assumed according to good practices.

The same job was done for controllers. They are all simplified controllers, either from the international IEEE practices or from the standard library of PSA/EUROSTAG.

Particular attention was given to respect the static or brushless character of the voltage regulations. The latter were completed with limiters:

- Over excitation activates as soon as the excitation current reaches 103% of its nominal value. The current is then limited to its nominal value.
- The under excitation limits the reactive power absorption to 10% of the nominal active power when the machine produces this nominal active power, and to 15% when its production is 0 MW.

Finally, all power/frequency controllers are equipped with maximum power limiter. This ensures a proper reaction of the machine governors in case of frequency transients.

3.3.3.2.2. Protections

Little information was collected about the machines protections settings and it was decided to assume standards values for all machines:

- Under speed protection: 47.5 Hz for 500 ms
- Over speed protection: 52.5 Hz for 500 ms
- Under voltage protection: 0.7 pu for 500 ms
- Over voltage protection: 1.2 pu for 500 ms

All these settings must be completed with a breaker action time of 100 ms when the conditions are fulfilled.

The WAPP operation manual states that generation units must remain connected to the grid for frequencies between 48.5 Hz and 51 HZ. The Consultant will comment this range in view of the simulations results.

3.4. Simulations

This section presents the situations investigated and the simulations performed. Three target years were examined: 2015, 2020 and 2025. The development of the system was foreseen according to the information received during the data collection and to the results of the economic study.

Scenarios studied are first described. Then simulations are presented and illustrated for the different years.

The year 2015 considers two scenarios, depending on the development of the system in terms of interconnections. The first scenario studies a situation where all countries are interconnected while the second scenario is a variant where the interconnected system is less robust. For 2015, simulations were performed at peak load and off-peak load, statically and dynamically. This approach permitted to detect all the potential problems the actual interconnected system will meet during its development towards a state where it is fully interconnected.

The years 2020 and 2025 were investigated statically, at peak load only. The goal is here to detect the reinforcement needs the system will face in order to reach a stable operation.

3.4.1. Scenarios

3.4.1.1. 2015 BASE CASE

Two different scenarios were considered in the study for 2015. They are described here below. The differences between them rely mainly in the interconnections available, provoking different exchanges levels between countries and different production units' commitment.

The Base Case examines the WAPP's system operation with all countries interconnected. The consumption corresponds to a 2015 peak load situation, as described in Table , Table and Table 1.

The following interconnections are in service:

- Coastal backbone from Nigeria to Ivory Coast
- North-core between Burkina Faso, Niger, Benin and Nigeria
- CSLG from Ivory Coast to Guinea passing through Liberia and Sierra Leone with the production of Kaleta.
- OMVG to connect Guinea Bissau and The Gambia to Senegal and Guinea
- Interzonal with:
  - Ivory Coast-Mali (Ferkessedougou-Sikasso-Segou)
  - Ghana-Burkina Faso (Bolgatanga-Ouagadougou)
  - Ghana-Burkina Faso-Mali (Bolgatanga-Kodeni-Sikasso-Bamako)

The following interconnections and production sites are not available in this 2015 situation:

- OMVG branch from Linsan to Tambacounda interconnecting the hydro site of Sambangalou. This production is consequently not yet operational.
- Guinea-Mali with the hydro site of Fomi.

- Interconnection between River and Centre-Eastern areas in Niger to connect the coal unit of Salkadamna.

Table 69 presents the balance for load, production and power exchanges between countries for the Base Case, at peak load conditions. The load level is as described above for a total of 17220 MW including the 48 MW export towards Mauritania. The losses represent 2.3 % of the global load and are particularly high in Guinea Bissau (15.8%) due to high power transit from Guinea to Senegal and The Gambia. The balance column provides the global active power import/export balance:

- Guinea (with Kaleta), Ivory Coast, Ghana and Nigeria are the exporting countries.
- Benin exports thanks to Maria Gleta Combined Cycle.
- Mali exports 20 MW thanks to Manantali and Felou hydro power plants, located on its territory.
- Burkina Faso, Togo, Senegal and Niger are the biggest importing countries in absolute value. Relatively, Togo imports 82% of its electricity and Burkina Faso 75%.

Country	Generation		Load		Losses	Balance
	MW	Mvar	MW	Mvar	MW	MW
Benin	455	95	299	185	9	147
Burkina Faso	69	14	239	148	10	-179
Ivory Coast	1354	310	1247	773	44	63
The Gambia	51	30	94	58	2	-45
Guinea bissau	20	9	38	24	6	-24
Ghana	2309	536	2114	1310	65	129
Guinea	528	106	287	193	18	223
Liberia	47	9	50	95	0	-4
Mali	404	56	366	227	18	20
Mauritania	0	0	48	30	0	-48
Nigeria	11649	2193	11225	6957	183	241
Niger	118	45	195	121	13	-90
Senegal	473	216	629	390	20	-176
Sierra Leone	83	17	110	100	4	-31
Togo	59	14	279	173	8	-228
TOTAL	17618	3649	17220	10783	399	0

Table 69 – Power balance for the Base Case scenario (peak load)

Concerning the spinning reserve, it is sized to the loss of the biggest unit in the WAPP area. That biggest unit is the combined cycle of Okpai (Kwale) in Nigeria, composed of two gas turbines and one steam turbine, each one rated 178.5 MW. Given the common mode between the gas turbines and the steam turbine, the loss of one gas turbine provokes a power reduction on the steam turbine. Assuming the plant is operated at its nominal level, the production loss corresponding to a contingency of a gas turbine is 267.75 MW (one gas turbine rated power and half of the steam turbine rated power).

To share this reserve among the system, each country has to be responsible for a part of it. Such participation is here assumed to be determined by the weight of each country in the global system load. This calculation is summarized in Table .

For each country, the generation plan and the reserve allocation was determined by the Consultant according to good practices.

Country Name	Load MW	Reserve expected MW	Actual reserve MW
Senegal	629	9.8	9.8
The Gambia	94	1.5	1.5
Guinea Bissau	38	0.6	0.6
Guinea	287	4.5	4.5
Mali	366	5.7	5.7
Sierra Leone	110	1.7	1.7
Liberia	50	0.8	0.8
Ivory Coast	1247	19.4	19.4
Burkina Faso	239	3.7	3.7
Ghana	2113	32.9	32.9
Togo + Bénin	578	9.0	9.0
Niger	195	3.0	3.0
Nigeria	11225	175.0	185.7
Total	17171	267.8	278.4

Table 70 – Spinning reserve per country

For the off peak load situation, a ratio of 70% was taken for all countries. The same levels of spinning reserves were kept. The same exchanges patterns are also kept though the levels of exchanges are lower.

Country	Generation		Load		Losses	Balance
	MW	Mvar	MW	Mvar	MW	MW
Benin	230	-6	209	130	5	16
Burkina Faso	56	-1	167	104	5	-117
Ivory Coast	985	198	873	541	31	81
The Gambia	46	14	66	41	0	-20
Guinea bissau	12	4	27	17	1	-15
Ghana	1591	55	1480	916	34	77
Guinea	260	15	201	140	11	48
Liberia	32	-1	35	86	1	-4
Mali	244	-1	256	159	8	-20
Mauritania	0	0	30	20	0	-30
Nigeria	8182	153	7858	4870	106	219
Niger	69	-4	102	63	7	-40
Senegal	393	154	441	273	6	-54
Sierra Leone	58	1	77	80	2	-21
Togo	78	0	195	121	3	-120
TOTAL	12236	581	12017	7561	220	0

Table 71 - Power balance for the Base Case scenario (off peak load)

3.4.1.2. 2015 SCENARIO 2

Scenario 2 is a variant of the Base Case. It is also representing a 2015 situation but the future production units and interconnections projects available are limited.

In comparison with the Base case, all projects expected for 2015 or later were removed. This leads to a situation where:

- The Gambia and Guinea Bissau are not interconnected.
- The WAPP network is a long interconnection from Niger to Senegal, with Burkina Faso as one antenna and the CLSG countries as another one.
- The absence of the North-core interconnection makes Niger connected only to Nigeria via the 132 kV level
- The link between Ghana and Burkina Faso is limited to the 330 kV line from Bolgatanga to Ouagadougou but is not supported by the 330 kV north-south project from Domini to Bolgatanga. Though the interconnection between Ivory Coast and Burkina Faso is still in service, the latter is weakly interconnected though it is the country with the biggest importation expectations.
- The 330 kV line between Ivory Coast and Ghana (Riviera-Prestea) is not in service. Moreover, Burkina Faso is not connected to Mali. Mali is only interconnected to Ivory Coast. As a consequence, the interconnection of Mali and Senegal is reduced to the minimum: one line with Ivory Coast.
- Guinea cannot count on any big hydro projects; neither Kaleta, nor Sambangalou nor Fomi are in service. Also Mount Coffee hydro power plant in Liberia is not yet available. And as a matter of fact, Sierra Leone, Liberia and Guinea are obliged to import electricity from Ivory Coast to complete their power balances.

Table lists all the interconnections and summarizes the status of each one of them for both scenarios. The existing interconnections are obviously in service. The 330 kV north-south project in Ghana is also indicated.

As a conclusion, the interest of this scenario is its fragility in terms of interconnections. It is a realistic stage towards the objective of a global WAPP interconnected system. The purpose of this scenario is to investigate the stability challenges of such stage to foresee and prevent any limitations.

Table presents the balance for load, production and power exchanges between countries for Scenario 2, at peak load condition. The global load reaches 17063 MW, which is lower than the load level for the Base case. The difference is due to the non-connection of The Gambia and Guinea Bissau, and to an increase in total grid losses. The losses represent 2.5 % of the global load and are particularly high in Liberia (14%) due to the transit of power towards Sierra Leone and Guinea on the CLSG interconnection. The balance column provides the global active power import/export balance:

- Ivory Coast, Ghana and Nigeria are still exporting countries. Guinea, due to the absence of Kaleta, imports power.
- Benin exports thanks to Maria Gleta Combined Cycle.
- Mali exports 108 MW from Manantali hydro power plant to Senegal and Mauritania. This export level is higher than for the Base case because the interconnection with Burkina Faso and Ghana is not yet commissioned. With the absence of Kaleta, and with Ivory Coast exporting already for the CLSG countries, the export from Ghana to Mali has to pass through Ivory Coast, limiting the transfer capacity.

- Burkina Faso, Togo, Senegal, Niger, Sierra Leone, Liberia and Guinea are the importing countries. Relatively, Togo imports 70% of its electricity. For this scenario, the import of Burkina Faso is limited to 21% due to weak interconnections.

Country	Generation		Load		Losses	Balance
	MW	Mvar	MW	Mvar	MW	MW
Benin	475	107	298	185	10	167
Burkina Faso	198	45	239	148	9	-50
Ivory Coast	1401	428	1247	773	56	98
The Gambia	0	0	0	0	0	0
Guinea bissau	0	0	0	0	0	0
Ghana	2279	663	2114	1310	69	95
Guinea	239	48	287	191	13	-61
Liberia	39	5	50	51	7	-17
Mali	492	69	366	227	18	108
Mauritania	0	0	48	30	0	-48
Nigeria	11491	2024	11225	6957	188	78
Niger	166	68	195	121	11	-40
Senegal	534	271	605	375	25	-96
Sierra Leone	77	19	110	68	7	-40
Togo	95	24	279	173	10	-194
TOTAL	17486	3772	17063	10608	423	0

Table 72 - Power balance for Scenario 2 (peak load)

For the spinning reserve, the sizing incident is still the loss of one GT and half a ST at Okpai (Kwale) combined cycle. It represents 267.75 MW.

In this scenario, the same reserve levels for each country are kept. The reserve part initially assigned to Guinea Bissau and The Gambia is here supported by Nigeria.

For the off peak load situation, a ratio of 70% was taken for all countries. The same levels of spinning reserves were kept. The same exchanges patterns are also kept though the levels of exchanges are lower.

Country	Generation		Load		Losses	Balance
	MW	Mvar	MW	Mvar	MW	MW
Benin	230	47	209	129	8	13
Burkina Faso	66	12	167	104	5	-106
Ivory Coast	1041	184	873	541	49	119
The Gambia	0	0	0	0	0	0
Guinea bissau	0	0	0	0	0	0
Ghana	1611	251	1480	916	51	80
Guinea	152	23	201	139	6	-55
Liberia	32	6	35	83	4	-7
Mali	279	46	256	159	10	14
Mauritania	0	0	30	20	0	-30
Nigeria	8165	1186	7858	4870	118	189
Niger	81	19	102	63	11	-32
Senegal	393	103	424	263	8	-39
Sierra Leone	58	6	77	80	4	-23
Togo	78	18	195	121	7	-124
TOTAL	12186	1901	11906	7486	281	0

Table 73 - Power balance for Scenario 2 (off peak load)

Substation 1 Name	Country 1 Name	Substation 2 Name	Country 2 Name	Voltage level kV	Project Name	Base case status	Scenario 2 status
Ikeja West	Nigeria	Sakete	Benin	330		existing	
Sakete	Benin	Lome	Togo	330		existing	
Elubo	Ghana	Abobo	Ivory Coast	225		existing	
Matam	Senegal	Kayes	Mali	225		existing	
Ferkedessougou	Ivory Coast	Kodeni	Burkina Faso	225		existing	
Lome	Togo	Asiekpe	Ghana	161		existing	
Lome	Togo	Aflao	Ghana	161		existing	
Birnin Kebbi	Nigeria	Niamey	Niger	132		existing	
Gaza	Niger	Katsina	Nigeria	132		existing	
Bawku	Ghana	Dapaong	Togo	161		existing 34.5 kV (on 161 kV in both scenarios)	
Birnin Kebbi	Nigeria	Niamey	Niger	330	Northcore	on	out
Birnin Kebbi	Nigeria	Malanville	Benin	330	Northcore	on	out
Niamey	Niger	Ouagadougou	Burkina Faso	330	Northcore	on	out
Niamey	Niger	Malanville	Benin	330	Northcore	on	out
Lome	Togo	Volta	Ghana	330	Coastal backbone	on	on
Prestea	Ghana	Riviera	Ivory Coast	330	Coastal backbone	on	out
Sakete	Benin	Oshogbo	Nigeria	330	Coastal backbone	out	out
Man	Ivory Coast	Yekepa	Liberia	225	CLSG	on	on
Mano	Liberia	Kenema	Sierra Leone	225	CLSG	on	on
Kamakwie	Sierra Leone	Linsan	Guinea	225	CLSG	on	on
Boke	Guinea	Saltinho	Guinea Bissau	225	OMVG	on	out
Mansoa	Guinea Bissau	Tanaf	Senegal	225	OMVG	on	out
Tanaf	Senegal	Soma	The Gambia	225	OMVG	on	out
Soma	The Gambia	Kaolack	Senegal	225	OMVG	on	out
Ferkedessougou	Ivory Coast	Sikasso	Mali	225	Inter zonal	on	on
Kodeni	Burkina Faso	Sikasso	Mali	225	Inter zonal	on	out
Kodeni	Burkina Faso	Bolgatanga	Ghana	225	Inter zonal	on	out
Nzerekore + Linsan	Guinea	Sikasso	Mali	225	Inter zonal	out	out
Bolgatanga	Ghana	Ouagadougou	Burkina Faso	225	Inter zonal	on	on
Aboadze	Ghana	Kumasi	Ghana	330	Inter zonal	on	out

Table 74 – Status of existing and future interconnections. Comparison between Base case and Scenario 2

3.4.1.3. 2020

The 2020 scenario is based on the results of the economic study.

For what consumption concerns, the load level is the 2020 peak load. The reactive power consumption was calculated using a power factor of 0.9, as recommended after the 2015 analysis.

For what production concerns, the new investments recommended by the economic study in terms of interconnection lines and power plants were modeled. In comparison with the 2015 situation, the list of new projects includes:

- The interconnection line between Fomi (Guinea) and Boundiali (Ivory Coast)
- The power plants in Table 752.

Based on that, the units commitment was chosen according to three different rules:

1) Starting the less expensive units first.
2) Approaching the average flows on the lines calculated by the economic study since the goal of the technical study is to check the results of the economic study are technically feasible.
3) Starting the regional units first. For instance, the amount of investments in Guinea, Sierra Leone and Liberia is very important. In the load flow, only a few units are running in these countries. The first reason is that it is impossible to have these countries export the whole power of all its units at maximum at the same time. The second reason is that many projects (Amarya, Mano River,…) are initially related to mines projects, so that their implementation might be more driven by the decision of operating mines than sharing the power for regional aspects. In particular, the regional projects of Kaleta, Sambangalou, Koukoutamba, Boureya, Balassa and Badoumbe were running. The projects of Digan, Nzebela and Franko were also running. All the other new hydro power plants in Guinea, Sierra Leone and Liberia were stopped.

With the new units, reinforcements were needed to support the flows in N condition, to evacuate this new power to the consumption centers and to absorb it in the importing countries. Particularly:

- Reinforcements in Dakar. In addition to the 225 kV loop Tobene-Kounoune-Sendou-Mbour-Kaolack-Touba, new 225 kV lines between Sendou and Kounoune, new 225/90 kV transformers at Kounoune and new 90 kV lines between Kounoune and Han are necessary to transit the power from Sendou to the consumption of Dakar.
- The Gouina project is accompanied by a 225 kV line from Kayes to Tambacounda. The dynamic studies for 2015 have shown the importance of such reinforcements to avoid the huge loop between OMVS-CLSG-OMVG. An important loop remains but this link improves the situation.
- The Amarya project is accompanied by 225 kV lines from Kaleta to Amarya and from Amarya to Matoto, where two transformers permit to feed the region of Conakry. This helps unloading the 110 kV inside Guinea.
- The OMVS projects of Boureya, Balassa, Koukoutamba and Badoumbe imply to create a line between Linsan and Manantali to connect them. The reinforcement of the line between Manantali and Bamako are also necessary to evacuate the power of these new units towards Mali and Burkina Faso. This line between Linsan and Manantali is another important investment to improve the stability of the area by reducing the huge loop OMVS-OMVG-CLSG.

- The project of Adajaralla implies new lines from the 161 kV substation of Adjaralla towards Ava and Nangbeto.
- The project of Ketou implies the reinforcement of the 161 kV line between Onigbolo and Sakete.
- Reinforcements in Bamako's network are necessary for the 225/150 kV transformer of Kodialani and for the 150 kV lines between Lafia and Kodialani and between Kodialani and Kalaba Coro. Also the 150 kV line between Selingue and Sirako should be reinforced because of the exports from Guinea towards Mali and Burkina Faso on the 225 kV line from Fomi.
- Reinforcements in Burkina Faso are necessary. The 225/90 kV transformer of Zagtouli must be doubled. The 33 kV lines between Ouagadougou, Patte d'oie, Zagtouli and Komsilga substations must also be doubled.
- In Ivory Coast, the 90 kV lines between Abobo and Vridi must be doubled.
- The project of Aboisso Comoe requires reinforcing the 90 kV line between Abobo and Bongo.
- A third 225/30kV transformer is installed in Bissau.
- A third 225/33kV transformer is installed in Monrovia.

Finally, the power balance for the 2020 peak load scenario is given in Table . The most important fact is the 1000 MW export of hydro power from Guinea. This power is absorbed by Guinea Bissau, The Gambia and Senegal thanks to the OMVG interconnection. Part of it goes to Mali via Koukoutamba and via Fomi. Finally an important part transits through the CLSG interconnection and via the line Fomi-Boundiali to reach Burkina Faso.

Besides this important fact, Benin is exporting a bit thanks to the presence of Maria Gleta, while Togo imports. Niger, with the apparition of Kandadji and Dyodyonga dams, also exports slightly. Ghana imports slightly and Nigeria imports 170 MW which is low in comparison with its national load, but important on the flows in the area.

Power plant	Power	Country	Substation	Voltage
	MW			kV
Sendou	250	Senegal	Sendou	225
Digan	93	Guinea	Labe	225
Amarya	300	Guinea	Amarya (Kaleta + Matoto)	225
Lafou	98	Guinea	Linsan	225
Kassa B	135	Guinea	Linsan	225
Koukoutamba	281	Guinea	Koukoutamba (Boureya + Linsan)	225
Boureya	160	Guinea	Boureya (Koukoutamba + Manantali)	225
Balassa	181	Guinea	Linsan	225
Kouya	86	Guinea	Mali	225
Fetore	124	Guinea	Labe	225
Kouravel	135	Guinea	Mali	225
Diareguela	72	Guinea	Koroussa	225
Nzebela	48	Guinea	Beyla	225
Grand Kinkon	291	Guinea	Labe	225
Bonkon Diaria	154	Guinea	Labe	225
Gozogueza	48	Guinea	Nzerekore	225
Franko	36	Guinea	Nzerekore	225
Poudadle	90	Guinea	Boke	225
Gouina	140	Mali	Kayes	225
Markala	10	Mali	Segou	225
Badoumbe	70	Mali	Badoumbe (Manantali)	225
Bonkongor	85.5	Sierra Leone	Bikongor	225
Bumbuna 3	90	Sierra Leone	Yiben	225
Bumbuna 4-5	95	Sierra Leone	Bumbuna	225
Mano river	180	Liberia	Mano	225
Boutoubre	156	Ivory Coast	Soubre	225
Soubre	270	Ivory Coast	Soubre	225
Aboisso comoe	90	Ivory Coast	Bong (Abobo)	90
Tiboto	225	Ivory Coast-Liberia	Tiboto (Soubre)	225
Hemang	93	Ghana	Cape Coast	330
Pwalugu	48	Ghana	Bolgatanga	225
Juale	87	Ghana	Yendi	161
Ketou	160	Benin	Onigbolo (Sakete)	161
Adjaralla	140	Togo	Adjaralla (Ava + Nangbeto)	161
Dyodyonga	26	Niger	Niamey	132
Kandadji	130	Niger	Kandadji (Niamey)	132
Zungeru	700	Nigeria	Zungeru (Jebba + Shiroro)	330
Mambilla	2600	Nigeria	Mambilla	760

Table 752 – New power plants for year 2020

Country	Generation		Load		Losses	Balance
	MW	Mvar	MW	Mvar	MW	MW
Benin	455	133	420	204	11	24
Burkina Faso	88	17	342	166	18	-272
Ivory Coast	1812	502	1652	800	108	52
The Gambia	45	49	135	65	1	-91
Guinea Bissau	35	16	83	40	6	-54
Ghana	2828	620	2775	1343	67	-15
Guinea	1445	156	340	180	62	1043
Liberia	91	10	68	93	4	19
Mali	585	100	550	266	104	-69
Mauritania	0	0	48	23	0	-48
Nigeria	15128	2372	14983	7257	312	-168
Niger	297	56	260	126	10	27
Senegal	635	239	891	431	34	-290
Sierra Leone	99	21	170	114	10	-82
Togo	360	26	425	206	11	-76
TOTAL	23903	4317	23143	11314	758	0

Table 76 - Power balance for 2020 peak load scenario

3.4.1.4. 2025

The 2025 scenario is based on the results of the economic study.

For what consumption concerns, the load level is the 2025 peak load. The reactive power consumption was calculated using a power factor of 0.9, as recommended after the 2015 analysis.

For what production concerns, the new investments recommended by the economic study in terms of interconnection lines and power plants were modeled. In comparison with the 2020 situation, the list of new projects includes the power plants listed in Table . There is no new interconnection project.

The same rules than for 2020 were use to choose the units commitment.

Power plant	Power	Country	Substation	Voltage
	MW			kV
Gribopopoli	112	Ivory Coast	Soubre	225
St Paul	192	Liberia	St Paul (Monrovia)	225
SAP	200	Ghana	Asogli	161
BTPP	250	Ghana	Smelter 2	161
CEM Power	250	Ghana	Smelter 2	161
Salkadamna	200	Niger	Salkadamna	330
Lome CC	450	Togo	Lome	161
Ethiopie	1200	Nigeria	Benin City North	330

Table 77 – New power plants for year 2025

With the new units, reinforcements are needed to support the flows in N condition, to evacuate this new power to the consumption centers and to absorb it in the importing countries. Table and Table 793 list the lines and transformers reinforcements needed.

These reinforcements are the minimum to implement in order to cover the flows in N condition. N-1 is not covered and will be studied further below.

On a regional level, the reinforcements of the lines between Manantali, Tkita, Kodialani and Sikasso, and between Soubre and Taabo are of utmost importance for evacuating the hydro power to the East.

Country	Substation 1	Substation 2	Voltage level
Name	Name	Name	kV
Burkina Faso	Bobo 1	Bobo 2	33
Burkina Faso	Zagtouli	Ouagadougou	90
Ivory Coast	Yopougnon	Vridi	90
Ivory Coast	Vridi	Bia sud	90
Ivory Coast	Daloa	Buyo	90
Ivory Coast	Soubre	Taabo	225
Mali	Manantali	Tkita	225
Mali	Tkita	Kodialani	225
Mali	Kodialani	Sikasso	225
Nigeria	Ikeja West	Akangba	330
Nigeria	Ikeja West	Erunkan	330
Nigeria	Owerri	Alaoji	330
Nigeria	Omtosho	Benin City	330
Senegal	Sococim	Thiona	90

Table 78 – Lines reinforcements needed in 2025

Country	Substation	Voltage levels	
Name	Name	kV	kV
Nigeria	Egbema	760	330
Sierra Leone	Bumbuna	225	161
Ivory Coast	Laboa	225	90
Ivory Coast	Abobo	225	90
Ivory Coast	Ferkessedougou	225	90
Guinea	Matoto	110	60
Guinea	Matoto	110	60
Ivory Coast	Taabo	225	90
Burkina Faso	Zagtouli	90	33
Burkina Faso	Zagtouli	90	33
Ivory Coast	Buyo	225	90

Table 793 – Transformers reinforcements needed in 2025

Finally, the power balance for the 2025 peak load scenario is given iTable n Table . As in 2020, there are 1000 MW export of hydro power from Guinea. This power is still absorbed by Guinea Bissau, The Gambia and Senegal thanks to the OMVG interconnection, by Mali via Koukoutamba and via Fomi and by Burkina Faso through the CLSG and the Fomi-Boundiali interconnections.

With the apparition of the combined-cycle in Togo, the latter is now exporting while Benin imports. Niger, though there is the new power plant of Salkadamna, imports. Nigeria still imports approximately 200 MW. Another big difference is the flow from Ivory Coast to Ghana, since part of the power from the new hydro units is exported to replace the thermal power plants in Ghana.

Country	Generation		Load		Losses	Balance
	MW	Mvar	MW	Mvar	MW	MW
Benin	465	160	593	287	14	-142
Burkina Faso	246	53	490	236	34	-278
Ivory Coast	2509	961	2142	1037	164	203
The Gambia	75	29	163	79	1	-89
Guinea Bissau	70	13	117	57	6	-53
Ghana	3624	1166	3674	1779	97	-146
Guinea	1393	53	405	211	50	937
Liberia	201	24	93	75	14	94
Mali	672	10	693	336	128	-149
Mauritania	0	0	48	23	0	-48
Nigeria	20330	4054	20000	9686	536	-206
Niger	174	59	252	122	4	-82
Senegal	974	307	1172	568	41	-239
Sierra Leone	301	12	217	137	8	77
Togo	732	104	600	291	10	122
TOTAL	31766	7005	30659	14923	1107	0

Table 80 - Power balance for 2025 peak load scenario

3.4.2. Static studies: Voltage management and reactive compensation

The voltage management and reactive compensation study optimizes the transformers tap position, capacitor and reactor bank step position, voltage set point of generators and reactive output of units. It is obtained by optimal power flow respecting all operational constraints (thermal capacity of lines and transformers, voltage profile in the +/-5% range) and optimizing the alignment of the reactive generation of the units.

The objective of aligning the reactive generation of the units is to maximize the reserves of reactive power. The essential advantage of this objective function is its determination of the best “mean” system voltage not depending of the system situation.

3.4.2.1. 2015

Though the network was already reinforced with new projects to simulate the 2015 situation, some parts of the low voltage network (below 90 kV) needed reinforcements to fulfill the criteria. It is expected each country will reinforce its network to face the load and flows in its national grid. Then it was assumed these investments are justified and they were implemented in the model.

The system study at peak load showed that reactive compensation was necessary to respect the operation criteria. Table shows all shunts to be implemented to respect the operation criteria in the Base case and Scenario 2 for peak load situations.

Node Name	Country Name	Voltage kV	Steps #	Rating Mvar/step	Capacity Mvar
Ikeja	Nigeria	330	5	100.0	500.0
Akangbe	Nigeria	330	3	100.0	300.0
Alagbo	Nigeria	330	2	100.0	200.0
Aja	Nigeria	330	2	100.0	200.0
Maukurdi	Nigeria	330	1	60.0	60.0
Ayede	Nigeria	330	1	13.0	13.0
Cotonou	Benin	161	1	50.0	50.0
Riviera	Ivory Coast	330	1	20.0	20.0
Atakko	Ivory Coast	90	1	12.0	12.0
Abengoa	Ivory Coast	90	1	12.0	12.0
Gagnoa	Ivory Coast	90	1	10.0	10.0
Lome port	Togo	161	1	5.0	5.0
Niamey	Niger	132	1	2.5	2.5
Yendi	Ghana	161	1	2.0	2.0
Balingue	Mali	30	1	1.0	1.0
Patte d'oie	Burkina Faso	33	1	1.0	1.0
Zagtouli	Burkina Faso	33	1	-8.0	-8.0

Table 81 – Capacitors and reactors banks added to the system – 2015 peak load

The lists show many shunt capacitors. These results are due to the modeling and the load connection at high voltage level. In the system, all loads were modeled with a power factor of 0.85 and were often connected at HV. These shunt capacitors must therefore be seen as a mean to compensate further the load and reduce the reactive flow, more than a mean to keep the HV voltage in acceptable range.

For off peak load situations, other reactive compensations were needed in order to respect the operation criteria.

Node Name	Country Name	Voltage kV	Steps #	Rating Mvar/step	Capacity Mvar
Birnin Kebbi	Nigeria	330	3	-33.0	-99.0
Makurdi	Nigeria	330	2	-50.0	-100.0
Kainji	Nigeria	330	3	-33.0	-99.0
Sokoto	Nigeria	330	2	-15.0	-30.0
Gombe	Nigeria	330	1	-30.0	-30.0
Jebbah	Nigeria	330	1	-33.0	-33.0
Kodeni	Burkina Faso	225	1	-20.0	-20.0
Bolgatanga	Ghana	330	1	-30.0	-30.0
Bolgatanga	Ghana	225	3	-10.0	-30.0
Boundiali	Ivory Coast	225	1	-5.0	-5.0
Ferkessedougou	Ivory Coast	225	8	-5.0	-40.0
Djougou	Benin	161	2	-5.0	-10.0
Dapaong	Togo	161	1	-5.0	-5.0
Mango	Togo	161	3	-5.0	-15.0
Nzerekore	Guinea	225	2	-5.0	-10.0

Table 82 - Capacitors and reactors banks added to the system – 2015 off peak load

In off peak load situation, the results show only reactor banks. At off peak load, the high voltage lines are low loaded and generate reactive power. The reactor banks are mandatory to absorb that reactive power generation and prevent over-voltages.

It is important to link reactors with the lines, so that in case of line tripping, the reactive power generation of the line disappears in the same time than the reactive power absorption of the reactor bank. Otherwise, there is a risk of low voltage and/or voltage collapse.

3.4.2.2. 2020

Besides all the investments presented in the scenario description, additional investments were needed to keep the voltages in the acceptable range.

The list of new capacitor banks is given in Table 834.

Mainly, the load centres of Abidjan (Ivory Coast), Dakar (Senegal), Bissau (Guinea Bissau), Bamako (Mali) and Ouagadougou (Burkina Faso) need capacitor banks to support their voltage while they are importing power.

Node Name	Country Name	Voltage kV	Steps #	Rating Mvar/step	Capacity Mvar
Lafia	Mali	150	3	10.0	30.0
Balingue	Mali	30	3	10.0	30.0
Balingue	Mali	15	3	10.0	30.0
Thiona	Senegal	90	1	20.0	20.0
tobene	Senegal	90	2	20.0	40.0
Taiba	Senegal	90	1	20.0	20.0
Bel Air	Senegal	90	2	15.0	30.0
Kayes	Senegal	225	1	-30.0	-30.0
Amarya	Guinea	225	1	-25.0	-25.0
Bissau	Guinea Bissau	30	2	10.0	20.0
Ouagadougou 190	Burkina Faso	90	3	10.0	30.0
Ouagadougou 290	Burkina Faso	90	1	10.0	10.0
Zagtouli	Burkina Faso	225	1	20.0	20.0
Bundiali	Ivory Coast	225	1	20.0	20.0
Bia Sud	Ivory Coast	90	7	10.0	70.0
Yopougnon	Ivory Coast	90	4	10.0	40.0
Korhogo	Ivory Coast	90	1	15.0	15.0
Daloa	Ivory Coast	90	1	15.0	15.0
Gagnoa	Ivory Coast	90	1	10.0	10.0
Bouake	Ivory Coast	90	4	10.0	40.0
Yamoussoukro	Ivory Coast	90	1	12.0	12.0
Dimbokro	Ivory Coast	90	1	12.0	12.0
Agnibilekrou	Ivory Coast	90	1	6.0	6.0
Divo	Ivory Coast	90	1	12.0	12.0
Dabou	Ivory Coast	90	1	12.0	12.0
Abobo	Ivory Coast	90	2	15.0	30.0

Table 834 - Capacitors and reactors banks added to the system – 2020 peak load

3.4.2.3. 2025

Besides all the investments presented in the scenario description, additional investments were needed to keep the voltages in the acceptable range.

The list of new capacitor banks is given in Table 845.

Mainly, the load centres of Abidjan and Yamoussoukro (Ivory Coast), Dakar (Senegal), Kumasi (Ghana), Bobo Diolasso and Ouagadougou (Burkina Faso) and Lagos, Abuja and Kano (Nigeria) need capacitor banks to support their voltage while they are importing power.

The north of Ivory Coast was also compensated to unload the 225/90 kV transformers of Boundiali and Ferkessedougou.

Node Name	Country Name	Voltage kV	Steps #	Rating Mvar/step	Capacity Mvar
Bobo 1	Burkina Faso	33	3	7	21
Kodeni	Burkina Faso	33	3	7	21
Ouaga 1	Burkina Faso	90	3	10	30
Patte d'oie	Burkina Faso	33	3	5	15
Ferkessedougou	Ivory Coast	90	5	5	25
Riviera	Ivory Coast	90	3	10	30
Bia sud	Ivory Coast	90	3	10	30
Yopougnon	Ivory Coast	90	3	10	30
Divo	Ivory Coast	90	1	12	12
Yamoussoukro	Ivory Coast	90	1	12	12
Attakro	Ivory Coast	90	1	6	6
Daloa	Ivory Coast	90	2	10	20
Agnibilekro	Ivory Coast	90	1	6	6
Achimota	Ghana	34.5	2	21.6	43.2
Kenyasi	Ghana	161	4	10	40
Mim	Ghana	161	1	10	10
Kumasi	Ghana	161	1	25	25
New Aberim	Ghana	161	2	10	20
Asawinso	Ghana	161	2	10	20
New Obuasi A	Ghana	11.5	1	5.4	5.4
New Obuasi B	Ghana	11.5	1	5.4	5.4
New Obuasi C	Ghana	11.5	1	5.4	5.4
Maiduguri	Nigeria	330	2	50	100
Ikeja West	Nigeria	330	5	100	500
Akangba	Nigeria	330	2	100	200
Zaria	Nigeria	330	2	50	100
Kano	Nigeria	132	2	100	200
Abuja	Nigeria	330	3	100	300
Ayiede	Nigeria	330	2	100	200
Oshogbo	Nigeria	330	3	100	300
Sakal	Senegal	30	5	5	25
Taiba	Senegal	90	1	5	5
Tobene	Senegal	90	2	5	10
Thiona	Senegal	90	2	10	20

Table 845 - Capacitors and reactors banks added to the system – 2025 peak load

3.4.3. Static studies: Security analysis

Another important planning criterion is the N-1. In case of loss of branches (line or transformer) the system must remain stable, must not present overloading of lines over 110% and of transformers over 120% and must keep all voltages in the +/-10% range.

The N-1 analysis is performed on basis of PSA model and contingencies on all branches (over 90 kV) were simulated to report the incidents that do not respect the criteria. Since the goal of this study is to analyze the interconnections, only the following issues are reported here:

- Problems appearing in a country's network following the loss of an interconnection;
- Problems appearing on interconnections following a contingency inside a country's network;
- Problems appearing on interconnections following the loss of an interconnection.

3.4.3.1. 2015

3.4.3.1.1. Base case peak load

Lines contingencies

Table presents the lines contingencies results for the Base case, at peak load.

Lines	Voltage level	Results
Name	**kV**	**Criteria not respected**
Bolgatanga - Zebila	161	Overvoltages in 161 kV - north Togo
Zebila - Bawku	161	Overvoltages in 161 kV - north Togo
Dapaong - Bawku	161	Overvoltages in 161 kV - north Togo
Guene - Kandi	161	Overvoltages in 161 kV - north Togo
Guene - Malanville	161	Overvoltages in 161 kV - north Togo
Sakal - Tobene	225	Overvoltages in 225kV - Mali and Senegal
Koutiala - Segou	225	Undervoltages at Segou 225 kV and 150 kV
Kodeni - Bolgatanga	225	Undervoltages in 330kV, 225kV, 132kV and 90kV - Ivory Coast and Burkina Faso
Pa - Kodeni	225	Undervoltage at Pa 225 kV - Burkina Faso

Table 85 – Lines contingencies for the Base case, peak load situation

For the lines listed here above, the system was not able to support a simple line tripping (without fault) and respect the operation criteria. The incidents are:

- Over-voltages in the north of Togo when a part of the interconnection between Bawku and Dapaong (Ghana-Togo) is tripped.
- Over-voltages in Mali and Senegal when the OMVS interconnection is tripped.
- Under-voltages at Segou when part of the interconnection between Mali and Ivory Coast is tripped.
- Under-voltages in Burkina Faso, and part of Ivory Coast, when parts of the interconnections towards Burkina Faso are tripped.

Transformers contingencies

Table presents the transformers contingencies results for the Base case, at peak load.

Transformer	Voltage level	Results
Name	kV	Criteria not respected
Malanville	330/161	Overvoltages in the north of Togo and Benin
Kodialani	225/150	Parallel transformer overloaded at Kodialani
Bolgatanga	225/161	Undervoltage in Burkina Faso and Niger

Table 86 – Transformers contingencies for the Base case, peak load situation

The incidents are:

- Over-voltages in the north of Benin when the North-core interconnection with Niger and Nigeria is tripped.
- Overload of the 225/150 kV transformer when the parallel transformer is tripped.
- Under-voltages in Burkina Faso and Niger when the 225/161 kV transformer is tripped in Bolgatanga (Ghana). This transformer supplies the two interconnections between Ghana and Burkina Faso.

Units contingencies

All units contingencies are supported by the system, while complying with the operation criteria. Only the contingency of Sendou coal unit, 125 MW, in Senegal, provokes an instability. This contingency was simulated dynamically and presented in section 3.2.2.3.2, in Figure and Figure .

3.4.3.1.2. Scenario 2 peak load

Lines contingencies

Table presents the lines contingencies results for Scenario 2, at peak load.

Branch	Voltage level	Results
Name	kV	Criteria not respected
Sikasso - Ferkessedougou	225	Overloaded line Zagtouli-Ouagadougou - Burkina Faso
Abobo - Elubo	225	Line Zebila - Bawku overloaded
Bolgatanga - Zebila	161	Overvoltage in the north of Togo - 161kV
Zebila - Bawku	161	Overvoltage in the north of Togo - 161kV
Dapaong - Bawku	161	Overvoltage in the north of Togo - 161kV
Onigbolo - Sakete	161	Overvoltage in the north of Benin - 161kV
Mango - Dapaong	161	Overvoltage in the north of Benin - 161kV
Kodialani - Kalaban Coro	150	Overloaded transformers in Segou - Mali
Koutiala - Segou	225	Undervoltage in Segou - Mali
Parakou - Onigbolo	161	Undervoltage in the north of Benin - 161kV

Table 87 – Lines contingencies for the Scenario 2, peak load situation

The results from the Base case are also valid for Scenario 2 except for:

- The contingencies on interconnection lines that are not in service in Scenario 2.
- The contingencies on the axes towards Burkina Faso (Kodeni – Bolgatanga and Pa – Kodeni). In scenario 2, Burkina Faso imports less power because fewer interconnections are available. There are more units in service inside the country and it is consequently easier to keep the voltages in the required range.
- The contingency on the line Sakal – Tobene. In the Base case, it provokes a flow redirection from Mali to Senegal via the OMVG interconnection. It does not fulfill the operation criteria in this static analysis and it will be shown in the dynamic simulations that the system loses stability. In scenario 2, this contingency provokes the split of Senegal from the main system. It will be observed dynamically whether Senegal can face such incident.

Other incidents are also detected:

- The contingency on the Ivory Coast-Mali interconnection provokes the overload of a 90 kV line inside Burkina Faso.
- The contingency on the 225 kV interconnection between Ghana and Ivory Coast provokes an overload on 161 kV line Bawku-Zebila in north Ghana.
- Contingencies in the 161 kV network of Togo and Benin provoke over and under-voltages in the north of Benin.
- The contingency on the 150 kV line between Kodialani and Kalaban Coro in Mali provokes the overload of the transformers at Segou.

Transformers contingencies

For Scenario 2, there is no transformer contingency provoking a network state that does not fulfil the criteria. In comparison with the Base case:

- The North-core interconnection is not yet commissioned. There is consequently no transformer in Malanville.
- The interconnection Ghana-Burkina Faso-Mali is not yet commissioned. There are fewer exchanges towards Mali and the transformer contingency in Kodialani respects the operation criteria.
- Burkina Faso is less interconnected and imports less energy. There are consequently more units and it is easier to maintain the voltages in the required range.

Units contingencies

For some machine contingencies, the system is not able to support the transient and recover to a steady-state satisfying the operation criteria. Table lists all machines contingencies leading to the non-respect of the operation criteria.

Unit	Results
Name	Criteria not respected
BLACKHG1/2/3	Under-voltage at Freetown - Sierra Leone
NIGERSOL	Voltage collapse in Niger
MANEAH	Voltage collapse in Guinea/Sierra Leone/Liberia
CAPDB19A	Low voltages in Senegal
KOUDI_1G/2G	Low voltages in Senegal
KAHONG71/2/3/4	Voltage collapse in Senegal
SENDOU1G	Low voltages in Senegal and loss of synchronism
CAPDB11A	Low voltages in Senegal and loss of synchronism
TOBIN_1G	Low voltages in Senegal and loss of synchronism
GTI_111A	Low voltages in Senegal and loss of synchronism
ALBATR1G	Loss of synchronism in Mali
4KOS6_11	Overload line Zagtouli-Ouagadougou 90 kV - Burkina Faso

Table 88 – Machines contingencies for Scenario 2, peak load situation

Many machines are in Senegal. Their contingency provokes an additional import to replace the power lost and the transit increase reaches states beyond the stability limits, provoking the loss of synchronism of other units in Senegal.

Other incidents are important in Freetown (Sierra Leone), Conakry (Guinea) and Niamey (Niger, River area) where the loss of one unit can cause low voltages or even voltage collapse.

The loss of ALBATR1G in Mali causes loss of synchronism of other units in Mali.

Finally, the loss of one unit in Burkina Faso provokes the overload of a 90 kV line close to Ouagadougou.

3.4.3.1.3. Base case off peak load

Lines contingencies

Table 896 presents the lines contingencies for the Base case, at off peak load condition.

Lines	Voltage level	Results
Name	kV	Criteria not respected
Buchanan - Monronvia	225	overvoltage at Buchanan 225 kV in Liberia
Guene - Malanville	161	overvoltage in 161 kV in North Benin
Kaleta - Linsan	225	voltage collapse in Sierra Leone
Kodialani - Kalaban coro	150	over and under voltages in 150 and 225 kV in Mali
Koutiala - Segou	225	undervoltage at Segou 225 kV - Mali
Mbour - Sococim	90	undervoltage at Mbour 90 kV - Senegal
Monrovia - Mano	225	overvoltage at Mano 225 kV - Liberia
Papalanto - Aiyede	330	undervoltage at Aiyede 330 kV in Nigeria
Sakete - Ikeja West	330	overvoltage in Benin around Sakete

Table 896 - Lines contingencies for the Base case, off peak load situation

The incidents are:

- The contingency on the line between Monrovia and Buchanan provokes overvoltage in Buchanan since the SVC in Monrovia cannot influence the voltage anymore. The same phenomenon appears for the line between Monrovia and Mano, with overvoltage at Mano.
- The 161 kV line between Guene and Malanville carries the power flow from Benin to Niger. If this line is tripped, the 161 kV lines in Benin towards Niger are overloaded. They generate reactive power and there is an overvoltage.
- The contingency on the line between Linsan and Kaleta provokes a redispatch of the flows from Kaleta to the CLSG interconnection. This new dispatching of the flows leads to the voltage collapse of Sierra Leone.
- The line between Kodialani and Kalaban Coro is important for voltage management in Mali.
- The contingency of the line between Koutiala and Segou, in Mali, provokes under-voltage in Segou, which becomes fed via the 150 kV lines in Mali.
- Ayiede in Nigeria experiences under-voltage when its connection with the Papalanto power station is lost. The only connection remaining comes from Oshogbo.
- The loss of the interconnection between Benin and Nigeria provokes over-voltages around Sakete due to unloaded lines in Benin.

Transformers contingencies

Contingencies on the transformers at Linsan and Malanville do not comply with the operation criteria. The contingency on the transformer at Linsan provokes the overloading of the parallel transformer. At Malanville, as for peak load situation, the contingency provokes overvoltages in the north of Togo and Benin.

Transformer	Voltage level	Results
Name	kV	Criteria not respected
Linsan	225/110	overload parallel transformer
Malanville	330/161	overvoltages in 161 kV in north Benin

Table 907 - Transformers contingencies for the Base case, off peak load situation

Units contingencies

Two unit contingencies do not fulfil the operation criteria. They are presented in Table 918.

Unit	Results
Name	Criteria not respected
SVCMONRO	Overvoltages in Liberia 225 kV
WIND__1G	Voltage collapse in Senegal

Table 918 - Machines contingencies for the Base case, off peak load situation

The loss of the SVC at Monrovia provokes high voltages along the CLSG interconnection. The highest voltage is located at Buchanan 225 kV bus bar, with 1.14 pu.

The contingency on the wind farm in Senegal leads to voltage collapse in Senegal. In this scenario, the wind farm produces 60 MW. The reason of the collapse is related to the maximum transfer capacity limit of the lines towards Senegal. This case will be illustrated in the section simulating dynamically the units' contingencies.

3.4.3.1.4. Scenario 2 off peak load

Lines contingencies

Table 929 lists the contingencies that do not comply with the operation criteria.

Branch	Voltage level	Results
Name	kV	Criteria not respected
Bolgatanga - Ouagadougou	225	voltage collapse in Burkina Faso
Papalanto - Aiyede	330	undervoltage at Aiyede 330 kV in Nigeria
Zebila - Bawku	161	overvoltage in North Benin 161 kV
Buchanan - Monrovia	225	overvoltage in 225 kV at Liberia, Guinea (Nzerekore) and Man
Ferkessedougou - Kodeni	225	voltage collapse in Bobo area in Burkina Faso
Kara - Djougou	161	overvoltages in 161 kV in North Togo and Benin
Abobo - Elubo	161	undervoltages in 161 kV in north Ghana
Bolgatanga - Zebila	161	overvoltage in North Benin 161 kV
Sakete - Ikeja West	330	overvoltages in 161 and 330 kV in Benin
Zagtouli - Ouagadougou	90	voltage collapse in Ouagadougou in Burkina Faso
Sakete - Onigbolo	161	overvoltage in North Benin 161 kV
Ouagadougou-Ouagadougou	90	voltage collapse in Ouagadougou in Burkina Faso

Table 929 - Lines contingencies for Scenario 2, off peak load situation

The incidents are the same than for the Base case, except for:

- The contingencies on interconnection lines that are not in service in Scenario 2.
- Incidents that now lead to the splitting of the system in two parts. For instance, in the Base case, the loss of the 150 kV line between Kodialani and Kalaban Coro in Mali provokes voltage problems. In Scenario 2, it provokes the splitting of the system in two parts: Senegal and one part of Mali, and the rest with the other part of Mali. The interconnection passes from 225 kV to 150 kV in Mali and back to 225 kV in Mali.

Besides, the incidents show:

- The loss of the interconnection between Ghana and Burkina leads to voltage collapse in Burkina Faso. This will be illustrated in the dynamic simulations
- The regions of north Togo and north Benin still have very sensitive voltages.
- The loss of the interconnection between Ivory Coast and Burkina Faso provokes a voltage collapse in Burkina Faso by exceeding the maximum transfer capacity on the only remaining line to supply Burkina Faso: the line Bolgatanga – Zagtouli.
- The loss of the interconnection between Ivory Coast and Ghana forces the energy that comes from Ghana and goes to Ivory Coast to pass through Burkina Faso. This additional flow provokes low voltages in 161 kV in north of Ghana.
- 90 kV lines inside Ouagadougou area in Burkina Faso should be reinforced to allow this area importing power.

Transformers contingencies

For Scenario 2, at off peak load situation, there is no transformer contingency provoking a network state that does not fulfill the criteria.

Units contingencies

Unit Name	Results Criteria not respected
2NEWCC-1/2	Overload on line Bawku-Zebila in Ghana
MANAN14/5A	Overload on line Bawku-Zebila in Ghana and tfo at Segou in Mali
20NTAG82/3	Overload on line Bawku-Zebila in Ghana
MANEAHG1/2	Overload on line Bawku-Zebila in Ghana
SVCMONRO	Overvoltages in Liberia 225 kV
4OUA24/5_5	Overload line Zagtouli-Ouagadougou 90 kV - Burkina Faso
2027VRID	Overload on line Bawku-Zebila in Ghana
GTI_111A	Low voltages in Senegal, Mali and Ivory Coast + Overloads of tfo at Segou and 150 kV line in Mali
BUI___G1	Overload on line Bawku-Zebila in Ghana

Table 10 - Machines contingencies for Scenario 2, off peak load situation

The loss of the SVC at Monrovia provokes high voltages on the CLSG interconnection.

In case of big unit contingency (Manantali, GTI in Senegal, …), there is a risk of overloading the transformers at Segou and the 150 kV lines in Mali, with low voltages in Ivory coast, Mali and Senegal. This is due to the flows redispatch with the unblocking of the primary reserve.

The 90 kV line between Ouagadougou and Zagtouli is overloaded for unit contingencies in Ouagadougou.

The 161 kV line between the north of Ghana and Togo, in case a machine greater than 40 MW is lost in Mali, Senegal, Guinea or Ivory Coast. This line between Bawku and Zebila has a low rating capacity of 43 MVA in comparison of other elements of the interconnection between the north of Ghana and Togo. The lines between Bawku and Dapaong are rated 120 MVA, while the line between Dapaong and Mango is rated 120 MVA.

3.4.3.2. 2020

In 2020, the system as it is presented does not comply with the N-1 criterion. All problems detected are listed in Table 9411, Table and Table .

The problems for lines contingencies are the following:

- Problems of power evacuation. The lines to evacuate the power from Adjaralla, Koukoutamba and Boureya are insufficient.
- Over-voltages in north of Benin and Togo, as already detected for 2015 remains.

- Large importations from some countries whose network's stability is very difficult to keep. It is the case for Senegal, Burkina Faso and Mali. A good coordination between the lines and the reactances should allow avoiding some problems but it is not enough to support the N-1. Voltage support is deficient and the import level is difficult to support. The possible solutions are the installation of SVC, the operation of more units inside the country to provide voltage support and reduce the imports or the reinforcement of the interconnections.
- Large loops composed of long interconnection whose stability is very difficult to keep. Some elements contingencies on the loop provoke flows redistributions that are not supported by the network. In case of reinforcements, the whole loop does not need to be doubled. Doubling only part of it is sufficient.
  - The loop Linsan-Manantali-Bamako-Fomi
  - The OMVG loop
  - The loop between Fomi-Kodialani-Sikasso-Ferkessedougou-Boundiali
  - The loop between Matam-Kayes-Tobene-Kaolack-Tambacounda

Lines	Voltage level	Results
Name	**kV**	**Criteria not respected**
Linsan-Dabola	225	overloads on 225 kV lines Boureya-Manantali-Tkita
Dabola-Koroussi	225	
Koroussi-Fomi	225	
Linsan-Kamakwie	225	overloads on 225 kV lines Boureya-Manantali
Kamakwie-Yiben	225	
Yiben-Bumbuna	225	
Sambangalou-Tambacounda	225	instability
Tambacounda-Kaolack	225	
Kaolack-Touba	225	
Kaleta-Boke	225	instability
Boke-Saltinho	225	
Saltinho-Bambadinca	225	
Bambadinca-Mansoa	225	
Mansoa-Tanaf	225	
Tanaf-Soma	225	
Linsan-Koukoutamba	225	instability
Boureya-Manantali	225	overload Linsan-Koukoutamba
Kayes-Matam	225	instability
Matam-Dagana	225	
Fomi-Bundialani	225	instability
Ouelessedougou-Kodialani	225	
Ouelessedougou-Sikasso	225	
Bundialani-Ferkessedougou	225	overload on 225 kV line Ouelessedougou-Kodialani
Fomi-Siguir	225	overload on 225 kV line Boureya-Manantali
Man-Yekepa	225	instability
Bolgatanga-Ouagadougou	225	instability
Ouagadougou est-Zagtouli	225	overload 90 kV line Zagtouli-Ouagadougou
Adjaralla-Ava	161	overload 161 kV lines Adjaralla-Nangbeto-Mome Hagou
Guene-Malanville	161	over-voltages in north Benin
Zabori-Malanville	330	over-voltages in north Benin
Zebila-Bawku	161	over-voltage in north Togo

Table 9411 - Lines contingencies for 2020 peak load situation

The problems for transformers contingencies are related to the problems detected for lines, except for the north of Ivory Coast that is insufficiently fed with the three transformers at Ferkessedougou, Boundiali and Laboa.

Transformer	Voltage level	Results
Name	**kV**	**Criteria not respected**
Selingue	225/150	overloads on 225/150 kV tfo at Kodialani and overloads on lines Kodialani Kalaba Coro in Mali
Malanville	330/161	over-voltages in north Benin
Ferkessedougou	225/90	instability in north Ivory Coast
Laboa	225/90	instability in north Ivory Coast
Bundialani	225/90	overloads of tfos at Ferkessedougou and Laboa

Table 95 - Transformers contingencies for 2020 peak load situation

Finally, for units contingencies, the problem detected for Senegal in 2015 remains. The contingency of one unit in Sendou provokes the loss of 125 MW. This loss is replaced by the unblocking of the primary reserve in Senegal but also in the other countries. Consequently, an additional flow appears on the lines towards Senegal provoking instability. In this scenario, the lines between Kayes and Matam and between Sambangalou and Kaolack are highly loaded. It is interesting to note that a contingency of 100 MW is supported by the system.

Unit	Power	Results
Name	**MW**	**Criteria not respected**
Sendou	125	collapse in Senegal

Table 96 - Units contingencies for 2020 peak load situation

3.4.3.3. 2025

The N-1 criterion is not respected in the system as it was studied for the peak load 2025 situation. The lines, transformers and units contingencies that do not comply with the operation criteria were reported in Table , Table , Table 9912 and Table .

At first, Table summarizes the lines contingencies which provoke overloads of the parallel lines. They mainly concerns internal problems:

- in 90 kV in Dakar (Senegal), Ouagadougou (Burkina Faso) and Abidjan (Ivory Coast),
- 150 kV in Bamako (Mali),
- in 161 kV in Cotonou (Benin), Lome (Togo) and Tema (Ghana),
- in 330 kV in Lagos and Benin City (Nigeria).

Regional problems are also appearing with the overloads:

- in 225 kV in north Ivory Coast, for exporting the hydro power coming from the CLSG interconnection and from the Soubre area to Burkina Faso.
- in 225 kV between Boureya, Manantali, Kodialani and Kodeni (Guinea, Mali, Burkina Faso) to export the hydro power from Guinea to Mali and Burkina Faso.

Lines	Voltage level	Results
Name	kV	Criteria not respected
Sococim-Thiona	90	parallel line overloaded
Zagtouli-Ouagadougou	90	parallel line overloaded
Maria Gleta-Cotonou	161	parallel line overloaded
Manantali-Tkita	225	parallel line overloaded
Ajaoku-Geregu	330	parallel line overloaded
Erunkan-Ikeja West	330	parallel line overloaded
Boureya-Manantali	225	parallel line overloaded
Volta-Tema	161	parallel line overloaded
Niamey-Birnin Kebbi	132	parallel line overloaded
Lome-Lome Port	161	parallel line overloaded
Sirako-Balingue	150	parallel line overloaded
Ouelessedougou-Kodialani	225	parallel line overloaded
Ouaga Est-Kossodo	90	parallel line overloaded
Treichville-Vridi	90	parallel line overloaded
Ouaga 1- PC	90	parallel line overloaded
PC-Kossodo	90	parallel line overloaded
Kounoune-Tobene	225	overload 90 kV line Mbour-Sococim
Bouake-Kossou	90	overload 90 kV line Bouake 1-Bouake 2
Ayiede-Oshogbo	330	overload 330 kV line Ayiede-Papalanto
Cap des biches - Sococim	90	overload 90 kV line Kounoune-Sococim
Ferkessedougou-Kodeni	225	overload 225 kV line Sikasso-Kodeni
Kounoune-sococim	90	overload 90 kV line Cap des biches-Sococim
Bundialani-Ferkessedougou	225	overload tfo 225/90 Bundialani
Ouaga Est-Zagtouli	225	overload 90 kV lines Zagtouli-Ouaga 2 and Ouaga 2-Ouaga 1 and tfos 225/90 Zagtouli

Table 97 – Lines contingencies provoking overload problems (peak load 2025 situation)

Secondly, Table lists all the lines contingencies leading to voltage problems and collapses. The following areas are concerned:

- 90 kV network around Kossou, Taabo and Boake in Ivory Coast.
- 161 kV in Freetown. The stability relies on the two lines from Bumbuna, which are insufficient.
- 161 kV in Kpan in Ghana
- Areas of Katsina and Maiduguri in north of Nigeria, that should be more compensated.
- Area of Ayiede in Nigeria, which is only connected via two lines and insufficiently compensated.
- Areas of Dagana and Sakal in Senegal, where the loss of the OMVS interconnection from Kayes provokes a flow redistribution that is not supported.
- The Gambia and Guinea Bissau, fed from Kaleta, do not support a contingency on the 225 kV lines between Kaleta and Mansoa. The flow redistribution provokes voltage collapses.
- The substation of Buchanan 225 kV, experiencing over-voltages when the link with the SVC of Monrovia is lost.
- Niamey, Salkadamna and north of Benin, experiencing overvoltages when the North-core interconnection is lost between Niger-Benin-Nigeria.

Also, the transmission of hydro power from West to East is a problem. The loss of one of these interconnections reduces the transfer capacity and leads to instability:

- CLSG interconnection between Man and Yekepa:
  - Fomi-Boundiali
  - Kodialani-Kodeni
  - Kodeni-Bolgatanga
  - Riviera-Prestea

Lines	Voltage level	Results
Name	**kV**	**Criteria not respected**
Buchanan-Monrovia	225	overvoltages at Buchanan
Agbo-Yopo	90	undervoltage at Agbo
Dagana-Sakal	225	overvoltages at Dagana and Matam
Kano-Katsina	330	undervoltage at Katsina
Birnin Kebbi-Malanville-Niamey	330	overvoltages in Niamey, Salkadamna and north Benin
Prestea-Riviera	330	instability
Gombe-Damaturi	330	voltage collapse in Maiduguri, Nigeria
Papalanto-Ayiede	330	voltage collapse in Ayiede
Kaolack-Touba	225	voltage collapse in Touba, Senegal
Bambadinka-Mansoa	225	instability
Bambadinka-Saltinho	225	
Boke-Saltinho	225	
Fomi-Bundialani	225	instability
Sikasso-Kodeni	225	instability
Sikasso-Ouelessedougou	225	instability
Man-Yekepa	225	instability
Soubre-San Pedro	225	instability
Tiboto-San Pedro	225	
Bouake 2-Kossou	225	collapse at Bouake
Kodeni-Bolgatanga	225	instability
Bumbuna-Freetown	161	voltage collapse in Freetown in Sierra Leone
Asie-Kpan	161	voltage collapse in Kpan in Ghana
Bouake 1-Bouake 2	90	voltage collapse in Bouake 1
Bouake-Agnibilekro	90	voltage collapse in area of Dimbokro-Attakro-Abengourou-Agnibilekro
Kossou-Yamoussoukro	90	
Taabo-Dimbokro	90	
Dimbokro-Attakro	90	
Attakro-Abengourou	90	
Gagnoa-Kossou	90	voltage collapse in Gagnoa, Ivory Coast
Hire-Taabo	90	voltage collapse at Divo, Ivory Coast
Hire-Divo	90	

Table 98 – Lines contingencies provoking voltage problems and instability (peak load 2025 situation)

The transformers contingencies, listed in Table 9912, confirm the problems already mentioned and show substations where transformers should be reinforced.

Finally, Table presents the units contingencies that are not supported by the system. These contingencies concern large units located in the eastern part of the WAPP system. Their contingencies provoke the unblocking of the primary reserve, mainly in Nigeria, leading to flow redistribution where the flows from East to West are reduced. This reduction provokes over-voltages in the north of Ivory Coast and leads to instability

Transformer	Voltage level	Results
Name	kV	Criteria not respected
Bumbuna	225/161	parallel tfo overloaded
Tobene	225/90	parallel tfo overloaded
Kumasi	330/161	parallel tfo overloaded
Riviera	330/225	parallel tfo overloaded
Segou	225/150	parallel tfo overloaded
Bouake	225/90	parallel tfo overloaded
Matam	225/90	parallel tfo overloaded
Kodeni	225/33	parallel tfo overloaded
Kano	330/132	voltage collapse in north of Nigeria
Katsina	330/132	voltage collapse in north of Nigeria

Table 9912 - Transformers contingencies for 2025 peak load situation

Unit	Power	Results
Name	MW	Criteria not respected
Kaleta	80	instability
Sendou	125	instability
Wind farm SE	100	instability

Table 100 - Units contingencies for 2025 peak load situation

3.4.4. Static studies: Short-circuit analysis

Short-circuit analysis were performed at peak load, for years 2015, 2020 and 2025.

3.4.4.1. 2015

Short-circuit analysis results are presented in appendix in Table , Table , Table and Table .

They were calculated for the Base case and for Scenario 2, first with the configuration of the scenario (the machines out of service are disconnected), second with all machines connected to reach the maximum short circuit level.

When compared to the breaker capacities, these short-circuit levels are all acceptable except for:

- Abobo 90 kV, Vridi 90 kV, Plateau 90 kV, Bia nord 90 kV and Treichville 90 kV in Ivory Coast.
  The area of Abidjan will see the installation of new units in Riviera and Vridi which are responsible for the high currents calculated. Some documents collected mentioned that breaker capacities will be or would be already upgraded for some of these substations. The calculations expect levels above 25 kA and even above 31.5 kA sometimes. The upgrade should consequently be important enough to cover these levels.

- Volta 161 kV and Smelter 161 kV in Ghana.

  The area between Akosombo and Tema was already facing high levels of short-circuit currents. In 2015, the apparition of new units in Tema and Asogli will increase even more these levels. Calculations also showed levels above 90% for Akosombo 161 kV, Tema TT1P 161 kV and Asogli 161 kV, though they are still acceptable.
- Afam 330 kV, Alaoji 330 kV, Benin City 330 kV, Benin North 330 kV, Egbin 330 kV, Erunkan 330 kV, Eyaen 330 kV, Ikeja West 330 kV, Ikot Ekpene 330 kV, Onitsha 330 kV and Owerri 330 kV in Nigeria.

  The south of Nigeria, with the region of Lagos, Benin City and Port Harcourt is already very dense and loaded. In 2015, several new power plants will be commissioned in these areas. The reinforcements in the 330 kV network and the installation of the 760 kV super grid will also contribute to increase the short-circuit levels. For the here-above quoted substations, the short-circuit current levels are above the breaker capacity. For Aja 330 kV, Ikot Abasi 330 kV and Sapele 330 kV nodes the short-circuit currents calculated are high (above 90% of rated breaker capacity) but still acceptable. Some documents collected mention breaker capacities above 31.5 kA (at 40 and 50 kA) but without detailing for which substations. It is important to make sure these substations are concerned.
- Cap des Biches 90 kV in Senegal.

  The maximum current calculated is acceptable. Attention is drawn here because it is between 90 and 100% of breaker capacity. This high level is due to the installation of new capacities at Cap des Biches.

The modeling assumptions must be kept in mind for analyzing the short-circuits levels calculated. For many countries, no information was collected about the internal reinforcements. Important parameters like step up transformers impedance were assumed.

3.4.4.2. 2020 AND 2025

The short-circuit calculations showed the same problems than for 2015. The development of large hydro power plants in the eastern part of the WAPP system is not problematic, for what concerns short-circuits levels, if the impedances of the step-up transformers is correctly designed, and assuming their connections in 225 kV with a breaking capacity of 31.5 kA.

The results are given in Table , Table and Table in appendix.

3.4.4.3. CONCLUSIONS

As a conclusion, the three phases short-circuit current levels could be reduced by taking the following actions:

- Designing the impedance of the step up transformers to limit such currents;
- Inserting serial reactances at critical substations;
- Avoiding locating all the units at the same site, or close from areas having already high short circuits levels.

The locations where values exceeding the breaking capacities were detected should be checked to verify that the assumptions done for the breaking capacities are underestimated.

3.4.5. Dynamic studies: Small signal stability

The small signal stability of the system was checked by calculation of the eigenvalues using HERCULES, according to the methodology described above.

3.4.5.1. 2015 PEAK LOAD: BASE CASE

For the Base case, the following modes have a damping coefficient lower than 5.0%.

Mode	Real	Imaginary	ζ (%)	Freq (Hz)
1	-0.016	3.146	0.51%	0.501
2	-0.194	5.980	3.24%	0.952
3	-0.076	2.207	3.43%	0.351
4	-0.238	5.403	4.41%	0.860

Table 101 - Characteristics of the least damped modes – Base case (peak load)

These modes are related to inter-area oscillations and the first three will be studied here:

- Mode 1 is an inter-area oscillation between Ghana/Ivory Coast and Senegal/Guinea.
- Mode 2 is an inter-area oscillation between Mali and Senegal.
- Mode 3 is an inter-area oscillation between Senegal/Guinea and Nigeria.

The tables and charts below illustrate the modes.

The mode shape graph in Figure illustrates the resonance between the two groups of machines for mode 1. It is an oscillation between Ghana/Ivory Coast and Senegal/Guinea. With the information in Table 13, one can understand the graph. The arrows on the left side represent the machines in Ghana and Ivory Coast. The module of the arrow gives the contribution of the machine to the oscillation and its angle gives the phase of the contribution in the oscillation. The arrows on the right side of the graph represent the machines in Senegal and Guinea. The phase opposition is visible.

The same graphs and tables are provided for modes 2 and 3.

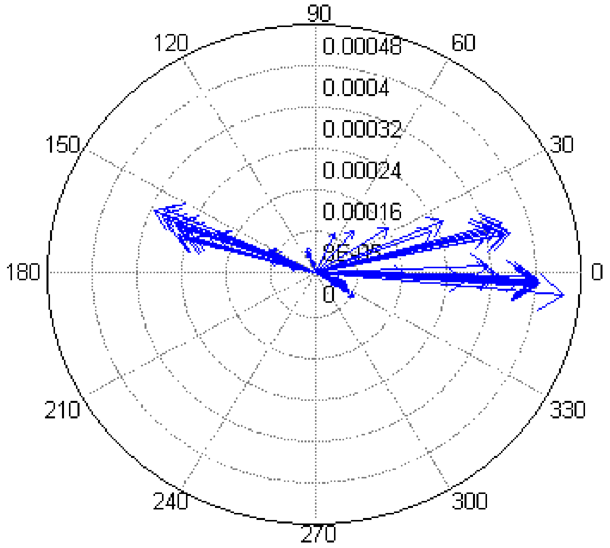


Figure 44 - Mode shape graph of mode 1 – Base case (peak load)

Machines in Phase Opposition							
Country	**Machine**	**Angle**	**Contribution**	**Country**	**Machine**	**Angle**	**Contribution**
GH	DOMIT1G2	-202.36	0.31	SE	SENDOU1G	-5.46	0.45
GH	DOMIT1G1	-202.36	0.31	SE	BELAIR1G	-2.76	0.40
GH	ABOAT1G1	-202.25	0.30	SE	BELAIR2G	-2.76	0.40
GH	ABOAT1G2	-202.25	0.30	SE	CAPDB19A	-2.09	0.40
GH	ABOAT2G1	-202.25	0.30	SE	B_AIRG62	-3.54	0.40
GH	ABOAT2ST	-204.52	0.30	SE	B_AIRG61	-3.54	0.40
GH	ABOAT1ST	-201.08	0.29	SE	GTI_113A	-2.03	0.40
CI	20NGTAG8	-200.51	0.26	SE	CAPDB145	-3.71	0.39
CI	20NTAG82	-200.51	0.26	SE	CAPDB144	-3.71	0.39
CI	2NEWCC-1	-200.23	0.26	SE	KOUN_1G1	-2.64	0.39
CI	2NEWCC-2	-200.23	0.26	SE	KOUN_1G6	-2.64	0.39
CI	2027VRID	-200.41	0.26	SE	KOUN_1G3	-2.64	0.39
CI	2028VRID	-200.39	0.26	SE	KOUN_1G4	-2.64	0.39
CI	2029VRID	-200.53	0.26	SE	KOUN_1G7	-2.64	0.39
CI	20NTAG83	-200.54	0.26	SE	KOUN_1G2	-2.64	0.39
GH	ABOA3CC1	-202.47	0.26	SE	KOUN_1G5	-2.64	0.39
CI	2034TAAB	-196.79	0.26	SE	CAPDB11A	-3.35	0.39
CI	2033TAAB	-196.79	0.26	SE	GTI_111A	-1.08	0.38
CI	2032TAAB	-196.80	0.26	GU	TOMBO5G1	12.68	0.36
GH	BUI___G1	-195.35	0.26	GU	TOMBO5G3	12.68	0.36
GH	BUI___G2	-195.35	0.26	GU	TOMBO5G2	12.68	0.36
GH	AKOSOMG1	-195.49	0.25	GU	GRCHUTG3	13.82	0.35
GH	AKOSOMG2	-195.49	0.25	GU	GRCHUTG4	13.84	0.35
GH	AKOSOMG3	-195.49	0.25	GU	GRCHUTG1	13.86	0.35
GH	AKOSOMG4	-195.49	0.25	GU	GRCHUTG2	13.86	0.35
GH	AKOSOMG6	-195.49	0.25	GU	DONKEAG1	15.95	0.35
GH	AKOSOMG5	-195.49	0.25	GU	DONKEAG2	15.95	0.35
GH	SASO2CC1	-201.02	0.24	GU	TOMBO3G4	12.43	0.35
GH	KPONGHG3	-195.13	0.24	GU	MANEAHG2	12.11	0.34
GH	KPONGHG4	-195.13	0.24	GU	MANEAHG1	12.11	0.34
GH	KPONGHG1	-195.13	0.24	GU	MANEAHG3	12.11	0.34
GH	KPONGHG2	-195.13	0.24	GU	KALETAG3	15.54	0.33
CI	2043KOSS	-195.75	0.23	GU	KALETAG2	15.54	0.33
CI	2042KOSS	-195.75	0.23	GU	KALETAG1	15.54	0.33

Table 13 – Machines in phase opposition – Mode 1 – Base case (peak load)

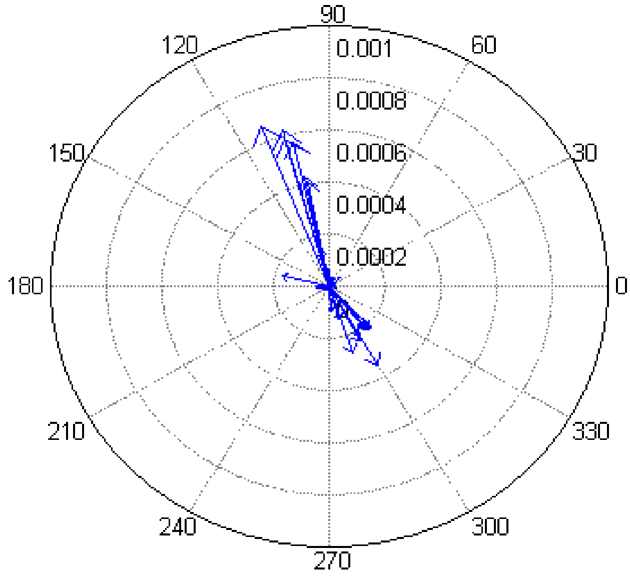


Figure 45 - Mode shape graph of mode 2 – Base case (peak load)

Machines in Phase Opposition							
Country	**Machine**	**Angle**	**Contribution**	**Country**	**Machine**	**Angle**	**Contribution**
MA	FELOU_3G	-248.36	0.66	SE	SENDOU1G	-60.08	0.35
MA	FELOU_1G	-248.36	0.66	SE	CAPDB19A	-49.81	0.22
MA	FELOU_2G	-248.36	0.66	SE	GTI_113A	-48.77	0.22
MA	MANAN11A	-254.38	0.62	SE	BELAIR1G	-50.20	0.22
MA	MANAN12A	-254.38	0.62	SE	BELAIR2G	-50.20	0.22
MA	MANAN14A	-254.38	0.62	SE	GTI_111A	-46.80	0.21
MA	MANAN15A	-254.38	0.62	SE	B_AIRG61	-51.44	0.21
MA	MANAN13A	-254.38	0.62	SE	B_AIRG62	-51.44	0.21
MA	KENIE_2G	-254.26	0.59	SE	CAPDB144	-52.45	0.21
MA	KENIE_1G	-254.26	0.59	SE	CAPDB145	-52.45	0.21
MA	KENIE_3G	-254.26	0.59	SE	KOUN_1G2	-49.78	0.20
MA	SELING1	-256.89	0.57	SE	KOUN_1G7	-49.78	0.20
MA	SELING2	-256.89	0.57	SE	KOUN_1G4	-49.78	0.20
MA	SELING3	-256.89	0.57	SE	KOUN_1G5	-49.78	0.20
MA	SELING4	-256.89	0.57	SE	KOUN_1G1	-49.78	0.20
MA	VICABO1G	-258.05	0.43	SE	KOUN_1G3	-49.78	0.20
MA	BALBIDG1	-258.97	0.40	SE	KOUN_1G6	-49.78	0.20
MA	BALBIDG2	-258.97	0.40	SE	CAPDB11A	-50.33	0.20

Table 103 – Machines in phase opposition – Mode 2 – Base case (peak load)

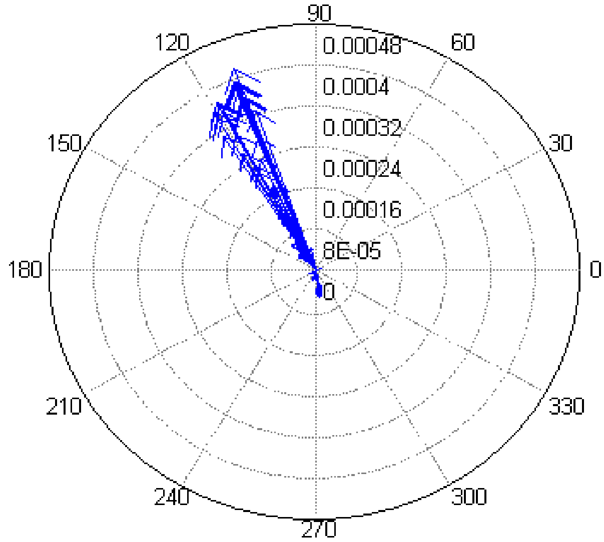


Figure 16 - Mode shape graph of mode 3 – Base case (peak load)

Machines in Phase Opposition							
Country	**Machine**	**Angle**	**Contribution**	**Country**	**Machine**	**Angle**	**Contribution**
SE	SENDOU1G	-249.33	0.42	NI	DELTAG18	-83.74	0.05
SE	BELAIR2G	-248.06	0.40	NI	DELTAG17	-83.74	0.05
SE	BELAIR1G	-248.06	0.40	NI	DELTAG20	-83.74	0.05
SE	CAPDB19A	-247.88	0.39	NI	DELTAG19	-83.74	0.05
SE	B_AIRG61	-248.67	0.39	NI	DELTAG16	-83.74	0.05
SE	B_AIRG62	-248.67	0.39	NI	DELTAG04	-84.01	0.05
SE	KOUN_1G1	-248.13	0.39	NI	DELTAG05	-84.01	0.05
SE	KOUN_1G4	-248.13	0.39	NI	DELTAG06	-84.01	0.05
SE	KOUN_1G7	-248.13	0.39	NI	DELTAG03	-84.01	0.05
SE	KOUN_1G2	-248.13	0.39	NI	AFAMGT20	-83.74	0.05
SE	KOUN_1G3	-248.13	0.39	NI	AFAMGT19	-83.74	0.05
SE	KOUN_1G5	-248.13	0.39	NI	DELTAG08	-83.60	0.05
SE	KOUN_1G6	-248.13	0.39	NI	DELTAG07	-83.60	0.05
SE	CAPDB11A	-248.28	0.39	NI	DELTAG09	-83.60	0.05
SE	CAPDB144	-248.84	0.39	NI	AFAMGT15	-83.76	0.05
SE	CAPDB145	-248.84	0.39	NI	AFAMGT16	-83.76	0.05
SE	GTI_113A	-247.95	0.39	NI	AFAMGT17	-83.76	0.05
SE	GTI_111A	-247.73	0.37	NI	AFAMGT18	-83.76	0.05
GU	TOMBO5G3	-241.34	0.37	NI	AFAMGT13	-83.48	0.05
GU	TOMBO5G1	-241.34	0.37	NI	AFAMGT14	-83.48	0.05
GU	TOMBO5G2	-241.34	0.37	NI	KWALCC3	-81.41	0.04
GU	TOMBO3G4	-241.74	0.37	NI	CALABGT2	-80.49	0.04
GU	MANEAHG1	-242.07	0.37	NI	CALABGT1	-80.49	0.04
GU	MANEAHG2	-242.07	0.37	NI	CALABGT3	-80.49	0.04
GU	MANEAHG3	-242.07	0.37	NI	CALABGT5	-80.49	0.04
GU	GRCHUTG3	-241.37	0.36	NI	CALABGT4	-80.49	0.04
GU	GRCHUTG4	-241.36	0.36	NI	ALAOJGT4	-80.43	0.04
GU	GRCHUTG2	-241.35	0.36	NI	ALAOJGT1	-80.36	0.04
GU	GRCHUTG1	-241.35	0.36	NI	ALAOJGT2	-80.36	0.04
SE	KOUDI_1G	-248.51	0.36	NI	ALAOJGT3	-80.42	0.04
SE	KOUDI_2G	-248.51	0.36	NI	EGBINST5	-84.31	0.04

Table 104 – Machines in phase opposition – Mode 3 – Base case (peak load)

These modes could be identified also in time domain simulations. Figures here below show the oscillations present in each mode.

Figure illustrates the phase opposition found in Mode 1, after a three-phase short circuit at Tobene 225 kV bus bar in Senegal during 100 ms. The oscillation period of mode 1 is about 2 seconds, its damping is not sufficient and the figure shows a clear phase opposition of machines Sendou (Senegal) and Akosombo (Ghana). It was confirmed by mode shape graph (see Figure).

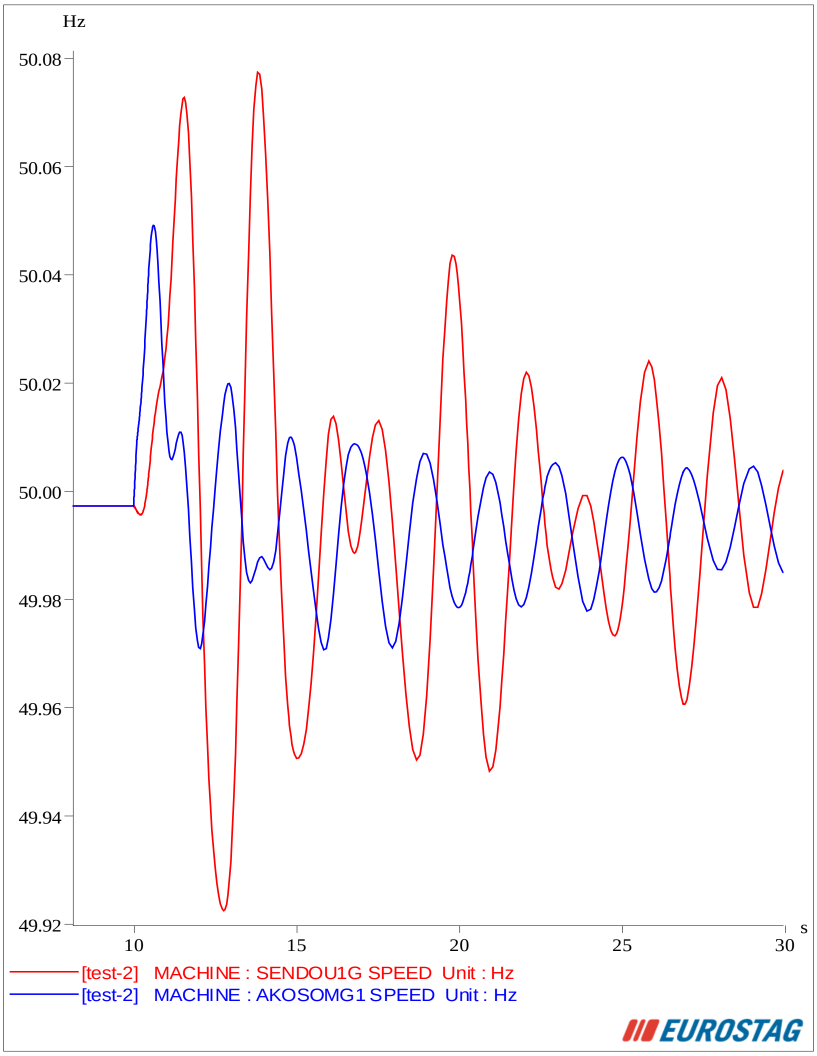


Figure 47 – Oscillations - Mode 1 – Base case (peak load)

To identify mode 2 in the dynamic simulations, a three-phase short circuit was performed at Manantali 225 kV bus bar (Mali) during 100 ms. Figure shows the oscillations.

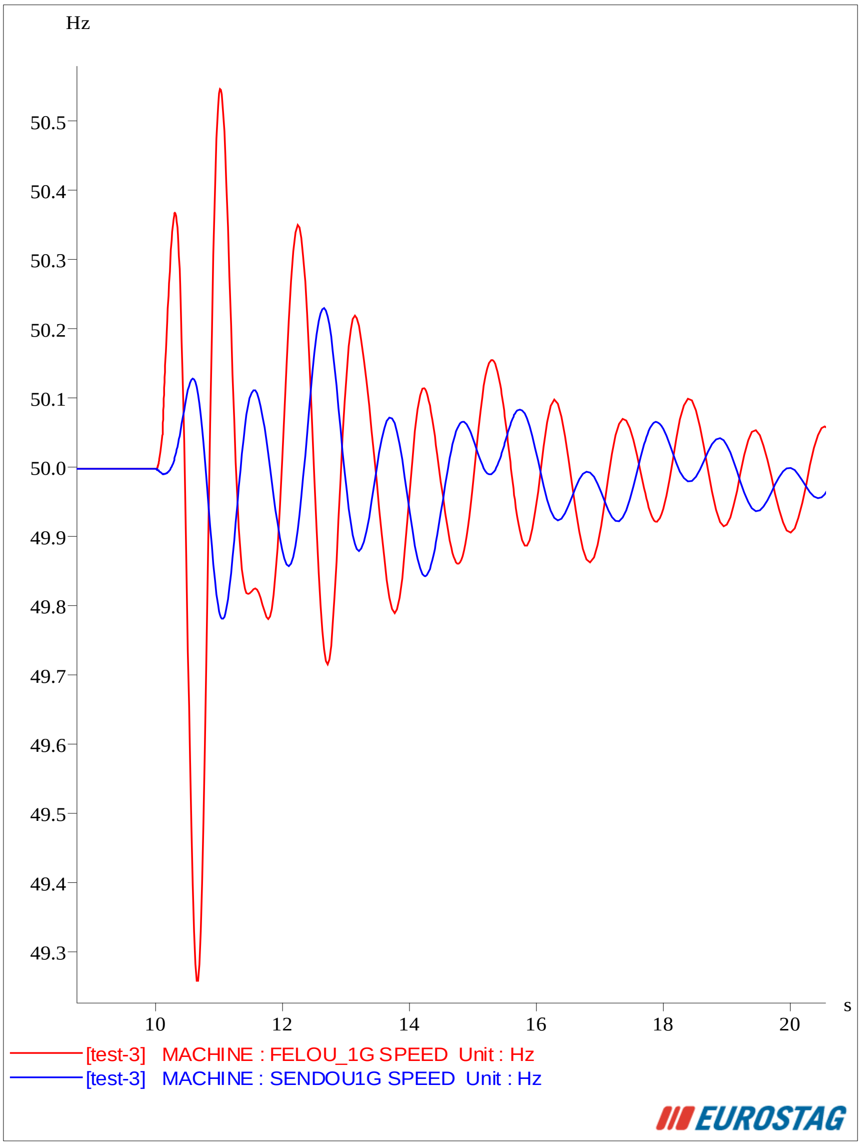


Figure 48 – Oscillations - Mode 2 – Base case (peak load)

Here, the period is around 1 second. A phase opposition between Felou (Mali) and Sendou (Senegal) units is shown, and its damping is not acceptable.

Another three-phase fault was performed to visualize mode 3. The node Birnin Kebbi 330 kV (Nigeria) was chosen for simulation of a 100 ms short-circuit. Figure illustrates the system response. The period of this mode is about 2.8 seconds. The figure shows phase opposition between Sendou (Senegal) and Delta (Nigeria) units and its damping is not sufficient.

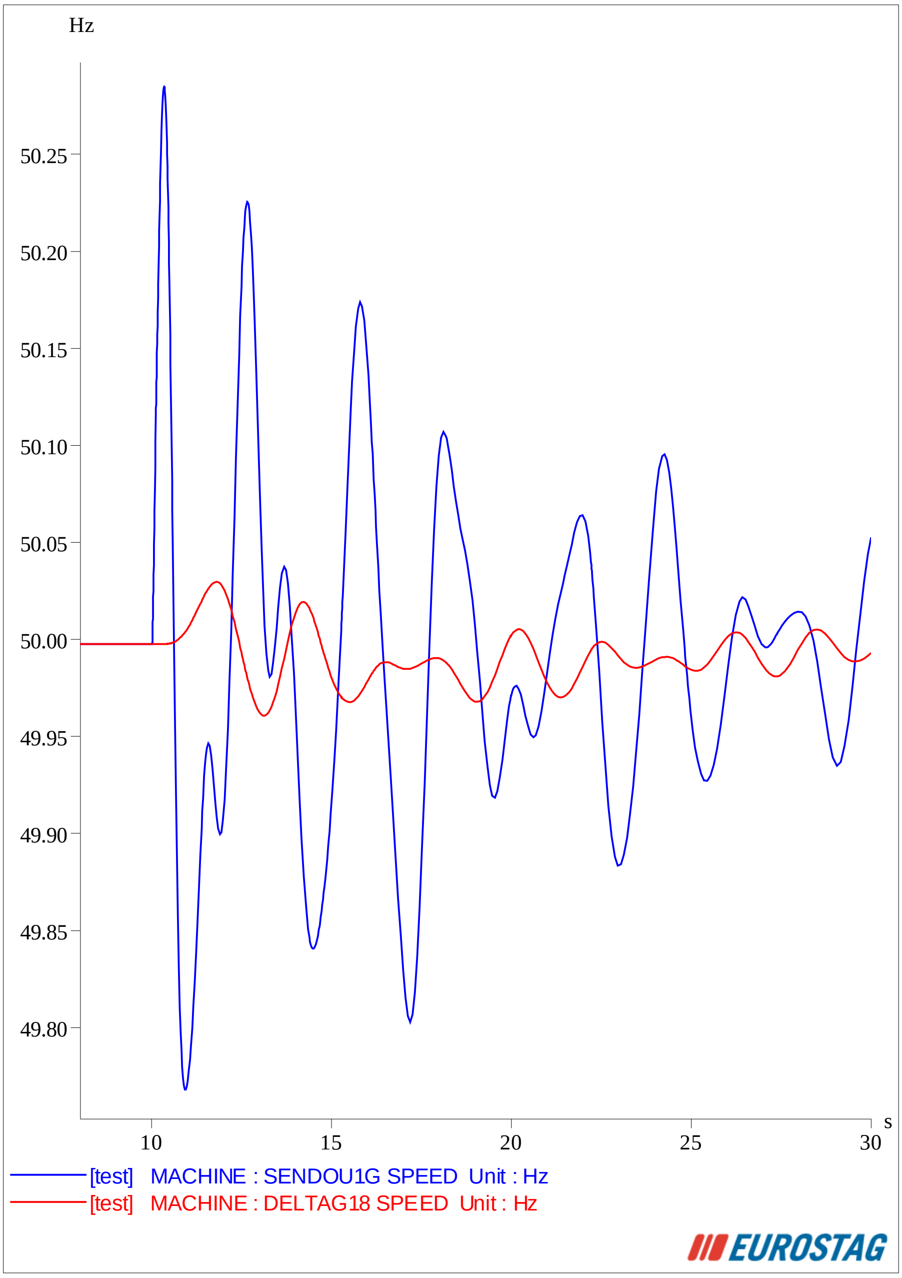


Figure 49 – Oscillations - Mode 3 – Base case (peak load)

The system damping could be improved with the installation of Power System Stabilizer (PSS). The controllability tool of HERCULES permitted to identify the machines whereto install these PSS in order to increase the damping coefficient of the system. The machines with the best impact on the oscillations are mainly located in Nigeria. The two best sites are Geregu and Calabar, in Nigeria.

In a general way, PSS should be installed on every large new unit in the system. Also the biggest units of each country should be equipped with PSS.

To check that improvement is feasible, PSS were installed on the machines in Table . The two best sites in Nigeria were equipped. Other big machines in Nigeria were selected, and machines in Guinea and Senegal because they participate to the modes examined above.

Units	Country
Geregu	Nigeria
Kaleta	Guinea
Sendou	Senegal
Ross Betio	Senegal
Jebba	Nigeria
Alaoji	Nigeria
Calaba	Nigeria
Eayen	Nigeria

Table 105 – Machines with PSS to improve damping

After installation of PSS on these units, the damping was calculated again. Table 10614 retains the two last modes whose damping is still below 5%. Their damping is now above 3% which is the minimum value recommended by the CIGRE task force for system stability. The mode whose damping was about 0.5% is now damped at 4.5%.

Mode	Real	Imaginary	ζ (%)	Freq (Hz)
1	-0.186	6.167	3.01%	0.982
2	-0.143	3.192	4.47%	0.508

Table 10614 - Characteristics of the least damped modes after PSS installation – Base case (peak load)

To visualize the improvement, a three-phase short circuit at Eyaen 330 kV was simulated during 50 ms and Figure compares the units' oscillations between the system with and without PSS. It clearly shows the action of PSS. This damping could be even better with the appropriate tuning of the PSS parameters.

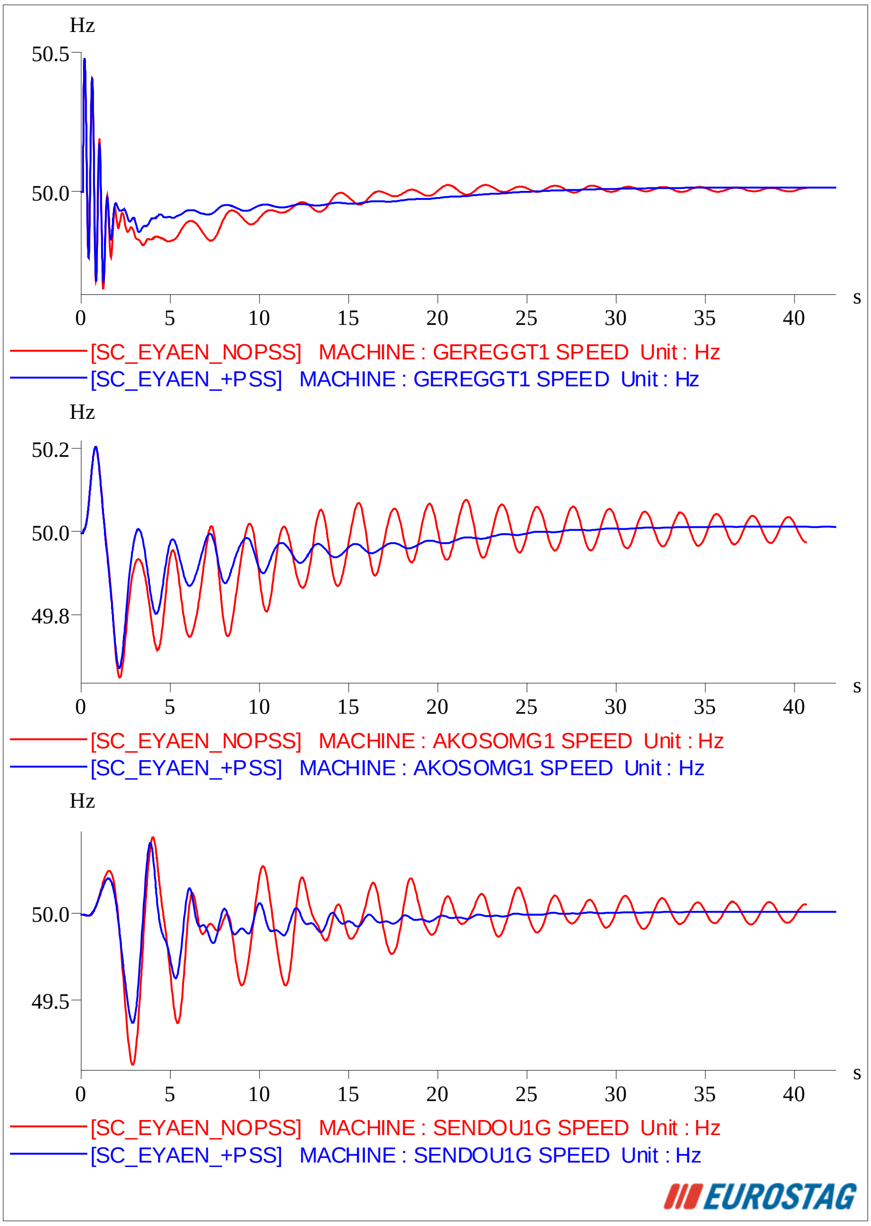


Figure 50 – Comparison of system responses with and without PSS – Base case (peak load)

3.4.5.2. 2015 PEAK LOAD: SCENARIO 2

With HERCULES, the eigenvalues of Scenario 2, peak load condition, were calculated. Table 10715 shows the modes with damping coefficient lower than 5%.

Mode	Real	Imaginary	ζ (%)	Freq (Hz)
1	-0.014	4.979	0.28%	0.793
2	-0.056	4.706	1.19%	0.749
3	-0.041	3.362	1.23%	0.535
4	-0.082	2.416	3.38%	0.385
5	-0.221	4.516	4.90%	0.719

Table 10715 - Characteristics of the least damped modes – Scenario 2 (peak load)

As also happened in the Base case, this scenario has the least damped modes related to inter-area oscillations. This analysis will present the first three ones:

- Mode 1 is an inter-area oscillation between Mali and Senegal.
- Mode 2 is an inter-area oscillation between Burkina Faso and Ivory Coast.
- Mode 3 is an inter-area oscillation between Ghana/Ivory Coast/Togo/Benin and Guinea/Sierra Leone.

The tables and charts below illustrate the modes.

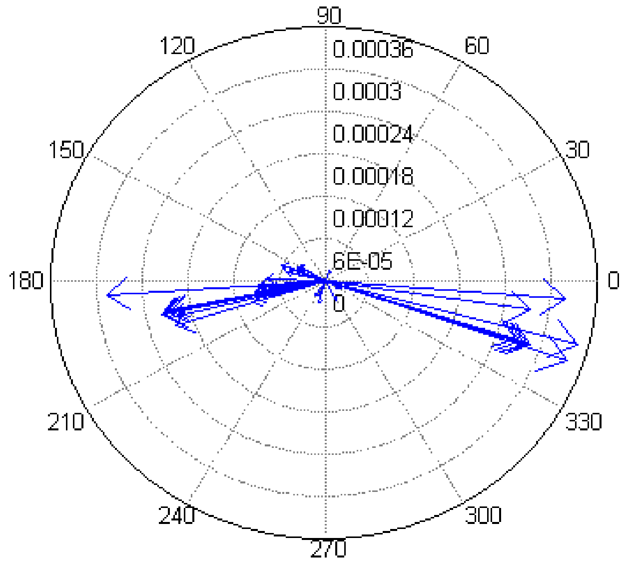


Figure 51 - Mode shape graph of mode 1 – Scenario 2 (peak load)

Machines in Phase Opposition							
Country	**Machine**	**Angle**	**Contribution**	**Country**	**Machine**	**Angle**	**Contribution**
SE	SENDOU1G	-176.11	0.29	MA	MANAN11A	-15.13	0.34
SE	CAPDB13A	-167.51	0.22	MA	MANAN13A	-15.13	0.34
SE	CAPDB19A	-167.54	0.22	MA	MANAN12A	-15.13	0.34
SE	GTI_113A	-167.09	0.22	MA	MANAN14A	-15.13	0.34
SE	CAPDB1G3	-167.32	0.22	MA	MANAN15A	-15.13	0.34
SE	TOBIN_1G	-168.27	0.21	MA	SELING1	-19.72	0.33
SE	BELAIR1G	-168.42	0.21	MA	SELING2	-19.72	0.33
SE	BELAIR2G	-168.42	0.21	MA	SELING3	-19.72	0.33
SE	GTI_111A	-165.40	0.21	MA	SELING4	-19.72	0.33
SE	KOUN_1G1	-168.20	0.21	MA	FELOU_1G	-4.59	0.32
SE	KOUN_1G3	-168.20	0.21	MA	FELOU_3G	-4.59	0.32
SE	KOUN_1G4	-168.20	0.21	MA	FELOU_2G	-4.59	0.32
SE	KOUN_1G2	-168.20	0.21	MA	DARSAL8G	-18.36	0.28
SE	KOUN_1G5	-168.20	0.21	MA	DARSAL1G	-18.59	0.28
SE	KOUN_1G6	-168.20	0.21	MA	DARASLA6	-18.59	0.28
SE	KOUN_1G7	-168.20	0.21	MA	DARASLA5	-18.56	0.28
SE	WIND__1G	-162.41	0.21	MA	DARASLA7	-18.56	0.28
SE	CAPDB11A	-168.90	0.20	MA	VICABO1G	-18.80	0.28
SE	KOUDI_1G	-162.58	0.10	MA	ALBATR1G	-8.41	0.27
SE	KOUDI_2G	-162.58	0.10	MA	SOPAM_01	-18.60	0.27

Table 10816 – Machines in phase opposition – Mode 1 – Scenario 2 (peak load)

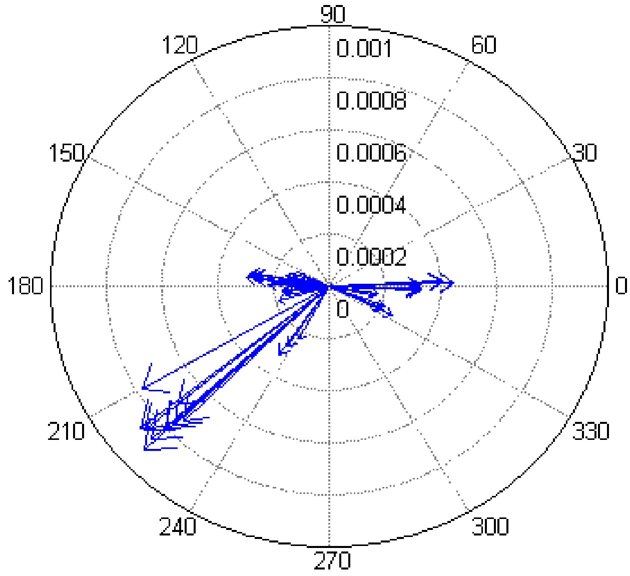


Figure 52 - Mode shape graph of mode 2 – Scenario 2 (peak load)

Machines in Phase Opposition							
Country	**Machine**	**Angle**	**Contribution**	**Country**	**Machine**	**Angle**	**Contribution**
BU	4KOS3_11	-136.47	0.91	CI	2032TAAB	1.83	0.45
BU	4KOMPI26	-137.28	0.87	CI	2033TAAB	1.79	0.44
BU	4KOMPI16	-137.28	0.87	CI	2034TAAB	1.79	0.44
BU	4KOS5_11	-141.26	0.87	CI	2043KOSS	2.69	0.40
BU	4KOS4_11	-141.26	0.87	CI	2042KOSS	2.69	0.40
BU	4KOS6_11	-140.20	0.86	CI	2044KOSS	2.61	0.40
BU	4BAGRE26	-137.10	0.80	CI	2093BUYO	-0.65	0.33
BU	4BAGRE16	-137.07	0.80	CI	2094BUYO	-0.66	0.33
BU	4OUA23_5	-149.89	0.78	CI	2NEWCC-1	-2.03	0.33
BU	KOMSILG5	-136.18	0.77	CI	2027VRID	-2.35	0.33
BU	KOMSILG1	-136.18	0.77	CI	2028VRID	-2.34	0.32
BU	KOMSILG3	-136.17	0.77	CI	20NTAG82	-2.48	0.32
BU	KOMSILG4	-136.17	0.77	CI	20NGTAG8	-2.48	0.32
BU	KOMSILG2	-135.50	0.74	CI	2029VRID	-2.55	0.32
BU	4OUA24_5	-140.70	0.70	CI	20NTAG83	-2.52	0.32
BU	4OUA25_5	-140.70	0.70	CI	FAYE_H_G	1.93	0.32
BU	4BOB25_5	-124.79	0.32	CI	2023VGT2	-3.09	0.31
BU	4BOB22_5	-122.47	0.27	CI	2023VGT1	-3.09	0.31
BU	4BOB21_5	-122.52	0.27	CI	2501AZI	-2.80	0.31

Table 10917 – Machines in phase opposition – Mode 2 – Scenario 2 (peak load)

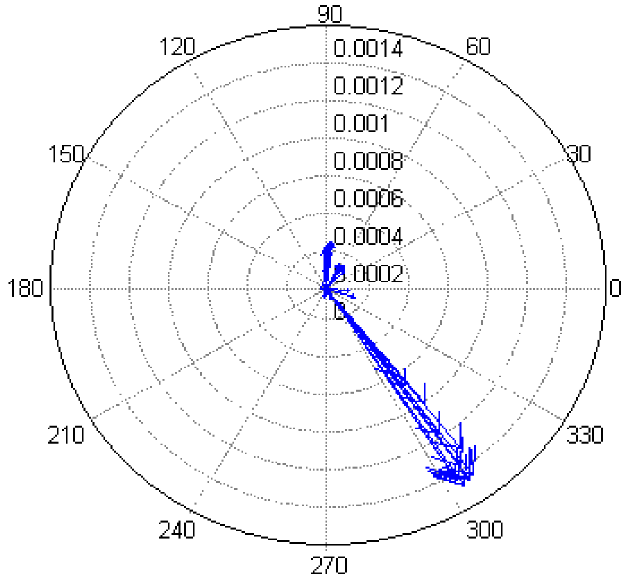


Figure 532 - Mode shape graph of mode 3 – Scenario 2 (peak load)

Machines in Phase Opposition							
Country	**Machine**	**Angle**	**Contribution**	**Country**	**Machine**	**Angle**	**Contribution**
GH	AKOSOMG2	-268.52	0.22	GU	TOMBO5G3	-56.26	1.26
GH	AKOSOMG3	-268.52	0.22	GU	TOMBO5G1	-56.26	1.26
GH	AKOSOMG4	-268.52	0.22	GU	TOMBO5G2	-56.26	1.26
GH	AKOSOMG5	-268.52	0.22	GU	GRCHUTG3	-54.46	1.25
GH	AKOSOMG1	-268.52	0.22	GU	GRCHUTG4	-54.45	1.25
GH	AKOSOMG6	-268.52	0.22	GU	DONKEAG1	-53.08	1.24
GH	KPONGHG2	-267.24	0.20	GU	DONKEAG2	-53.08	1.24
GH	KPONGHG4	-267.24	0.20	GU	GRCHUTG2	-54.41	1.24
GH	KPONGHG1	-267.24	0.20	GU	GRCHUTG1	-54.41	1.24
GH	KPONGHG3	-267.24	0.20	GU	TOMBO3G4	-56.77	1.22
TB	3NEWIPP	-268.83	0.13	GU	TOMBO3G2	-56.77	1.22
CI	2023VGT1	-263.96	0.11	GU	TOMBO3G3	-56.76	1.22
CI	2023VGT2	-263.96	0.11	GU	TOMBO3G1	-56.76	1.22
CI	2027VRID	-268.52	0.11	GU	MANEAHG1	-56.94	1.20
CI	2028VRID	-268.04	0.11	GU	GARAFIG1	-54.01	1.16
CI	20NTAG82	-268.68	0.11	GU	GARAFIG2	-54.01	1.16
CI	20NGTAG8	-268.68	0.11	GU	GARAFIG3	-54.01	1.16
CI	2029VRID	-268.19	0.11	SL	BUMBU1G2	-51.26	1.09
CI	20NTAG83	-268.66	0.11	SL	BUMBU1G1	-51.26	1.09
TB	3061NANG	-269.08	0.09	SL	BLACKHG3	-53.71	0.96
TB	3062NANG	-269.08	0.09	SL	BLACKHG1	-53.71	0.96
CI	2501AZI	-265.91	0.07	SL	BLACKHG2	-53.71	0.96
TB	MA_GLE3G	-269.57	0.05	SL	GOMA_HG1	-50.34	0.79

Table 11018 – Machines in phase opposition – Mode 3 – Scenario 2 (peak load)

Time domain simulations allowed observing these modes. The phase opposition found in mode 1 is illustrated in Figure 543. The disturbance chosen was a three-phase short circuit at Manantali 225 kV bus bar (Mali) during 100 ms.

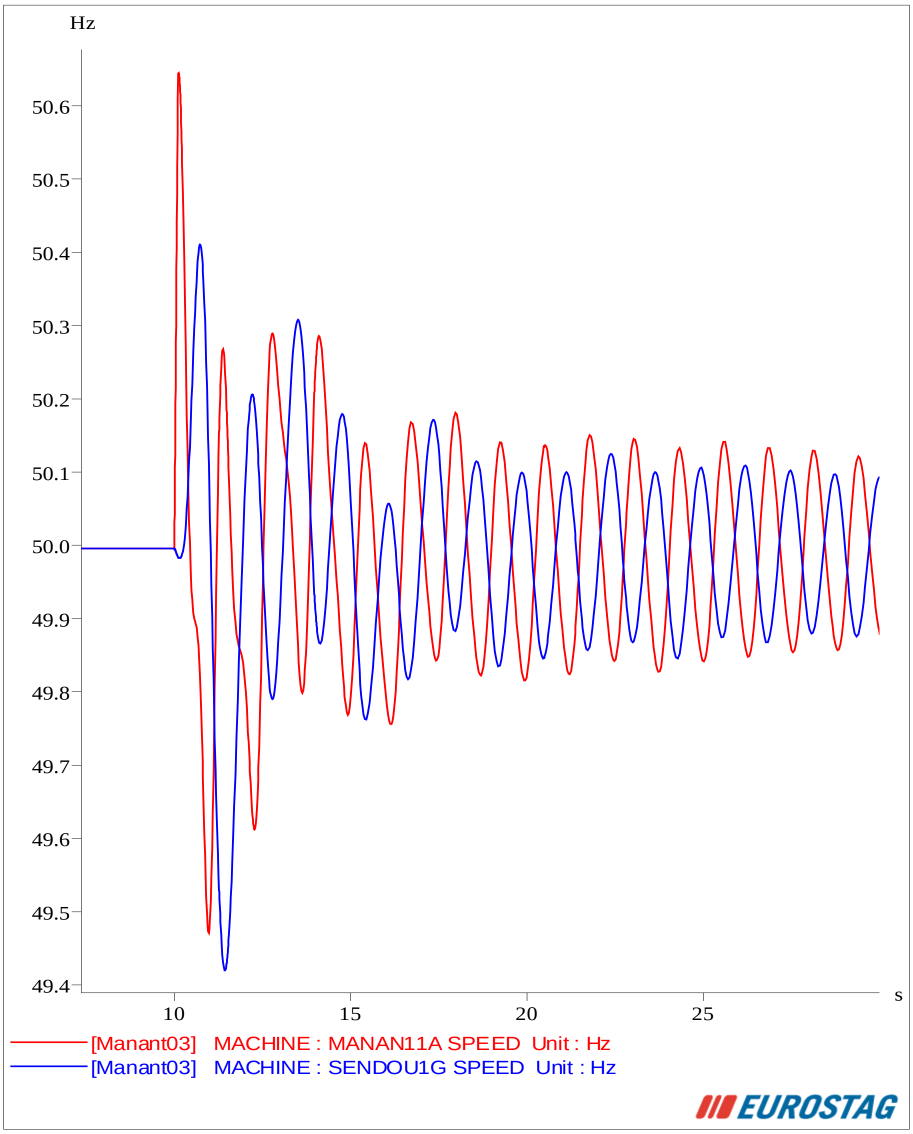


Figure 543 – Oscillations - Mode 1 – Scenario 2

This figure shows phase opposition of Sendou (Senegal) and Manantali (Mali) units. It was confirmed by mode shape graph. The period of oscillations is around 1.2 seconds. Its damping is unacceptable.

A three-phase short circuit was executed at Zagtouli 225 kV bus bar (Burkina Faso) during 100 ms in order to observe mode 2. Figure shows the oscillations.

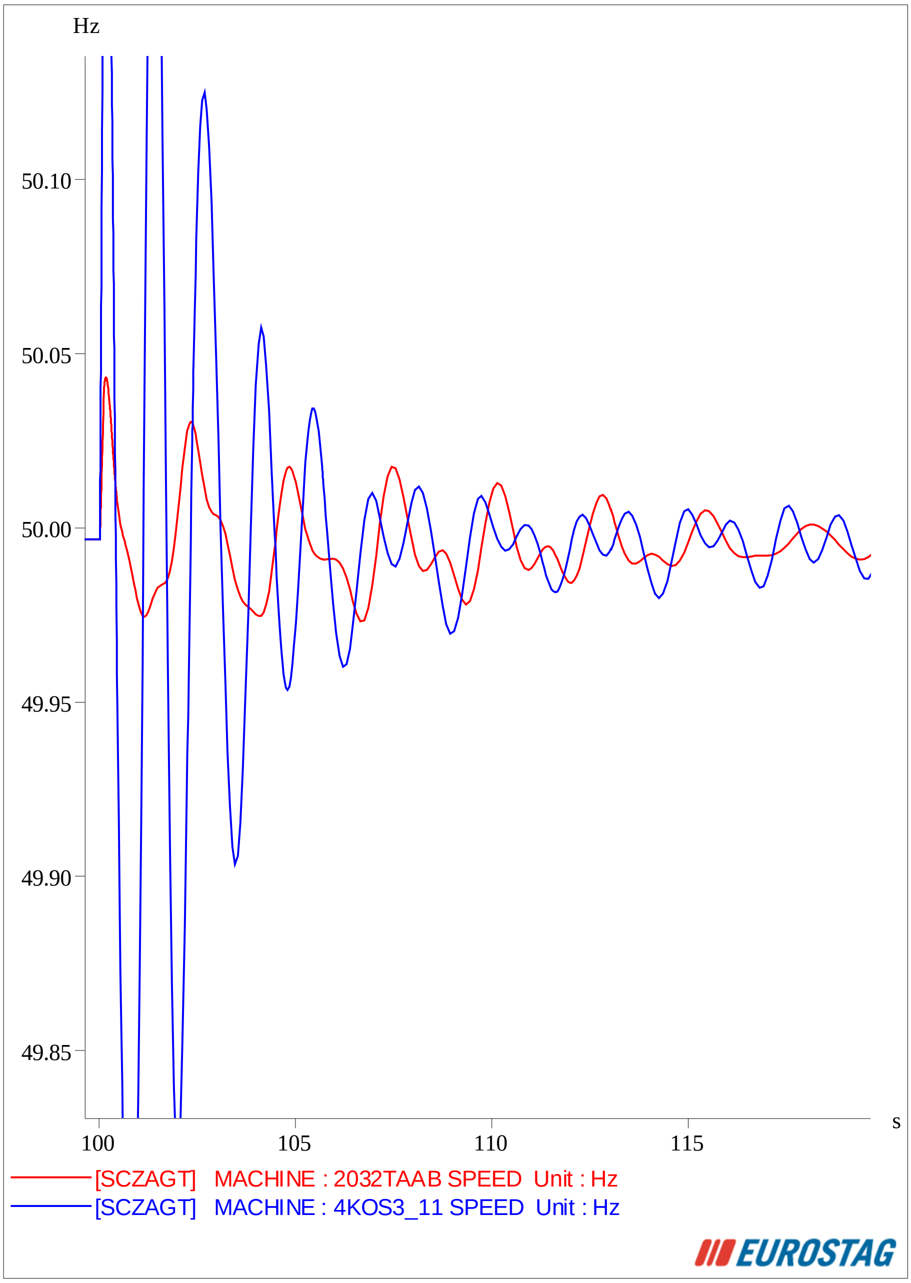


Figure 55 – Oscillations - Mode 2 – Scenario 2 (peak load)

Here, the period is around 1.4 second. A phase opposition between Kossodo (Burkina Faso) and Taabo (Ivory Coast) units can be observed and its damping is not sufficient. This mode is visible though the oscillations present two or more modes overlapping.

To identify mode 3 in the dynamic simulations, a three-phase short circuit was carried out at Prestea 225 kV bus bar (Ghana) during 100 ms. Figure shows the oscillations.

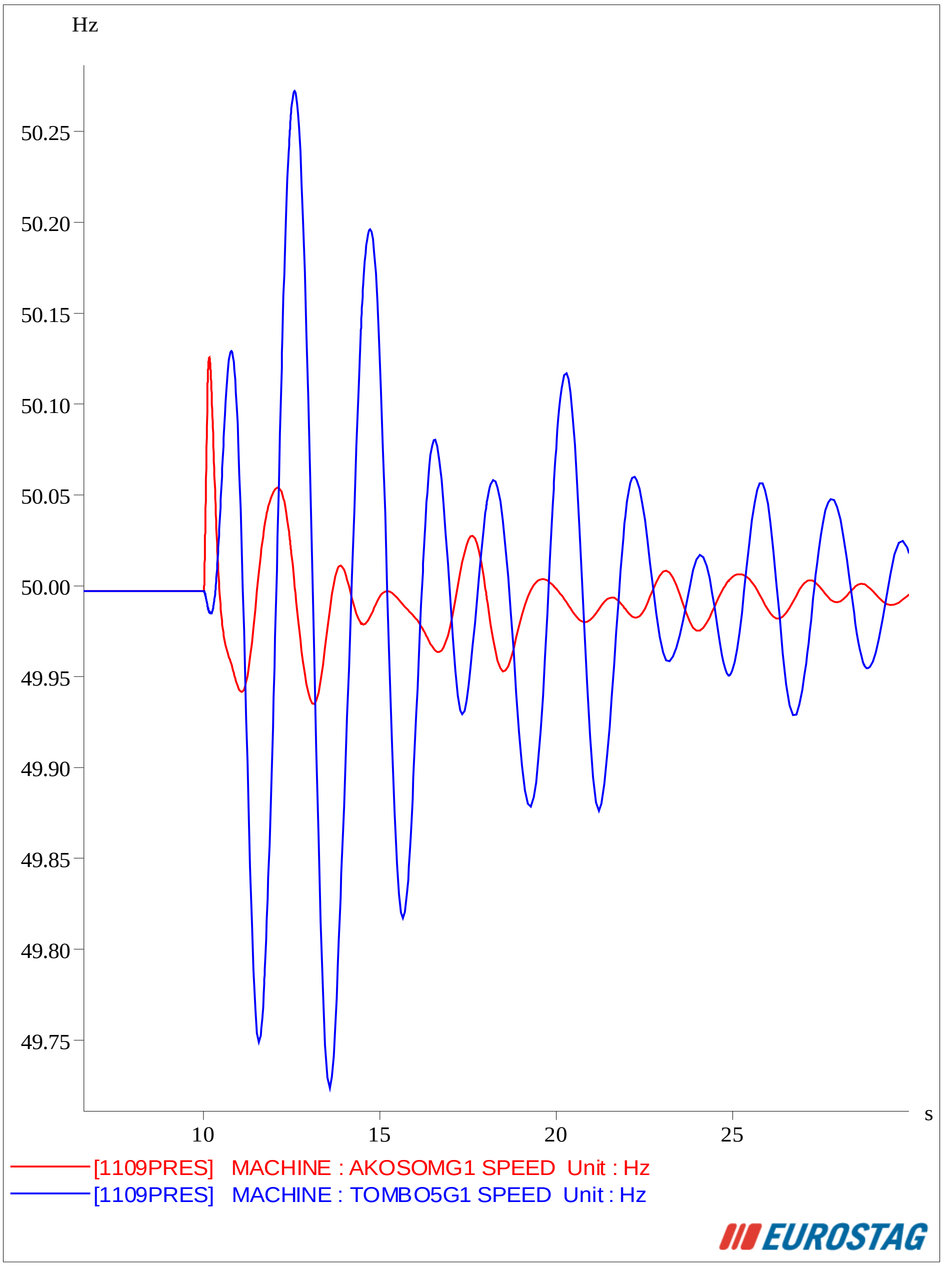


Figure 56 – Oscillations - Mode 3 – Scenario 2 (peak load)

The period of this mode is about 1.9 seconds. The figure shows phase opposition between Akosombo (Ghana) and Tombo (Guinea) units and its damping is not sufficient. Again, there are two or more modes overlapping but the oscillation is visible.

3.4.5.3. 2015 OFF PEAK LOAD: BASE CASE

In this scenario, the modes lower than 6.0% are showed in the following table.

Mode	Real	Imaginary	ζ (%)	Freq (Hz)
1	-0.042	3.528	1.19%	0.562
2	-0.039	2.640	1.49%	0.420
3	-0.487	10.564	4.61%	1.682
4	-0.473	8.926	5.29%	1.421
5	-0.329	5.705	5.75%	0.908
6	-0.652	11.273	5.77%	1.795

Table 111 - Characteristics of the least damped modes – Base case (off-peak load)

The first three modes are under 5% and will be analyzed here:

- Mode 1 is an inter-area oscillation between Ghana/Ivory Coast and Senegal/Guinea.
- Mode 2 is an inter-area oscillation between Senegal/Guinea and Nigeria.
- Mode 3 is an electromechanical oscillation between machine ZINDCC1G in Niger and SHIRGH1/ SHIRGH2 in Nigeria.

The tables and charts below illustrate the modes.

The mode shape graph in Figure 574demonstrates the phase opposition between the two groups of machines for mode 1. It is an oscillation between Ghana/Ivory Coast and Senegal/Guinea. Table 11219 helps to understand better the graph. The module of the arrow gives the contribution of the machine to the oscillation and its angle gives the phase of the contribution in the oscillation.

The same graphs and tables are provided for mode 2.

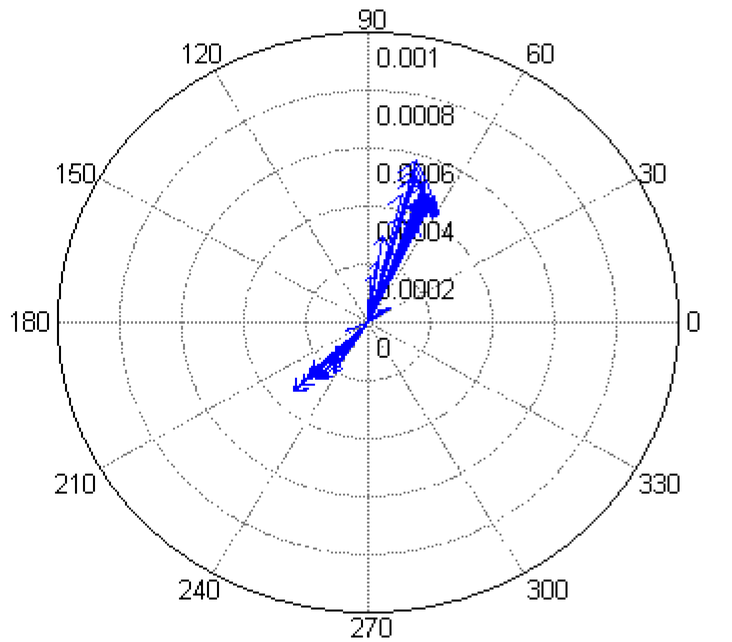


Figure 574 - Mode shape graph of mode 1 – Base case (off-peak load)

Machines in Phase Opposition							
Country	**Machine**	**Angle**	**Contribution**	**Country**	**Machine**	**Angle**	**Contribution**
GH	DOMIT1G1	-135.38	0.34	GU	KALETAG1	74.53	0.58
GH	DOMIT1G2	-135.38	0.34	GU	KALETAG2	74.53	0.58
GH	ABOAT1G1	-135.33	0.33	GU	KALETAG3	74.53	0.58
GH	ABOAT1G2	-135.33	0.33	GU	DONKEAG1	73.99	0.55
GH	ABOAT2G1	-135.33	0.33	GU	DONKEAG2	73.99	0.55
GH	ABOAT1ST	-134.16	0.30	GU	GRCHUTG1	72.64	0.53
GH	ABOA3CC1	-135.44	0.27	GU	GARAFIG1	73.20	0.52
CI	2029VRID	-135.51	0.26	GU	TOMBO5G3	69.14	0.52
CI	20NGTAG8	-133.90	0.25	GU	TOMBO5G2	69.14	0.52
CI	20NTAG82	-133.90	0.25	GU	TOMBO3G4	69.61	0.50
CI	2027VRID	-134.10	0.25	GU	MANEAHG1	69.53	0.50
GH	AKOSOMG1	-131.22	0.25	GB	GBISSEQG	65.77	0.49
GH	AKOSOMG2	-131.22	0.25	GA	GAMB_EQG	63.71	0.48
CI	2NEWCC-1	-134.16	0.25	SE	CAPDB19A	66.41	0.48
CI	2NEWCC-2	-134.16	0.25	SE	BELAIR1G	64.48	0.47
CI	20NTAG83	-133.87	0.25	SE	BELAIR2G	64.48	0.47
CI	2032TAAB	-128.73	0.25	SE	GTI_113A	66.25	0.47
GH	SASO2CC1	-136.56	0.25	SE	B_AIRG61	64.47	0.47
GH	BUI___G1	-129.87	0.24	SE	B_AIRG62	64.47	0.47
CI	2033TAAB	-130.09	0.24	SE	KOUN_1G1	65.93	0.47
GH	TEMAT1G2	-137.37	0.24	SE	KOUN_1G2	65.93	0.47
GH	KPONGHG1	-126.60	0.24	SE	KOUN_1G3	65.93	0.47
GH	KPONGHG2	-126.60	0.24	SE	KOUN_1G4	65.93	0.47
GH	KPONGHG3	-126.60	0.24	SE	KOUN_1G5	65.93	0.47
GH	KPONGHG4	-126.60	0.24	SE	CAPDB144	64.63	0.47
GH	SUNASOG1	-133.51	0.24	SE	CAPDB145	64.63	0.47
CI	2043KOSS	-122.87	0.20	SE	CAPDB11A	65.73	0.46
CI	2044KOSS	-125.48	0.19	SE	KAHONG71	66.28	0.46
CI	FAYE_H_G	-132.26	0.17	SE	KAHONG72	66.28	0.46

Table 11219 - Machines in phase opposition - Mode 1 - Base case off-peak load

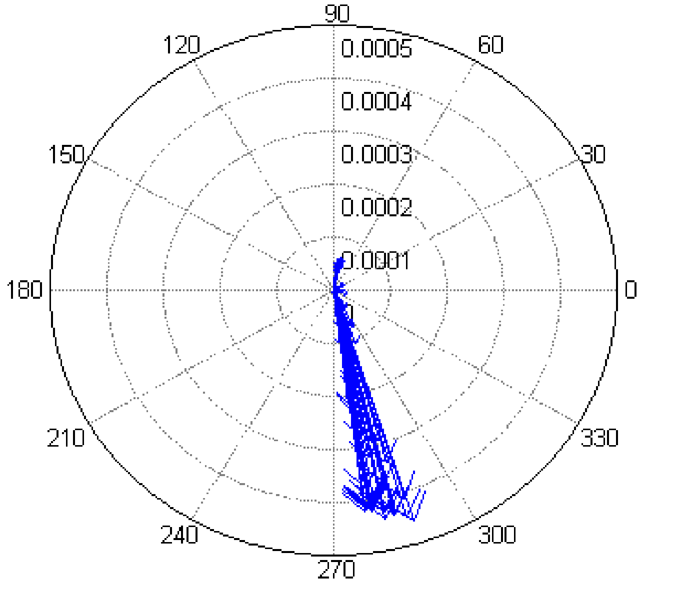


Figure 58 - Mode shape graph of mode 2 - Base case (off-peak load)

Machines in Phase Opposition							
Country	Machine	Angle	Contribution	Country	Machine	Angle	Contribution
GU	KALETAG1	-72.04	0.46	NI	DELTAG18	77.09	0.06
GU	KALETAG2	-72.04	0.46	NI	DELTAG19	77.09	0.06
GU	KALETAG3	-72.04	0.46	NI	DELTAG20	77.09	0.06
GU	DONKEAG1	-73.14	0.45	NI	AFAMGT19	77.71	0.06
GU	DONKEAG2	-73.14	0.45	NI	AFAMGT20	77.71	0.06
GU	TOMBO5G3	-78.13	0.44	NI	AFAMGT15	77.64	0.06
GU	TOMBO5G2	-78.13	0.44	NI	AFAMGT13	78.01	0.06
GU	GRCHUTG1	-75.81	0.44	NI	AFAMGT14	78.01	0.06
GU	GARAFIG1	-75.44	0.43	NI	DELTAG03	78.11	0.06
GU	TOMBO3G4	-78.01	0.43	NI	DELTAG04	78.11	0.06
GU	MANEAHG1	-78.12	0.43	NI	DELTAG05	78.11	0.06
GB	GBISSEQG	-80.72	0.42	NI	EGBINST1	75.89	0.06
GA	GAMB_EQG	-82.42	0.42	NI	EGBINST2	75.89	0.06
SE	CAPDB19A	-80.85	0.42	NI	EGBINST3	75.89	0.06
SE	BELAIR1G	-82.34	0.42	NI	EGBINST4	75.89	0.06
SE	BELAIR2G	-82.34	0.42	NI	EGBINST5	75.89	0.06
SE	KOUN_1G1	-81.20	0.42	NI	EGBINST6	75.89	0.06
SE	KOUN_1G2	-81.20	0.42	NI	KWALCC3	81.36	0.06
SE	KOUN_1G3	-81.20	0.42	NI	IBOMGT01	82.33	0.06
SE	KOUN_1G4	-81.20	0.42	NI	IBOMGT02	82.33	0.06
SE	KOUN_1G5	-81.20	0.42	NI	IBOMGT03	82.76	0.06
SE	B_AIRG61	-82.36	0.42	NI	CALABGT3	82.68	0.06
SE	B_AIRG62	-82.36	0.42	NI	CALABGT4	82.68	0.06
SE	GTI_113A	-81.17	0.41	NI	CALABGT5	82.68	0.06
SE	CAPDB144	-82.18	0.41	NI	ALAOJGT4	82.68	0.06
SE	CAPDB145	-82.18	0.41	NI	ALAOJGT3	82.72	0.06
SE	KAHONG71	-80.92	0.41	NI	TOTALFG1	82.85	0.06
SE	KAHONG72	-80.92	0.41	NI	TOTALFG2	82.85	0.06
SE	KAHONG73	-80.92	0.41	NI	ALAOCCG2	83.99	0.06

Table 113 - Machines in phase opposition - Mode 2 - Base case (off-peak load)

The time domain simulations can also show these modes. Figures here below show the oscillations present in each mode.

To illustrate mode 1, a three-phase short-circuit was simulated at Akosombo 161 kV bus bar during 100 ms. The oscillation period of mode 1 is about 1.7 seconds, its damping is not sufficient and the figure shows a clear phase opposition of machines Kaleta (Guinea) and Domini (Ghana).

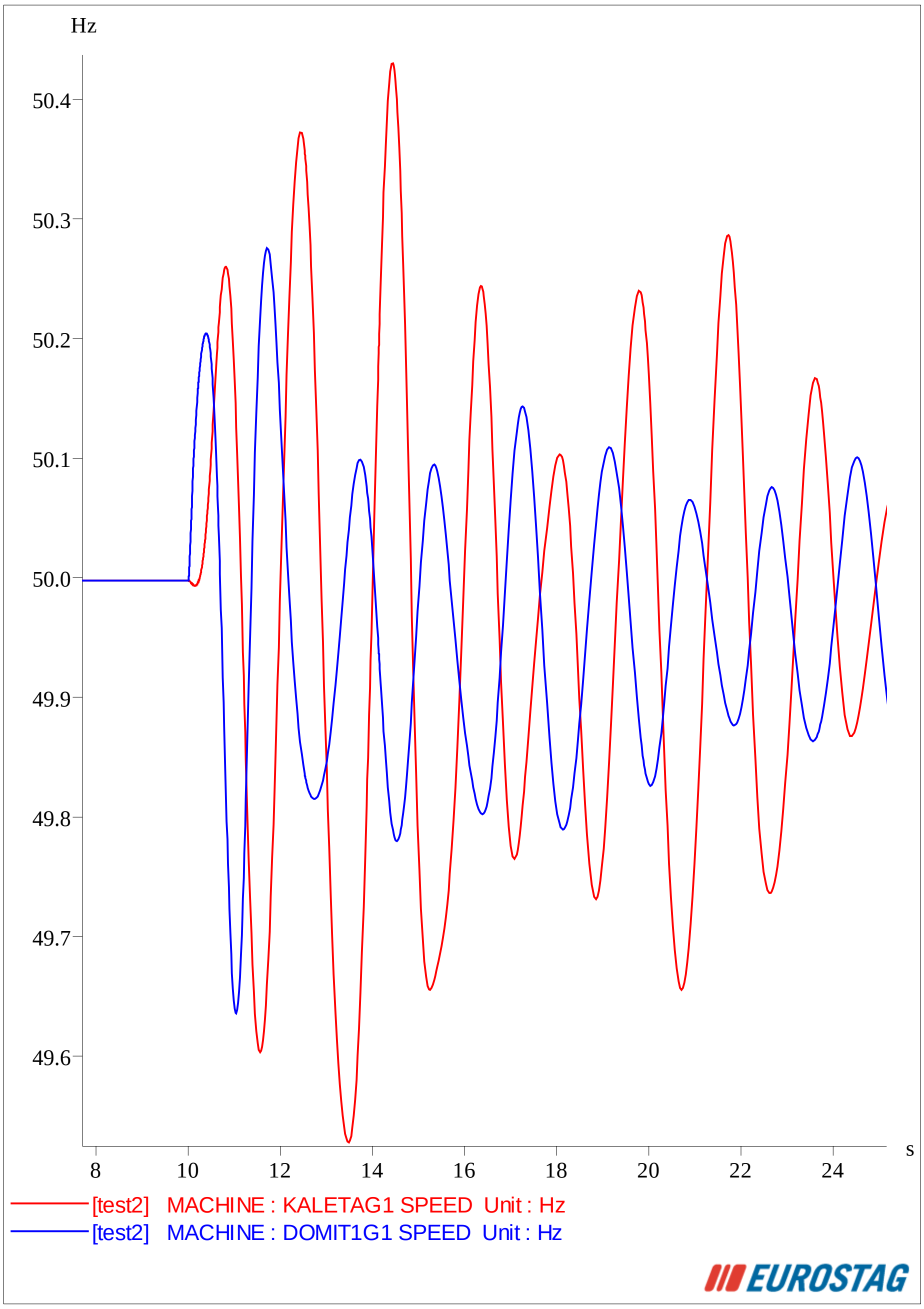


Figure59– Oscillations - Mode 1 – Base case (off-peak load)

To identify mode 2 in the dynamic simulations, a three-phase short circuit was performed at Tobene 225 kV bus bar (Senegal) during 100 ms. Table 907 shows the oscillations.

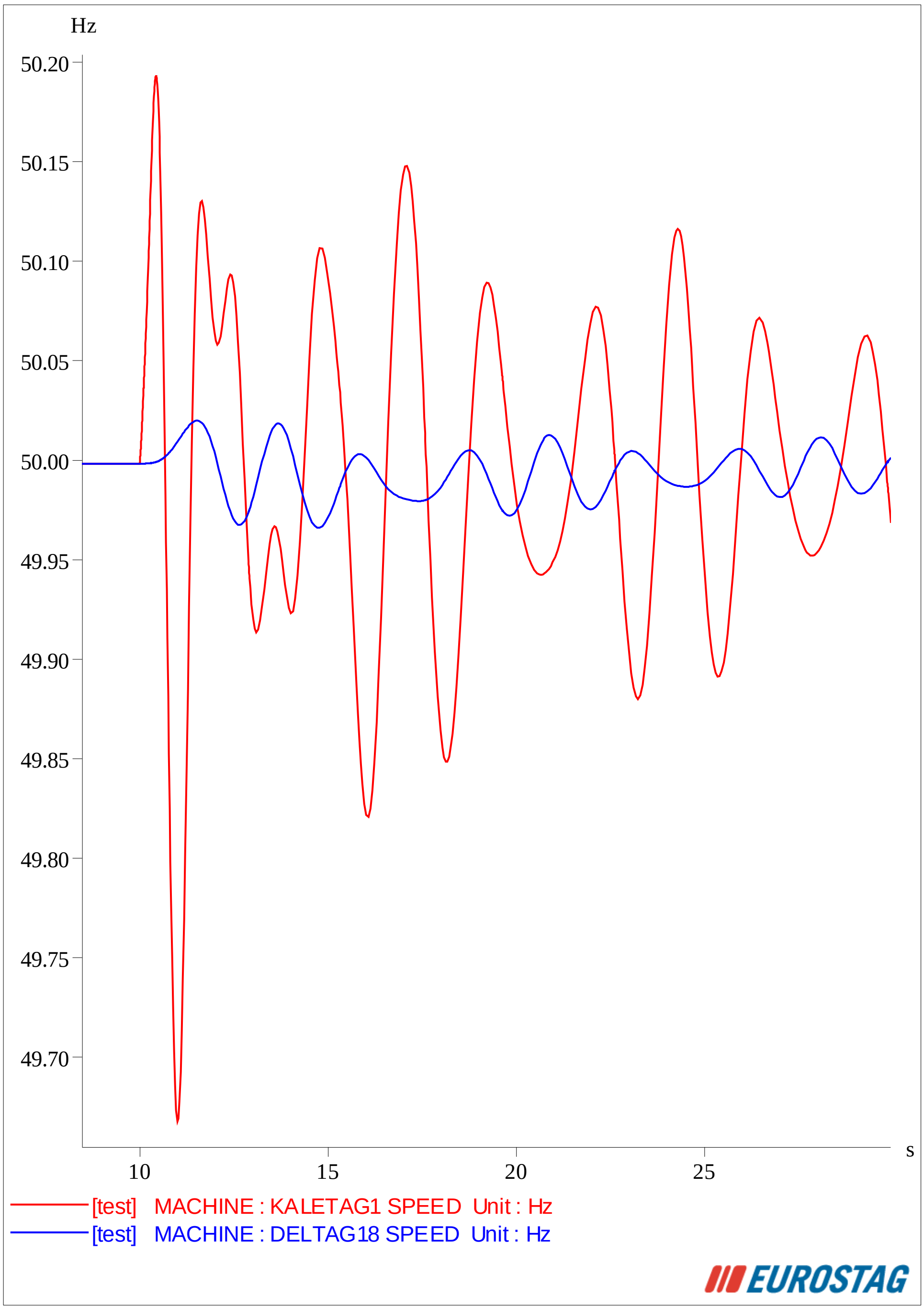


Figure 605– Oscillations - Mode 2 – Base case off-peak load

A phase opposition between Kaleta (Guinea) and Delta (Nigeria) is observed. The period is around 2.4 seconds and its damping is not acceptable.

Mode 3 corresponds to the electromechanical oscillations of machines located in Niger and Nigeria. The next figures illustrate the shape graph representing the participation factor of each unit to this mode (coming from right eigenvectors). The magnitude of each vector is proportional to the participation coefficient of the corresponding machine

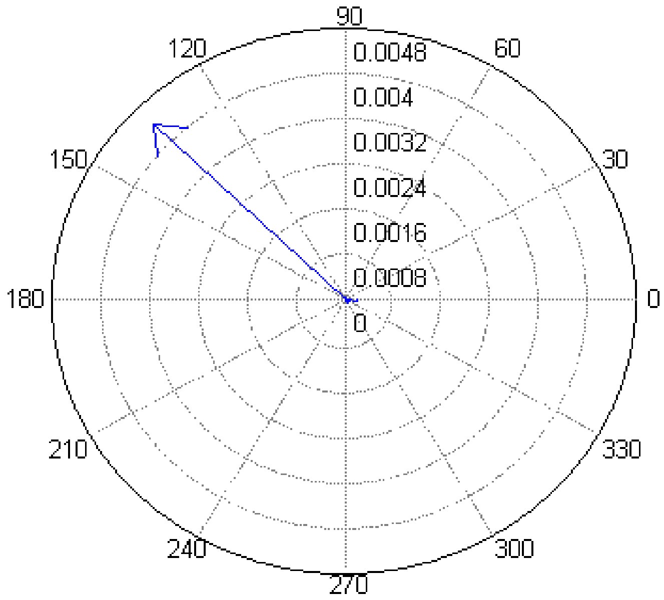


Figure 616 - shape graph of mode 3 – Base case (off-peak load)

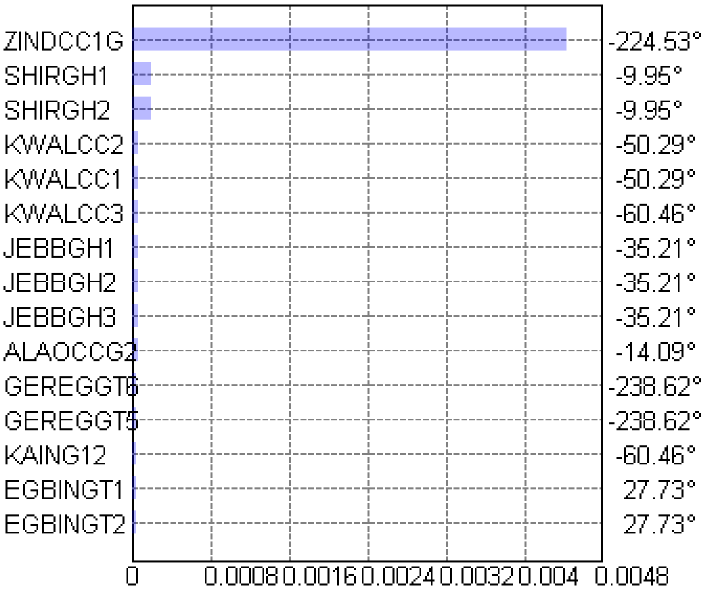


Figure 627 – Contribution to shape graph of mode 3 – Base case (off-peak load)

3.4.5.4. 2015 OFF PEAK LOAD: SCENARIO 2

The eigenvalues for this scenario were calculated using HERCULES. The modes with damping lower than 6.0% are showed in the table below.

Mode	Real	Imaginary	ζ (%)	Freq (Hz)
1	-0.105	4.968	2.11%	0.791
2	-0.474	8.916	5.30%	1.420
3	-0.414	7.571	5.46%	1.206
4	-0.645	11.634	5.54%	1.853
5	-0.399	7.133	5.58%	1.136

Table 114 - Characteristics of the least damped modes - Scenario 2 (off-peak load)

This analysis will present only the lowest mode. The others are over 5.0% and are acceptable. Mode 1 is an inter-area oscillation between Guinea/Senegal and Ivory Coast. The tables and charts below illustrate this mode.

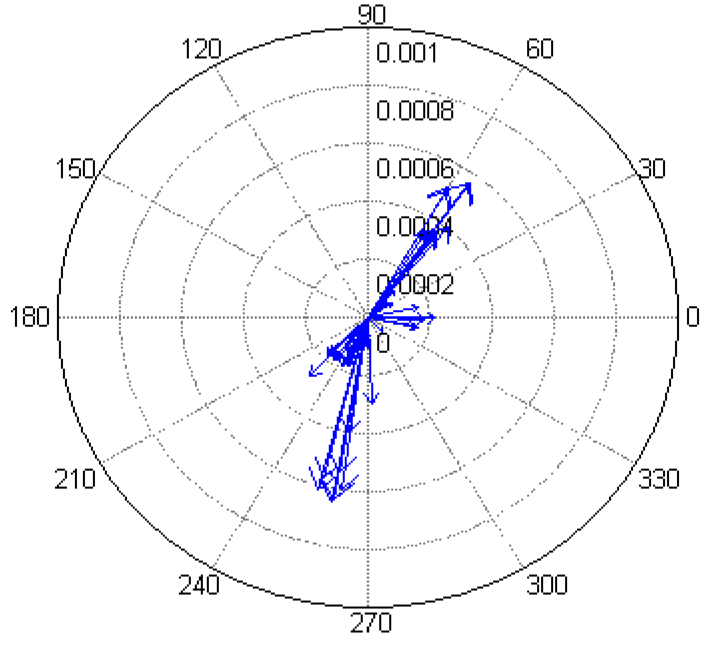


Figure 638 - Mode shape graph of mode 1 – Scenario 2 off-peak load

Machines in Phase Opposition							
Country	Machine	Angle	Contribution	Country	Machine	Angle	Contribution
GU	DONKEAG2	-100.47	0.64	CI	2033TAAB	54.70	0.57
GU	DONKEAG1	-100.47	0.64	CI	2032TAAB	54.80	0.56
GU	GRCHUTG1	-99.72	0.64	CI	2043KOSS	60.19	0.52
GU	TOMBO5G3	-105.07	0.61	CI	2044KOSS	60.08	0.50
GU	TOMBO5G2	-105.07	0.61	CI	2029VRID	50.19	0.40
GU	GARAFIG1	-98.16	0.60	CI	2093BUYO	55.26	0.37
GU	MANEAHG2	-104.38	0.57	CI	20NGTAG8	52.95	0.36
GU	MANEAHG1	-104.38	0.57	CI	20NTAG82	52.95	0.36
GU	TOMBO3G4	-104.25	0.57	CI	20NTAG83	52.89	0.36
SL	BUMBU1G1	-99.42	0.54	CI	2NEWCC-2	53.60	0.36
SL	BLACKHG1	-98.69	0.40	CI	2NEWCC-1	53.60	0.36
SL	BLACKHG2	-98.69	0.40	CI	2025VRID	52.73	0.36
SL	BLACKHG3	-98.69	0.40	CI	2024VRID	52.79	0.35
SL	GOMA_HG2	-87.92	0.29	CI	2027VRID	52.96	0.35
SL	GOMA_HG1	-87.92	0.29	CI	FAYE_H_G	57.68	0.35

Table 115 - Machines in phase opposition - Mode 1 - Scenario 2 (off-peak load)

This inter-area oscillation can be seen in the time domain simulations. A three-phase short-circuit was made at Taabo 225 kV during 100 ms.

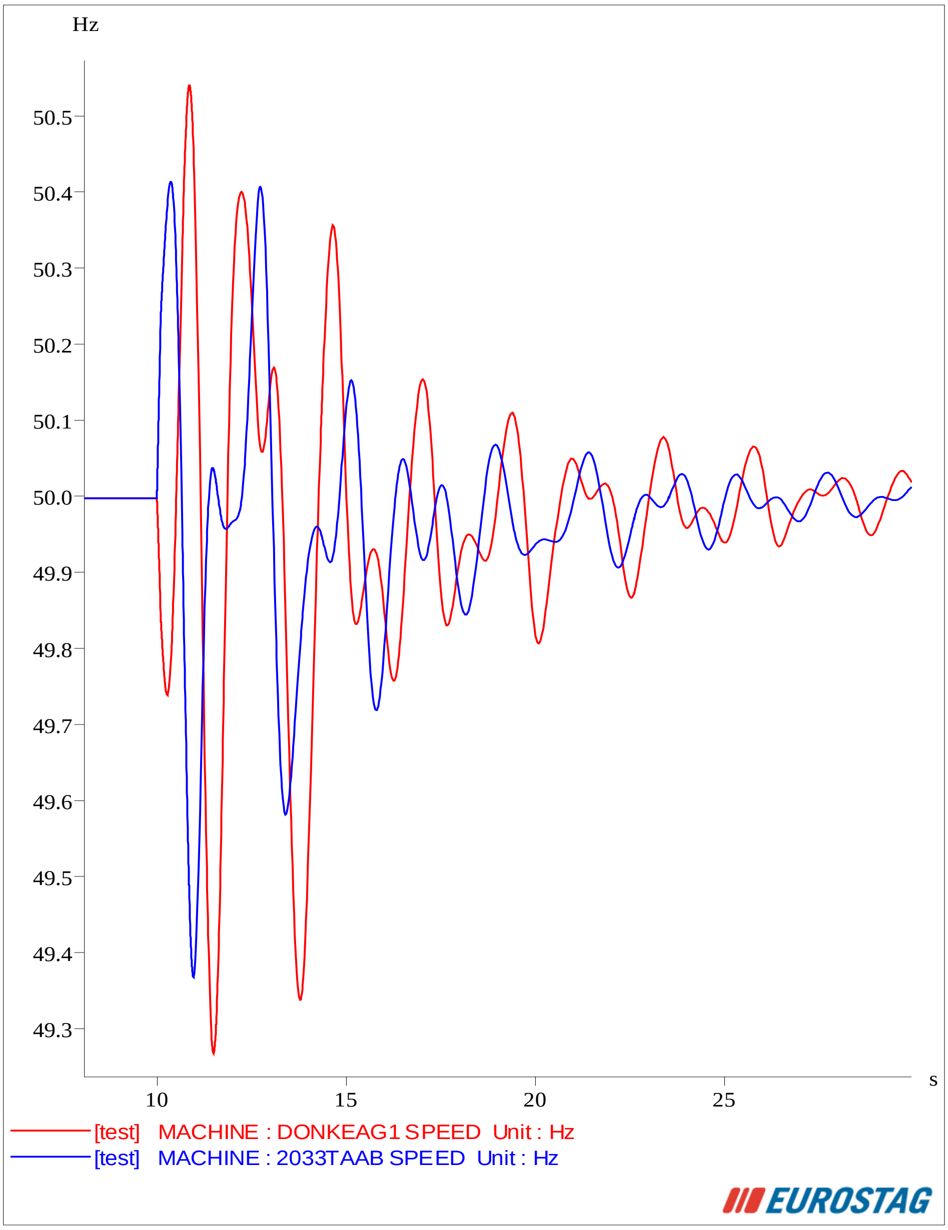


Figure 64– Oscillations - Mode 1 – Scenario 2 (off-peak load)

The phase opposition between Donkea (Guinea) and Taabo (Ivory Coast) is illustrated here and confirmed by mode shape graph. The damping is not acceptable and the period is around 1.2 seconds. This mode is visible though the oscillations present two or more modes overlapping

3.4.5.5. CONCLUSIONS OF THE SMALL SIGNAL STABILITY ANALYSIS

The small signal stability analysis detected several inter-area oscillations for both cases studied. The least damped modes were all related to inter-area oscillations:

- between Ghana/Ivory Coast and Senegal/Guinea,
- between Mali and Senegal,
- between Senegal/Guinea and Nigeria,
- between Burkina Faso and Ivory Coast,

- between Ghana/Ivory Coast/Togo/Benin and Guinea/Sierra Leone,
- between Niger (zone center-east) and Nigeria,
- between Guinea/Senegal and Ivory Coast.

The main conclusion is that there is a risk of instability due to inter-area oscillations. In order to limit this risk, it is recommended to:

- install PSS on all new large units to be commissioned in the system,
- check if PSS do not already exist on the biggest machines of every country and, if not, install PSS there,
- Stress the importance of inter-area oscillations analysis in detailed feasibility studies of future interconnections,

The importance of such oscillations on the stability also recommends undertaking a deeper data collection and looking for all accurate information on the dynamics of the main and biggest power units of the system. The goal is to build a more accurate dynamic model of the WAPP system to be able to perform such advanced simulations.

The quality of such analysis depends highly on the quality of the dynamic model used in the calculations. In this case, many assumptions were done for building the dynamic model, by lack of information in many countries. If the model quality is good enough to identify the risks of inter-area oscillations, it is not accurate enough to perform a detailed PSS tuning analysis.

Finally, the installation of WAMS (Wide Area Monitoring Systems) is recommended to detect and observe the inter-area oscillations. Moreover, it would be very useful to confirm they are correctly damped after PSS installations.

3.4.6. Dynamic studies: Transient stability

The critical clearing times (CCT) were calculated for faults at all HV nodes from 760 to 90 kV close from generation units, on all 2015 situations. All results are in appendix.

First simulations calculated the CCT for faults close to the nodes and disappearing spontaneously, without line tripping. In a second time, the CCT were calculated for faults close to the nodes cleared by tripping a line connected to the substation considered. When several lines were connected to the node, the one with the greatest short-circuit contribution was chosen for tripping, since it is the most constraining scenario.

Akosombo unit 1 in Ghana was chosen as reference machine for the analysis. Any machine whose angular position is different from plus or minus 360 degrees with Akosombo's angular position was declared as losing synchronism.

Table and Table give the results for the Base case at peak load, with and without line tripping. The comparison shows that, apart for some special cases (of unit islanding for instance), the CCT without line tripping are slightly higher than with line tripping.

CCT were calculated with 5 ms accuracy. When they were above 500 ms, they were not calculated accurately. Values above 500 ms are not problematic for stability.

As visible in the tables, for the Base case at peak load, all CCT are above 100 ms except for two nodes in Nigeria: Eyaen and Alaoji 330 kV. Figure and Figure 669 show the stability of the system for a 80 ms short-circuit at Eyaen 330 kV (Nigeria) while there are losses of synchronism if it is cleared after 100 ms.

The values of CCT are influenced by the small signal stability of the system. They can increase of 0 ms to important values if the small signal stability is improved. To check the possible improvement, the same CCT were computed for a system with PSS on the machines indicated in Table . The results are given in Table and Table .

The most spectacular variation in this Base case is for a short circuit at Ikot Abasi 330 kV bus bar, in Nigeria: the CCT increased of 116 ms. More important, the CCT that were below 100 ms, for short-circuits at Eyaen and Alaoji, are now above 100 ms with the PSS.

Table and Table list the results for Scenario 2 at peak load. The conclusion is that the stability is reduced compared with the Base case. It is normal given that the system is less interconnected.

More nodes present CCT below 100 ms but the tables show that the machine losing synchronism is remote from the fault, which is a good indication that the problem is more related to small signal stability than transient stability. Here again, PSS installation and proper tuning should increase the stability and the CCT should reach values above 100 ms.

Table and Table list the results for off peak load situations for the Base case and Scenario 2, for faults with line tripping. Here again, some values are below 100 ms but the installation of PSS should help them pass above 100 ms.

If the installation of PSS can improve the transient stability of the system, it should clearly be accomplished. Nevertheless, if such system can reduce the oscillations that have a negative effect on the transient stability, it has no impact on the transient stability limit and it will not prevent the machines from losing synchronism when this limit is reached.

To prevent the instability propagation in cases of loss of synchronism, the system should be split temporarily, to resynchronize after both parts stabilized. To this purpose, it is recommended to install out of step protections on the main and longest interconnections.

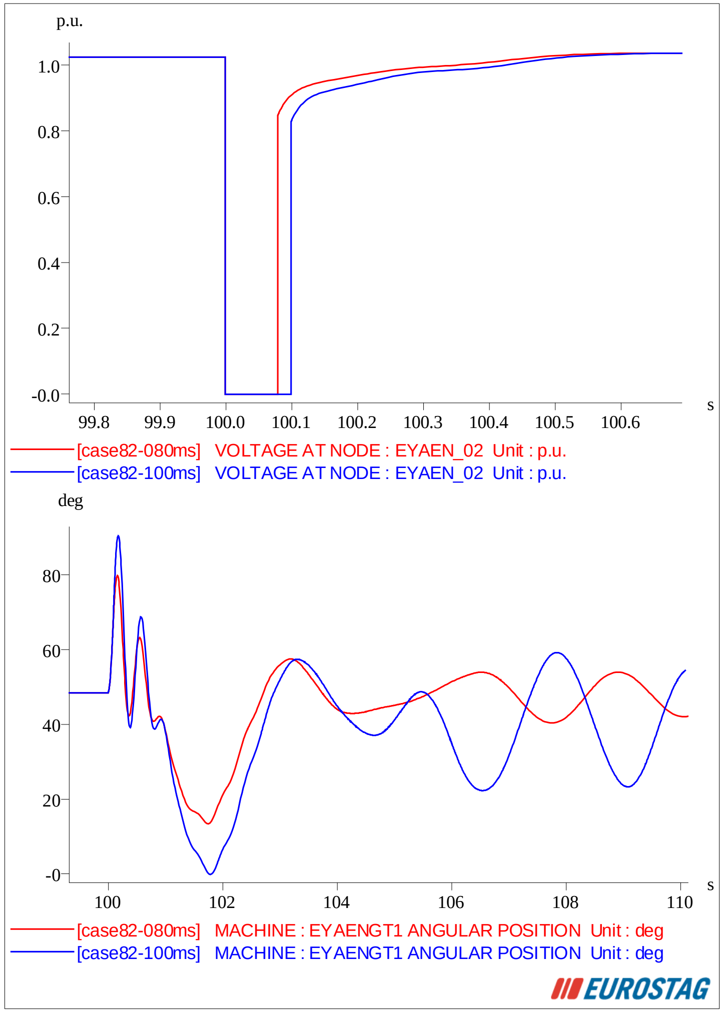


Figure 65 – Base case (peak load) – 80 and 100 ms 3ph short-circuit at Eyaen 330 kV (Nigeria): voltage and machine angular position at Eyaen

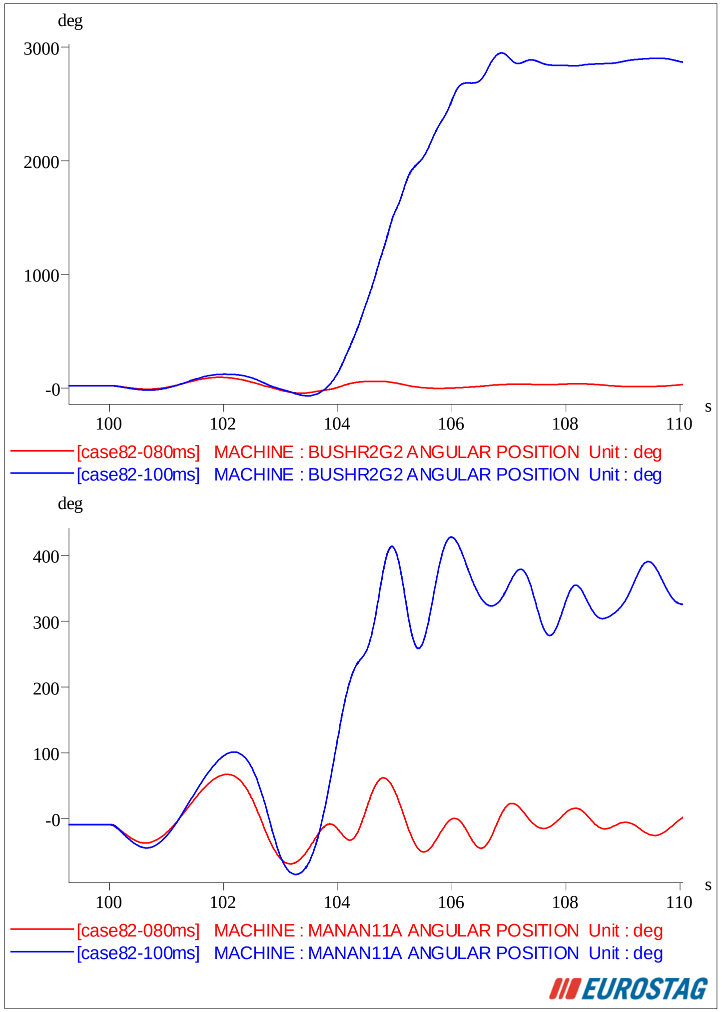


Figure 669 – Base case (peak load) – 80 and 100 ms 3ph short-circuit at Eyaen 330 kV (Nigeria): machines angular positions at Monrovia and Manantali

3.4.7. Dynamic security assessment: unit contingencies

For both 2015 scenarios, at peak and off peak load, the loss of each unit of the system was simulated dynamically. The stability of the system was checked and particular attention was brought to frequency transients.

The contingency provoking the largest frequency transient is the loss of one GT and the power of half a ST in the combined cycle of Okpai (Kwale) in Nigeria.

For the Base case, at peak load condition, Figure 6710 and Figure illustrate the network behavior for this contingency. The active power production of GT1 disappears from the system balance, and the active power production of the ST slowly decreases to half its initial level with the steam transient. The average frequency of the network decreases down to 49.3 Hz before recovering just below 49.9 Hz. The active power of GT2 at Okpai CC and the machines speed in the network show oscillations. In particular, an inter-area oscillation is visible with machines responses in phase opposition from Nigeria to Senegal. This inter-zonal oscillation was described in the small signal stability analysis.

For the Base case at peak load condition, another incident must be mentioned: the loss of Sendou coal unit. This contingency represents a loss of 125 MW for Senegal. Consequently, the same amount of power is unblocked on the spinning reserve and an important part of it flows from the other countries to Senegal. Consequently, the flow on the lines to Senegal increases and the maximum transfer capacity is exceeded, causing the system instability. Figure and Figure depicts the system response and the voltage collapse. The flow value reaches approximately 175 MW on the 225 kV line from Manantali while the tables in the maximum transfer capacity analysis (N condition) indicate a maximum of 160 MW on this line. There is a voltage collapse in Senegal after the machines, one after the other, try to inject more reactive power to support the voltages and see their reactive power production limited by the over-excitation limiter.

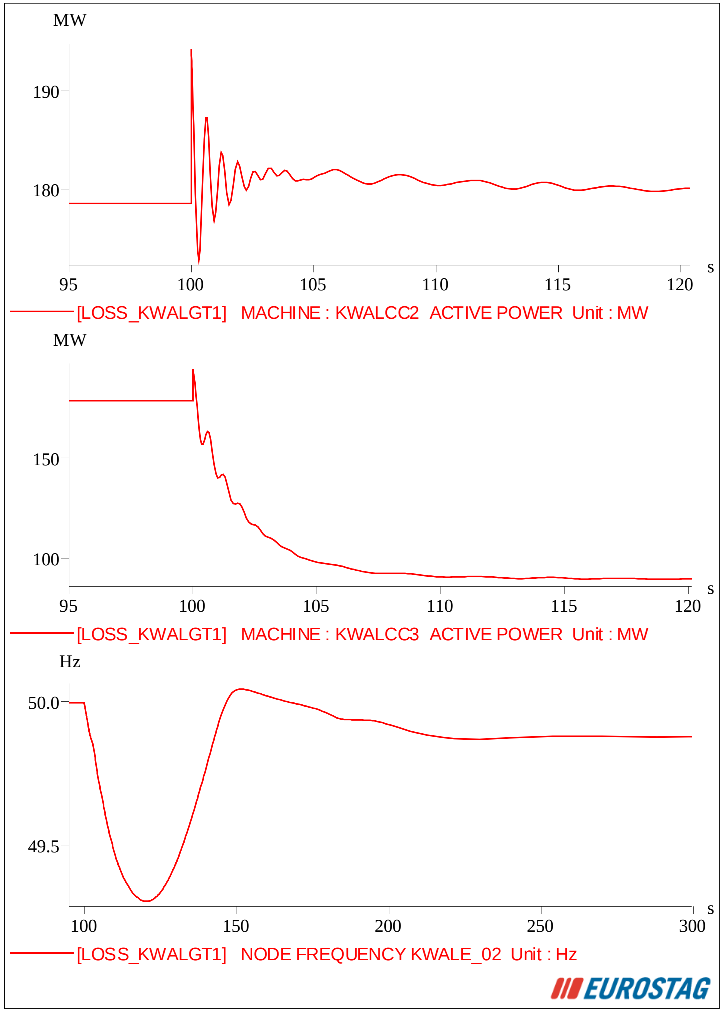


Figure 6710 – Base case (peak load): Okpai GT+1/2ST contingency: power of GT2 and ST at Okpai CC, and average network frequency

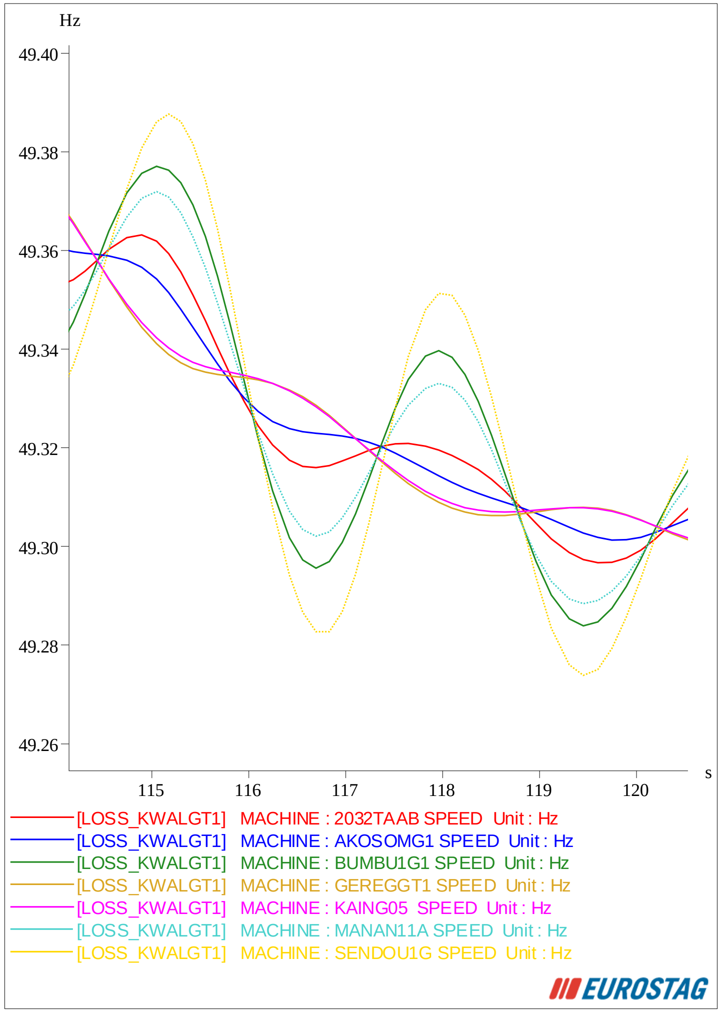


Figure 68 - Base case (peak load): Okpai GT+1/2ST contingency: machines speed and inter-area oscillations

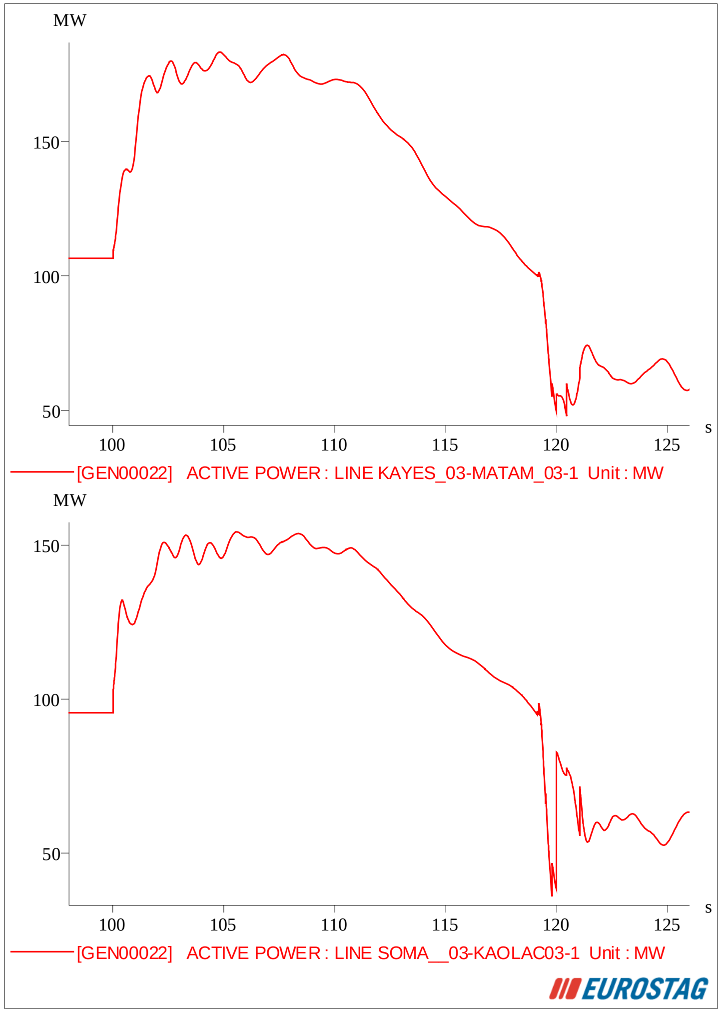


Figure 69 – Base case (peak load): Sendou coal unit contingency: active power flows on interconnection lines towards Senegal

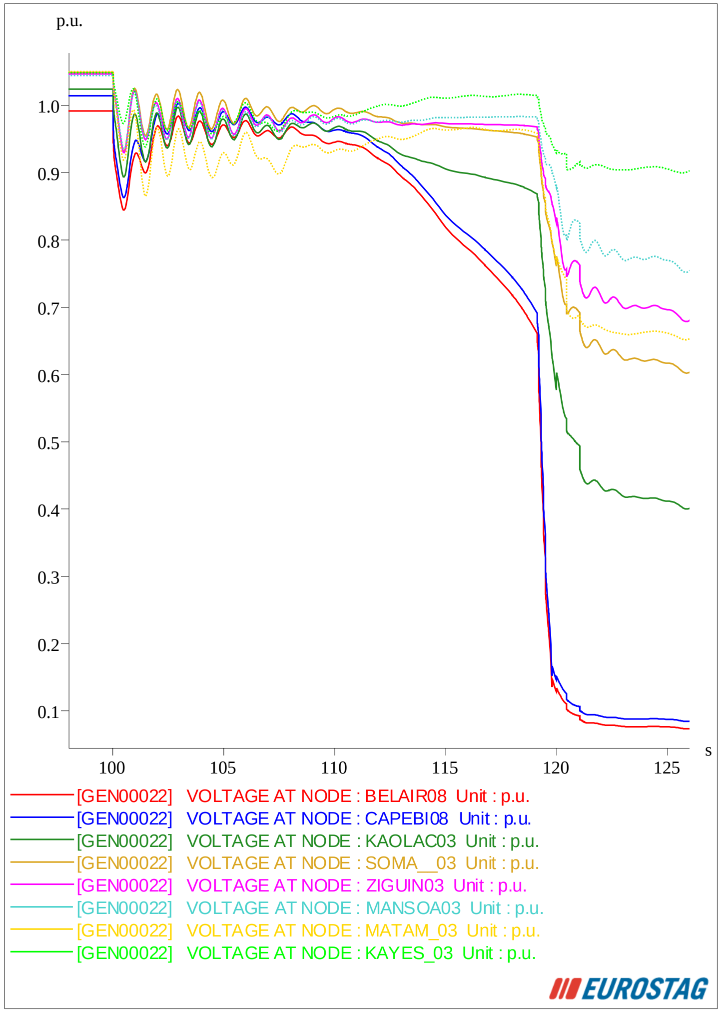


Figure 70 – Base case (peak load): Sendou coal unit contingency: voltages in and around Senegal

For Scenario 2 at peak load condition, since Okpai CC is running, the most constraining contingency is also the loss of a GT and half the power of the ST. Figure and Figure illustrate the system responses to the contingency. It is visible that the average system frequency drops down to 49.5 Hz before recovering up to 49.9 Hz. The response is more favorable than the one in the Base case because of the reserve allocation. In this scenario, the reserve was shared among more units.

For what concerns the inter area oscillations, they are still present and even more important. Because the system is less interconnected, it is more prone to experience such type of oscillations.

For off peak load situations, for the Base case, the loss of one GT and half a ST at Kwale provokes a frequency drop down to 49.5 Hz and recovers to 49.85 Hz. The transient is illustrated in Figure and it is acceptable.

For off peak load situation for the Base case, one unit contingency provokes the loss of stability: the wind farm in Senegal. It produces 60 MW and its loss provokes the unblocking of the primary reserve in the WAPP system. Active power flows towards Senegal increase to replace the loss of production, provoking the instability. This situation is illustrated in Figure and Figure .

For off peak load situation for Scenario 2, the loss of one GT and half a ST at Kwale provokes a frequency drop down to 49.5 Hz and recovers to 49.85 Hz. The transient is illustrated in Figure and it is acceptable.

For off peak load situation for Scenario 2, no unit contingency provokes the loss of stability.

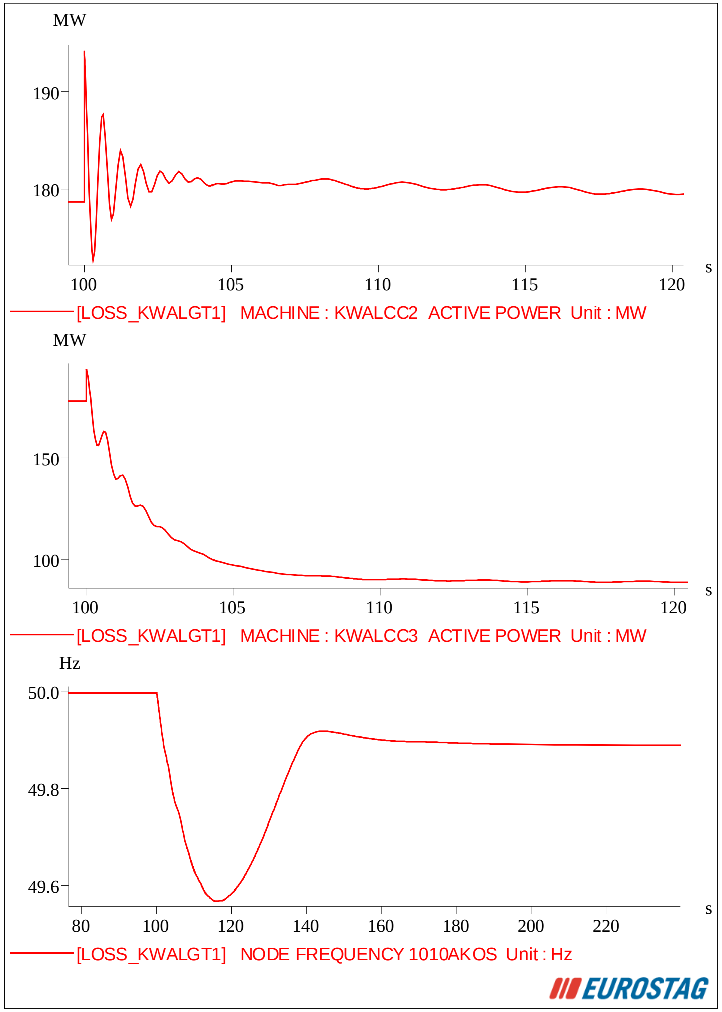


Figure 71 – Scenario 2 (peak load): Okpai GT+1/2ST contingency: power of GT2 and ST at Okpai CC, and average network frequency

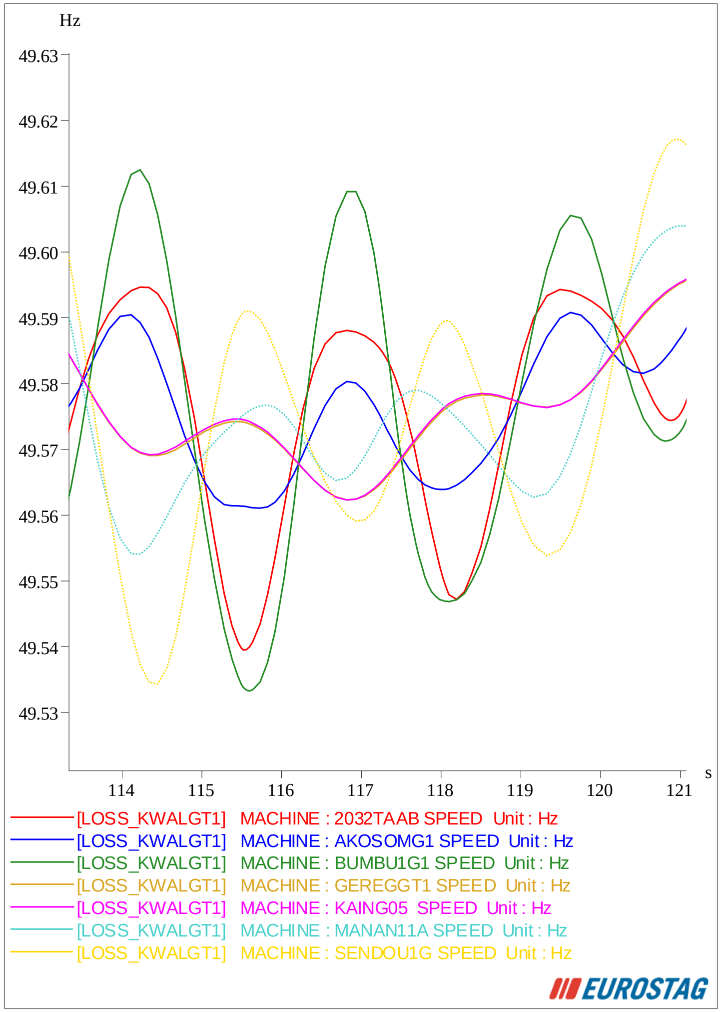


Figure 72 – Scenario 2 (peak load): Okpai GT+1/2ST contingency: machines speed and inter-area oscillations

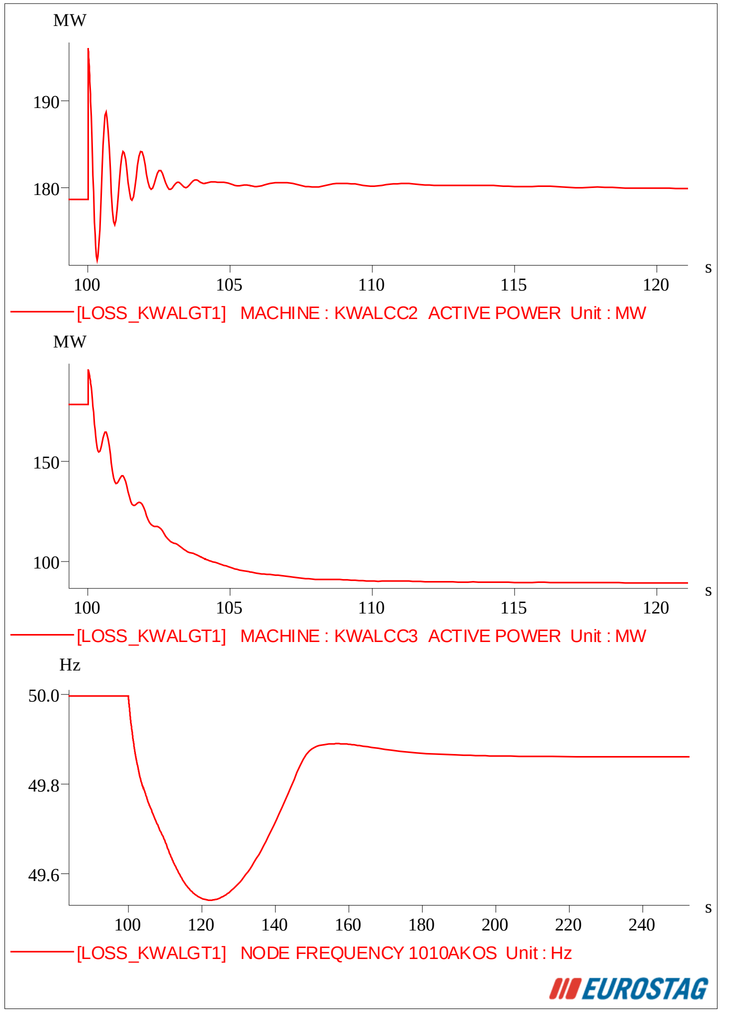


Figure 73 – Base case (off peak load): Okpai GT+1/2ST contingency: power of GT2 and ST at Okpai CC, and average network frequency

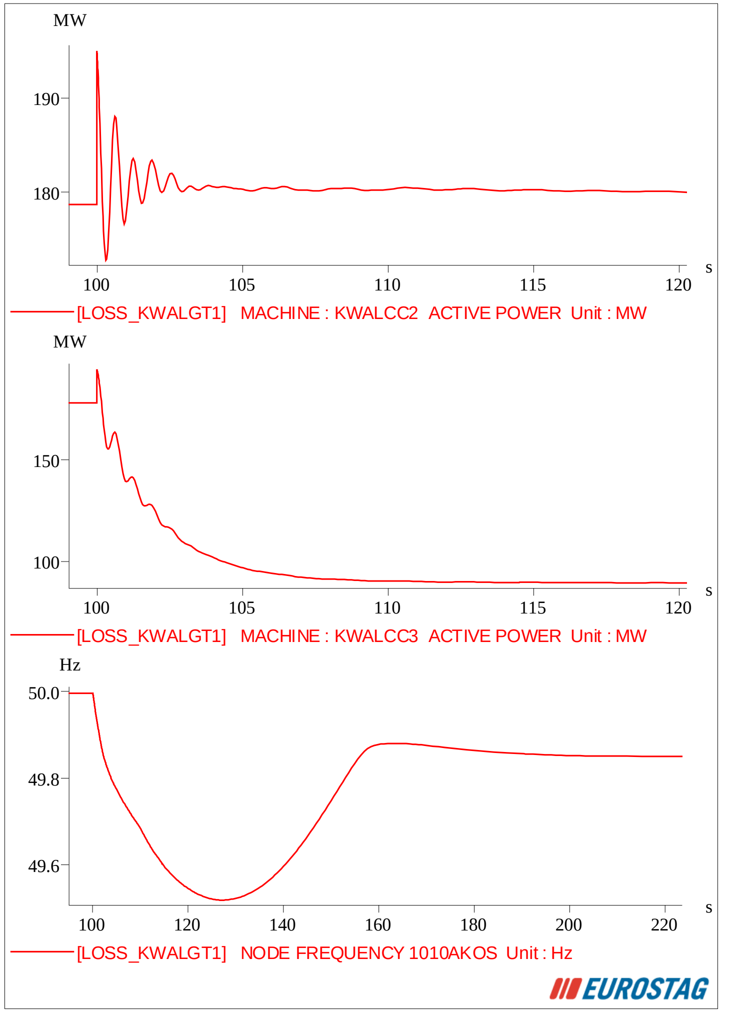


Figure 74 - Scenario 2 (off peak load): Okpai GT+1/2ST contingency: power of GT2 and ST at Okpai CC, and average network frequency

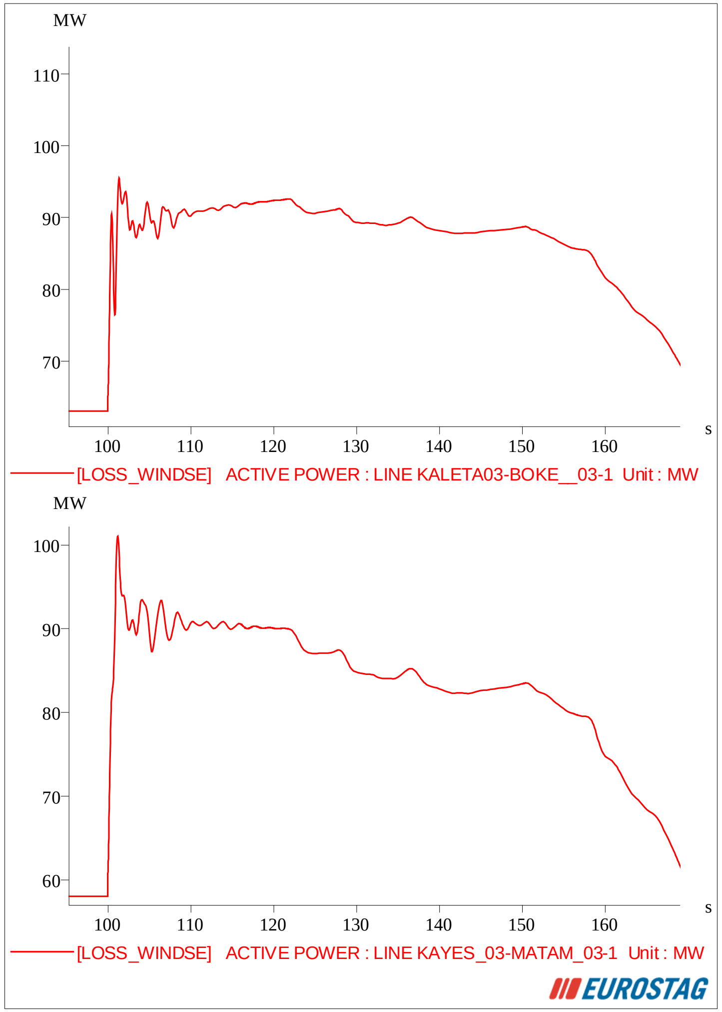


Figure 75 - Base case (off peak load): Wind farm contingency: active power flows on interconnection lines towards Senegal

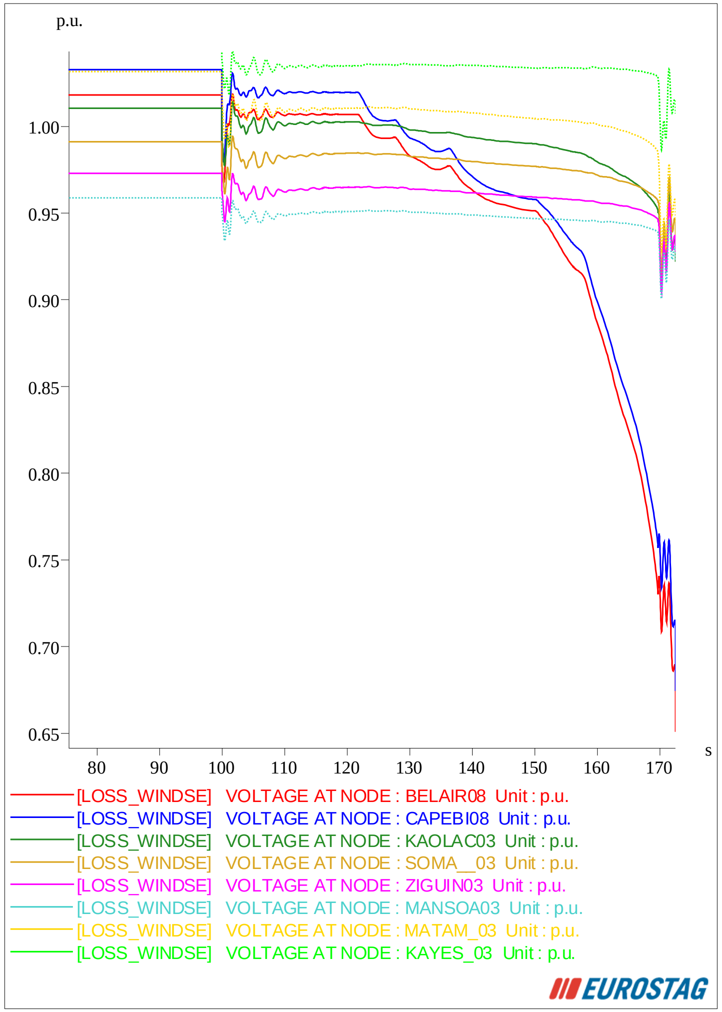


Figure 76 - Base case (off peak load): Wind farm contingency: voltages in and around Senegal

3.4.8. Dynamic security assessment: Short-circuit on lines

In order to check the stability of the system, a three-phase fault with no impedance and duration of 100 ms was executed on each line. The criteria checked were given in the methodology.

The simulations were carried out for a total of 550 lines in the system[2]. Simulations of short-circuits were performed twice: a first time at 0.1% distance on the line and a second time at 99.9% distance. The analysis was done for the Base case and for Scenario 2, at peak and off peak load conditions.

Actually, the static security analysis has already showed that the N-1 criterion is not satisfied even for contingencies without faults. Here, in addition of the contingency, there is a three-phase fault. The system response will consequently be less favourable, and all incidents already listed in the security analysis could be listed here as well.

Among all the results, the problems detected can be classified in three categories:

- The problems due to inter-area oscillations.
- The voltage collapses due to the incapacity of the system to recover the voltage after the drop provoked by the fault
- The instabilities related to the maximum transfer capacities.

Figure presents the system response and the oscillations for a fault in the north of Nigeria. It illustrates the problems of inter-area oscillations. With the short-circuit, the oscillations modes are excited and it reduces the system stability. In the situation shown, the oscillations responses in Senegal are large enough to provoke the under-voltage protection activation at Ross Betio units in Dagan. With PSS, this phenomenon would be avoided.

Figure illustrates the problem of voltage collapse. The sensitivity of Niger is presented, with the system response and the voltage collapse in Niger for a fault in the south of Nigeria. While the system recovers in Nigeria, it does not in Niger, even though Niger is further from the fault. This phenomenon is typical from areas were few generation units are in service. Typically, importing countries are concerned. For this problem, it is important to keep a minimum amount of generation running to ensure the voltage support. Otherwise, the installation of SVC is also a solution.

Finally, the last problem category, the maximum transfer capacity, will also be illustrated in the next section. The problem is not related to the fault, but to the line tripping and the consequences this tripping has in terms of flows redistribution. In the scenarios investigated, this phenomenon was detected several times.

[2] 550 lines for the Base case.

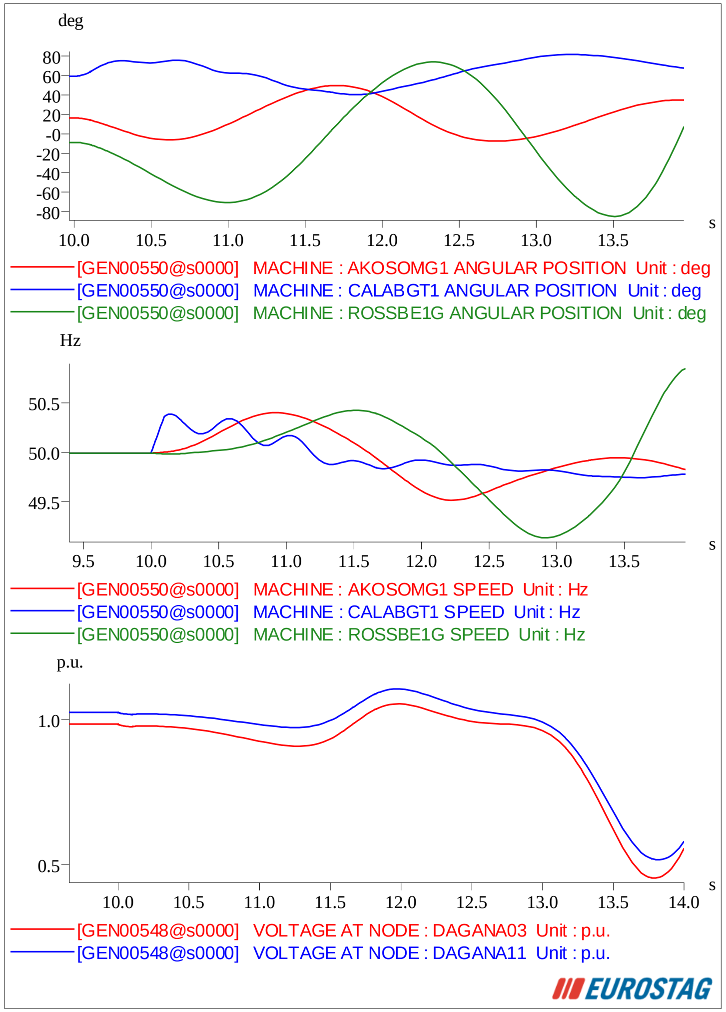


Figure 77 – Base case (peak load) - 3 phase short-circuit on line between Shiroro and Gwagwalada (Nigeria). Machines oscillations in the system and under-voltage in Senegal

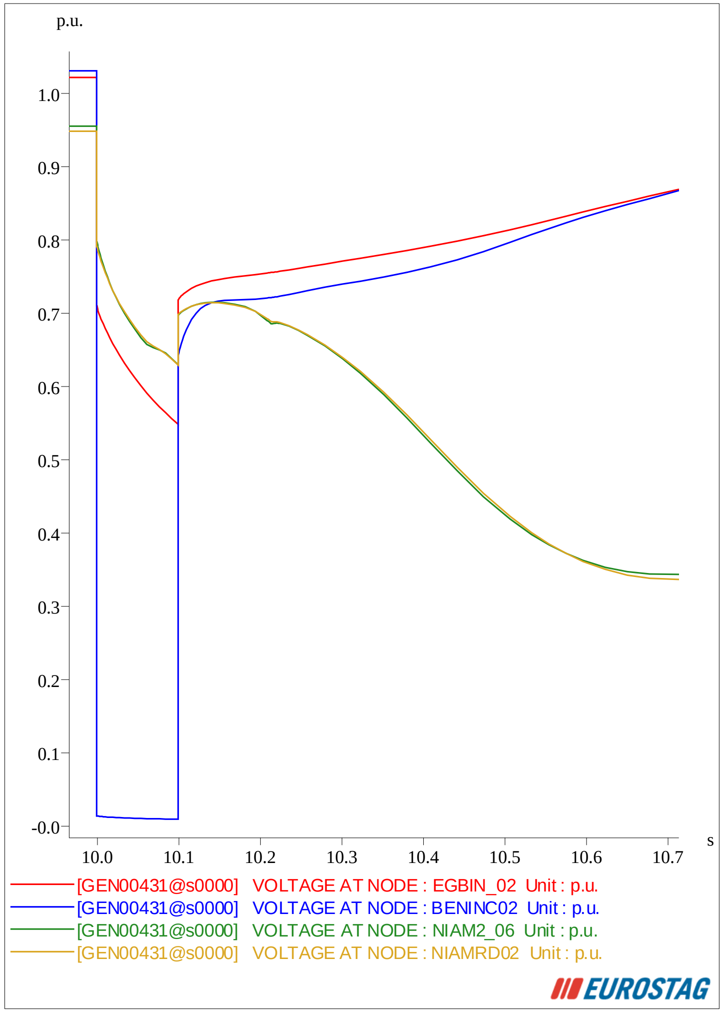


Figure 78 – Base case (peak load) - 3 phase short-circuit on line between Benin City and Egbin (Nigeria). Voltage response in Nigeria and collapse in Niamey (Niger)

As a conclusion, the system does not support three phase faults anywhere. This incident is very severe and it is not recommended to use it as a sizing incident for planning studies.

Instead, it is recommended to set up defence schemes and protections to operate the system without being able to support three phase faults, but being able to limit the propagation of such incidents to the whole system in case instability would appear. To this purpose, out-of-step protections should be installed on the interconnections and other long lines, and UFLS and UVLS should be set up and/or harmonized in all countries.

Finally the proportion of rotating loads at peak condition should be confirmed. The dynamic load model used for this analysis is composed of 40% of rotating loads. It is a high proportion and it influences the stability margins because in case of low voltages, the motors start stalling and prevent the voltage to recover.

3.4.9. Dynamic security assessment: Maximum transfer capacities

The maximum transfer capacity is the maximum flow the system can support on a line. This limit depends on several aspects, among others:

- **The criteria** applied to decide whether a situation is stable or not, acceptable or not. If the criteria are related to operational criteria (like acceptable voltage range, tolerated overloads,…) the maximum transfer capacity will be reduced compared with the value that could be obtained when operating the system up to the limit of stability (voltage collapse, frequency collapse and/or loss of synchronism).
- **The contingencies** to be supported by the system. The maximum transfer capacity is higher without contingency. It is lower when the system has to support a single phase fault, and even lower in case of three phase faults.
- **The computation scenario** applied. The transfer capacity will be different according to the production plan set up in the computation scenario. The operation of generation units close to the loads and to the interconnections has an influence on the stability.

In this section, the criterion applied will be the intrinsic stability of the system. The behavior of the system is acceptable if it does not lead to any voltage collapse, frequency collapse and/or loss of synchronism.

The contingencies to be supported will cover the tripping of any element (line, transformer, machine) of the system without short circuit. As shown in the previous section, the system does not support three phase faults everywhere. And when the induction motors share in the load is not too important, a line tripping with or without single phase fault is not very different.

Finally, the computed scenario always starts with the Base case or Scenario 2, at peak or off-peak load conditions. Production is increased in one country and load is increased in another one. The production scheme is not changed in the importing country.

It is important to state that PSS were installed on the machines listed in Table to improve the system damping. Without these PSS, the contingencies performed in the analysis provoke oscillations reducing the stability margins. Given that the future system damping will be acceptable, it is important to do this maximum transfer capacity analysis with an acceptable damping.

3.4.9.1. N TRANSFER

At first, the maximum transfer capacities were calculated without taking the contingencies into account. The operation criteria are not taken into account either. The limit is reached when the system loses stability by voltage collapse, frequency collapse and/or loss of synchronism.

Table lists the transfer limits between countries for the Base case, at peak load. To establish these limits, the flow from one country to another was increased progressively and slowly, to let the system automatically adjust to the variations (excitation systems of the machines, SVC controllers, automatic tap changers of transformers,…).

Because the electricity laws have to be respected, the flow is divided between the different possible paths to reach the load. The table shows the loopflows, i.e. the flows transiting through other countries via parallel paths.

For instance, when Senegal imports power from Mali, an important part of it, instead of going to Senegal via the 225 kV OMVS interconnection, flows through the CLSG and OMVG interconnections. When 54 MW flow via the direct path, 24 MW take the deviation via CLSG and OMVG interconnections.

Table gives the maximum transfer capacities in N condition for Scenario 2, at peak load. As a result, the values are lower, because the system is less interconnected.

Figure 7911 and Figure illustrate the limits of stability for the transfer from Ivory Coast to Burkina Faso, in Scenario 2, at peak load.

The initial situation has a big importance in the results obtained and must be taken into account when reading the tables. An initial situation with different production commitment and exchanges on the interconnection would lead to different results.

For instance, when looking at the case concerning the transit from Ivory Coast to Guinea, the results are negative values for the Base case at peak load. In the initial situation, Kaleta produces 240 MW so that Guinea exports towards Senegal, The Gambia, Guinea Bissau, Sierra Leone and Liberia. The initial transit on the line between Man and Yekepa is null. When the flow is increased from Ivory Coast to Guinea, this flow progressively changes to reach 97 MW from Man to Yekepa before the stability is lost. These 97 MW are the maximum transfer capacity for this scenario. They concern the CLSG interconnection only, without adding the 45 MW loopflow that passes first through Senegal before going to Guinea.

In Scenario 2 at peak load, the same transit from Ivory Coast to Guinea reaches the stability for a value of 172 MW. There are two reasons for such difference: the initial situation (generation at Kaleta and exchanges levels) and the loopflows (with the OMVG interconnection). Actually the Base case is more stable thanks to the OMVG interconnection though the results in the table tend to conclude the opposite. It just depends on the initial situation.

The table permits also to conclude that the N maximum transfer capacity is always lower than the thermal capacity of the interconnections. One exception to this rule goes for the interconnections between Ghana and Togo, where the 161 kV lines were overloaded before the system lost stability.

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW
Mali	Senegal	Kayes	Matam	234	106	160
		Soma	Kaolack	250	96	120
Mali	Burkina Faso	Sikasso	Kodeni	250	-26	102
		Ferkessedougou	Kodeni	327	-1	42
Guinea	Senegal	Boke	Saltinho	250	190	245
		Kayes	Matam	234	106	127
Guinea	Ivory Coast	Linsan	Kamakwie	250	40	175
		Sikasso	Ferkessedougou	250	-54	-16
Ivory Coast	Mali	Ferkessedougou	Sikasso	250	56	122
		Matam	Kayes	234	-99	-85
		Kodeni	Sikasso	250	26	61
Ivory Coast	Guinea	Man	Yekepa	250	0	97
		Boke	Kaleta	250	-191	-146
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	-1	26
		Sikasso	Kodeni	250	-26	11
		Bolgatanga	Kodeni	250	62	60
		Bolgatanga	Zagtouli	327	46	86
Ivory Coast	Ghana	Riviera	Prestea	1100	36	512
		Abobo	Elubo	327	-30	269
		Kodeni	Bolgatanga	250	-59	34
		Zagtouli	Bolgatanga	327	-45	-35
Ghana	Ivory Coast	Prestea	Riviera	1100	-36	193
		Elubo	Abobo	327	30	170
		Bolgatanga	Kodeni	250	62	105
		Bolgatanga	Zagtouli	327	46	48
Ghana	Burkina Faso	Bolgatanga	Kodeni	250	62	80
		Bolgatanga	Zagtouli	327	46	82
		Ferkessedougou	Kodeni	327	-1	8
Ghana	Mali	Kodeni	Sikasso	250	27	65
		Ferkessedougou	Sikasso	250	56	106
Ghana	Togo/Benin	Volta	Lome	1100	4	617
		Asiekpe	Lome	128	26	212
		Aflao	Lome	128	24	182
		Bawku	Dapaong	182	-21	71
Benin	Niger	Malanville	Zabori	777	2	19
		Birnin Kebbi	Zabori	777	157	195
		Ouagadougou	Niamey	777	-100	-68
		Birnin Kebbi	Dosso	95	57	79
Nigeria	Burkina Faso	Niamey	Ouagadougou	777	102	136
		Bolgatanga	Zagtouli	327	46	63
		Bolgatanga	Kodeni	250	62	69
Nigeria	Benin	Ikeja West	Sakete	777	49	566
		Zabori	Malanville	777	-2	20
		Zagtouli	Bolgatanga	327	-45	21
Nigeria	Niger	Birnin Kebbi	Zabori	777	157	230
		Birnin Kebbi	Dosso	95	57	94
		Malanville	Zabori	777	2	7
		Ouagadougou	Niamey	777	-100	-74

Table 116 – Base case, peak load– Maximum transfer capacity without contingency

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW
Mali	Senegal	Kayes	Matam	234	150	194
Ivory Coast	Mali	Ferkessedougou	Sikasso	250	35	102
Ivory Coast	Guinea	Man	Yekepa	250	119	172
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	-5	66
		Bolgatanga	Zagtouli	327	53	101
Ivory Coast	Ghana	Abobo	Elubo	327	-53	427
		Zagtouli	Bolgatanga	327	-52	57
Ghana	Ivory Coast	Elubo	Abobo	327	54	394
		Bolgatanga	Zagtouli	327	53	119
Ghana	Burkina Faso	Bolgatanga	Zagtouli	327	53	113
		Ferkessedougou	Kodeni	327	-5	41
Ghana	Benin	Volta	Lome	1100	-19	429
		Asiekpe	Lome	128	23	152
		Aflao	Lome	128	21	138
		Bawku	Dapaong	182	-31	36
Nigeria	Benin	Ikeja West	Sakete	777	32	493
Nigeria	Niger	Birnin Kebbi	Dosso	95	65	146

Table 117 – Scenario 2, peak load – Maximum transfer capacity without contingency

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW
Mali	Senegal	Kayes	Matam	234	58	128
		Soma	Kaolack	250	10	41
Mali	Burkina Faso	Sikasso	Kodeni	250	-29	108
		Ferkessedougou	Kodeni	327	-5	42
Guinea	Senegal	Boke	Saltinho	250	62	157
		Kayes	Matam	234	58	89
Guinea	Ivory Coast	Linsan	Kamakwie	250	-9	197
		Sikasso	Ferkessedougou	250	-46	12
Ivory Coast	Mali	Ferkessedougou	Sikasso	250	47	142
		Matam	Kayes	234	-56	-30
		Kodeni	Sikasso	250	30	84
Ivory Coast	Guinea	Man	Yekepa	250	38	113
		Boke	Kaleta	250	-62	-27
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	-5	31
		Sikasso	Kodeni	250	-29	19
		Bolgatanga	Kodeni	250	52	51
		Bolgatanga	Zagtouli	327	38	103
Ivory Coast	Ghana	Riviera	Prestea	1100	30	581
		Abobo	Elubo	327	-31	285
		Kodeni	Bolgatanga	250	-51	51
		Zagtouli	Bolgatanga	327	-38	-27
Ghana	Ivory Coast	Prestea	Riviera	1100	-30	396
		Elubo	Abobo	327	32	258
		Bolgatanga	Kodeni	250	52	128
		Bolgatanga	Zagtouli	327	38	43
Ghana	Burkina Faso	Bolgatanga	Kodeni	250	52	80
		Bolgatanga	Zagtouli	327	38	103
		Ferkessedougou	Kodeni	327	-5	12
Ghana	Mali	Kodeni	Sikasso	250	30	91
		Ferkessedougou	Sikasso	250	47	121
Ghana	Togo/Benin	Volta	Lome	1100	13	629
		Asiekpe	Lome	128	-5	192
		Aflao	Lome	128	-5	165
		Bawku	Dapaong	182	-13	76
Benin	Niger	Malanville	Zabori	777	8	45
		Birnin Kebbi	Zabori	777	94	157
		Ouagadougou	Niamey	777	-61	-4
		Birnin Kebbi	Dosso	95	33	76
Nigeria	Burkina Faso	Niamey	Ouagadougou	777	61	130
		Bolgatanga	Zagtouli	327	38	68
		Bolgatanga	Kodeni	250	52	67
Nigeria	Benin	Ikeja West	Sakete	777	124	750
		Zabori	Malanville	777	-8	19
		Zagtouli	Bolgatanga	327	-38	42
Nigeria	Niger	Birnin Kebbi	Zabori	777	94	210
		Birnin Kebbi	Dosso	95	33	80
		Malanville	Zabori	777	8	15
		Ouagadougou	Niamey	777	-61	-43

Table 118 – Base case, off peak load– Maximum transfer capacity without contingency

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW
Mali	Senegal	Kayes	Matam	234	69	150
Ivory Coast	Mali	Ferkessedougou	Sikasso	250	55	125
Ivory Coast	Guinea	Man	Yekepa	250	84	168
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	29	57
		Bolgatanga	Zagtouli	327	77	94
Ivory Coast	Ghana	Abobo	Elubo	327	-51	394
		Zagtouli	Bolgatanga	327	-75	15
Ghana	Ivory Coast	Elubo	Abobo	327	52	299
		Bolgatanga	Zagtouli	327	77	125
Ghana	Burkina Faso	Bolgatanga	Zagtouli	327	77	100
		Ferkessedougou	Kodeni	327	29	47
Ghana	Benin	Volta	Lome	1100	12	621
		Asiekpe	Lome	128	-11	182
		Aflao	Lome	128	-11	160
		Bawku	Dapaong	182	-35	58
Nigeria	Benin	Ikeja West	Sakete	777	156	714
Nigeria	Niger	Birnin Kebbi	Dosso	95	64	91

Table 119 – Scenario 2, off peak load – Maximum transfer capacity without contingency

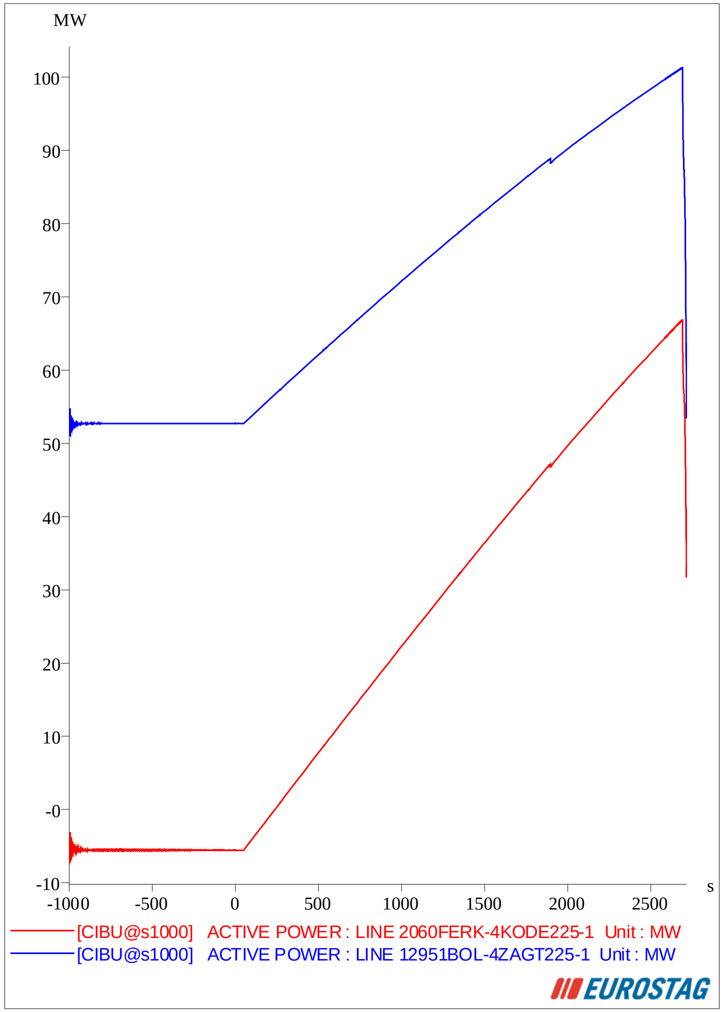


Figure 7911 – Scenario 2 (peak load) – Maximum transfer capacity from Ivory Coast to Burkina Faso: active power flows on interconnection lines

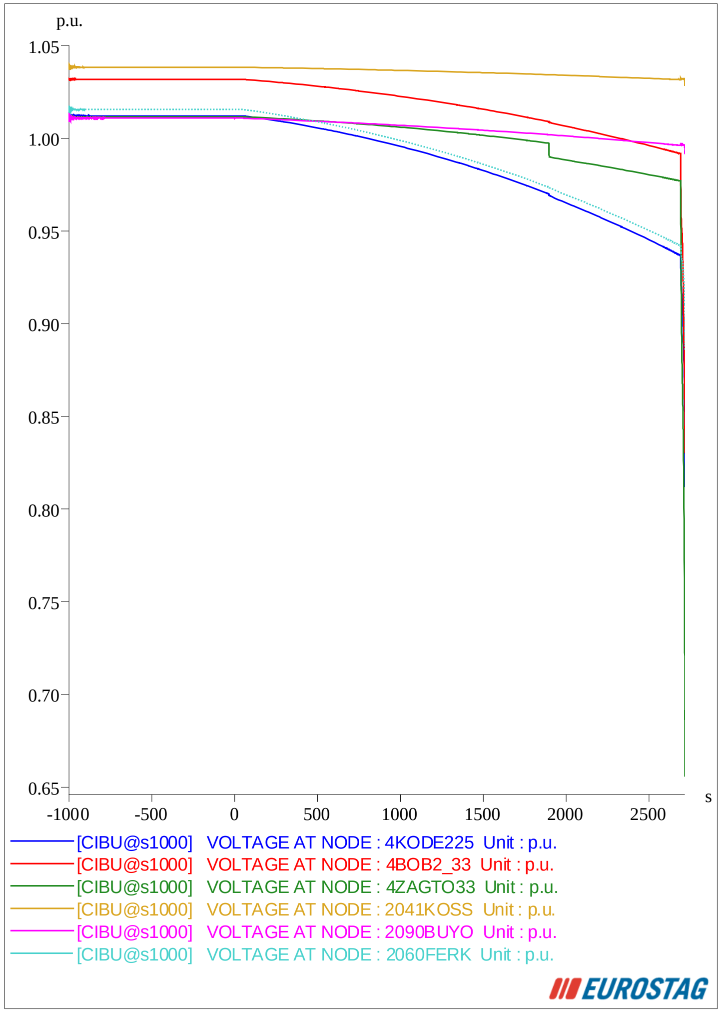


Figure 80 – Scenario 2 (peak load) – Maximum transfer capacity from Ivory Coast to Burkina Faso: voltage profile

3.4.9.2. N-1 TRANSFER

With the application of the N-1 criterion, the WAPP system should be operated in such situations that the loss of one element of the system will not lead to its instability. It means the contingencies around the interconnections and on the interconnections must be supported by the system.

In case of radial system or in case of single interconnection between two countries (as it is the case now between Senegal and Mali for instance), the issue of maximum transfer capacity in N-1 condition is limited to two possible scenarios:

1) The contingency concerns an element internal to one of both systems and the interconnection remains in service. The stability must be maintained on the interconnection.
2) The contingency concerns the interconnection. In this case, the scenario leads to the splitting of both systems. The exporting system must be able to reduce its power production before reaching over-frequency limits, or to shed production units. The importing system must be able to use its spinning reserve to compensate the loss of imported power, or it must rely on defense schemes like Under Frequency Load Shedding.

For this kind of systems, i.e. radial systems, it is possible to define a maximum transfer capacity, even though the availability of certain means to support the voltage will have an influence.

In case of meshed networks, like the WAPP existing and future system, the situation is more complex. At first, the power flows control is more difficult. The flows will respect the laws of electricity, creating loopflows, as explained and showed in the N transfer analysis above. Secondly, the point number two described above is not a possible scenario anymore. Because there are several interconnections between the countries, an interconnection contingency does not provoke the splitting of the system in two parts. The flows are redirected instantaneously, according to the electricity laws. Such flow changes can immediately lead to instability.

An excellent example is Senegal. Presently, Senegal is interconnected only with Mali via a single 225 kV line. In case of interconnection contingency, both systems are separated and the scenario is as described in point 2 above. In the future, Senegal will be interconnected with Mali and with the OMVG countries in such a way that a loop is created. In case of loss of interconnection between Senegal and Mali, the power exported from Mali to Senegal will not disappear but will flow by the only way left: the OMVG interconnection. Such high loopflow through several countries and thousands of kilometers will reduce the stability of the system.

As a matter of fact, because of the N-1 criterion, it is possible that the maximum transfer capacity determined for an interconnection feeding a radial system is reduced once this radial system becomes meshed with the addition of another interconnection.

3.4.9.2.1. 2015 Base case, peak load

For the Base case at peak load,

Table and Table summarize the maximum transfer calculations. The transfers between countries are presented with:

- The countries at the origin and destination of the transfer.
- The interconnection lines involved. Sometimes, the latter are not directly related to the transfer but are indicated because they experience loopflows.
- The thermal rated power of each interconnection line involved.
- The initial active power flow of each interconnection line involved.
- The active power flow of each interconnection involved just before the system loses stability in N condition.
- The active power flow of each interconnection just before the system loses stability in N-1 condition. The worst incident is here considered.
- The list of incidents that were taken into account for calculating the maximum transfer capacity in N-1 condition. These incidents are limited to those with the biggest impact on the transfer studied. Colors are attributed to the incidents according to their severity and their consequences in the scenario:
  - Red color for incidents that are not supported by the system in the initial situation. The system loses stability for that incident, before any power transfer is increased.
  - Orange color for the incident that limits the capacity in N-1 condition. It is the most severe of the list for the transfer studied.
- A comment on the instability experienced by the system in N-1 condition.

Figure and Figure illustrate the system behavior for the transfer increase from Mali to Burkina Faso, with contingency on 225 kV line Sikasso-Kodeni.

For the Base case, at peak load, several interconnections losses are not supported by the system. There are two major problems:

- The loop created by the OMVS, OMVG and CLSG interconnections is not able to support a contingency. The flows redistribution provokes voltage collapses and losses of synchronism.
- The North-core project is very important for Niger, where voltage collapse occurs in Niamey in case of contingency on the line Birnin Kebbi-Malanville-Niamey, following the flows redistribution.

Despite the foreseen interconnections, Senegal and Niger are the two countries where the system operation will not respect the N-1 criteria unless the flows on the lines are reduced to low values. Such reduction being not economically affordable, it is advised to rely on defense schemes instead of supporting the N-1 criterion.

The contingency on the 225 kV line between Kaleta and Boke is illustrated in Figure and Figure . The loss of the interconnection between Guinea and Senegal provokes a redirection of the flows to the interconnection between Mali and Senegal. The system cannot support it and it loses stability with the loss of synchronism between the units in Senegal on one side and the units in Guinea, Sierra Leone and Liberia on the other side.

For all other interconnections, the initial situation is stable and maximum transfer capacities in N-1 conditions were established.

3.4.9.2.2. 2015 Scenario 2, peak load

For Scenario 2, Table summarizes the maximum transfer calculations. Because there are fewer interconnections, the network is more radial and less meshed. Only Ghana, Ivory Coast, Burkina Faso, Togo and Benin are part of this meshed network and maximum transfer capacities in N-1 condition could be calculated for the interconnections between these countries. The other countries are in radial parts of the network.

Figure illustrates the transfer limit for exchanges from Ghana to Ivory Coast. The most severe incident for such exchange is the tripping of the 225 kV line between Abobo and Elubo. When the stability limit is reached, it causes the loss of synchronism of Burkina Faso first, followed by a loss of synchronism between the block Ghana/Togo/Benin/Niger/Nigeria on one side and the other block Ivory Coast/Liberia/Sierra Leone/Guinea/Mali/Senegal on the other side. Figure illustrates the transfer limit for exchanges from Ghana to Burkina Faso. The most severe incident for such exchange is the tripping of the 225 kV line between Bolgatanga and Zagtouli. When the stability limit is reached, it causes the loss of synchronism first between Guinea/Sierra Leone on one side, Liberia on another side and all the other countries on a third side. Right after, it provokes the loss of synchronism of Burkina Faso.

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW	Max N-1 MW	Incident list	Comment
Mali	Senegal	Kayes	Matam	234	106	160		line Kayes-Matam	Loss of synchronism and voltage collapse
		Soma	Kaolack	250	96	120		line Kaleta-Boke	Initial flows are too important
								Sendou unit	
Mali	Burkina Faso	Sikasso	Kodeni	250	-26	102	69	line Sikasso - Kodeni	loss of synchronism in Burkina Faso
		Ferkessedougou	Kodeni	327	-1	42	33	line Ferkessedougou - Kodeni	
								Manasema unit	
Guinea	Senegal	Boke	Saltinho	250	190	245		line Kaleta - Boke	Loss of synchronism and voltage collapse
		Kayes	Matam	234	106	127		line Kayes - Matam	Initial flows are too important
								Sendou unit	
Guinea	Ivory Coast	Linsan	Kamakwie	250	40	175		line Kaleta - Boke	Loss of synchronism and voltage collapse
		Sikasso	Ferkessedougou	250	-54	-16		line Kaleta - Linsan	Initial flows are too important
								line Linsan - Kamakwie	
								line Kayes - Matam	
								2NewCC unit	
								Buyo unit	
Ivory Coast	Mali	Ferkessedougou	Sikasso	250	56	122		line Ferkessedougou - Sikasso	Loss of synchronism and voltage collapse
		Matam	Kayes	234	-99	-85		line Kayes - Matam	Initial flows are too important
		Kodeni	Sikasso	250	26	61		line Kodeni - Sikasso	
								line Ferkessedougou - Kodeni	
								line Manantali - Tkita	
								Manantali unit	
								Vicabo unit	
Ivory Coast	Guinea	Man	Yekepa	250	0	97		line Man - Yekepa	Loss of synchronism and voltage collapse
		Boke	Kaleta	250	-191	-146		Line Kayes - Matam	Initial flows are too important
								line Ferkessedougou - Sikasso	
								line Linsan - Kaleta	
								line Kaleta - Boke	
								line Linsan - Kamakwie	
								Kaleta unit	
								Maneah unit	
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	-1	26	7	line Ferkessedougou - Kodeni	
		Sikasso	Kodeni	250	-26	11	-15	line Sikasso - Kodeni	
		Bolgatanga	Kodeni	250	62	60	62	line Ferkessedougou - Sikasso	
		Bolgatanga	Zagtouli	327	46	86	58	line Bolgatanga - Kodeni	
								line Bolgatanga - Zagtouli	
								line Riviera - Prestea	
								Manasema unit	
Ivory Coast	Ghana	Riviera	Prestea	1100	36	512	329	line Ferkessedougou - Sikasso	loss of synchronism between Ivory Coast and Ghana
		Abobo	Elubo	327	-30	269	149	line Ferkessedougou - Kodeni	
		Kodeni	Bolgatanga	250	-59	34	-3	line Riviera - Prestea	
		Zagtouli	Bolgatanga	327	-45	-35	-39	line Abobo - Elubo	
								line Bolgatanga - Kodeni	
								line Bolgatanga - Zagtouli	
								Aksombo unit	
								Saso2CC1 unit	

Table 120 – Base case (peak load) - Maximum transfer capacities in N-1 condition (1/2)

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW	Max N-1 MW	Incident list	Comment
Ghana	Ivory Coast	Prestea	Riviera	1100	-36	193	177	line Riviera - Prestea	Low voltages and loss of synchronism in Burkina Faso
		Elubo	Abobo	327	30	170	161	line Abobo - Elubo	Elubo-Abobo flow close to thermal capacity
		Bolgatanga	Kodeni	250	62	105	104	line Bolgatanga - Zagtouli	
		Bolgatanga	Zagtouli	327	46	48	49	line Bolgatanga - Kodeni	
								2NewCC unit	
Ghana	Burkina Faso	Bolgatanga	Kodeni	250	62	80	65	line Bolgatanga - Zagtouli	loss of synchronism in Burkina Faso
		Bolgatanga	Zagtouli	327	46	82	67	line Bolgatanga - Kodeni	
		Ferkessedougou	Kodeni	327	-1	8	5	Manasema unit	
Ghana	Mali	Kodeni	Sikasso	250	27	65	63	line Bolgatanga - Kodeni	loss of synchronism in Burkina Faso
		Ferkessedougou	Sikasso	250	56	106	101	line Bolgatanga - Zagtouli	
								line Ferkessedougou - Sikasso	
								line Ferkessedougou - Kodeni	
								line Manantali - Tkita	
								line Sikasso - Kodeni	
								Manantali unit	
								Vicabo unit	
Ghana	Togo/Benin	Volta	Lome	1100	4	617	419	line Volta - Lome	lVoltage collapse in Ghana (node 1391DCEM)
		Asiekpe	Lome	128	26	212	154	line Asiekpe - Lome	
		Aflao	Lome	128	24	182	139	line Aflao - Lome	
		Bawku	Dapaong	182	-21	71	42	line Bawku - Dapaong	
								Maria Gleta unit (1GT+1/2ST)	
Benin	Niger	Malanville	Zabori	777	2	19		line Malanville-Zabori-Niamey-Birnin	Voltage collapse at Niamey
		Birnin Kebbi	Zabori	777	157	195		line Ouagadougou-Niamey	Initial flows are too important
		Ouagadougou	Niamey	777	-100	-68		line Birnin Kebbi - Dosso	
		Birnin Kebbi	Dosso	95	57	79		Nigereol unit	
Nigeria	Burkina Faso	Niamey	Ouagadougou	777	102	136		line Ouagadougou-Niamey	Voltage collapse at Niamey
		Bolgatanga	Zagtouli	327	46	63		line Malanville-Zabori-Niamey-Birnin	Initial flows are too important
		Bolgatanga	Kodeni	250	62	69		line Bolgatanga - Zagtouli	
								line Bolgatanga - Kodeni	
								Manasema unit	
Nigeria	Benin	Ikeja West	Sakete	777	49	566		line Ikeja West - Sakete	Voltage collapse at Niamey
		Zabori	Malanville	777	-2	20		line Malanville-Zabori-Niamey-Birnin	Initial flows are too important
		Zagtouli	Bolgatanga	327	-45	21		Saso2CC1 unit	
Nigeria	Niger	Birnin Kebbi	Zabori	777	157	230		line Malanville-Zabori-Niamey-Birnin	Voltage collapse at Niamey
		Birnin Kebbi	Dosso	95	57	94		line Birnin Kebbi - Dosso	Initial flows are too important
		Malanville	Zabori	777	2	7		line Ouagadougou-Niamey	
		Ouagadougou	Niamey	777	-100	-74		Nigereol unit	

Table 121 – Base case (peak load) - Maximum transfer capacities in N-1 condition (2/2)

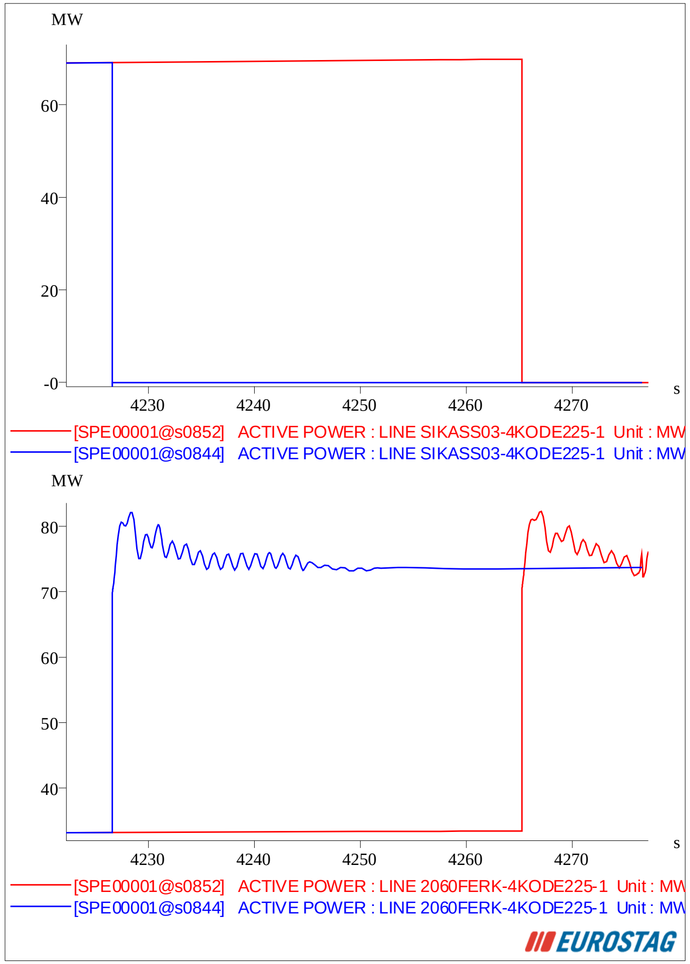


Figure 81 – Base case (peak load) – Maximum capacity transfer in N-1 condition from Mali to Burkina Faso: contingency on line Sikasso-Kodeni 225 kV (upper chart: transfer on line Sikasso-Kodeni 225 kV, lower chart: transfer on line Ferkessedougou-Kodeni)(red curves: unstable case, blue curves: stable case)

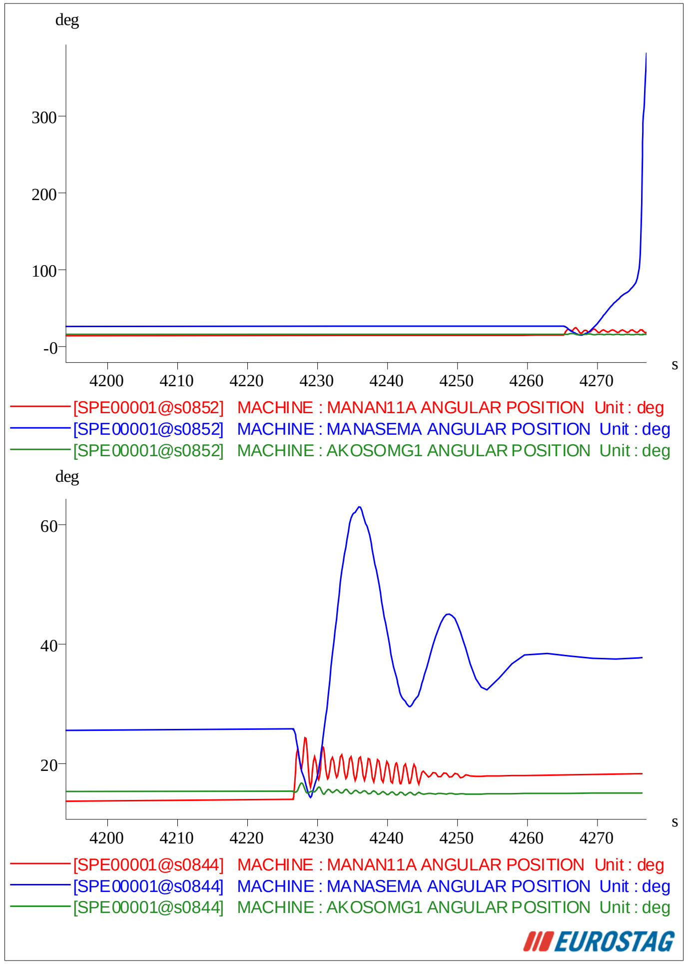


Figure 82 – Base case (peak load) – Maximum capacity transfer in N-1 condition from Mali to Burkina Faso: contingency on line Sikasso-Kodeni 225 kV (upper chart: unstable case, lower chart: stable case)

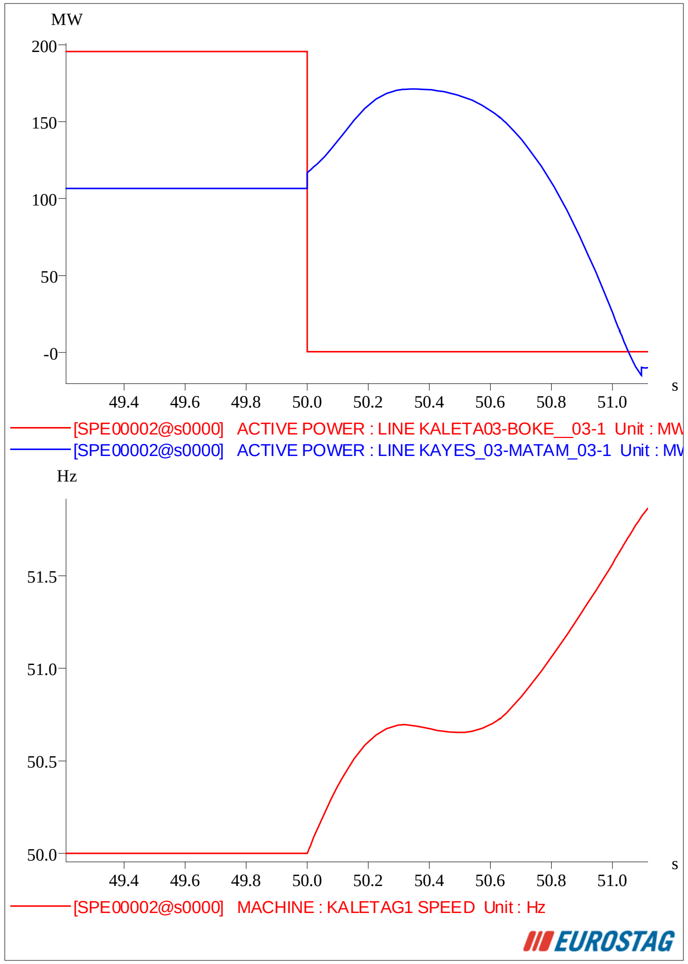


Figure 83 – Base case (peak load) – Contingency on 225 kV line between Kaleta and Boke (upper chart: active power flows on line Kaleta-Boke and Kayes-Matam (Senegal-Mali border), lower chart: machine speed at Kaleta in Guinea)

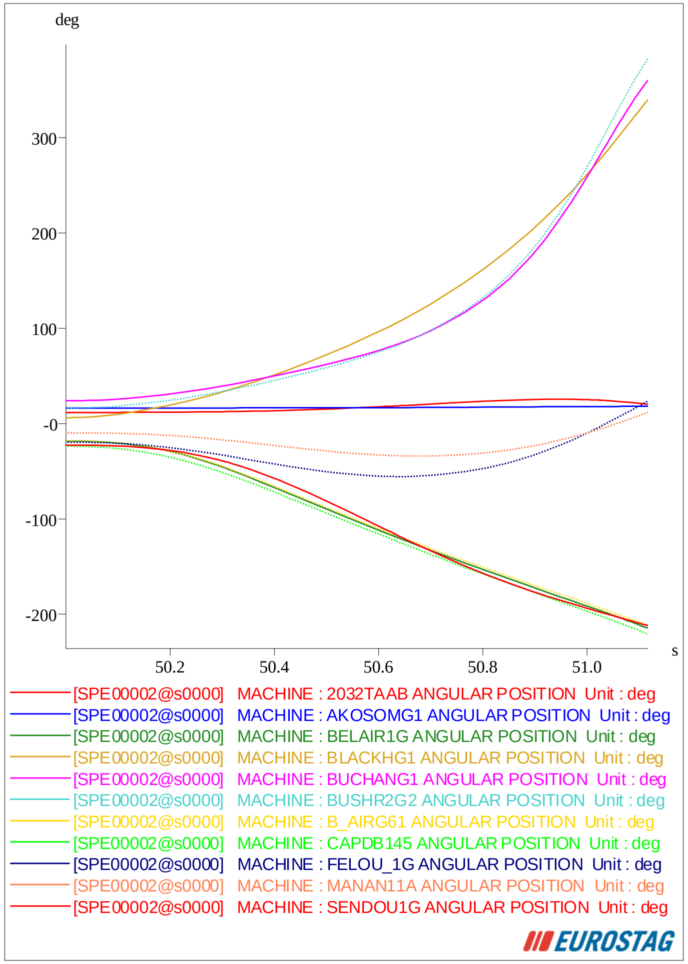


Figure 84 – Base case (peak load) – Contingency on 225 kV line between Kaleta and Boke: machines angular positions (loss of synchronism between Guinea and Senegal)

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW	Max N-1 MW	Incident list	Comment
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	-5	66	21	line Ferkessedougou - Kodeni	Loss of synchronism in Burkina Faso
		Bolgatanga	Zagtouli	250	53	101	71	line Ferkessedougou - Sikasso	
								line Bolgatanga - Zagtouli	
								line Abobo-Elubo	
								Manasema unit	
Ivory Coast	Ghana	Abobo	Elubo	327	-53	427	65	line Ferkessedougou - Sikasso	Loss of synchronism between Ivory Coast and
		Zagtouli	Bolgatanga	327	-52	57	-26	line Ferkessedougou - Kodeni	Ghana/Burkina Faso
								line Bolgatanga - Zagtouli	
								line Abobo - Elubo	
								Aksombo unit	
								Saso2CC1 unit	
Ghana	Ivory Coast	Elubo	Abobo	327	54	394	85	line Ferkessedougou - Sikasso	Loss of synchronism in Burkina Faso
		Bolgatanga	Zagtouli	327	53	119	59	line Ferkessedougou - Kodeni	
								line Bolgatanga - Zagtouli	
								line Abobo - Elubo	
								2NewCC unit	
Ghana	Burkina Faso	Bolgatanga	Zagtouli	250	53	113	74	line Bolgatanga - Zagtouli	Loss of synchronism between Guinea, Burkina Faso
		Ferkessedougou	Kodeni	327	-5	41	9	line Ferkessedougou - Kodeni	and Ghana/Ivory Coast
								line Abobo - Elubo	
								Manasema unit	
Ghana	Benin	Volta	Lome	1100	-19	429	389	line Volta - Lome	Low voltages in Togo
		Asiekpe	Lome	128	23	152	141	line Asiekpe - Lome	
		Aflao	Lome	128	21	138	129	line Aflao - Lome	
		Bawku	Dapaong	182	-31	36	31	line Bawku - Dapaong	
								Maria Gleta unit (1GT+1/2ST)	

Table 122 – Scenario 2 (peak load) - Maximum transfer capacities in N-1 condition

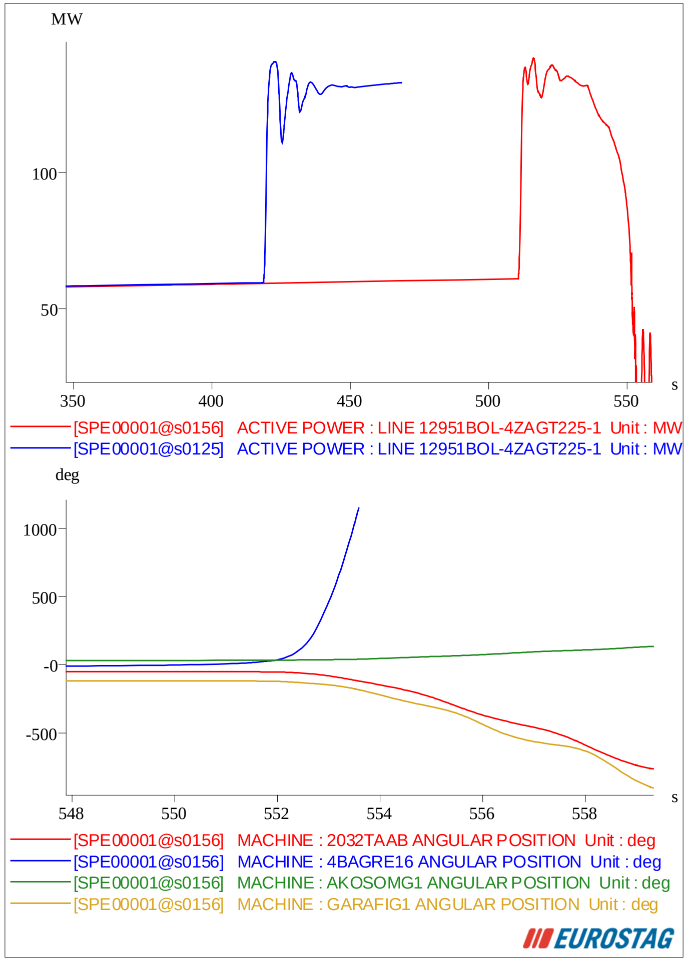


Figure 85 – Scenario 2 (peak load) - Maximum capacity transfer in N-1 condition from Ghana to Ivory Coast: contingency on line Abobo-Elubo 225 kV (upper chart: transfer on line Bolgatanga-Zagtouli: red curve=unstable, blue curve = stable. lower chart: machines angular positions in the different countries for the unstable case)

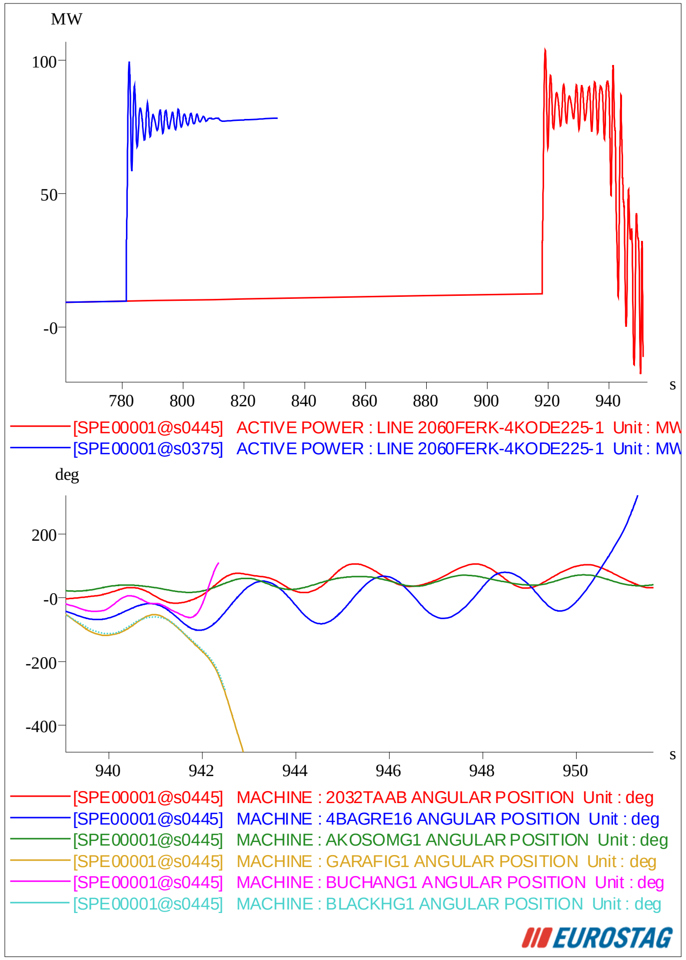


Figure 86 – Scenario 2 (peak load) - Maximum capacity transfer in N-1 condition from Ghana to Burkina Faso: contingency on line Bolgatanga-Zagtouli 225 kV (upper chart: transfer on line Ferkessedougou-Kodeni: red curve=unstable, blue curve = stable. lower chart: Machines angle in the different countries for the unstable case)

3.4.9.2.3. 2015 Base case, off peak load

Table and Table provide the maximum transfer capacities for the Base case, in off peak load condition.

As can be seen, two incidents provoked the instability of the system and prevented the calculation of N-1 maximum transfer capacities:

- The contingency on the wind farm in Senegal. It was showed in section 3.4.7, and in Figure and Figure that it provokes the instability of Senegal.
- The contingency of the line between Kaleta and Linsan. The flows redistribution, with all the power from Kaleta going to Senegal, provokes voltage drops and loss of synchronism in Guinea and Sierra Leone. The system response is illustrated in Figure .

3.4.9.2.4. 2015 Scenario 2, off peak load

Table presents the maximum transfer capacities for Scenario 2, in off peak load condition.

The incident on line Bolgatanga – Zagtouli is not supported by the system. The flow redistribution provokes voltage collapse in Burkina Faso and north of Ivory Coast, as depicted in Figure 8812.

3.4.9.3. CONCLUSIONS FOR THE MAXIMUM TRANSFER CAPACITIES

For meshed systems, it is impossible to attribute one single value to each line as the maximum transfer capacity in N-1 condition. As explained above, it depends on many elements, and above all the initial situation. This analysis is willing to provide an idea of the transfer level it is possible to reach between countries considering the expected scenario of exchanges. It also shows the most constraining incident for each transfer.

In large meshed interconnected systems, as the WAPP will be, maximum transfer capacities are calculated daily, on basis of information collected from each country. It is recommended to initiate such system and prepare to collect such information in order to be ready calculating the dynamic stability limits of the system when the interconnections will be commissioned. In the end, the goal is to calculate regularly the maximum transfer capacities for the network loads, productions and exchanges foreseen. Then the calculations would permit to identify the loopflows and the expected flows on the interconnections could be compared with the maximum transfer capacities calculated.

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW	Max N-1 MW	Incident list	Comment
Mali	Senegal	Kayes	Matam	234	58	128		line Kayes-Matam	voltage collapse and loss of synchronism in Senegal,
		Soma	Kaolack	250	10	41		line Kaleta-Boke	The Gambia and Guinea Bissau
								Wind farm	
Mali	Burkina Faso	Sikasso	Kodeni	250	-29	108	96	line Sikasso - Kodeni	voltage collapse in Burkina Faso
		Ferkessedougou	Kodeni	327	-5	42	40	line Ferkessedougou - Kodeni	
								Manasema unit	
Guinea	Senegal	Boke	Saltinho	250	62	157	74	line Kaleta - Boke	voltage collapse and loss of synchronism in Senegal,
		Kayes	Matam	234	58	89	60	line Kayes - Matam	The Gambia and Guinea Bissau
								Wind farm	
Guinea	Ivory Coast	Linsan	Kamakwie	250	-9	197		line Kaleta - Boke	loss of sychronism in Guinea
		Sikasso	Ferkessedougou	250	-46	12		line Kaleta - Linsan	
								line Linsan - Kamakwie	
								line Kayes - Matam	
								2NewCC unit	
								Buyo unit	
Ivory Coast	Mali	Ferkessedougou	Sikasso	250	47	142	137	line Ferkessedougou - Sikasso	low voltages in Mali
		Matam	Kayes	234	-56	-30	-33	line Kayes - Matam	
		Kodeni	Sikasso	250	30	84	81	line Kodeni - Sikasso	
								line Ferkessedougou - Kodeni	
								line Manantali - Tkita	
								Manantali unit	
								Vicabo unit	
Ivory Coast	Guinea	Man	Yekepa	250	38	113		line Man - Yekepa	loss of sychronism in Guinea
		Boke	Kaleta	250	-62	-27		Line Kayes - Matam	
								line Ferkessedougou - Sikasso	
								line Linsan - Kaleta	
								line Kaleta - Boke	
								line Linsan - Kamakwie	
								Kaleta unit	
								Maneah unit	
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	-5	31	22	line Ferkessedougou - Kodeni	loss of sychronism and low voltages in Burkina Faso
		Sikasso	Kodeni	250	-29	19	6	line Sikasso - Kodeni	
		Bolgatanga	Kodeni	250	52	51	52	line Ferkessedougou - Sikasso	
		Bolgatanga	Zagtouli	327	38	103	87	line Bolgatanga - Kodeni	
								line Bolgatanga - Zagtouli	
								line Riviera - Prestea	
								Manasema unit	
Ivory Coast	Ghana	Riviera	Prestea	1100	30	581	355	line Ferkessedougou - Sikasso	loss of synchronism between Ghana and Ivory Coast
		Abobo	Elubo	327	-31	285	150	line Ferkessedougou - Kodeni	
		Kodeni	Bolgatanga	250	-51	51	8	line Riviera - Prestea	
		Zagtouli	Bolgatanga	327	-38	-27	-32	line Abobo - Elubo	
								line Bolgatanga - Kodeni	
								line Bolgatanga - Zagtouli	
								Aksombo unit	
								Saso2CC1 unit	

Table 123 - Base case (off peak load) - Maximum transfer capacities in N-1 condition (1/2)

case number	From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW	Max N-1 MW	Incident list	Comment
19	Ghana	Ivory Coast	Prestea	Riviera	1100	-30	396	275	line Riviera - Prestea	voltage collapse in Burkina Faso
			Elubo	Abobo	327	32	258	198	line Abobo - Elubo	
			Bolgatanga	Kodeni	250	52	128	109	line Bolgatanga - Zagtouli	
			Bolgatanga	Zagtouli	327	38	43	42	line Bolgatanga - Kodeni	
									2NewCC unit	
20	Ghana	Burkina Faso	Bolgatanga	Kodeni	250	52	80	65	line Bolgatanga - Zagtouli	voltage collapse in Burkina Faso
			Bolgatanga	Zagtouli	327	38	103	83	line Bolgatanga - Kodeni	
			Ferkessedougou	Kodeni	327	-5	12	8	Manasema unit	
21	Ghana	Mali	Kodeni	Sikasso	250	30	91	82	line Bolgatanga - Kodeni	voltage collapse in Burkina Faso
			Ferkessedougou	Sikasso	250	47	121	109	line Bolgatanga - Zagtouli	
									line Ferkessedougou - Sikasso	
									line Ferkessedougou - Kodeni	
									line Manantali - Tkita	
									line Sikasso - Kodeni	
									Manantali unit	
									Vicabo unit	
23	Ghana	Togo/Benin	Volta	Lome	1100	13	629	401	line Volta - Lome	loss of synchronism between Ghana and Togo
			Asiekpe	Lome	128	-5	192	116	line Asiekpe - Lome	
			Aflao	Lome	128	-5	165	108	line Aflao - Lome	
			Bawku	Dapaong	182	-13	76	44	line Bawku - Dapaong	
									Maria Gleta unit (1GT+1/2ST)	
26	Benin	Niger	Malanville	Zabori	777	8	45	15	line Malanville-Zabori-Niamey-Birnin	Low voltages in Niger
			Birnin Kebbi	Zabori	777	94	157	114	line Ouagadougou-Niamey	
			Ouagadougou	Niamey	777	-61	-4	-47	line Birnin Kebbi - Dosso	
			Birnin Kebbi	Dosso	95	33	76	42	Nigereol unit	
27	Nigeria	Burkina Faso	Niamey	Ouagadougou	777	61	130	81	line Ouagadougou-Niamey	voltage collapse in Burkina Faso
			Bolgatanga	Zagtouli	327	38	68	47	line Malanville-Zabori-Niamey-Birnin Kebbi	
			Bolgatanga	Kodeni	250	52	67	56	line Bolgatanga - Zagtouli	
									line Bolgatanga - Kodeni	
									Manasema unit	
28	Nigeria	Benin	Ikeja West	Sakete	777	124	750	138	line Ikeja West - Sakete	Loss of synchronism in Benin
			Zabori	Malanville	777	-8	19	-7	line Malanville-Zabori-Niamey-Birnin Kebbi	
			Zagtouli	Bolgatanga	327	-38	42	-38	Saso2CC1 unit	
31	Nigeria	Niger	Birnin Kebbi	Zabori	777	94	210	120	line Malanville-Zabori-Niamey-Birnin	voltage collapse in Niger
			Birnin Kebbi	Dosso	95	33	80	41	line Birnin Kebbi - Dosso	
			Malanville	Zabori	777	8	15	10	line Ouagadougou-Niamey	
			Ouagadougou	Niamey	777	-61	-43	-55	Nigereol unit	

Table 124 - Base case (off peak load) - Maximum transfer capacities in N-1 condition (2/2)

From Country	To Country	From Substation	To Substation	Rated SN MVA	Initial flow MW	Max N MW	Max N-1 MW	Incident list	Comment
Ivory Coast	Burkina Faso	Ferkessedougou	Kodeni	327	29	57		line Ferkessedougou - Kodeni	voltage collapse in Burkina Faso
		Bolgatanga	Zagtouli	250	77	94		line Ferkessedougou - Sikasso	
								line Bolgatanga - Zagtouli	
								line Abobo-Elubo	
								Komsilga1 unit	
Ivory Coast	Ghana	Abobo	Elubo	327	-51	394		line Ferkessedougou - Sikasso	voltage collapse in Burkina Faso
		Zagtouli	Bolgatanga	327	-75	15		line Ferkessedougou - Kodeni	
								line Bolgatanga - Zagtouli	
								line Abobo - Elubo	
								Aksombo unit	
								Saso2CC1 unit	
Ghana	Ivory Coast	Elubo	Abobo	327	52	299		line Ferkessedougou - Sikasso	voltage collapse in Burkina Faso
		Bolgatanga	Zagtouli	327	77	125		line Ferkessedougou - Kodeni	
								line Bolgatanga - Zagtouli	
								line Abobo - Elubo	
								2NewCC unit	
Ghana	Burkina Faso	Bolgatanga	Zagtouli	250	77	100		line Bolgatanga - Zagtouli	voltage collapse in Burkina Faso
		Ferkessedougou	Kodeni	327	29	47		line Ferkessedougou - Kodeni	
								line Abobo - Elubo	
								Komsilga1 unit	
Ghana	Benin	Volta	Lome	1100	12	621	418	line Volta - Lome	low voltages in Ghana and Togo
		Asiekpe	Lome	128	-11	182	115	line Asiekpe - Lome	
		Aflao	Lome	128	-11	160	107	line Aflao - Lome	
		Bawku	Dapaong	182	-35	58	26	line Bawku - Dapaong	
								Maria Gleta unit (1GT+1/2ST)	

Table 125 - Scenario 2 (off peak load) - Maximum transfer capacities in N-1 condition

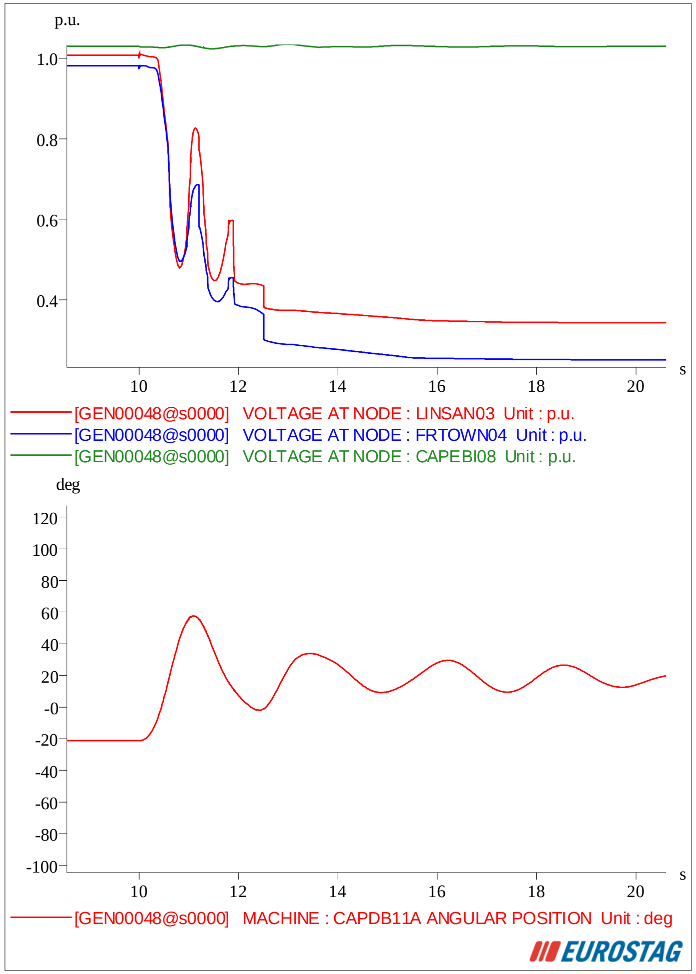


Figure 87 – Base case (off peak load) – Contingency on line Kaleta – Linsan (upper chart: voltages in Senegal, Guinea and Sierra Leone. lower chart: machine angular position in Senegal)

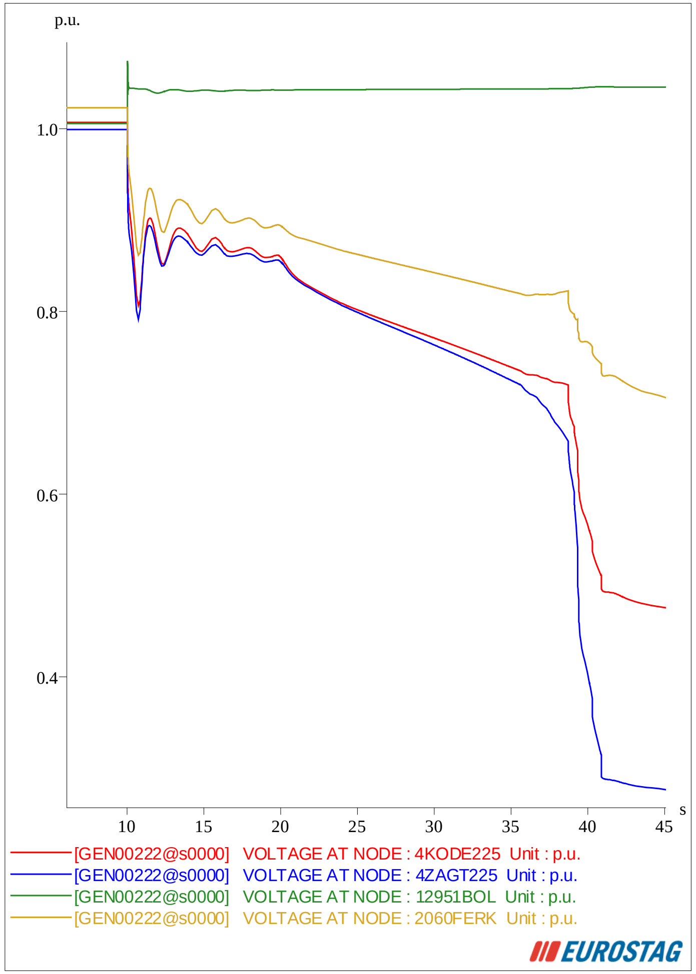


Figure 8812 – Scenario 2 (off peak load) – Contingency on line Bolgatanga – Ouagadougou (voltage collapse in Burkina Faso and North of Ivory Coast)

3.5. Operation of the system and control centers

While the previous sections examined the static and dynamic stability of the systems from a planning point of view, this section treats the stability of the systems from an operation point of view.

Parts of the WAPP system are already interconnected and already apply a set of rules to operate together. The operation of the interconnected systems is managed by the control centers, according to national and regional rules. The regional rules are described in the "Operation Manual for WAPP interconnected system" and are implemented progressively.

Nevertheless, these rules are not always respected. The best example is the frequency control and the spinning reserve. It seems that, neither in the block composed by Ghana-Ivory Coast-Burkina Faso-Togo-Benin, nor in the block Nigeria-Niger-Benin, there is a sufficient spinning reserve to cover any unit contingency without shedding load or experiencing a black out. In Nigeria, the frequency largely varies and blackouts occur several times a year. The consequence is that, though physically interconnected, these blocks are presently operated separately by opening lines in Benin.

As first and main recommendation, this section encourages the application of the "Operation Manual for WAPP interconnected system". The most important recommendations are already described in the manual and will not be repeated. This section is willing to complete and/or amend this manual. It is therefore organized according to the manual structure.

Finally, some operation issues should be controlled at a higher level than those controlled by the control centers. It could be a future role to be played by the WAPP, and particularly the ICC. These issues will be stressed here below.

3.5.1. Policy 1: Load frequency control

The most important recommendation concerning the load frequency control is the strict respect of the spinning reserves levels attributed to each country. The non respect of this rules by one member puts all the other members in danger of facing at least load shedding, at worst a black out. It also provokes uncontrolled frequency variations, leading to uneconomic operation such as the example of the unsynchronized operation of the block Ivory Coast-Burkina Faso-Ghana-Togo-Benin and the block Nigeria-Niger-Benin.

A first step towards the good respect of the spinning reserve rules is to relax the level required. The WAPP operation manual mentions the simultaneous contingency of the two largest units as the sizing incident (220 MW of Egbin ST in Nigeria and 170 MW of Akosombo unit in Ghana). It is recommended to take advantage of the opportunity to reduce the spinning reserve thanks to the interconnections. The probability of a simultaneous contingency on the two largest units of the system is very low. Keeping such an amount of spinning reserve for an incident with low probability is not economically justified; it increases the operation costs to support an event that is unlikely to happen. It is recommended to cover only the contingency on the largest unit, which is presently to loss of one GT in Kwale CC in Nigeria with the consequent impact on the power output of the associated steam turbine (total of 267.8 MW).

On the other hand, the members should be intransigent on the respect of the levels attributed. The WAPP and the ICC should monitor the production levels of the units and check these levels are respected.

After respecting the agreed amount of spinning reserve and spreading it in the system, it is important to ensure the frequency regulation. It is the role of the primary and secondary controls. These controls are of utmost importance and are already described in the WAPP operation manual.

For what concerns the primary frequency control, The WAPP operation manual mentions, with the associated equations, the K-factor. It is recommended to impose a range of permitted values for this parameter (usually around 5%) for each machine willing to participate to the primary frequency regulation. This makes sure the machines respond in a coordinated way to the frequency transients, avoiding one machine to reach its maximum power output while another one barely responded.

And in addition to the WAPP operation manual, it is recommended to release a technical note describing the requirements in terms of voltage and frequency control for each new unit to be connected to the network. Such note should be approved by all country and included in their respective grid codes.

3.5.2. Policy 2: Interchange scheduling and accounting between control areas

Policy 2 addresses the issue of maximum transfer capacities and this section will describe with more details the procedure that should be applied to calculate the TTC (Total Transfer Capacity) and NTC (Net Transfer Capacity).

As already explained in the section calculating the maximum transfer capacities here above, the results of the TTC calculations will depend on three parameters:

- The system situation studied (peak load, off peak load,…)
- The contingencies the system must be able to support (N-1, N-2, single-phase short-circuits, three-phase short circuits,…)
- The criteria applied to check the system operation and determine, after contingency, whether it is acceptable.

It is recommended to apply the following parameters:

- At the beginning, the situation studied should be the synchronous daily peak load of the interconnected system. Afterwards, when the procedure gained experience and is fully operational, it is recommended to carry it on an hourly basis, with calculation of the TTC for 24 situations each day.
- The contingencies to be supported should cover the single contingency of any element of the system (line, generating unit, transformer, SVC, reactive bank,…), without fault. The apparition of a three phase fault has a probability that is too low for being considered preventively. For such faults, it is better to rely on special protection schemes and defense schemes.
- The applied criteria to judge the final situation are those used for the normal operation of the system (levels of overloads tolerated on lines and transformers, acceptable voltages ranges,…)

These parameters are to be agreed by the countries and the control centers. After that, it will be possible to apply an automatic procedure for calculating the transfer capacities.

This procedure implies the cooperation of all countries and all control centers. Since the WAPP and the ICC are responsible for assessing and publishing the TTC and NTC, it is proposed that the ICC carries out the automatic day ahead calculations of TTC and NTC.

All countries and control centers should be responsible for providing, one day in advance, all information regarding load, generation and transmission system for the next day. This information should be provided in one predefined format corresponding to a power system calculation software, and delivered to the ICC. The same day, the ICC should carry out the calculations and publish the results on the WAPP's website.

When all "day ahead" information is gathered, it should be assembled by the ICC to form one single load flow representing the whole interconnected system.

At this stage, a static representation of the system is available. To this representation, the dynamic data of the system should be added for performing the dynamic simulations.

Dynamic simulations are necessary because, due to the long distances of the interconnections, the system is more likely to reach the dynamic stability limits before experiencing static limitations like the thermal rating of the equipments. This has been shown in the simulations of this study.

It is therefore important to have at disposal a dynamic model of the interconnected system. Such model should be built once and kept up to date. It does not depend on the situation studied, so that every day, the static representation will be different but the dynamic model used will be unique (except for the changes due to system development).

All countries and control centers are responsible for providing all the dynamic information concerning their systems, and for keeping such information up to date with the latest system developments. The quality of the model is of utmost importance since it will have an impact on the TTC results.

With the static and dynamic model of the system, the contingencies will be simulated and the criteria will be applied to judge whether the situation is acceptable. Initially, the situation should be acceptable since it represents the expected operation of the system. From this situation, the flows on the lines should be increased and the contingencies should be simulated to determine the transfer limit.

3.5.3. Policy 3: Operational security

The policy 3 of the Operation Manual of the WAPP interconnected system could be completed with the following points:

- Regular on-line simulations should be performed to assess the security of the system. Such calculations:
    - could be carried out at least once a day at the beginning, and every 15 minutes when the whole system and procedure are automatic.
    - should include simulations of contingencies on the interconnections with the neighboring zones, and of the most important elements inside the neighboring zones.
    - should be performed dynamically. It is therefore necessary to have a dynamic model at disposal. For each neighboring zone, the model could limit itself to the zone concerned with an equivalent model representing the neighboring areas. A complete dynamic model of the system should be available and centralized by the ICC.

- The protections settings must have the same tuning on both sides of the interconnections. International blackouts have already occurred because the system operators assumed it was like that, though it was not.

3.5.4. Policy 5: Emergency procedures

The policy 5 of the Operation Manual of the WAPP interconnected system should be amended with the following points:

- UFLS should be harmonized between all countries, with thresholds from 49 Hz to 48 Hz. A frequency limit should be agreed for keeping the system interconnected. For instance, starting from 48.5 Hz, it could be more interesting to trip the interconnections and limit the problem to the country where it happened instead of letting it propagate to the whole system. It is also important to leave a frequency margin to the other controllers to recover the system to an acceptable state. The note in appendix provides more information on the harmonization and tuning of UFLS in interconnected systems.
- All units should remain connected between 47.5 Hz and 52.5 Hz, to be coherent with the UFLS proposed. Such requirement should be made public in the national gridcode of each country.
- Though voltage management is to be controlled locally, it is also a regional issue because voltage problems can lead to losses of synchronism and/or voltage collapses that will propagate to the interconnected systems. Consequently, it is recommended to install Under Voltage Load Shedding (UVLS) in the networks.

3.6. Conclusions and recommendations

Static and dynamic studies were carried out for different scenarios in order to analyze the transmission network performances and stability. This section summarizes the study and its results, and concludes the analysis with the recommendations and the impact on the results of the economic study.

3.6.1. Model construction and scenarios investigated

Model construction

The transmission network performances and stability analysis was performed first for year 2015, at peak and off peak load conditions. For this year, an important work was furnished to build the simulation model with the limited information collected. Several assumptions were done to reinforce the national grids. It was supposed each country will undertake the necessary reinforcements inside its national network to face the load growth and the consequent power flows in its network. For the dynamic model, the information received was modeled but a lot of data were missing. As a consequence, data based on experience and good practices were used to complete the model.

In a second stage, the 2020 and 2025 peak load situations were investigated statically.

Scenarios definition

Two different scenarios were investigated for 2015:

- A first scenario, referred as the Base case, including all future network elements expected for 2015. The peak load forecasted, the new generation units and new transmission projects as listed in the inception report were used for building this scenario. Elements expected for after 2015 were not included in the model, except for the North-core interconnection and the OMVG interconnection. These exceptions were made in order to study a situation where all countries are interconnected and these two projects are of particular importance for Senegal, The Gambia, Guinea Bissau and Niger.
- A second scenario, referred as Scenario 2, being a variant of the Base case. In this variant, several network elements were removed. The goal of such scenario is to analyze the stability of the system for a realistic intermediate stage between the actual situation of the WAPP system and the expected Base case scenario. The situation examined is interesting for its weaknesses due to the limited number of commissioned interconnections:
- OMVG interconnection and Kaleta power plant are not in service. The Gambia and Guinea Bissau are not connected to the main system. Senegal is connected as an antenna on Mali. And the CLSG interconnection is another antenna connected to Ivory Coast.
- North-core interconnection is not in service. Niger is consequently interconnected only with Nigeria in 132 kV.
- Ghana-Burkina Faso-Mali interconnection is not in service (Bolgatanga-Kodeni-Sikasso).
- Ghana-Burkina Faso interconnection is limited to its 225 kV part from Bolgatanga to Ouagadougou and is not supported by the 330 kV north-south link in Ghana. The latter is not in service.

- The interconnection between Ghana and Ivory Coast is limited to the 225 kV between Abobo and Elubo. The 330 kV link between Riviera and Prestea is not in service.

As a result, in Scenario 2, the WAPP system is a long line of interconnected countries from Niger to Senegal, with an antenna for the CLSG interconnection and with the interconnection of Burkina Faso to Ivory Coast and Ghana.

For 2020 and 2025, the new transmission and production projects and the international exchanges recommended by the economic study were integrated.

3.6.2. Conclusions of static studies

Operation optimization and reactive compensation

Static studies were first carried out. The system operation was optimized to respect all operation criteria (voltage ranges and overloads) and maximize the reactive margins on the generator units. When operation criteria could not be respected, reactive compensation was installed to reach an acceptable steady-state operation.

As a general conclusion, the power factor of the load in 2015 was assumed to be 0.85 everywhere in the network, and it is recommended to install capacitor banks to increase this power factor and reduce the reactive transits, particularly in Nigeria but also in Ghana, Ivory Coast, Togo, Benin and Mali. A target value of 0.9 is recommended for the power factor in general and it is even recommended to reach a power factor of 1 in the main load centers (big cities and industrial areas).

The network being composed of long interconnection lines, it clearly comes out of the study that capacitor banks should be installed at low voltage levels to improve the power factor and reduce the reactive power flows, and that reactor banks should be installed at high voltage levels to absorb the reactive power produced by the long and low loaded interconnection lines. Finally, a good coupling between the high voltage lines and the reactances absorbing the reactive power they produce is mandatory to avoid large over or under-voltages in case of contingencies.

Security analysis

The security analysis simulated all lines, transformers and units contingencies.

As a general conclusion, there are three main problems:

- The voltage management with few areas at risk: the north of Togo and Benin, parts of Mali (particularly Segou substation), Senegal and Burkina Faso. It is recommended to install additional voltage control means, like capacitor/reactor banks or SVC, to control adequately the voltages in these sensitive areas. It is also recommended to keep a minimum number of generation units running in the importing countries to support the voltage.
- The reinforcements needed to evacuate properly the power from the new projects. Particularly the evacuation of the hydro power from Guinea, Sierra Leone, Liberia and Ivory Coast to the other countries will need transmission reinforcements.
- The long loops formed by the interconnections. Contingencies on these loops do not comply with the N-1 criterion. Their contingencies often provoke instability due to the consequent flows redistribution.

Short-circuit study

The short-circuit study revealed risks in Nigeria (in the south), Ghana (Tema area) and Ivory Coast (Abidjan area), due to the important generation projects foreseen in these zones.

By lack of information, assumptions were done for the breaker capacities according to the voltage levels. These breaker capacities should be verified to make sure the short-circuit currents calculated are below. Otherwise, it is recommended to install breakers with higher breaking capacities. The levels to be reached are indicated in section 3.4.4.

3.6.3. Conclusions of dynamic studies

The dynamic studies detected stability issues of primordial importance that are here highlighted.

Small signal stability

The conclusions of the small signal stability are among the most important of this study.

The small signal stability was performed for both scenarios, calculating the eigenvalues to detect the least damped oscillation modes. Several modes were detected which are all related to inter-area oscillations. The least damped ones are between:

- The block Ghana/Ivory Coast and the block Senegal/Guinea,
- Mali and Senegal,
- The block Senegal/Guinea and Nigeria,
- Burkina Faso and Ivory Coast,
- The block Ghana/Ivory Coast/Togo/Benin and the block Guinea/Sierra Leone.

The time domain simulations in the study also confirmed these oscillations modes and concluded that they strongly reduce the stability margins (transient stability margins, maximum transfer capacities,…). To damp these oscillations and get rid of the stability limits they impose on the system, it is strongly recommended to:

- Install PSS on all new large future units to be installed in the system.
- Check if PSS do not already exist on the biggest machines of every country and, if not, install one.
- Stress the importance of inter-area oscillations analysis in detailed feasibility studies of future interconnections.
- Install Wide Area Monitoring Systems (WAMS) at different places in the network to detect and observe the inter-area oscillations. Moreover, it would be very useful to confirm they are correctly damped after PSS installations.

Transient stability

The transient stability study calculated the critical clearing times for metallic three phases short-circuits at all HV nodes were generators are connected. The results were compared to the base clearing time of the protections, assumed to be 100 ms, to verify the units will not lose synchronism in case of fault.

The results showed some values below 100 ms. After installation of PSS in the system, the same simulations calculated values above 100 ms. This stresses the impact of the inter-zonal oscillations on the overall stability of the system.

As a conclusion, the installation of PSS, as recommended in the small signal stability conclusions, will remove the risk of seeing one single unit lose synchronism in case of three phase fault cleared in base time. Losses of synchronism will still be possible, but they will concern parts of the network and not single units.

Units contingencies

Units contingencies were simulated dynamically. The goal was to check the operation criteria in case of contingency.

For the Base case, all units contingency are supported, except the loss of the coal power unit of Sendou, in Senegal. This contingency provokes an increase of the imported power on the interconnections and the maximum transfer capacity is reached, causing the loss of synchronism and the voltage collapse of Senegal.

For Scenario 2, since there are fewer interconnections, the voltage control is more difficult. After units contingencies, voltage collapses or voltages out of the +10/-10% range allowed after contingencies were detected in Senegal, Mali, Burkina Faso, Niger, Guinea, Liberia and Sierra Leone.

Spinning reserve, primary frequency control and WAPP operation manual

The spinning reserve was sized to the largest unit contingency in the system: one gas turbine and half the power of the steam turbine in the combined cycle of Okpai (Kwale) in Nigeria. This represents 267.8 MW.

The spinning reserve was distributed among the countries according to a rule based on their national load level in comparison with the global load of the WAPP system.

With such level of spinning reserve spread sufficiently on the running units, it was observed that the frequency drop can be limited to values above 49.3 Hz, which is satisfactory. The lowest frequency reached will depend on the amount of active power lost, but also on the repartition of the spinning reserve on the running units. It is recommended to spread this reserve on as many units as possible.

In case a country is interconnected to the rest of the system via a single line, it is important that this country keeps enough spinning reserve to face the loss of the interconnection, with the related imports. Another solution to face such incident is to rely on special protection schemes and defense schemes.

Moreover, the analysis of the WAPP operation manual revealed that:

- The first UFLS thresholds are set at 49.5 and 49.2 Hz.
- All units must remain connected between 48.5 Hz and 51 Hz.

It is recommended to review these values. The first UFLS threshold should be set at 49 Hz, to support the frequency drop and the speed requirements for generating units should be enlarged to 47.5 Hz and 52.5 Hz. Generation units are usually able to support such speed levels, and it would leave a frequency range from 49 to 48Hz to set up the UFLS thresholds.

Finally, UFLS should be installed in all countries, and should be harmonized for countries where it already exists. A proposal for harmonization has already been done for Ghana, Ivory Coast, Burkina Faso, Togo and Benin, in the frame of Ghana’s Transmission Masterplan Study. This study was performed recently and the note with the recommendations for the harmonization of the UFLs can be found in appendix.

Use of the three phase fault as a sizing incident

The simulation of metallic three phase faults on lines showed the incapacity of the system to support the transient and recover to a stable state.

Once again, many problems are worsened by the poor damping of the inter-area oscillations and installing PSS would increase the stability of the system facing three phase faults.

Nevertheless, problems remain even after installation of PSS. The three phase fault is a too severe incident for the system stability.

It is consequently recommended to use the single phase fault as sizing incident and rely on protection and defense schemes in case three-phase faults would occur. The latter has a low probability of occurrence and in large systems with long distances as the WAPP, it is usually not supported.

Maximum transfer capacities: OMVG and North-core critical contingencies

Dynamic simulations of lines contingencies revealed the critical stability issues of the North-core and OMVG interconnections:

- With the installation of the OMVG network, a loop is created, formed by the OMVG, CLSG and OMVS interconnections. In case of contingency of one element of this loop, the initial flows are redirected on the remaining part of the loop. The long distances and the importance of the redirected flows are such that the system is unable to support them. It will provoke voltage collapses and losses of synchronism. This is critical for Senegal, which expects to increase its importation with the OMVG interconnection.
- The North-core interconnection is of utmost importance for Niger and will also permit to send power from Nigeria to Burkina Faso. In this study, the part of the interconnection between Birnin Kebbi (Nigeria) and Niamey (Niger) is assumed to be a single line with tapping to Malanville (Benin). In case of contingency, the three sides of the line are tripped and the stability in Niger is highly compromised.

The problems detected on these interconnections are related to the high flows expected. Reducing these flows could be a stable solution but would be unaffordable for the economics of the system. It is consequently recommended to:

- Reinforce these interconnections. Different possible solutions exist:
  - doubling the circuits,
  - planning new interconnections (from Manantali in Mali to Tambacounda in Senegal, linking the OMVG and OMVS grids, for instance to reinforce the loop OMVS-OMVG-CLSG),
  - changing the foreseen topology of the interconnections (the feasibility study of the North-core interconnection studied different cases for different topologies between Niamey, Birnin Kebbi, Malanville and Zabori for instance).
  - Installing SVC. In these cases, Niamey in Niger and Tobene in Senegal are good locations. The SVC would improve the operation but will not solve the problems of loop instability.
- In the meantime, before such reinforcements are operational, operate the system beyond the N-1 stability limits relying on protection schemes and defense schemes (out of step protections, UFLS, UVLS). The installation of such defense actions is strongly recommended because these areas are so weak that the loss of a line could lead to blackout in Senegal or in Niger.

Maximum transfer capacities: Determination of the stability limit

For meshed interconnected systems, the maximum transfer capacities are established for defined scenarios. Depending on the scenarios characteristics (production plan, load level, exchanges forecast,…) the results will be different.

The study examined the maximum transfer capacities for the two scenarios considered. It showed the stability of the system in N condition for the exchanges levels foreseen. It also showed the instability of the system in N-1 condition for the loop created by OMVG, CLSG and OMVS interconnections, and for the line between Nigeria, Benin and Niger in the North-core interconnection. For what concerns the other interconnections, the system is stable in N-1 condition while reaching the exchanges levels foreseen.

Because the maximum transfer capacity depends on too many parameters, it is never recommended, in meshed systems, to limit the transfer to a fixed and determined value. The usual practice consists in carrying out daily dynamic simulations to reproduce the expected network state for the next day, and calculate the maximum transfer capacities for that scenario.

It requires the installation of a communication system to exchange information between countries. With such information, it is possible to simulate the network state expected for the next day, check the impact of loopflows and verify the maximum transfer capacity limits are respected.

It is recommended to initiate such communication system and be ready for doing these daily simulations when the OMVG and North-core interconnections will be commissioned.

Dynamic simulation model

Given the importance of the dynamic simulations results presented above, it is necessary to emphasize the limits of the dynamic model used in this study.

As already explained, a lot of assumptions were done to complete the missing information. The experience of the Consultant and international good practices were applied to this task.

Though the quality of the dynamic model is sufficient to perform this study and does not put into question the validity of its results, it is recommended to undertake a dedicated data collection to improve this dynamic model.

The goal of this improvement is to reach a sufficient quality to perform other studies such as:

- The tuning of the protection schemes and defense schemes
- The daily calculation of maximum transfer capacities

To this purpose the data collected on dynamics of the generators must be improved, in terms of dynamic parameters and transfer functions of controllers, especially the biggest ones. But also the load model, and its share of rotating loads, must be improved thanks to dedicated data collection and/or recordings of the system behavior. The share of rotating load has a great impact on the voltage recovery in the system after a fault.

3.6.4. Critical conclusions

The set of interconnection projects that have been considered constitute the minimum regional transmission equipment that is necessary to for the long term development of the WAPP countries. The projects taken into account are priority investments but still they are not sufficient. Indeed, even after implementing all these projects, some weaknesses remain on the system. The weak points are the following:

- The presence of inter-zonal oscillations in the future interconnected system, reducing the stability. Their future presence is very likely, whatever the interconnections planned in the system. Such oscillations appear in large system, with long interconnection lines. Given the geography, and the willingness of the WAPP countries to interconnect, any investment list would lead to intermediate network situation where inter-zonal oscillations would appear. Nevertheless, this project should improve in the future, with the progressive reinforcements of the interconnections.
- The incapacity to cover the N-1 criterion on the OMVG, CLSG, OMVS and North-core interconnections. Unless two or more interconnections are built at the same time, there will be an intermediate development stage of the system where configurations like the OMVG, CLSG and OMVS loop will appear.

As a conclusion, it is recommended to:

- Install PSS to improve the small signal stability of the system.
- Add transmission lines to evacuate the power from the hydro projects in Guinea, Sierra Leone, Liberia and Ivory Coast to the other countries. The following interconnections are in first positions: Linsan-Manantali, Manantanli-Kodialani-Sikasso, Fomi-Boundiali, OMVG and CLSG.
- Reinforce the interconnections with Senegal to make the OMVG-OMVS-CLSG loop stable in N-1 condition for the expected exchanges level. Different options are possible:
  - Doubling the circuits
  - Adding new interconnections (Kayes-Tambacounda, Linsan-Fomi-Kodialani, Linsan-Manantali and Fomi-Boundiali are good examples)
- Reinforce the interconnections with Niger to make the North-core interconnection stable in N-1 condition with the expected flow levels. Different options are possible:
  - Doubling the circuits
  - Reviewing the foreseen topology (commissioning of an intermediate substation at Zabori or separation of the line Birnin Kebbi-Niamey with tapping to Malanville into two different lines from Malanville to Niamey and from Malanville to Birnin Kebbi, for instance).
- Rely on defense schemes for operating the system beyond the limits imposed by the N-1 criterion before these reinforcements are commissioned.
- Harmonize the UFLS schemes of the different countries.
- Compensate the load to reach a minimum power factor of 0.9. A power factor of 1 should be reached in the main urban centers.
- Install additional means to keep the voltages in admitted ranges inside national grids (north Togo and Benin, Burkina Faso, Mali, Senegal). SVC in Niger and Senegal could improve the stable operation of the huge loops formed by the OMVG-OMVS-CLSG and the North-core-Coastal backbone interconnections.
- Improve the dynamic simulation model of the WAPP countries.
- Implement a communication system to exchange data between countries.

- Prepare to perform daily calculations of maximum transfer capacities according to the network state expected for the next day.

3.6.5. Impact on the results of the economic study

The technical study examined the recommendations of the economic study and investigated the operation problems the new production projects and the associated power flows will provoke.

Besides all the recommendations above-mentioned, the main goal is to determine the impact of technical issues on the priority investment list, i.e. on the conclusions of the master plan.

The critical issues detected that will influence the priority projects list are the following:

- The evacuation of the hydro power from Guinea, Sierra Leone, Liberia and Ivory Coast to the other countries. The most economic development plan for the WAPP system is to invest in hydro projects in these countries and export the power to the other countries, replacing the expensive thermal plants. This implies new interconnection lines and reinforcements of existing interconnection lines to support the power flows. It is very important to link the production projects with transmission projects to avoid developing the transmission projects without having any power to export.
- The stability of the long interconnection loops and the compliance with the N-1 criterion. The example of the CLSG-OMVG-OMVS loop has been quoted above. Such loops are very difficult to operate in a stable way, while keeping the high power flows levels expected and respecting the N-1 criterion. They are prone to lead the system to instability and should be avoided and/or shortened. The interconnection between Guinea and Mali, passing through Fomi, should shorten the loop but it is not sufficient to ensure a stable operation.
- The voltage support in the importing countries. The importing countries tend to shut down their generation for importing power. Doing this, there are less units in service and the voltage support is consequently weakened. The stability in these countries is usually the factor determining the maximum power transfer capacity on the interconnections. In this case, the use of SVC is a good solution. Building new production plants in these countries is another solution.

Based on these issues, the following influence can be noted on the projects to be supported at regional level.

The interconnection line between Linsan and Manantali, with the development of the hydro power plants of Boureya and Koukoutamba, and reinforcements of the lines towards Bamako in Mali

This interconnection line will permit to evacuate the power from the hydro sites of Boureya and Koukoutamba. It will also permit to reduce the loop formed by the OMVG-OMVS and CLSG interconnection, and consequently improve the stability in the area.

The study showed that the creation of this line increases the flows on the lines from Manantali to Bamako in Mali and Kodeni (Bobo Diolasso) and Zagtouli (Ouagadougou) in Burkina Faso. At least the line from Manantali to Kodialani should be reinforced.

This project should be implemented as soon as possible, as recommended in the economic study which quotes 2018.

The issue of the connection to Linsan or Labe was raised. It is recommended to connect it to Linsan. With Kaléta and Sambangalou, there is enough production to feed Sénégal, The Gambia and Guinea Bissau. The power of these plants will then be transited to the CLSG countries, to Mali, Burkina Faso and Ghana. It is consequently better to connect to Linsan instead of Labe to shorten the distances these flows will travel.

The coal power plant of Salkadamna with interconnection of River and Center-East areas in Niger, and interconnection to Nigeria

The North-core interconnection between Benin, Niger and Nigeria is a critical interconnection for the stability in Niger. The reinforcement of the area can be achieved by developing the project of Salkadamna, with interconnection of the River and Center-East areas in Niger.

The project could be developed in two phases, with priority for the River area connection, to be realized as soon as possible, especially if the hydro projects of Kandadji and Dyodyodonga are not implemented. Nevertheless, the interconnection with the zone of Kano and Katsina in north Nigeria would be very useful to supply this area of north Nigeria. This zone should be fed also by the 760 kV foreseen in Nigeria. This second phase is less urgent and could be realized after 2020.

The 225 kV line between Kayes and Tambacounda with the project of Gouina

The project of Gouina is decided and it is expected to be accompanied with a 225 kV line from Kayes to Tambacounda. This line is critical to improve the stability of the interconnections and imports towards Senegal. It is important, on a technical point of view, to ensure that this line will be built with the project of Gouina.

The production projects in Senegal: coal power plant of Sendou and renewables

The large imports of power in Senegal represent a threat for the stability of this area located at the extreme West of the WAPP system. Increasing the production in Senegal is necessary to follow the national load but it also means reducing its imports and improving the stability. Therefore, the coal plant project of Sendou and the renewable opportunities (wind energy) should be supported, and realized as soon as possible.

Renewable projects in importing countries: Burkina Faso, Mali and Niger

These three countries have important renewable opportunities (wind or solar). The latter would permit to reduce the imports, while in the same time improving the stability and providing voltage support sources.

These productions would permit to face the eventual delays in the development of hydro power in Guinea. They would also avoid the investment of new interconnection lines to transit such hydro power.

They could be realized as soon as possible.

The interconnection line between Fomi and Boundiali

This line is useful to export the hydro power from Guinea to Burkina Faso. It also reduces the size of the loop composed of the CLSG-OMVG-OMVS interconnections.

Nevertheless, the stability improvements only are not sufficient to justify the investment. Since the goal is to export hydro power, this project should be realized in addition with hydro projects in the area. Most of the projects with a regional character are not located in this area. And even the realization of hydro project in the area of Linsan could see their power first evacuated via the 225 kV line from Linsan to Fomi before going to Boundiali.

The reinforcement of the western part of the OMVG interconnection

This interconnection should be reinforced because it is of utmost importance for The Gambia and Guinea Bissau, it permits to evacuate the hydro power from Guinea, and it improves the stability of the loop OMVG-OMVS-CLSG.

To couple it with a hydro production project, Poudadlé, Amarya or Balassa are good candidates

The reinforcement of the CLSG interconnection and/or the interconnection line between Monrovia (Liberia) and San Pedro (Ivory Coast)

On one side, when the flows from Ivory Coast to Liberia will reverse with the development of the hydro project in Guinea, Sierra Leone and Liberia, the CLSG interconnection will have to be reinforced. On the other side, the hydro project of Tiboto is located exactly on the border between Liberia and Ivory Coast and its realization supposes the interconnection from Monrovia to San Pedro, which is parallel to the CLSG interconnection.

The best proposal would be to reinforce the CLSG interconnection between Monrovia and Man, while developing the Tiboto project with connection to Ivory Coast only. This proposal is justified by the distance ratio between Tiboto/San Pedro and Tiboto/Monrovia, and by the expected flows direction from Ivory Coast to Ghana and Burkina Faso. This proposal is not incompatible with the fact that Liberia would have its share of the energy of Tiboto, since it is located on the border and this share is just a matter of flows measurements.

Nevertheless, if this proposal was unacceptable for Liberia, developing both the interconnection Monrovia-San Pedro and doubling the CLSG between Monrovia and Man is not necessary on the medium term, but could become necessary on the long term if more hydro projects were to be developed in Sierra Leone or Liberia.

The median backbone project and the hydro plant of Zungeru (Nigeria)

The hydro project of Zungeru could be fully absorbed by Niger and Nigeria, without need of new evacuation lines to the north of Togo and Benin. Nevertheless, the median backbone interconnection is important to reduce the loop formed by the North-core and the Coastal backbone interconnections.

If Zungeru is a priority and could be developed as soon as possible, the median backbone is not urgent.

The coastal backbone reinforcement

This reinforcement does not seem to be a priority according to the technical study. Togo is expected to import in the coming years and the economic study proposed to build a combined-cycle in the country. This will reduce the imports and the need of reinforcements of this interconnection.

The reinforcement of the north-south axis in Benin

Neither the load in the north of Benin nor the export from Benin to Niger seem important enough to label this reinforcement as high priority according to the technical study results.

From a stability point of view, this reinforcement reduces the instability of the loop formed by the North-core and the Coastal backbone interconnections.

The reinforcements in northern Ivory Coast, in Mali and in Burkina Faso

In case an important number of projects are developed in Guinea, Sierra Leone, Liberia and Ivory Coast, with purpose of exporting towards Mali, Burkina Faso and Ghana, other high voltage lines should be reinforced:

- 225 kV line Manantali-Kodialani (Mali)
- 225 kV line Kodialani-Sikasso-Kodeni (Mali-Burkina Faso)
- 225 kV line Soubre-Man-Laboa-Boundiali-Ferkessedougou (Ivory Coast)
- 225 kV line Ferkessedougou-Kodeni (Ivory Coast-Burkina Faso)
- 225 kV line Soubre-Taabo (Ivory Coast)
- 225 kV line Kodeni-Zagtouli (Burkina Faso)

Here again, these reinforcements projects are difficult to implement in association with the development of a particular hydro project. It is very important to develop them only if the flows were to increase.

Given the uncertainties on the capability of developing so many projects in Guinea, Sierra Leone and Liberia, and the fact that some hydro projects are usually associated with mines projects rather than exports to neighboring countries, these reinforcement projects could be considered on the long term only.

4. APPENDIX: STATIC STUDIES: SHORT-CIRCUIT ANALYSIS: RESULTS

Node Name	Voltage kV	Breaker rating kA	Country Name	3ph SC current Base case kA	3ph SC current BC all units kA	3ph SC current Scenario 2 kA	3ph SC current SC2 all units kA
AEROPO08	90	25	SE	7.11	9.88	8.10	9.84
BELAIR08	90	25	SE	9.72	15.84	11.44	15.73
CAPEBI08	90	25	SE	12.2	23.87	16.63	23.59
DAGANA03	225	31.5	SE	2.24	2.36	2.17	2.21
FICT1_08	90	25	SE	8.57	12.96	10.32	12.88
FICT2_08	90	25	SE	6	6.91	6.30	6.75
HANN__08	90	25	SE	10.51	17.72	12.81	17.58
KAHO1_03	225	31.5	SE	3.48	3.69	2.30	2.40
KAOLAC08	90	25	SE	4.61	4.78	3.81	3.92
KOUNOU03	225	31.5	SE	2.29	2.66	2.41	2.60
KOUNOU08	90	25	SE	11.22	17.29	13.47	17.03
MATAM_03	225	31.5	SE	1.74	1.90	1.85	1.87
MATAM_08	90	25	SE	3.34	3.57	3.50	3.52
MBAO__08	90	25	SE	10.07	16.83	12.79	16.70
MBOUR_08	90	25	SE	3.32	3.55	3.33	3.45
MECKHE08	90	25	SE	2.43	2.50	2.36	2.40
PATTED08	90	25	SE	9.72	15.63	11.72	15.52
SAKAL_03	225	31.5	SE	2.68	2.84	2.44	2.52
SIBA__08	90	25	SE	5.39	6.88	6.05	6.86
SOCOCI08	90	25	SE	12.07	18.16	14.48	17.82
SOMETA08	90	25	SE	3.39	3.66	3.49	3.62
TAIBA_08	90	25	SE	3.85	4.01	3.66	3.75
TAMBAC03	225	31.5	SE	1.48	1.59	1.28	1.38
TANAF_03	225	31.5	SE	2.67	2.88		
THIONA08	90	25	SE	4.84	5.27	4.86	5.08
TOBENE03	225	31.5	SE	3.08	3.31	2.70	2.81
TOBENE08	90	25	SE	5.92	6.30	5.48	5.68
TOUBA_03	225	31.5	SE	3.04	3.23	2.39	2.49
UNIVER08	90	25	SE	7.37	10.42	8.37	10.38
ZIGUIN03	225	31.5	SE	1.59	1.78		
BRIKAM03	225	31.5	GA	2.78	2.87		
SOMA__03	225	31.5	GA	3.25	3.43		
BAMBAD03	225	31.5	GB	2.47	2.56		
BISSAU03	225	31.5	GB	2.4	2.51		
MANSOA03	225	31.5	GB	2.58	2.71		
SALTHI03	225	31.5	GB	2.47	2.54		
BOKE__03	225	31.5	GU	2.76	2.81		
DONKEA07	110	25	GU	3.78	3.85	3.19	3.21
GARAFI07	110	25	GU	4.89	4.93	3.79	3.82
GRCHUT07	110	25	GU	5	5.16	3.98	4.01
KALETA03	225	31.5	GU	4.43	4.51		
KINDIA07	110	25	GU	4.65	4.75	3.61	3.64
LINSAN03	225	31.5	GU	3.57	3.69	1.68	1.72
LINSAN07	110	25	GU	6.13	6.24	3.90	3.96
MAMOU_07	110	25	GU	2.33	2.34	1.89	1.91
MATOTO07	110	25	GU	4.73	5.03	3.85	3.86
NZEREK03	225	31.5	GU	1.52	1.68	1.46	1.55
BALING05	150	25	MA	3.85	6.19	3.54	5.34
FANA__05	150	25	MA	1.75	2.04	1.79	1.97
KALABA05	150	25	MA	3.88	5.65	3.60	4.73
KAYES_03	225	31.5	MA	2.33	2.99	2.95	2.96
KENIE_05	150	25	MA	3.04	3.94	2.47	3.12
KODIAL03	225	31.5	MA	2.8	3.38	2.13	2.41
KODIAL05	150	25	MA	3.85	5.50	3.56	4.57
KOUTIA03	225	31.5	MA	1.79	2.32	1.61	1.74
LAFIA_05	150	25	MA	3.36	4.68	3.23	4.00
MANANT03	225	31.5	MA	4.06	4.33	4.05	4.13
OULESS03	225	31.5	MA	2.52	2.94		
SEGOU_03	225	31.5	MA	1.31	1.56	1.27	1.34
SEGOU_05	150	25	MA	1.51	1.77	1.59	1.67
SELING05	150	25	MA	1.98	2.23	1.94	2.12
SIKASS03	225	31.5	MA	3.06	3.83	1.99	2.17
SIRAKO05	150	25	MA	4.14	6.68	3.81	5.63
TKITA_03	225	31.5	MA	2.61	2.88	2.25	2.42
BIKONG03	225	31.5	SL	1.84	2.13	1.55	1.68
BUMBUN03	225	31.5	SL	2.23	2.60	1.76	1.89
BUMBUN04	161	31.5	SL	2.45	3.36	2.21	2.45
FRTOWN04	161	31.5	SL	1.35	2.00	1.30	1.88
KAMAKW03	225	31.5	SL	2.36	2.54	1.61	1.68
KENEMA03	225	31.5	SL	1.77	2.12	1.52	1.68
YIBEN_03	225	31.5	SL	2.24	2.48	1.65	1.74
BUCHAN03	225	31.5	LI	1.72	2.19	1.60	1.81
MANO__03	225	31.5	LI	1.7	2.12	1.51	1.67
MONROV03	225	31.5	LI	1.76	2.40	1.59	1.80
YEKEPA03	225	31.5	LI	1.74	1.96	1.67	1.79
2000HIRE	90	25	CI	3.88	3.92	3.87	3.90
200SIR90	90	25	CI	11.4	12.40		
2010ABOB	225	31.5	CI	12.99	17.10	12.84	15.32
2011ABOB	90	25	CI	22.69	27.30	22.07	25.47
2020VRID	225	31.5	CI	13.93	18.10	13.11	15.60
2021VRID	90	25	CI	26.66	33.09	25.65	30.75
2030TAAB	225	31.5	CI	8.47	9.14	8.38	8.87
2031TAAB	90	25	CI	7.83	8.05	7.80	7.96
2040KOSS	225	31.5	CI	5.38	5.58	5.27	5.43
2041KOSS	90	25	CI	7.58	7.75	7.50	7.65

Table 126 – 3ph short-circuit current levels for 2015 (1/4)

Node Name	Voltage kV	Breaker rating kA	Country Name	3ph SC current Base case kA	3ph SC current BC all units kA	3ph SC current Scenario 2 kA	3ph SC current SC2 all units kA
2050BOUA	225	31.5	CI	2.99	3.10	2.84	2.92
2051BOUA	90	25	CI	3.16	3.19	3.11	3.13
2060FERK	225	31.5	CI	3.07	3.61	2.38	2.57
2061FERK	90	25	CI	3.03	3.20	2.71	2.80
2070SOUB	225	31.5	CI	3.82	4.08	3.79	4.03
2071SUBR	90	25	CI	3.6	3.68	3.59	3.67
2080S-PE	225	31.5	CI	1.87	1.93	1.87	1.92
2081PEDR	90	25	CI	3.49	3.57	3.48	3.55
2090BUYO	225	31.5	CI	3.47	3.93	3.42	3.86
2091BUYO	90	25	CI	3.55	5.00	3.53	4.97
20FAYE90	90	25	CI	1.98	2.00	1.98	1.99
2100MAN-	225	31.5	CI	2.21	2.40	2.12	2.26
2101MAN-	90	25	CI	2.54	2.63	2.49	2.56
2110LABO	225	31.5	CI	1.69	1.78	1.60	1.66
2111LABO	90	25	CI	2.11	2.16	2.04	2.08
2120AGBO	90	25	CI	3.16	3.21	3.16	3.19
2130DABO	90	25	CI	2.15	2.17	2.15	2.17
2140BONG	90	25	CI	2.73	3.20	2.73	3.19
2150PLAT	90	25	CI	22.45	26.82	21.73	25.08
2160BIAN	90	25	CI	22.33	26.66	21.61	24.90
2170AYAM	90	25	CI	2.06	3.47	2.05	3.46
2180AYAM	90	25	CI	2.06	3.51	2.06	3.50
2190ABRO	90	25	CI	2.82	3.35	2.81	3.34
2200BASS	90	25	CI	4.27	4.74	4.23	4.69
2209RIVI	225	31.5	CI	13.74	16.84	11.14	12.82
2210RIVI	90	25	CI	19.51	22.59	18.43	20.84
2220BIAS	90	25	CI	19.22	22.22	18.50	20.92
2229YOPO	225	31.5	CI	13	17.49	12.83	15.48
2230YOPO	90	25	CI	14.1	15.66	13.85	15.13
2231YOPO	90	25	CI	14.43	16.14	14.28	15.47
2240TREI	90	25	CI	22.38	26.71	21.66	25.01
2250YAMO	90	25	CI	2.83	2.84	2.82	2.83
2260DIMB	90	25	CI	2.71	2.73	2.70	2.72
2270ATAK	90	25	CI	1.2	1.20	1.20	1.20
2280ABEN	90	25	CI	1.06	1.06	1.06	1.06
2290AGNE	90	25	CI	0.97	0.97	0.97	0.97
2300SERE	90	25	CI	0.88	0.88	0.87	0.87
2310DIVO	90	25	CI	2.27	2.28	2.27	2.28
2320GAGN	90	25	CI	1.84	1.85	1.84	1.85
2330ZUEN	90	25	CI	1.3	1.30	1.30	1.30
2340BOUA	90	25	CI	4.7	4.79	4.56	4.62
2350MARA	90	25	CI	1.27	1.27	1.26	1.26
2360KORH	90	25	CI	2.01	2.08	1.88	1.92
2370BUND	90	25	CI	2.54	2.63	2.38	2.43
2371BUND	225	31.5	CI	1.83	1.95	1.64	1.70
2380ODIE	90	25	CI	1.36	1.38	1.32	1.33
2390SEGU	90	25	CI	0.95	0.96	0.94	0.94
2400DANA	90	25	CI	1.08	1.09	1.07	1.08
2410DALO	90	25	CI	1.96	2.06	1.95	2.05
2500AZIT	225	31.5	CI	13.41	18.39	13.23	16.13
RIVIER02	330	31.5	CI	6.02	6.62		
4BAGR132	132	25	BU	1.16	1.21	0.93	0.94
4KODE225	225	31.5	BU	2.86	3.56	1.74	1.88
4KOMP132	132	25	BU	0.86	0.88	0.76	0.76
4KOSSO90	90	25	BU	5.61	8.74	3.58	4.56
4OUAG190	90	25	BU	5.34	8.30	3.70	4.72
4OUAG290	90	25	BU	5.22	8.07	3.75	4.76
4PTDO132	132	25	BU	2.2	2.70	1.12	1.17
4ZAGT225	225	31.5	BU	3.18	4.23	1.76	1.92
4ZAGTO90	90	25	BU	4.83	6.69	4.00	4.67
4ZANO132	132	25	BU	1.29	1.36	0.99	1.01
4_PA_225	225	31.5	BU	2.14	2.45	1.53	1.63
4_PC_090	90	25	BU	5.39	8.37	3.68	4.68
OUAGAE02	330	31.5	BU	2.01	2.55		
OUAGAE03	225	31.5	BU	3.2	4.32		
OUAGAE08	90	25	BU	6.96	9.94		
PATDOI08	90	25	BU	4.36	5.50	1.26	1.30
1010AKOS	161	31.5	GH	25.1	31.09	25.38	28.92
1020VOLT	161	31.5	GH	19.47	33.57	20.84	28.43
1021SME2	161	31.5	GH	18.24	32.64	19.76	27.11
1029VOLT	330	31.5	GH	7.11	8.78	7.10	8.13
1031SMEL	161	31.5	GH	17.62	30.72	19.03	25.76
1032SMEL	161	31.5	GH	17.62	30.72	19.03	25.76
1033SMEL	161	31.5	GH	17.62	30.72	19.03	25.76
1034SMEL	161	31.5	GH	17.62	30.72	19.03	25.76
1035SMEL	161	31.5	GH	17.62	30.72	19.03	25.76
1036SMEL	161	31.5	GH	17.62	30.72	19.03	25.76
1040TEMA	161	31.5	GH	17.89	29.84	19.04	25.79
1050ACHI	161	31.5	GH	13.93	18.65	14.41	17.12
1060WINN	161	31.5	GH	5.29	5.66	5.28	5.52
1070C-CO	161	31.5	GH	5.11	5.31	5.01	5.18
1080TAKO	161	31.5	GH	14.24	15.61	12.86	13.93
1090TARK	161	31.5	GH	12.56	13.49	9.73	10.17
1095NEWT	161	31.5	GH	10.44	11.08	8.24	8.55
1100PRES	161	31.5	GH	13.75	14.96	9.51	9.90

Table 127 – 3ph short-circuit current levels for 2015 (2/4)

Node Name	Voltage kV	Breaker rating kA	Country Name	3ph SC current Base case kA	3ph SC current BC all units kA	3ph SC current Scenario 2 kA	3ph SC current SC2 all units kA
1109PRES	225	31.5	GH	7.1	7.57	5.82	5.99
1110DUNK	161	31.5	GH	6.66	6.93	5.95	6.16
1120OBUA	161	31.5	GH	7.47	7.81	6.56	6.82
1130KUMA	161	31.5	GH	9.25	9.85	6.63	6.98
1138T261	161	31.5	GH	4.54	4.67	4.18	4.31
1138T262	161	31.5	GH	7.75	8.17	5.91	6.20
1139K2BS	161	31.5	GH	9.48	10.07	5.80	6.04
1140NKAW	161	31.5	GH	7.86	8.20	6.84	7.07
1150TAFO	161	31.5	GH	9.56	10.14	9.21	9.59
1160AKWA	161	31.5	GH	4.5	4.60	4.34	4.42
1170KPON	161	31.5	GH	16.51	19.89	16.79	18.79
1180KONO	161	31.5	GH	5.12	5.27	4.43	4.55
1190KPON	161	31.5	GH	11.79	13.07	11.92	12.68
1200ASAW	161	31.5	GH	4.55	4.71	4.18	4.35
1210JUAB	161	31.5	GH	3.22	3.30	3.02	3.12
1210N-OB	161	31.5	GH	8.01	8.41	6.95	7.25
1220ASIE	161	31.5	GH	5.55	5.90	5.60	5.83
1252KPAN	161	31.5	GH	2.45	2.51	2.46	2.50
1260TECH	161	31.5	GH	6.54	7.10	5.39	5.98
1270SUNY	161	31.5	GH	5.24	5.52	4.67	4.98
1278MIM	161	31.5	GH	3.15	3.23	2.94	3.05
1280TAMA	161	31.5	GH	2.48	2.55	2.05	2.14
1290BOLG	161	31.5	GH	4.87	5.23	2.35	2.48
12951BOL	225	31.5	GH	3.11	3.43	1.58	1.68
1300BOGO	161	31.5	GH	11.41	12.21	8.45	8.76
1309WEXF	161	31.5	GH	5.22	5.37	4.50	4.58
1320ABOA	161	31.5	GH	18.98	21.63	16.77	18.91
1340WA	161	31.5	GH	1.59	1.63	1.44	1.48
1350YEND	161	31.5	GH	1.22	1.23	1.10	1.13
1360ESSI	161	31.5	GH	6.47	6.91	5.70	5.78
1370MALL	161	31.5	GH	11.64	14.48	11.90	13.57
1380SAWL	161	31.5	GH	1.91	1.97	1.77	1.85
1390DCEM	161	31.5	GH	8.78	11.00	9.18	10.85
1392 AFT	161	31.5	GH	9.01	11.35	9.43	11.20
1413KENY	161	31.5	GH	6.32	6.70	5.56	5.95
1470TT1P	161	31.5	GH	16.15	28.61	17.80	23.95
1480ZEB	161	31.5	GH	3.17	3.32	1.95	2.06
1500BUI	161	31.5	GH	7.79	9.70	6.56	8.42
15533BSP	161	31.5	GH	17.17	26.54	18.14	23.32
1580N_AB	161	31.5	GH	4.33	4.43	4.00	4.07
1590KIN	161	31.5	GH	6.94	7.62	4.56	5.11
1591KIN3	330	31.5	GH	3.58	3.83		
1600OPB-	161	31.5	GH	6.88	9.31	5.39	5.43
1610BUIP	161	31.5	GH	3.19	3.31	2.63	2.78
1620TUMU	161	31.5	GH	1.8	1.84	1.46	1.50
1630HAN	161	31.5	GH	1.61	1.64	1.39	1.43
1700ASOG	161	31.5	GH	16.95	29.97	18.21	24.72
1750BONY	161	31.5	GH	11.36	13.76	7.78	7.87
1758BON3	330	31.5	GH	5.32	5.97		
1800ELUB	161	31.5	GH	8.23	8.97	7.32	7.44
1809ELUB	225	31.5	GH	6.35	6.86	5.91	6.04
1850ATEB	161	31.5	GH	2.49	2.57	2.09	2.19
1900TESI	161	31.5	GH	6.29	7.32	5.43	6.51
1901TES2	161	31.5	GH	5.72	6.65	5.03	6.02
1990AYAN	161	31.5	GH	4.59	4.72	4.23	4.37
ABOA_330	330	31.5	GH	6.69	7.26	5.52	5.95
BAWKU_04	161	31.5	GH	1.98	2.07	1.53	1.63
BOLGA330	330	31.5	GH	2.31	2.43		
KSI330	330	31.5	GH	4.93	5.27		
PRES330	330	31.5	GH	7.01	7.76		
30101LOM	330	31.5	TB	5.49	6.53	5.63	6.38
3010LOME	161	31.5	TB	10.07	13.25	10.62	13.04
3020MOME	161	31.5	TB	7.66	8.51	7.77	8.45
3030COTO	161	31.5	TB	13.53	17.50	13.73	17.43
3040SAKA	161	31.5	TB	14.15	16.10	14.15	15.96
3050ONIG	161	31.5	TB	5.02	5.27	4.88	5.18
3060NANG	161	31.5	TB	3.76	3.92	3.69	3.88
3ATAK161	161	31.5	TB	2.65	2.77	2.58	2.73
3BOHI161	161	31.5	TB	3.01	3.09	2.96	3.06
3DJOU161	161	31.5	TB	1.69	2.19	1.44	1.99
3KARA161	161	31.5	TB	1.86	2.40	1.64	2.23
3LOME161	161	31.5	TB	7.37	9.26	7.80	9.16
AVA___04	161	31.5	TB	6.01	6.45	6.05	6.43
BEMBER04	161	31.5	TB	1.73	1.95	0.98	1.19
DAPAON04	161	31.5	TB	1.68	1.78	1.40	1.53
GUENE_04	161	31.5	TB	2.4	2.55		
KANDI_04	161	31.5	TB	1.92	2.07	0.81	0.92
MALANV02	330	31.5	TB	2.44	2.72		
MALANV04	161	31.5	TB	2.82	3.00		
MANGO_04	161	31.5	TB	1.6	1.76	1.40	1.58
MA_GLE04	161	31.5	TB	14.96	19.08	15.23	19.00
NATITI04	161	31.5	TB	1.07	1.39	0.96	1.31
PARAKO04	161	31.5	TB	1.92	2.49	1.40	1.96
SAKETE02	330	31.5	TB	9.97	10.57	9.86	10.38
TANZOU04	161	31.5	TB	7.81	8.33	7.80	8.28

Table 128 – 3ph short-circuit current levels for 2015 (3/4)

Node Name	Voltage kV	Breaker rating kA	Country Name	3ph SC current Base case kA	3ph SC current BC all units kA	3ph SC current Scenario 2 kA	3ph SC current SC2 all units kA
DIFFA_02	330	31.5	NR	2.29	2.31	2.29	2.31
DOSSO02	330	31.5	NR	2.87	3.42		
DOSSO_06	132	25	NR	3.13	2.64	4.16	3.66
FRONT_06	132	25	NR	3.02	3.22	3.21	3.30
GAZAOU06	132	25	NR	2.74	2.88	2.74	2.88
MARADI06	132	25	NR	1.18	1.30	1.18	1.30
NIAM2C06	132	25	NR	0.73	0.60	0.98	0.80
NIAM2_06	132	25	NR	4.96	8.43	4.13	5.32
NIAMRD02	330	31.5	NR	2.51	3.41		
NIAMRD06	132	25	NR	5.06	8.27		
ZABORI02	330	31.5	NR	3.21	3.72		
ZINDER06	132	25	NR	2.6	2.75	2.60	2.75
ABUJA_01	760	31.5	NI	6.59	6.78	6.57	6.73
AFAM__02	330	31.5	NI	23.89	37.14	24.41	34.99
AIYEDE02	330	31.5	NI	10.84	11.06	10.65	10.84
AJAOKU01	760	31.5	NI	9.24	9.69	9.20	9.58
AJAOKU02	330	31.5	NI	21.02	21.78	20.94	21.59
AJA___02	330	31.5	NI	26.01	29.88	25.72	28.39
AKANGB02	330	31.5	NI	21.32	22.60	20.28	21.25
ALADJA02	330	31.5	NI	13.04	14.10	13.13	13.68
ALAGBO02	330	31.5	NI	17.53	19.20	17.39	18.56
ALAOJI02	330	31.5	NI	27.99	45.98	28.90	41.30
ALIADE02	330	31.5	NI	10.18	10.71	10.18	10.63
BENINC02	330	31.5	NI	37.22	42.31	36.98	41.15
BENINN01	760	31.5	NI	11.43	12.31	11.32	12.06
BENINN02	330	31.5	NI	34.67	38.35	34.41	37.45
BIRNIN02	330	31.5	NI	4.22	4.69	3.65	3.68
BIRNIN06	132	25	NI	3.78	4.04	3.91	3.96
CALABA02	330	31.5	NI	13.6	16.20	13.71	15.93
DAMATU02	330	31.5	NI	3.01	3.04	3.01	3.04
DELTA_02	330	31.5	NI	14.91	16.64	15.13	15.70
DELTA_06	132	25	NI	10.07	13.06	11.80	13.00
EGBEMA01	760	31.5	NI	7.18	7.91	7.18	7.80
EGBEMA02	330	31.5	NI	20.81	25.45	20.91	24.90
EGBIN_02	330	31.5	NI	31.75	38.25	31.44	35.86
EGBIN_06	132	25	NI	17.74	18.08	17.68	17.93
EPE___02	330	31.5	NI	18.72	20.18	18.45	19.48
ERUNKA01	760	31.5	NI	8.84	9.26	8.45	8.79
ERUNKA02	330	31.5	NI	29.52	32.15	26.05	27.82
EYAEN_02	330	31.5	NI	31.51	34.45	31.29	33.73
GANMO_02	330	31.5	NI	10.21	10.46	10.11	10.33
GEREGU02	330	31.5	NI	20.26	20.94	20.19	20.77
GOMBE_01	760	31.5	NI	1.78	1.80	1.78	1.80
GOMBE_02	330	31.5	NI	4.42	4.48	4.41	4.47
GWAGWA02	330	31.5	NI	14.48	14.81	14.43	14.72
IKEJAW02	330	31.5	NI	30.41	33.11	28.37	30.31
IKOTAB02	330	31.5	NI	10.21	23.64	10.30	23.34
IKOTAB06	132	25	NI	11.86	29.02	11.91	28.94
IKOTEK02	330	31.5	NI	22.48	36.04	22.91	34.27
JALING01	760	31.5	NI	1.82	1.85	1.82	1.84
JALING02	330	31.5	NI	3.72	3.77	3.72	3.76
JEBBAP02	330	31.5	NI	17.24	18.31	16.96	17.88
JEBBA_02	330	31.5	NI	18.3	19.39	17.97	18.89
JOS___02	330	31.5	NI	7.68	7.85	7.67	7.81
KADUNA01	760	31.5	NI	4.91	5.01	4.89	4.99
KADUNA02	330	31.5	NI	11.97	12.24	11.94	12.17
KAINJI02	330	31.5	NI	13.27	13.80	12.80	13.06
KANKIA06	132	25	NI	3.19	3.20	3.18	3.20
KANO__01	760	31.5	NI	3.49	3.55	3.49	3.54
KANO__02	330	31.5	NI	7.6	7.73	7.59	7.70
KANO__06	132	25	NI	13.37	13.53	13.35	13.50
KATAMP02	330	31.5	NI	14.48	14.82	14.44	14.73
KATSIN02	330	31.5	NI	4.1	4.15	4.09	4.15
KATSIN06	132	25	NI	7.61	7.72	7.60	7.71
KWALE_02	330	31.5	NI	13.72	14.48	13.74	14.35
LOKOJA02	330	31.5	NI	15.62	16.04	15.58	15.93
MAKURD01	760	31.5	NI	4.98	5.17	4.98	5.14
MAKURD06	330	31.5	NI	10.81	11.29	10.81	11.21
MAMBIL01	760	31.5	NI	2.18	2.21	2.17	2.21
NEWHAS02	330	31.5	NI	13.62	15.41	13.69	15.19
NEWHAV02	330	31.5	NI	13.41	15.12	13.47	14.90
NNEWI_02	330	31.5	NI	21.78	25.60	21.92	24.98
OMOKU_02	330	31.5	NI	14.4	17.76	14.45	17.51
OMOKU_06	132	25	NI	6.12	8.15	6.12	8.13
OMOTOS02	330	31.5	NI	23.01	24.43	22.49	23.44
ONITSH02	330	31.5	NI	26.91	31.56	27.05	30.77
OSHOGB01	760	31.5	NI	9.77	10.27	9.47	9.88
OSHOGB02	330	31.5	NI	22.9	24.02	22.42	23.36
OWERRI02	330	31.5	NI	25.16	31.71	25.42	30.63
PAPALA02	330	31.5	NI	23.5	24.70	22.52	23.45
PORTHA02	330	31.5	NI	13.52	16.96	13.68	16.49
SAPELE02	330	31.5	NI	26.2	30.58	26.15	30.04
SHIROR02	330	31.5	NI	16.23	16.59	16.17	16.49
SOKOTO02	330	31.5	NI	2.68	2.86	2.44	2.45
YOLA__02	330	31.5	NI	3.4	3.44	3.40	3.43
ZARIA_02	330	31.5	NI	7.28	7.38	7.27	7.36

Table 129 – 3ph short-circuit current levels for 2015 (4/4)

Node Name	Voltage kV	Breaker rating kA	Country Name	2020 kA	2025 kA	Node Name	Voltage kV	Breaker rating kA	Country Name	2020 kA	2025 kA
AEROPO08	90	25	SE	8.5	10.9	FANA__05	150	25	MA	1.9	2.1
BELAIR08	90	25	SE	12.4	18.9	KALABA05	150	25	MA	5.1	7.3
CAPEBI08	90	25	SE	15.8	26.2	KAYES_03	225	31.5	MA	4.9	5.1
DAGANA03	225	31.5	SE	2.4	2.6	KENIE_05	150	25	MA	3.5	4.3
FICT1_08	90	25	SE	10.4	14.1	KODIAL03	225	31.5	MA	4.6	6.4
FICT2_08	90	25	SE	6.1	9.7	KODIAL05	150	25	MA	5.2	7.3
HANN__08	90	25	SE	14.2	22.1	KOUTIA03	225	31.5	MA	2.1	2.4
KAOLAC03	225	31.5	SE	4.1	5.0	LAFIA_05	150	25	MA	4.7	6.5
KOUNOU03	225	31.5	SE	7.5	9.5	MANANT03	225	31.5	MA	7.3	8.4
KOUNOU08	90	25	SE	16.5	24.9	OULESS03	225	31.5	MA	3.5	5.3
MATAM_03	225	31.5	SE	2.1	2.2	SEGOU_03	225	31.5	MA	1.4	1.6
MATAM_08	90	25	SE	3.9	3.9	SEGOU_05	150	25	MA	1.6	1.9
MBAO__08	90	25	SE	12.5	18.2	SELING03	225	31.5	MA	3.5	4.0
MBOUR_03	225	31.5	SE	3.0	3.2	SELING05	150	25	MA	4.5	5.3
MECKHE08	90	25	SE	2.5	2.6	SIKASS03	225	31.5	MA	3.8	4.7
PATTED08	90	25	SE	12.6	18.5	SIRAKO05	150	25	MA	5.2	7.9
SAKAL_03	225	31.5	SE	2.9	3.2	TKITA_03	225	31.5	MA	4.6	6.2
SENDOU03	225	31.5	SE	7.7	9.6	BIKONG03	225	31.5	SL	2.1	3.9
SIBA__08	90	25	SE	6.1	7.2	BUMBUN03	225	31.5	SL	2.8	4.9
SOCOCI08	90	25	SE	12.5	17.3	BUMBUN04	161	31.5	SL	3.1	5.0
SOMETA08	90	25	SE	3.4	6.0	FRTOWN04	161	31.5	SL	1.5	2.7
TAIBA_08	90	25	SE	4.0	4.4	KAMAKW03	225	31.5	SL	3.2	4.0
TAMBAC03	225	31.5	SE	3.4	3.8	KENEMA03	225	31.5	SL	2.0	3.4
TANAF_03	225	31.5	SE	2.9	3.4	YIBEN_03	225	31.5	SL	2.9	4.0
THIONA08	90	25	SE	5.0	7.4	BUCHAN03	225	31.5	LI	2.2	2.9
TOBENE03	225	31.5	SE	3.5	3.9	MANO__03	225	31.5	LI	2.1	3.7
TOBENE08	90	25	SE	6.4	7.3	MONROV03	225	31.5	LI	2.4	3.6
TOUBA_03	225	31.5	SE	3.4	3.9	STPAUL03	225	31.5	LI	1.6	2.3
UNIVER08	90	25	SE	8.8	11.6	YEKEPA03	225	31.5	LI	3.1	2.8
ZIGUIN03	225	31.5	SE	1.7	1.8	2000HIRE	90	25	CI	4.0	4.4
KAHO1_03	225	31.5	SE	4.1	5.0	200SIR90	90	25	CI	11.2	12.5
KAHO2_03	225	31.5	SE	4.1	5.0	2010ABOB	225	31.5	CI	13.8	17.1
BRIKAM03	225	31.5	GA	2.9	3.2	2011ABOB	90	25	CI	24.3	30.1
SOMA__03	225	31.5	GA	3.5	4.0	2020VRID	225	31.5	CI	14.4	17.9
BAMBAD03	225	31.5	GB	2.7	3.3	2021VRID	90	25	CI	26.0	34.3
BISSAU03	225	31.5	GB	2.6	3.3	2030TAAB	225	31.5	CI	10.0	11.4
MANSOA03	225	31.5	GB	2.8	3.5	2031TAAB	90	25	CI	8.3	10.8
SALTHI03	225	31.5	GB	2.7	3.3	2040KOSS	225	31.5	CI	5.8	6.1
AMARYA03	225	31.5	GU	3.1	3.3	2041KOSS	90	25	CI	7.9	8.2
BEYLA_03	225	31.5	GU	2.8	2.2	2050BOUA	225	31.5	CI	3.2	3.3
BOKE__03	225	31.5	GU	3.1	4.2	2051BOUA	90	25	CI	3.2	3.3
BOUREY03	225	31.5	GU	6.1	8.3	2060FERK	225	31.5	CI	3.8	4.3
DABOLA03	225	31.5	GU	3.2	3.2	2061FERK	90	25	CI	3.3	5.0
DONKEA07	110	25	GU	4.4	4.5	2070SOUB	225	31.5	CI	8.9	11.3
FOMI__03	225	31.5	GU	4.2	4.2	2071SUBR	90	25	CI	4.7	5.0
GARAFI07	110	25	GU	5.8	5.9	2080S-PE	225	31.5	CI	3.2	4.1
GRCHUT07	110	25	GU	6.2	6.4	2081PEDR	90	25	CI	4.9	5.6
KALETA03	225	31.5	GU	5.8	6.5	2090BUYO	225	31.5	CI	4.4	4.7
KANKAN03	225	31.5	GU	3.1	3.0	2091BUYO	90	25	CI	3.9	5.9
KINDIA07	110	25	GU	5.7	5.8	20FAYE90	90	25	CI	2.3	2.5
KOROUS03	225	31.5	GU	3.4	3.4	2100MAN-	225	31.5	CI	3.0	3.0
KOUKOU03	225	31.5	GU	7.3	9.4	2101MAN-	90	25	CI	2.9	2.9
LABE__03	225	31.5	GU	4.8	4.0	2110LABO	225	31.5	CI	2.1	2.1
LINSAN03	225	31.5	GU	9.4	10.7	2111LABO	90	25	CI	2.3	3.1
LINSAN07	110	25	GU	8.8	9.1	2120AGBO	90	25	CI	3.2	3.3
MALI__03	225	31.5	GU	3.9	3.8	2130DABO	90	25	CI	2.1	2.2
MAMOU_07	110	25	GU	2.7	2.7	2140BONG	90	25	CI	7.5	7.6
MATOTO03	225	31.5	GU	2.8	2.9	2150PLAT	90	25	CI	22.9	28.0
MATOTO07	110	25	GU	6.8	7.2	2160BIAN	90	25	CI	23.0	28.0
NZEREK03	225	31.5	GU	3.0	2.6	2170AYAM	90	25	CI	3.9	4.0
SAMBAG03	225	31.5	GU	3.8	4.0	2180AYAM	90	25	CI	3.9	4.0
SIGUIR03	225	31.5	GU	3.0	3.2	2190ABRO	90	25	CI	3.4	3.5
BADOUM03	225	31.5	MA	4.2	4.5	2200BASS	90	25	CI	4.7	4.8
BALING05	150	25	MA	4.6	6.9	2209RIVI	225	31.5	CI	14.4	16.9

Table 130 – 3ph short-circuit current levels for 2020 and 2025 (1/3)

Node Name	Voltage kV	Breaker rating kA	Country Name	2020 kA	2025 kA
2210RIVI	90	25	CI	20.4	23.8
2220BIAS	90	25	CI	20.7	26.6
2229YOPO	225	31.5	CI	13.7	17.1
2230YOPO	90	25	CI	16.3	20.9
2231YOPO	90	25	CI	14.8	16.3
2240TREI	90	25	CI	22.7	27.7
2250YAMO	90	25	CI	2.9	2.9
2260DIMB	90	25	CI	2.8	2.9
2270ATAK	90	25	CI	1.2	1.2
2280ABEN	90	25	CI	1.1	1.1
2290AGNE	90	25	CI	1.0	1.0
2300SERE	90	25	CI	0.9	0.9
2310DIVO	90	25	CI	2.3	2.4
2320GAGN	90	25	CI	1.9	1.9
2330ZUEN	90	25	CI	1.3	1.3
2340BOUA	90	25	CI	4.9	5.0
2350MARA	90	25	CI	1.3	1.3
2360KORH	90	25	CI	2.2	2.5
2370BUND	90	25	CI	3.0	3.1
2371BUND	225	31.5	CI	2.7	2.7
2380ODIE	90	25	CI	1.5	1.5
2390SEGU	90	25	CI	1.0	1.1
2400DANA	90	25	CI	1.1	1.1
2410DALO	90	25	CI	2.0	2.8
2500AZIT	225	31.5	CI	14.1	17.9
RIVIER02	330	31.5	CI	6.5	6.9
TIBOTO03	225	31.5	CI	2.3	3.9
4BAGR132	132	25	BU	0.5	0.5
4KOMP132	132	25	BU	0.5	0.5
4ZANO132	132	25	BU	0.5	0.5
4KODE225	225	31.5	BU	3.4	3.9
4KOSSO90	90	25	BU	5.8	8.7
4OUAG190	90	25	BU	5.6	8.3
4OUAG290	90	25	BU	5.5	8.2
4PTDO132	132	25	BU	2.0	2.4
4ZAGT225	225	31.5	BU	3.3	4.3
4ZAGTO90	90	25	BU	5.2	7.8
4_PA_225	225	31.5	BU	2.3	2.5
4_PC_090	90	25	BU	5.6	8.4
OUAGAE02	330	31.5	BU	2.1	2.5
OUAGAE03	225	31.5	BU	3.3	4.3
OUAGAE08	90	25	BU	6.5	9.7
PATDOI08	90	25	BU	4.1	5.2
1010AKOS	161	31.5	GH	25.1	32.9
1020VOLT	161	31.5	GH	27.2	36.7
1021SME2	161	31.5	GH	26.1	35.4
1029VOLT	330	31.5	GH	10.8	13.0
1031SMEL	161	31.5	GH	24.8	33.2
1032SMEL	161	31.5	GH	24.8	33.2
1033SMEL	161	31.5	GH	24.8	33.2
1034SMEL	161	31.5	GH	24.8	33.2
1035SMEL	161	31.5	GH	24.8	33.2
1036SMEL	161	31.5	GH	24.8	33.2
1040TEMA	161	31.5	GH	24.2	31.7
1050ACHI	161	31.5	GH	22.2	26.7
1060WINN	161	31.5	GH	7.9	8.1
1070C-CO	161	31.5	GH	12.0	12.4
1080TAKO	161	31.5	GH	16.1	16.5
1090TARK	161	31.5	GH	13.7	13.9
1095NEWT	161	31.5	GH	11.2	11.4
1100PRES	161	31.5	GH	15.5	15.9
1109PRES	225	31.5	GH	7.7	7.8
1110DUNK	161	31.5	GH	9.9	10.0
1115DUNK	330	31.5	GH	6.8	6.9
1120OBUA	161	31.5	GH	8.6	8.7
1130KUMA	161	31.5	GH	10.6	10.8
1138T261	161	31.5	GH	4.9	4.9
1138T262	161	31.5	GH	8.7	8.8
1139K2BS	161	31.5	GH	11.2	11.4
1140NKAW	161	31.5	GH	8.2	8.4
1150TAFO	161	31.5	GH	9.7	10.3
1160AKWA	161	31.5	GH	4.6	4.7
1170KPON	161	31.5	GH	17.2	20.4
1180KONO	161	31.5	GH	5.4	5.4
1190KPON	161	31.5	GH	11.6	13.2
1200ASAW	161	31.5	GH	5.1	5.1
1210JUAB	161	31.5	GH	3.5	3.5
1210N-OB	161	31.5	GH	9.5	9.7
1220ASIE	161	31.5	GH	5.7	6.1
1252KPAN	161	31.5	GH	2.5	2.5
1260TECH	161	31.5	GH	7.5	7.6
1270SUNY	161	31.5	GH	5.8	5.8
1278MIM	161	31.5	GH	3.4	3.4
1280TAMA	161	31.5	GH	3.7	3.7
1290BOLG	161	31.5	GH	5.9	6.0
12951BOL	225	31.5	GH	3.9	4.1
1300BOGO	161	31.5	GH	12.6	12.9
1309WEXF	161	31.5	GH	5.5	5.5
1320ABOA	161	31.5	GH	23.5	24.3
1340WA	161	31.5	GH	1.7	1.7
1350YEND	161	31.5	GH	3.0	3.1
1360ESSI	161	31.5	GH	6.9	6.9
1370MALL	161	31.5	GH	19.9	23.1
1380SAWL	161	31.5	GH	2.0	2.0
1390DCEM	161	31.5	GH	10.1	14.8
1392 AFT	161	31.5	GH	10.3	15.5
1413KENY	161	31.5	GH	7.1	7.2
1470TT1P	161	31.5	GH	23.2	30.5
1480ZEB	161	31.5	GH	4.4	4.4
1500BUI	161	31.5	GH	10.1	10.2
15533BSP	161	31.5	GH	24.6	31.6
1560A4BS	330	31.5	GH	10.5	12.2
1561A4BS	161	31.5	GH	21.3	25.2
1580N_AB	161	31.5	GH	4.4	4.5
1590KIN	161	31.5	GH	8.4	8.5
1591KIN3	330	31.5	GH	4.3	4.4
1600OPB-	161	31.5	GH	7.8	7.9
1610BUIP	161	31.5	GH	3.9	3.9
1620TUMU	161	31.5	GH	1.9	1.9
1630HAN	161	31.5	GH	1.7	1.7
1700ASO2	330	31.5	GH	10.5	12.5
1700ASOG	161	31.5	GH	23.9	30.9
1750BONY	161	31.5	GH	14.1	14.4
1758BON3	330	31.5	GH	9.1	9.3
1800ELUB	161	31.5	GH	9.0	9.1
1809ELUB	225	31.5	GH	6.8	7.0
1850ATEB	161	31.5	GH	4.0	4.0
1850BERE	161	31.5	GH	4.2	4.2
1870CAPE	161	31.5	GH	12.3	12.6
1900TESI	161	31.5	GH	7.6	7.6
1901TES2	161	31.5	GH	6.9	6.9
1990AYAN	161	31.5	GH	5.4	5.5
ABOA_330	330	31.5	GH	11.4	12.1
BAWKU_04	161	31.5	GH	2.3	2.3
BOLGA330	330	31.5	GH	2.6	2.7
CAPE330	330	31.5	GH	7.5	7.8
KSI330	330	31.5	GH	6.7	6.9
PRES330	330	31.5	GH	9.5	9.8

Table 131 – 3ph short-circuit current levels for 2020 and 2025 (2/3)

Node Name	Voltage kV	Breaker rating kA	Country Name	2020 kA	2025 kA	Node Name	Voltage kV	Breaker rating kA	Country Name	2020 kA	2025 kA
30101LOM	330	31.5	TB	7.6	9.5	DELTA_02	330	31.5	NI	14.2	14.2
3010LOME	161	31.5	TB	11.9	19.7	DELTA_06	132	25	NI	9.5	7.2
3020MOME	161	31.5	TB	8.6	9.4	EGBEMA01	760	31.5	NI	7.6	9.9
3030COTO	161	31.5	TB	15.8	16.2	EGBEMA02	330	31.5	NI	22.9	28.6
3040SAKA	161	31.5	TB	18.2	18.5	EGBIN_02	330	31.5	NI	31.4	39.4
3050ONIG	161	31.5	TB	9.9	9.9	EGBIN_06	132	25	NI	14.8	18.1
3060NANG	161	31.5	TB	5.6	5.2	EPE___02	330	31.5	NI	19.1	21.4
3ATAK161	161	31.5	TB	3.3	3.2	ERUNKA01	760	31.5	NI	8.9	9.7
3BOHI161	161	31.5	TB	3.8	3.7	ERUNKA02	330	31.5	NI	29.0	35.8
3DJOU161	161	31.5	TB	1.8	1.8	EYAEN_02	330	31.5	NI	33.1	42.1
3KARA161	161	31.5	TB	2.0	2.0	GANMO_02	330	31.5	NI	10.5	10.8
3LOME161	161	31.5	TB	8.3	11.4	GBARAN02	330	31.5	NI	7.7	8.1
ADJARA04	161	31.5	TB	6.1	6.4	GBARAN06	132	25	NI	11.8	12.0
AVA___04	161	31.5	TB	8.1	8.2	GEREGU02	330	31.5	NI	20.3	23.1
BEMBER04	161	31.5	TB	1.8	1.8	GOMBE_01	760	31.5	NI	3.0	3.0
DAPAON04	161	31.5	TB	1.8	1.8	GOMBE_02	330	31.5	NI	6.9	7.1
GUENE_04	161	31.5	TB	2.5	2.5	GWAGWA02	330	31.5	NI	15.9	16.6
KANDI_04	161	31.5	TB	2.0	2.0	IKEJAW02	330	31.5	NI	30.4	36.7
MALANV02	330	31.5	TB	2.6	2.8	IKOTAB02	330	31.5	NI	16.6	20.7
MALANV04	161	31.5	TB	2.9	3.0	IKOTAB06	132	25	NI	20.2	24.9
MANGO_04	161	31.5	TB	1.7	1.7	IKOTEK02	330	31.5	NI	27.7	35.1
MA_GLE04	161	31.5	TB	17.6	18.0	JALING01	760	31.5	NI	4.0	4.2
NATITI04	161	31.5	TB	1.1	1.1	JALING02	330	31.5	NI	6.8	7.0
PARAKO04	161	31.5	TB	2.0	2.0	JEBBAP02	330	31.5	NI	18.8	19.8
SAKETE02	330	31.5	TB	16.5	17.7	JEBBA_02	330	31.5	NI	20.1	21.2
TANZOU04	161	31.5	TB	8.9	9.0	JOS___02	330	31.5	NI	9.6	9.8
AKOKAN06	132	25	NR	0.6	0.6	KADUNA01	760	31.5	NI	5.4	5.6
ANOU 06	132	25	NR	1.6	1.6	KADUNA02	330	31.5	NI	13.5	14.0
DIFFA_02	330	31.5	NR	2.8	2.8	KAINJI02	330	31.5	NI	13.9	14.3
DOSSO02	330	31.5	NR	3.3	3.6	KANKIA06	132	25	NI	3.2	3.2
DOSSO_06	132	25	NR	2.7	2.9	KANO__01	760	31.5	NI	3.7	3.8
FRONT_06	132	25	NR	3.2	3.2	KANO__02	330	31.5	NI	8.1	8.3
GAZAOU06	132	25	NR	2.7	3.1	KANO__06	132	25	NI	14.0	14.2
KANDAD06	132	25	NR	5.2	3.3	KATAMP02	330	31.5	NI	16.0	16.6
MARADI06	132	25	NR	1.2	1.7	KATSIN02	330	31.5	NI	4.2	4.3
NIAM2C06	132	25	NR	0.6	0.7	KATSIN06	132	25	NI	7.8	8.0
NIAM2_06	132	25	NR	7.4	6.3	KWALE_02	330	31.5	NI	14.2	14.8
NIAMRD02	330	31.5	NR	3.1	3.1	LOKOJA02	330	31.5	NI	16.0	17.4
NIAMRD06	132	25	NR	7.3	6.4	MAKURD01	760	31.5	NI	7.7	8.1
ZABORI02	330	31.5	NR	3.6	3.9	MAKURD06	330	31.5	NI	14.1	14.7
ZINDER06	132	25	NR	2.6	2.7	MAMBIL01	760	31.5	NI	8.7	9.7
SALKAD02	330	31.5	NR	1.5	1.9	MAMBIL02	330	31.5	NI	22.3	25.7
SALKAD06	132	25	NR	2.3	2.9	NEWHAS02	330	31.5	NI	15.2	16.2
ABUJA_01	760	31.5	NI	7.3	7.7	NEWHAV02	330	31.5	NI	14.9	15.8
AFAM__02	330	31.5	NI	26.8	36.4	NNEWI_02	330	31.5	NI	23.9	27.8
AHOADA02	330	31.5	NI	10.6	11.4	OMOKU_02	330	31.5	NI	16.0	19.1
AIYEDE02	330	31.5	NI	10.8	11.3	OMOKU_06	132	25	NI	7.1	8.2
AJAOKU01	760	31.5	NI	10.6	11.7	OMOTOS02	330	31.5	NI	26.0	31.2
AJAOKU02	330	31.5	NI	21.3	24.2	ONITSH02	330	31.5	NI	29.5	33.9
AJA___02	330	31.5	NI	25.9	30.9	OSHOGB01	760	31.5	NI	10.0	10.9
AKANGB02	330	31.5	NI	21.3	27.3	OSHOGB02	330	31.5	NI	23.8	25.4
ALADJA02	330	31.5	NI	12.9	13.2	OWERRI02	330	31.5	NI	28.7	36.7
ALAGBO02	330	31.5	NI	17.5	19.6	PAPALA02	330	31.5	NI	23.2	26.1
ALAOJI02	330	31.5	NI	33.8	45.8	PORTHA02	330	31.5	NI	14.4	16.8
ALIADE02	330	31.5	NI	12.3	12.7	SAPELE02	330	31.5	NI	27.8	32.4
BENINC02	330	31.5	NI	39.6	50.1	SHIROR02	330	31.5	NI	18.8	19.4
BENINN01	760	31.5	NI	12.3	14.2	SOKOTO02	330	31.5	NI	2.8	2.9
BENINN02	330	31.5	NI	36.7	48.3	YENAGO02	330	31.5	NI	7.9	8.3
BIRNIN02	330	31.5	NI	4.6	4.8	YOLA__02	330	31.5	NI	5.3	5.4
BIRNIN06	132	25	NI	4.0	4.0	ZARIA_02	330	31.5	NI	7.8	8.0
CALABA02	330	31.5	NI	13.4	16.1	ZUNGER02	330	31.5	NI	16.9	17.2
DAMATU02	330	31.5	NI	4.0	4.0	GUSAU_02	330	31.5	NI	0.0	0.0

Table 132 - 3ph short-circuit current levels for 2020 and 2025 (3/3)

5. APPENDIX: DYNAMIC STUDIES: TRANSIENT STABILITY ANALYSIS: CRITICAL CLEARING TIMES RESULTS

Node	Voltage	Country	CCT calculations without line tripping			CCT calculations with line tripping			
Name	kV	Name	min	max	Machines losing synhronism	Faulted line tripped	min	max	Machines losing synhronism
KAOLAC03	225	SE	222	225	KAHONG71/72/73/74	BIRKEL03_SOMA__03_1	184	188	CAPDB11A
BELAIR08	90	SE	269	272	GAMB_EQG	BELAIR08-HANN__08-1	268	272	GAMB_EQG
CAPEBI08	90	SE	234	237	GAMB_EQG	CAPEBI08-SOCOCI08-1	230	234	ROSSBE1G/2G
KOUNOU08	90	SE	263	266	GOMA_HG1/2	CAPEBI08-KOUNOU08-1	260	264	KENIE_1G/2G/3G + BALBIDG1/2
SOCOCI08	90	SE	275	278	GAMB_EQG	CAPEBI08-SOCOCI08-1	272	276	ROSSBE1G/2G
DAGANA03	225	SE	228	231	ROSSBE1G/2G	DAGANA03-SAKAL_03-1	260	264	ROSSBE1G/2G
TAMBAC03	225	SE	222	225	KOUDI_1G/2G	BIRKEL03_TAMBAC03_1	500		
ZIGUIN03	225	SE	500			TANAF_03_ZIGUIN03_1	500		
BRIKAM03	225	GA	500			SOMA__03_BRIKAM03_1	500		
BISSAU03	225	GB	381	384	GBISSEQG	BISSAU03_MANSOA03_1	382	386	GBISSEQG
DONKEA07	110	GU	394	397	DONKEAG1/G2	GRCHUT07-DONKEA07-1	424	428	MANEAHG1/2/3
GARAFI07	110	GU	328	331	GARAFIG1/2/3	LINSAN07-GARAFI07-1	325	329	GARAFIG1/2/3
GRCHUT07	110	GU	284	287	MANEAHG1/2/3	GRCHUT07-GARAFI07-1	276	279	MANEAHG1/2/3
MATOTO07	110	GU	234	237	BUCHANG1	GRCHUT07-MATOTO07-1	234	238	MANEAHG1/2/3
FOMI__03	225	GU	500			KOROUS03-FOMI__03-1	500		
KALETA03	225	GU	272	275	BUCHANG1	KALETA03-LINSAN03-1	176	180	GAMB_EQG
SAMBAG03	225	GU	500			SAMBAN03-MALI__03-1	500		
DABOLA03	225	GU	500			DABOLA03-KOROUS03-1	500		
MANANT03	225	MA	244	247	MANAN11A/12A/13A/14A/15A + FELOU_1G/2G/3G	MANANT03_TKITA_03_1		0	MANAN11A/12A/13A/14A/15A + FELOU_1G/2G/3G
SEGOU_05	150	MA	500			FANA__05_SEGOU_05_1	500		
SIRAKO05	150	MA	225	228	VICABO1G	KALABA05_SIRAKO05_1	184	188	BALBIDG1/2
LAFIA_05	150	MA	406	409	VICABO1G	KODIAL05_LAFIA_05_1	417	412	VICABO1G
SELING05	150	MA	328	331	SELING1/2/3/4	SIRAKO05_SELING05_1	500		
BALING05	150	MA	247	250	BALBIDG1	SIRAKO05_BALING05_1	245	249	BALBIDG1/2
KAYES_03	225	MA	406	409	FELOU_1G/2G/3G	KAYES_03-MANANT03-1	299	302	FELOU_1G/2G/3G
KOUTIA03	225	MA	500			SIKASS03_KOUTIA03_1	500		
SIKASS03	225	MA	500			SIKASS03_2060FERK_1	500		
KENIE_05	150	MA	425	428	KENIE_1G/2G/3G	SIRAKO05_KENIE_05_1	428	432	VICABO1G
KENEMA03	225	SL	356	359	BUSHR2G2/3/4/5/6/7	KENEMA03-BIKONG03-1	318	321	BUSHR2G2/3/4/5/6/7
BUMBUN04	161	SL	281	284	BLACKHG1/2/3	BUMBUN04-FRTWON04-1	302	306	BUMBUNG1/2
FRTOWN04	161	SL	222	225	BLACKHG1/2/3	BUMBUN04-FRTWON04-1	497	500	BLACKHG1/2/3
MONROV03	225	LI	222	225	BUSHR2G2/3/4/5/6/7	BUCHAN03-MONROV03-1	218	222	BUSHR2G2/3/4/5/6/7
BUCHAN03	225	LI	209	213	BUCHANG1	BUCHAN03-MONROV03-1	199	203	BUCHANG1
2090BUYO	225	CI	269	272	2093BUYO	2090BUYO-2070SOUB-1	222	226	2092BUYO/3BUYO
2091BUYO	90	CI	500			2091BUYO-2410DALO-1	500		
2040KOSS	225	CI	472	475	2042KOSS/43KOSS	2040KOSS-2030TAAB-1	455	459	2042KOSS/43KOSS
2030TAAB	225	CI	306	309	MANAN11A/12A/13A/14A/15A	2030TAAB-2010ABOB-2	325	329	2033TAAB/4TAAB
2500AZIT	225	CI	203	206	MANAN11A/12A/13A/14A/15A	2500AZIT-2020VRID-1	188	192	BUCHANG1
2020VRID	225	CI	194	197	ROSSBE1G/2G	2500AZIT-2020VRID-1	184	188	ROSSBE1G/2G
2170AYAM	90	CI	500			2170AYAM-2180AYAM-1	500		
2180AYAM	90	CI	500			2180AYAM-2190ABRO-1	500		
2021VRID	90	CI	206	209	ROSSBE1G/2G + MANAN11A/12A/13A/14A/15A	2240TREI-2021VRID-1	203	207	ROSSBE1G/2G
20FAYE90	90	CI	500			2081PEDR-20FAYE90-1	500		
2209RIVI	225	CI	191	194	BUCHANG1	2209RIVI-2020VRID-1	188	192	BUCHANG1
4KODE225	225	BU	500			SIKASS03_4KODE225_1	500		
4BAGR132	132	BU	247	250	4BAGRE16	4BAGR132-4ZANO132-1	455	459	4KOMPI16/26
4KOMP132	132	BU	328	331	4KOMPI16/26	4KOMP132-4ZANO132-1	500		
4KOSSO90	90	BU	350	353	MANASEMA	OUAGAE08-KOSSOD08-1	348	352	MANASEMA
4OUAG190	90	BU	391	394	MANASEMA	4OUAG190-4_PC_090-1	386	390	MANASEMA
4OUAG290	90	BU	416	419	MANASEMA	4OUAG190-4OUAG290-1	417	421	MANASEMA
4ZAGTO90	90	BU	475	478	4BAGRE16/26	4ZAGTO90-4OUAG290-1	474	478	4BAGRE16/26

Table 133 – Critical clearing times for the Base case, with and without lines tripping (1/2)

Node	Voltage	Country	CCT calculations without line tripping			CCT calculations with line tripping			
Name	kV	Name	min	max	Machines losing synhronism	Faulted line tripped	min	max	Machines losing synhronism
OUAGAE08	90	BU	228	231	MANASEMA	PATDOI08-OUAGAE08-1	226	230	MANASEMA
1010AKOS	161	GH	228	231	MANAN11A/12A/13A/14A/15A	1010AKOS-1190KPON-1	226	230	MANAN11A/12A/13A/14A/15A
1040TEMA	161	GH	319	322	BUCHANG1	1020VOLT-1040TEMA-1	341	344	BUSHR2G2/3/4/5/6/7
1190KPON	161	GH	438	441	KPONGHG1/2/3/4	1010AKOS-1190KPON-1	405	409	KPONGHG1/2/3/4
1320ABOA	161	GH	278	281	ROSSBE1G/2G	1090TARK-1320ABOA-1	276	279	ROSSBE1G/2G
1600OPB-	161	GH	500			1600OPB-1750BONY-1	500		
1470TT1P	161	GH	347	350	BUSHR2G2/3/4/5/6/7	1021SME2-1470TT1P-2	344	348	MANAN11A/12A/13A/14A/15A
1700ASOG	161	GH	309	313	MANAN11A/12A/13A/14A/15A	1700ASOG-1021SME2-1	310	314	MANAN11A/12A/13A/14A/15A
ABOA_330	330	GH	325	328	ROSSBE1G/2G	1029VOLT-ABOA330-1	291	295	BUSHR2G2/3/4/5/6/7
1500BUI	161	GH	225	228	BUI___G1/2	1500BUI-1590KIN	211	215	BUI___G1/2
1750BONY	161	GH	416	419	DOMIT1G1/2	1750BONY-1800ELUB-1	405	409	DOMIT1G1/2
3030COTO	161	TB	256	259	MA_GLE3G	MA_GLE04_3030COTO_3	257	260	MA_GLE3G
3010LOME	161	TB	500			1392AFT-3010LOME-1	500		
3060NANG	161	TB	284	287	3061NANG/2NANG	3060NANG-3020MOME-1	276	279	3061NANG/2NANG
3LOME161	161	TB	500			3010LOME-3LOME161-1	500		
3KARA161	161	TB	500			3ATAK161-3KARA161-1	500		
PARAKO04	161	TB	500			PARAKO04_3050ONIG_1	500		
MANGO_04	161	TB	500			MANGO_04_DAPAON04_1	500		
MA_GLE04	161	TB	219	222	MA_GLE3G	3040SAKA_MA_GLE04_1	215	218	MA_GLE3G
KANDI_04	161	TB	500			GUENE_04_KANDI_04_1	500		
NATITI04	161	TB	500			3DJOU161_NATITI04_1	500		
MARADI06	132	NR	500			GAZAOU06-MARADI06-1	500		
ZINDER06	132	NR	178	181	ZINDCC1G	GAZAOU06-ZINDER06-1	455	459	ZINDCC1G
NIAM2_06	132	NR	409	413	GOUDELG1	NIAM2_06-NIAMRD06-1	409	413	GOUDELG1
DOSSO_06	132	NR	500			DOSSO_06-NIAM2C-1	500		
SALKAD02	330	NR	500			DOSSO_02-SALKAD02-1	500		
DELTA_06	132	NI	381	384	DELTAG03/4/5/6	no line connected	---	---	---
DELTA_02	330	NI	284	287	BUSHR2G2/3/4/5/6/7	BENINC02-DELTA_02-1	279	283	BUSHR2G2/3/4/5/6/7
SAPELE02	330	NI	106	109	ROSSBE1G/2G	BENINC02-SAPELE02-1	104	108	BUSHR2G2/3/4/5/6/7
OMOTOS02	330	NI	138	141	ROSSBE1G/2G	OMOTOS02-BENINC02-1	138	142	MANAN11A/12A/13A/14A/15A
GEREGU02	330	NI	122	125	ROSSBE1G/2G	AJAOKU02-GEREGU02-1	119	123	BUSHR2G2/3/4/5/6/7
EYAEN_02	330	NI	83	87	KENIE_1G/2G/3G	BENINN02-EAYEN_02-1	85	89	ROSSBE1G/2G
IKOTAB06	132	NI	500			no line connected	---	---	---
AFAM__02	330	NI	113	116	ROSSBE1G/2G	ALAOJI02-AFAM__02-1	112	115	ROSSBE1G/2G
ALAOJI02	330	NI	95	98	MANAN11A/12A/13A/14A/15A	OWERRI02-ALAOJI02-1	93	96	ROSSBE1G/2G
CALABA02	330	NI	159	163	VICABO1G	IKOTEK02-CALABA02-1	154	157	ROSSBE1G/2G
KWALE_02	330	NI	225	228	ROSSBE1G/2G	KWALE_02-ONITSH02-1	215	218	KWALCC3
EGBEMA02	330	NI	113	116	MANAN11A/12A/13A/14A/15A	OWERRI02-EGBEMA02-1	115	119	ROSSBE1G/2G
OMOKU_02	330	NI	169	172	MANAN11A/12A/13A/14A/15A	EGBEMA02-OMOKU_02-1	169	173	BUSHR2G2/3/4/5/6/7
IKOTAB02	330	NI	275	278	MANAN11A/12A/13A/14A/15A	IKOTEK02-IKOTAB02-1	279	283	ROSSBE1G/2G
OMOKU_06	132	NI	500			no line connected	---	---	---
GBARAN06	132	NI	500			no line connected	---	---	---
EGBIN_06	132	NI	222	225	EGBINGT7/8/9	no line connected	---	---	---
EGBIN_02	330	NI	106	109	MANAN11A/12A/13A/14A/15A	ERUNKA02-EGBIN_02-1	104	108	ROSSBE1G/2G
IKEJAW02	330	NI	103	106	MANAN11A/12A/13A/14A/15A	IKEJAW02-ERUNKA02-1	104	108	VICABO1G
ERUNKA02	330	NI	100	103	MANAN11A/12A/13A/14A/15A	ERUNKA02-EGBIN_02-1	100	104	MANAN11A/12A/13A/14A/15A
PAPALA02	330	NI	134	138	ROSSBE1G/2G	IKEJAW02-PAPALA02-1	135	138	MANAN11A/12A/13A/14A/15A
JEBBAP02	330	NI	219	222	ROSSBE1G/2G	JEBBAP02-JEBBA_02-1	218	222	ROSSBE1G/2G
KAINJI02	330	NI	284	287	MANAN11A/12A/13A/14A/15A	KAINJI02-JEBBA_02-1	279	283	MANAN11A/12A/13A/14A/15A
SHIROR02	330	NI	159	163	BUSHR2G2/3/4/5/6/7	JEBBA_02-SHIROR02-2	161	165	ROSSBE1G/2G

Table 134 - Critical clearing times for the Base case, with and without lines tripping (2/2)

Node	Voltage	Country	CCT calculations with line tripping				CCT calculations with line tripping and with PSS			
Name	kV	Name	Faulted line tripped	min	max	Machines losing synhronism	Faulted line tripped	min	max	Machines losing synhronism
KAOLAC03	225	SE	BIRKEL03_SOMA__03_1	184	188	CAPDB11A	BIRKEL03_SOMA__03_1	192	196	KAHONG71/2/3/4
BELAIR08	90	SE	BELAIR08-HANN__08-1	268	272	GAMB_EQG	BELAIR08-HANN__08-1	274	278	ROSSBE1G/2G
CAPEBI08	90	SE	CAPEBI08-SOCOCI08-1	230	234	ROSSBE1G/2G	CAPEBI08-SOCOCI08-1	243	247	ROSSBE1G/2G
KOUNOU08	90	SE	CAPEBI08-KOUNOU08-1	260	264	KENIE_1G/2G/3G + BALBIDG1/2	CAPEBI08-KOUNOU08-1	282	286	ROSSBE1G/2G
SOCOCI08	90	SE	CAPEBI08-SOCOCI08-1	272	276	ROSSBE1G/2G	CAPEBI08-SOCOCI08-1	289	293	ROSSBE1G/2G
DAGANA03	225	SE	DAGANA03-SAKAL_03-1	260	264	ROSSBE1G/2G	DAGANA03-SAKAL_03-1	258	262	ROSSBE1G/2G
TAMBAC03	225	SE	BIRKEL03_TAMBAC03_1	500			BIRKEL03_TAMBAC03_1	500		
ZIGUIN03	225	SE	TANAF_03_ZIGUIN03_1	500			TANAF_03_ZIGUIN03_1	500		
BRIKAM03	225	GA	SOMA__03_BRIKAM03_1	500			SOMA__03_BRIKAM03_1	500		
BISSAU03	225	GB	BISSAU03_MANSOA03_1	382	386	GBISSEQG	BISSAU03_MANSOA03_1	383	387	GBISSEQG
DONKEA07	110	GU	GRCHUT07-DONKEA07-1	424	428	MANEAHG1/2/3	GRCHUT07-DONKEA07-1	422	426	MANEAHG1/2/3
GARAFI07	110	GU	LINSAN07-GARAFI07-1	325	329	GARAFIG1/2/3	LINSAN07-GARAFI07-1	325	329	GARAFIG1/2/3
GRCHUT07	110	GU	GRCHUT07-GARAFI07-1	276	279	MANEAHG1/2/3	GRCHUT07-GARAFI07-1	278	282	MANEAHG1/2/3
MATOTO07	110	GU	GRCHUT07-MATOTO07-1	234	238	MANEAHG1/2/3	GRCHUT07-MATOTO07-1	235	239	MANEAHG1/2/3
FOMI__03	225	GU	KOROUS03-FOMI__03-1	500			KOROUS03-FOMI__03-1	500		
KALETA03	225	GU	KALETA03-LINSAN03-1	176	180	GAMB_EQG	KALETA03-LINSAN03-1	161	165	KALETAG1/2/3
SAMBAG03	225	GU	SAMBAN03-MALI__03-1	500			SAMBAN03-MALI__03-1	500		
DABOLA03	225	GU	DABOLA03-KOROUS03-1	500			DABOLA03-KOROUS03-1	500		
MANANT03	225	MA	MANANT03_TKITA_03_1		0	MANAN11A/12A/13A/14A/15A + FELOU_1G/2G/3G	MANANT03_TKITA_03_1		0	FELOU_1G/2G/3G
SEGOU_05	150	MA	FANA__05_SEGOU_05_1	500			FANA__05_SEGOU_05_1	500		
SIRAKO05	150	MA	KALABA05_SIRAKO05_1	184	188	BALBIDG1/2	KALABA05_SIRAKO05_1	184	188	SELING1/2/3/4 + BALBIDG1/2
LAFIA_05	150	MA	KODIAL05_LAFIA_05_1	417	412	VICABO1G	KODIAL05_LAFIA_05_1	422	426	VICABO1G
SELING05	150	MA	SIRAKO05_SELING05_1	500			SIRAKO05_SELING05_1	500		
BALING05	150	MA	SIRAKO05_BALING05_1	245	249	BALBIDG1/2	SIRAKO05_BALING05_1	247	251	BALBIDG1/2
KAYES_03	225	MA	KAYES_03-MANANT03-1	299	302	FELOU_1G/2G/3G	KAYES_03-MANANT03-1	328	332	FELOU_1G/2G/3G
KOUTIA03	225	MA	SIKASS03_KOUTIA03_1	500			SIKASS03_KOUTIA03_1	500		
SIKASS03	225	MA	SIKASS03_2060FERK_1	500			SIKASS03_2060FERK_1	500		
KENIE_05	150	MA	SIRAKO05_KENIE_05_1	428	432	VICABO1G	SIRAKO05_KENIE_05_1	430	434	VICABO1G
KENEMA03	225	SL	KENEMA03-BIKONG03-1	318	321	BUSHR2G2/3/4/5/6/7	KENEMA03-BIKONG03-1	317	321	BUSHR2G2/3/4/5/6/7
BUMBUN04	161	SL	BUMBUN04-FRTWON04-1	302	306	BUMBUNG1/2	BUMBUN04-FRTWON04-1	301	305	BUMBUNG1/2
FRTOWN04	161	SL	BUMBUN04-FRTWON04-1	497	500	BLACKHG1/2/3	BUMBUN04-FRTWON04-1	496	500	BLACKHG1/2/3
MONROV03	225	LI	BUCHAN03-MONROV03-1	218	222	BUSHR2G2/3/4/5/6/7	BUCHAN03-MONROV03-1	219	223	BUSHR2G2/3/4/5/6/7
BUCHAN03	225	LI	BUCHAN03-MONROV03-1	199	203	BUCHANG1	BUCHAN03-MONROV03-1	200	204	BUCHANG1
2090BUYO	225	CI	2090BUYO-2070SOUB-1	222	226	2092BUYO/3BUYO	2090BUYO-2070SOUB-1	223	227	2092BUYO/3BUYO
2091BUYO	90	CI	2091BUYO-2410DALO-1	500			2091BUYO-2410DALO-1	500		
2040KOSS	225	CI	2040KOSS-2030TAAB-1	455	459	2042KOSS/43KOSS	2040KOSS-2030TAAB-1	453	457	2042KOSS/43KOSS
2030TAAB	225	CI	2030TAAB-2010ABOB-2	325	329	2033TAAB/4TAAB	2030TAAB-2010ABOB-2	325	328	2033TAAB/4TAAB
2500AZIT	225	CI	2500AZIT-2020VRID-1	188	192	BUCHANG1	2500AZIT-2020VRID-1	235	239	2032/3/4TAAB+2093/94BUYO
2020VRID	225	CI	2500AZIT-2020VRID-1	184	188	ROSSBE1G/2G	2500AZIT-2020VRID-1	215	219	MANAN11A/12A/13A/14A/15A
2170AYAM	90	CI	2170AYAM-2180AYAM-1	500			2170AYAM-2180AYAM-1	500		
2180AYAM	90	CI	2180AYAM-2190ABRO-1	500			2180AYAM-2190ABRO-1	500		
2021VRID	90	CI	2240TREI-2021VRID-1	203	207	ROSSBE1G/2G	2240TREI-2021VRID-1	235	239	ROSSBE1/2G+MANAN11/2/3/4/5
20FAYE90	90	CI	2081PEDR-20FAYE90-1	500			2081PEDR-20FAYE90-1	500		
2209RIVI	225	CI	2209RIVI-2020VRID-1	188	192	BUCHANG1	2209RIVI-2020VRID-1	243	247	2032/TAAB/3TAAB/4TAAB
4KODE225	225	BU	SIKASS03_4KODE225_1	500			SIKASS03_4KODE225_1	500		
4BAGR132	132	BU	4BAGR132-4ZANO132-1	455	459	4KOMPI16/26	4BAGR132-4ZANO132-1	453	457	4KOMPI16/26
4KOMP132	132	BU	4KOMP132-4ZANO132-1	500			4KOMP132-4ZANO132-1	500		
4KOSSO90	90	BU	OUAGAE08-KOSSOD08-1	348	352	MANASEMA	OUAGAE08-KOSSOD08-1	348	352	MANASEMA
4OUAG190	90	BU	4OUAG190-4_PC_090-1	386	390	MANASEMA	4OUAG190-4_PC_090-1	391	395	MANASEMA
4OUAG290	90	BU	4OUAG190-4OUAG290-1	417	421	MANASEMA	4OUAG190-4OUAG290-1	410	414	MANASEMA
4ZAGTO90	90	BU	4ZAGTO90-4OUAG290-1	474	478	4BAGRE16/26	4ZAGTO90-4OUAG290-1	473	477	4BAGRE16/26

Table 135 - Critical clearing times for the Base case, with lines tripping, improvements with PSS (1/2)

Node	Voltage	Country	CCT calculations with line tripping				CCT calculations with line tripping and with PSS			
Name	kV	Name	Faulted line tripped	min	max	Machines losing synhronism	Faulted line tripped	min	max	Machines losing synhronism
OUAGAE08	90	BU	PATDOI08-OUAGAE08-1	226	230	MANASEMA	PATDOI08-OUAGAE08-1	227	231	MANASEMA
1010AKOS	161	GH	1010AKOS-1190KPON-1	226	230	MANAN11A/12A/13A/14A/15A	1010AKOS-1190KPON-1	239	243	BUSHR2G2/3/4/5/6/7
1040TEMA	161	GH	1020VOLT-1040TEMA-1	341	344	BUSHR2G2/3/4/5/6/7	1020VOLT-1040TEMA-1	332	336	BUSHR2G2/3/4/5/6/7
1190KPON	161	GH	1010AKOS-1190KPON-1	405	409	KPONGHG1/2/3/4	1010AKOS-1190KPON-1	403	406	KPONGHG1/2/3/4
1320ABOA	161	GH	1090TARK-1320ABOA-1	276	279	ROSSBE1G/2G	1090TARK-1320ABOA-1	325	328	ROSSBE1/2G
1600OPB-	161	GH	1600OPB-1750BONY-1	500			1600OPB-1750BONY-1	500		
1470TT1P	161	GH	1021SME2-1470TT1P-2	344	348	MANAN11A/12A/13A/14A/15A	1021SME2-1470TT1P-2	364	367	BUSHR2G2/3/4/5/6/7
1700ASOG	161	GH	1700ASOG-1021SME2-1	310	314	MANAN11A/12A/13A/14A/15A	1700ASOG-1021SME2-1	328	332	BUSHR2G2/3/4/5/6/7
ABOA_330	330	GH	1029VOLT-ABOA330-1	291	295	BUSHR2G2/3/4/5/6/7	1029VOLT-ABOA330-1	360	364	ABOA3CC1
1500BUI	161	GH	1500BUI-1590KIN	211	215	BUI___G1/2	1500BUI-1590KIN	212	215	BUI___G1/2
1750BONY	161	GH	1750BONY-1800ELUB-1	405	409	DOMIT1G1/2	1750BONY-1800ELUB-1	406	410	DOMIT1G1/2
3030COTO	161	TB	MA_GLE04_3030COTO_3	257	260	MA_GLE3G	MA_GLE04_3030COTO_3	254	258	MA_GLE3G
3010LOME	161	TB	1392AFT-3010LOME-1	500			1392AFT-3010LOME-1	500		
3060NANG	161	TB	3060NANG-3020MOME-1	276	279	3061NANG/2NANG	3060NANG-3020MOME-1	274	278	3061NANG/2NANG
3LOME161	161	TB	3010LOME-3LOME161-1	500			3010LOME-3LOME161-1	500		
3KARA161	161	TB	3ATAK161-3KARA161-1	500			3ATAK161-3KARA161-1	500		
PARAKO04	161	TB	PARAKO04_3050ONIG_1	500			PARAKO04_3050ONIG_1	500		
MANGO_04	161	TB	MANGO_04_DAPAON04_1	500			MANGO_04_DAPAON04_1	500		
MA_GLE04	161	TB	3040SAKA_MA_GLE04_1	215	218	MA_GLE3G	3040SAKA_MA_GLE04_1	215	218	MA_GLE3G
KANDI_04	161	TB	GUENE_04_KANDI_04_1	500			GUENE_04_KANDI_04_1	500		
NATITI04	161	TB	3DJOU161_NATITI04_1	500			3DJOU161_NATITI04_1	500		
MARADI06	132	NR	GAZAOU06-MARADI06-1	500			GAZAOU06-MARADI06-1	500		
ZINDER06	132	NR	GAZAOU06-ZINDER06-1	455	459	ZINDCC1G	GAZAOU06-ZINDER06-1	457	461	ZINDCC1G
NIAM2_06	132	NR	NIAM2_06-NIAMRD06-1	409	413	GOUDELG1	NIAM2_06-NIAMRD06-1	406	410	GOUDELG1
DOSSO_06	132	NR	DOSSO_06-NIAM2C-1	500			DOSSO_06-NIAM2C-1	500		
SALKAD02	330	NR	DOSSO_02-SALKAD02-1	500			DOSSO_02-SALKAD02-1	500		
DELTA_06	132	NI	no line connected	---	---	---	no line connected	---	---	---
DELTA_02	330	NI	BENINC02-DELTA_02-1	279	283	BUSHR2G2/3/4/5/6/7	BENINC02-DELTA_02-1	332	336	ROSSBE1G/2G
SAPELE02	330	NI	BENINC02-SAPELE02-1	104	108	BUSHR2G2/3/4/5/6/7	BENINC02-SAPELE02-1	126	130	ROSSBE1G/2G
OMOTOS02	330	NI	OMOTOS02-BENINC02-1	138	142	MANAN11A/12A/13A/14A/15A	OMOTOS02-BENINC02-1	161	165	ROSSBE1G/2G
GEREGU02	330	NI	AJAOKU02-GEREGU02-1	119	123	BUSHR2G2/3/4/5/6/7	AJAOKU02-GEREGU02-1	145	149	ROSSBE1G/2G
EYAEN_02	330	NI	BENINN02-EAYEN_02-1	85	89	ROSSBE1G/2G	BENINN02-EAYEN_02-1	106	110	ROSSBE1G/2G
IKOTAB06	132	NI	no line connected	---	---	---	no line connected	---	---	---
AFAM__02	330	NI	ALAOJI02-AFAM__02-1	112	115	ROSSBE1G/2G	ALAOJI02-AFAM__02-1	145	149	ROSSBE1G/2G
ALAOJI02	330	NI	OWERRI02-ALAOJI02-1	93	96	ROSSBE1G/2G	OWERRI02-ALAOJI02-1	118	122	MANAN11A/12A/13A/14A/15A
CALABA02	330	NI	IKOTEK02-CALABA02-1	154	157	ROSSBE1G/2G	IKOTEK02-CALABA02-1	157	161	CALABAGT1/2/3/4/5
KWALE_02	330	NI	KWALE_02-ONITSH02-1	215	218	KWALCC3	KWALE_02-ONITSH02-1	215	218	KWALCC3
EGBEMA02	330	NI	OWERRI02-EGBEMA02-1	115	119	ROSSBE1G/2G	OWERRI02-EGBEMA02-1	141	145	ROSSBE1G/2G
OMOKU_02	330	NI	EGBEMA02-OMOKU_02-1	169	173	BUSHR2G2/3/4/5/6/7	EGBEMA02-OMOKU_02-1	227	231	MANAN11A/12A/13A/14A/15A
IKOTAB02	330	NI	IKOTEK02-IKOTAB02-1	279	283	ROSSBE1G/2G	IKOTEK02-IKOTAB02-1	395	399	ROSSBE1G/2G
OMOKU_06	132	NI	no line connected	---	---	---	no line connected	---	---	---
GBARAN06	132	NI	no line connected	---	---	---	no line connected	---	---	---
EGBIN_06	132	NI	no line connected	---	---	---	no line connected	---	---	---
EGBIN_02	330	NI	ERUNKA02-EGBIN_02-1	104	108	ROSSBE1G/2G	ERUNKA02-EGBIN_02-1	126	130	ROSSBE1G/2G
IKEJAW02	330	NI	IKEJAW02-ERUNKA02-1	104	108	VICABO1G	IKEJAW02-ERUNKA02-1	122	126	MANAN11A/12A/13A/14A/15A
ERUNKA02	330	NI	ERUNKA02-EGBIN_02-1	100	104	MANAN11A/12A/13A/14A/15A	ERUNKA02-EGBIN_02-1	122	126	ROSSBE1G/2G
PAPALA02	330	NI	IKEJAW02-PAPALA02-1	135	138	MANAN11A/12A/13A/14A/15A	IKEJAW02-PAPALA02-1	161	165	ROSSBE1G/2G
JEBBAP02	330	NI	JEBBAP02-JEBBA_02-1	218	222	ROSSBE1G/2G	JEBBAP02-JEBBA_02-1	258	262	ROSSBE1G/2G
KAINJI02	330	NI	KAINJI02-JEBBA_02-1	279	283	MANAN11A/12A/13A/14A/15A	KAINJI02-JEBBA_02-1	286	289	ROSSBE1G/2G
SHIROR02	330	NI	JEBBA_02-SHIROR02-2	161	165	ROSSBE1G/2G	JEBBA_02-SHIROR02-2	223	227	ROSSBE1G/2G

Table 136 - Critical clearing times for the Base case, with lines tripping, improvements with PSS (2/2)

Node	Voltage	Country	CCT calculations without line tripping			CCT calculations with line tripping			
Name	kV	Name	MIN	MAX	MACHINES	line tripped	MIN	MAX	MACHINES
KAOLAC03	225	SE	215	219	ALBATR1G	BIRKEL03_SOMA__03_1	215	219	ALBATR1G
BELAIR08	90	SE	231	235	ALBATR1G	BELAIR08-HANN__08-1	231	235	ALBATR1G
CAPEBI08	90	SE	173	176	ALBATR1G	CAPEBI08-SOCOCI08-1	173	176	ALBATR1G
KOUNOU08	90	SE	208	212	ALBATR1G	CAPEBI08-KOUNOU08-1	208	212	ALBATR1G
SOCOCI08	90	SE	208	212	ALBATR1G	CAPEBI08-SOCOCI08-1	204	208	ALBATR1G
DAGANA03	225	SE	254	258	ALBATR1G	DAGANA03-SAKAL_03-1	0		ALBATR1G
TAMBAC03	225	SE	239	243	KOUDI_1G/2G	BIRKEL03_TAMBAC03_1	484	488	ALBATR1G
ZIGUIN03	225	SE	500			TANAF_03_ZIGUIN03_1	500		
BRIKAM03	225	GA	500			SOMA__03_BRIKAM03_1	500		
BISSAU03	225	GB	500			BISSAU03_MANSOA03_1	500		
DONKEA07	110	GU	239	243	BUSHRD1G	GRCHUT07-DONKEA07-1	204	208	BUSHRD1G
GARAFI07	110	GU	227	231	BUSHRD1G	LINSAN07-GARAFI07-1	227	231	BUSHRD1G
GRCHUT07	110	GU	176	180	BUSHRD1G	GRCHUT07-GARAFI07-1	184	188	BUSHRD1G
MATOTO07	110	GU	165	169	BUSHRD1G	GRCHUT07-MATOTO07-1	169	173	BUSHRD1G
FOMI__03	225	GU	500			KOROUS03-FOMI__03-1	500		
KALETA03	225	GU	500			KALETA03-LINSAN03-1	500		
SAMBAG03	225	GU	500			SAMBAN03-MALI__03-1	500		
DABOLA03	225	GU	500			DABOLA03-KOROUS03-1	500		
MANANT03	225	MA	192	196	ALBATR1G	MANANT03_TKITA_03_1		0	MANAN11A/12A/13A/14A/15A + FELOU_1G/2G/3G
SEGOU_05	150	MA	500			FANA__05_SEGOU_05_1	500		
SIRAKO05	150	MA	215	219	ALBATR1G	KALABA05_SIRAKO05_1	184	188	SELING1/2/3/4
LAFIA_05	150	MA	247	251	DARSAL8G	KODIAL05_LAFIA_05_1	309	313	ALBATR1G
SELING05	150	MA	340	344	SELING1/2/3/4	SIRAKO05_SELING05_1	500		
BALING05	150	MA	235	239	ALBATR1G	SIRAKO05_BALING05_1	235	239	ALBATR1G
KAYES_03	225	MA	184	188	ALBATR1G	KAYES_03-MANANT03-1	0		MANAN11A/12A/13A/14A/15A + SELING1/2/3/4 + DARSAL8G + VICABO1G
KOUTIA03	225	MA	500			SIKASS03_KOUTIA03_1	500		
SIKASS03	225	MA	500			SIKASS03_2060FERK_1	500		
KENIE_05	150	MA	379	383	ALBATR1G	SIRAKO05_KENIE_05_1	375	379	ALBATR1G
KENEMA03	225	SL	293	297	ALBATR1G	KENEMA03-BIKONG03-1	332	336	BUSHRD1G
BUMBUN04	161	SL	278	282	BUSHRD1G	BUMBUN04-FRTWON04-1	325	328	BUMBUNG1/2
FRTOWN04	161	SL	235	239	BLACKHG1/2/3	BUMBUN04-FRTWON04-1			
MONROV03	225	LI	212	215	BUSHRD1G	BUCHAN03-MONROV03-1	157	161	BUSHRD1G
BUCHAN03	225	LI	200	204	BUCHANG1	BUCHAN03-MONROV03-1	212	215	BUSHRD1G
2090BUYO	225	CI	215	219	BUSHRD1G	2090BUYO-2070SOUB-1	169	173	BUSHRD1G
2091BUYO	90	CI	500			2091BUYO-2410DALO-1	500		
2040KOSS	225	CI	247	251	BUSHRD1G	2040KOSS-2030TAAB-1	243	247	BUSHRD1G
2030TAAB	225	CI	161	165	BUSHRD1G	2030TAAB-2010ABOB-2	161	165	BUSHRD1G
2500AZIT	225	CI	130	134	BUSHRD1G	2500AZIT-2020VRID-1	122	126	BUSHRD1G
2020VRID	225	CI	130	134	BUSHRD1G	2500AZIT-2020VRID-1	126	130	BUSHRD1G
2170AYAM	90	CI	500			2170AYAM-2180AYAM-1	500		
2180AYAM	90	CI	500			2180AYAM-2190ABRO-1	500		
2021VRID	90	CI	145	149	BUSHRD1G	2240TREI-2021VRID-1	141	145	BUSHRD1G
20FAYE90	90	CI	500			2081PEDR-20FAYE90-1	500		
2209RIVI	225	CI	153	157	BUSHRD1G	2209RIVI-2020VRID-1	153	157	BUSHRD1G
4KODE225	225	BU	500			SIKASS03_4KODE225_1	500		
4BAGR132	132	BU	239	243	4BAGRE16	4BAGR132-4ZANO132-1	410	414	4KOMPI16/26
4KOMP132	132	BU	321	325	4KOMPI16/26	4KOMP132-4ZANO132-1	500		
4KOSSO90	90	BU	332	336	4KOMPI16/26	OUAGAE08-KOSSOD08-1	332	336	4KOMPI16/26
4OUAG190	90	BU	325	328	4BAGRE16/26	4OUAG190-4_PC_090-1	321	325	4KOMPI16/26 + 4BAGRE16/26
4OUAG290	90	BU	321	325	4BAGRE16	4OUAG190-4OUAG290-1	305	309	4OUA23_5
4ZAGTO90	90	BU	317	321	4KOMPI16/26	4ZAGTO90-4OUAG290-1	293	297	4KOMPI16/26 + 4BAGRE16/26

Table 137 - Critical clearing times for Scenario 2, with and without lines tripping (1/2)

Node Name	Voltage kV	Country Name	CCT calculations without line tripping MIN	MAX	MACHINES	CCT calculations with line tripping line tripped	MIN	MAX	MACHINES
OUAGAE08	90	BU	500			PATDOI08-OUAGAE08-1	500		
1010AKOS	161	GH	102	106	ALAOJGT4	1010AKOS-1190KPON-1	102	106	AFAMGT15/16/17/18 + ALAOJGT4
1040TEMA	161	GH	130	134	GOMA_HG1	1020VOLT-1040TEMA-1	130	134	GOMA_HG1
1190KPON	161	GH	258	262	ALAOJGT4	1010AKOS-1190KPON-1	262	266	AFAMGT15/16/17/18 + ALAOJGT4
1320ABOA	161	GH	165	169	BUSHRD1G	1090TARK-1320ABOA-1	165	169	BUSHRD1G
1600OPB-	161	GH	500			1600OPB-1750BONY-1	500		
1470TT1P	161	GH	134	137	BUSHRD1G	1021SME2-1470TT1P-2	134	137	GOMA_HG1
1700ASOG	161	GH	126	130	BUSHRD1G	1700ASOG-1021SME2-1	126	130	BUSHRD1G
ABOA_330	330	GH	231	235	GOMA_HG1	1029VOLT-ABOA330-1	231	235	BUSHRD1G
1500BUI	161	GH	212	215	BUI___G1/2	1500BUI-1590KIN	204	208	BUI___G1/2
1750BONY	161	GH	356	360	DOMIT1G1/2	1750BONY-1800ELUB-1	278	282	BUSHRD1G
3030COTO	161	TB	243	247	CAI___1G/2G	MA_GLE04_3030COTO_3	243	247	CAI___1G/2G
3010LOME	161	TB	215	219	LOME__1G	1392AFT-3010LOME-1	212	215	LOME__1G
3060NANG	161	TB	274	278	3061NANG/2NANG	3060NANG-3020MOME-1	262	266	3061NANG/2NANG
3LOME161	161	TB	301	305	3NEWIPP	3010LOME-3LOME161-1	301	305	3NEWIPP
3KARA161	161	TB	500			3ATAK161-3KARA161-1	500		
PARAKO04	161	TB	500			PARAKO04_3050ONIG_1	500		
MANGO_04	161	TB	500			MANGO_04_DAPAON04_1	500		
MA_GLE04	161	TB	200	204	CAI___1G/2G	3040SAKA_MA_GLE04_1	200	204	CAI___1G/2G
KANDI_04	161	TB	500			GUENE_04_KANDI_04_1	500		
NATITI04	161	TB	500			3DJOU161_NATITI04_1	500		
MARADI06	132	NR	500			GAZAOU06-MARADI06-1	500		
ZINDER06	132	NR	173	176	ZINDCC1G	GAZAOU06-ZINDER06-1	453	457	ZINDCC1G
NIAM2_06	132	NR	235	239	GOUDELG2/3/4	NIAM2_06-NIAMRD06-1	235	239	GOUDDELG2/3/4
DOSSO_06	132	NR	71	75	NIGERSOL	DOSSO_06-NIAM2C-1	114	118	GOUDELG2/3/4
SALKAD02	330	NR	500			DOSSO_02-SALKAD02-1	500		
DELTA_06	132	NI	395	399	DELTAG03/4/5/6	no line connected	---	---	---
DELTA_02	330	NI	215	219	BUSHRD1G	BENINC02-DELTA_02-1	219	223	BUSHRD1G
SAPELE02	330	NI	83	87	ALBATR1G	BENINC02-SAPELE02-1	83	87	ALBATR1G
OMOTOS02	330	NI	114	118	GOMA_HG1	OMOTOS02-BENINC02-1	122	126	ALBATR1G
GEREGU02	330	NI	87	91	ALBATR1G	AJAOKU02-GEREGU02-1	87	91	ALBATR1G
EYAEN_02	330	NI	67	71	ALBATR1G	BENINN02-EAYEN_02-1	67	71	ALBATR1G
IKOTAB06	132	NI	500			no line connected	---	---	---
AFAM__02	330	NI	67	71	CALABAGT1/2/3/4/5	ALAOJI02-AFAM__02-1	71	75	CALABAGT1/2/3/4/5
ALAOJI02	330	NI	56	59	CALABAGT1/2/3/4/5	OWERRI02-ALAOJI02-1	56	59	CALABAGT1/2/3/4/5
CALABA02	330	NI	87	91	CALABAGT1/2/3/4/5	IKOTEK02-CALABA02-1	83	87	CALABAGT1/2/3/4/5
KWALE_02	330	NI	188	192	BUSHRD1G	KWALE_02-ONITSH02-1	188	192	AFAMGT13/14
EGBEMA02	330	NI	83	87	CALABAGT1/2/3/4/5	OWERRI02-EGBEMA02-1	83	87	CALABAGT1/2/3/4/5
OMOKU_02	330	NI	126	130	CALABAGT1/2/3/4/5	EGBEMA02-OMOKU_02-1	122	126	CALABAGT1/2/3/4/5
IKOTAB02	330	NI	145	149	CALABAGT1/2/3/4/5	IKOTEK02-IKOTAB02-1	145	149	CALABAGT1/2/3/4/5
OMOKU_06	132	NI	500			no line connected	---	---	---
GBARAN06	132	NI	500			no line connected	---	---	---
EGBIN_06	132	NI	219	223	EGBINGT7/8/9	no line connected	---	---	---
EGBIN_02	330	NI	91	95	ALBATR1G	ERUNKA02-EGBIN_02-1	87	91	ALBATR1G
IKEJAW02	330	NI	91	95	ALBATR1G	IKEJAW02-ERUNKA02-1	95	98	ALBATR1G
ERUNKA02	330	NI	91	95	ALBATR1G	ERUNKA02-EGBIN_02-1	91	95	ALBATR1G
PAPALA02	330	NI	118	122	ALBATR1G	IKEJAW02-PAPALA02-1	118	122	ALBATR1G
JEBBAP02	330	NI	165	169	BUSHRD1G	JEBBAP02-JEBBA_02-1	165	169	BUSHRD1G
KAINJI02	330	NI	212	215	NIGERSOL	KAINJI02-JEBBA_02-1	204	208	NIGERSOL
SHIROR02	330	NI	122	126	ALBATR1G	JEBBA_02-SHIROR02-2	126	130	ALBATR1G

Table 138 - Critical clearing times for Scenario 2, with and without lines tripping (2/2)

				Base case off peak load			Scenario 2 off peak load		
Node	Voltage	Country		CCT calculations with line tripping			CCT calculations with line tripping		
Name	kV	Name	Faulted line tripped	min	max	Machines losing synhronism	min	max	Machines losing synhronism
KAOLAC03	225	SE	BIRKEL03_SOMA__03_1	201	205	FELOU1G/2/3G	217	221	GTI_113A
BELAIR08	90	SE	BELAIR08-HANN__08-1	260	264	BUSHR2G2/3/4	244	248	GTI_113A
CAPEBI08	90	SE	CAPEBI08-SOCOCI08-1	221	225	BUSHR2G2/3/4	194	198	KENIE_1/2/3G
KOUNOU08	90	SE	CAPEBI08-KOUNOU08-1	264	268	BUSHR2G2/3/4	225	229	KENIE_1/2/3G
SOCOCI08	90	SE	CAPEBI08-SOCOCI08-1	299	303	BUSHR2G2/3/4	264	268	GTI_113A
DAGANA03	225	SE	DAGANA03-SAKAL_03-1	237	240	ROSSBE1G	268	272	ROSSBE1/2G
TAMBAC03	225	SE	BIRKEL03_TAMBAC03_1	487	490	KOUDI_1G/2G	463	467	GTI_113A
ZIGUIN03	225	SE	TANAF_03_ZIGUIN03_1	500			500		
BRIKAM03	225	GA	SOMA__03_BRIKAM03_1	479	483	BUCHANG1	500		
BISSAU03	225	GB	BISSAU03_MANSOA03_1	500			500		
DONKEA07	110	GU	GRCHUT07-DONKEA07-1	381	385	TOMBO5G2/3	283	287	BUSHR2G2/3/4
GARAFI07	110	GU	LINSAN07-GARAFI07-1	405	408	GARAFIG1	330	334	BUSHR2G2/3/4
GRCHUT07	110	GU	GRCHUT07-GARAFI07-1	280	283	TOMBO3G4	237	240	GOMA_HG1/2
MATOTO07	110	GU	GRCHUT07-MATOTO07-1	240	244	TOMBO3G4	213	217	BUSHR2G3
FOMI__03	225	GU	KOROUS03-FOMI__03-1	500			500		
KALETA03	225	GU	KALETA03-LINSAN03-1	61	65	GOMA_HG1/2	500		
SAMBAG03	225	GU	SAMBAN03-MALI__03-1	500			500		
DABOLA03	225	GU	DABOLA03-KOROUS03-1	500			500		
MANANT03	225	MA	MANANT03_TKITA_03_1	287	291	MANAN15A	283	287	MANAN14/5A
SEGOU_05	150	MA	FANA__05_SEGOU_05_1	500			500		
SIRAKO05	150	MA	KALABA05_SIRAKO05_1	61	65	VICABO1G	135	139	BALBIDG1/2
LAFIA_05	150	MA	KODIAL05_LAFIA_05_1	287	291	VICABO1G	350	354	KENIE_1/2/3G
SELING05	150	MA	SIRAKO05_SELING05_1	500			500		
BALING05	150	MA	SIRAKO05_BALING05_1	209	213	VICABO1G	233	237	KENIE_1/2/3G
KAYES_03	225	MA	KAYES_03-MANANT03-1	354	358	FELOU1/2/3G		0	
KOUTIA03	225	MA	SIKASS03_KOUTIA03_1	500			500		
SIKASS03	225	MA	SIKASS03_2060FERK_1	500			500		
KENIE_05	150	MA	SIRAKO05_KENIE_05_1	291	295	VICABO1G	287	291	SELING1/2/3/4
KENEMA03	225	SL	KENEMA03-BIKONG03-1	315	319	BUSHR2G2/3/4	346	350	BUSHR2G3
BUMBUN04	161	SL	BUMBUN04-FRTWON04-1	299	303	BUMBU1G1	334	338	BUMBU1G1
FRTOWN04	161	SL	BUMBUN04-FRTWON04-1	500			500		
MONROV03	225	LI	BUCHAN03-MONROV03-1	198	201	BUSHR2G2/3/4	186	190	BUSHR2G3
BUCHAN03	225	LI	BUCHAN03-MONROV03-1	201	205	BUCHANG1	233	237	BUCHANG1
2090BUYO	225	CI	2090BUYO-2070SOUB-1	237	240	2093BUYO	186	190	2093BUYO
2091BUYO	90	CI	2091BUYO-2410DALO-1	500			500		
2040KOSS	225	CI	2040KOSS-2030TAAB-1	459	463	2043KOSS	291	295	BUSHR2G3
2030TAAB	225	CI	2030TAAB-2010ABOB-2	479	483	2093BUYO	190	194	BUSHR2G2/3/4
2500AZIT	225	CI	2500AZIT-2020VRID-1	237	240	BUSHR2G2/3/4	139	143	BUSHR2G2/3/4
2020VRID	225	CI	2500AZIT-2020VRID-1	229	233	BUSHR2G2/3/4	143	147	GOMA_HG1/2
2170AYAM	90	CI	2170AYAM-2180AYAM-1	500			500		
2180AYAM	90	CI	2180AYAM-2190ABRO-1	500			500		
2021VRID	90	CI	2240TREI-2021VRID-1	209	213	20NTAG83	158	162	BUSHR2G2/3/4
20FAYE90	90	CI	2081PEDR-20FAYE90-1	500			500		
2209RIVI	225	CI	2209RIVI-2020VRID-1	240	244	BUSHR2G2/3/4	162	166	BUSHR2G3
4KODE225	225	BU	SIKASS03_4KODE225_1	500			500		
4BAGR132	132	BU	4BAGR132-4ZANO132-1	500			500		
4KOMP132	132	BU	4KOMP132-4ZANO132-1	500			500		
4KOSSO90	90	BU	OUAGAE08-KOSSOD08-1	330	334	MANASEMA	408	412	4OUA24/25_5
4OUAG190	90	BU	4OUAG190-4_PC_090-1	358	362	MANASEMA	397	401	4OUA24/25_5
4OUAG290	90	BU	4OUAG190-4OUAG290-1	373	377	MANASEMA	393	397	4OUA24/25_5
4ZAGTO90	90	BU	4ZAGTO90-4OUAG290-1	500			354	358	4OUA24/25_5

Table 139 - Critical clearing times for Base case and Scenario 2 off peak load situation, with line tripping (1/2)

Node Name	Voltage kV	Country Name	Faulted line tripped	CCT calculations with line tripping min	max	Machines losing synhronism	CCT calculations with line tripping min	max	Machines losing synhronism
OUAGAE08	90	BU	PATDOI08-OUAGAE08-1	213	217	MANASEMA	500		
1010AKOS	161	GH	1010AKOS-1190KPON-1	280	283	TOMBO5G2	225	229	GOMA_HG1/2
1040TEMA	161	GH	1020VOLT-1040TEMA-1	303	307	BUSHR2G2/3/4	205	209	BUSHR2G3
1190KPON	161	GH	1010AKOS-1190KPON-1	500			471	475	BUSHR2G2/3/4
1320ABOA	161	GH	1090TARK-1320ABOA-1	291	295	ABOAT1ST	217	221	BUSHR2G3
1600OPB-	161	GH	1600OPB-1750BONY-1	500			455	459	DOMIT1G1/2
1470TT1P	161	GH	1021SME2-1470TT1P-2	311	315	BUSHR2G2/3/4	213	217	BUSHR2G2/3/4
1700ASOG	161	GH	1700ASOG-1021SME2-1	295	299	BUSHR2G2/3/4	205	209	BUSHR2G2/3/4
ABOA_330	330	GH	1029VOLT-ABOA330-1	276	280	BUSHR2G2/3/4	221	225	BUSHR2G3
1500BUI	161	GH	1500BUI-1590KIN	229	233	BUI___G1	233	237	BUI___G1
1750BONY	161	GH	1750BONY-1800ELUB-1	389	393	DOMIT1G1/2	256	260	DOMIT1G1/2
3030COTO	161	TB	MA_GLE04_3030COTO_3	287	291	MA_GLE1G	295	299	MA_GLE1G
3010LOME	161	TB	1392AFT-3010LOME-1	198	201	LOME__1G	213	217	LOME__1G
3060NANG	161	TB	3060NANG-3020MOME-1	500			500		
3LOME161	161	TB	3010LOME-3LOME161-1	303	307	3NEWIPP	307	311	3NEWIPP
3KARA161	161	TB	3ATAK161-3KARA161-1	500			500		
PARAKO04	161	TB	PARAKO04_3050ONIG_1	500			500		
MANGO_04	161	TB	MANGO_04_DAPAON04_1	500			500		
MA_GLE04	161	TB	3040SAKA_MA_GLE04_1	248	252	MA_GLE1G	252	256	MA_GLE1G
KANDI_04	161	TB	GUENE_04_KANDI_04_1	500			500		
NATITI04	161	TB	3DJOU161_NATITI04_1	500			500		
MARADI06	132	NR	GAZAOU06-MARADI06-1	500			500		
ZINDER06	132	NR	GAZAOU06-ZINDER06-1	444	448	ZINDCC1G	467	471	ZINDCC1G
NIAM2_06	132	NR	NIAM2_06-NIAMRD06-1	385	389	GOUDELG1	221	225	GOUDELG1/2/3
DOSSO_06	132	NR	DOSSO_06-NIAM2C-1	500			500		
SALKAD02	330	NR	DOSSO_02-SALKAD02-1	500			500		
DELTA_06	132	NI	no line connected	---	---	---			
DELTA_02	330	NI	BENINC02-DELTA_02-1	268	272	BUSHR2G2/3/4	295	299	KENIE_1/2/3G
SAPELE02	330	NI	BENINC02-SAPELE02-1	104	108	BUSHR2G2/3/4	100	104	SELING01/2/3/4+KENIE_1/2/3G
OMOTOS02	330	NI	OMOTOS02-BENINC02-1	127	131	BUSHR2G2/3/4	123	127	KENIE_1/2/3G
GEREGU02	330	NI	AJAOKU02-GEREGU02-1	131	135	BUSHR2G2/3/4	166	170	VICABO1G
EYAEN_02	330	NI	BENINN02-EAYEN_02-1	92	96	BUSHR2G2/3/4	104	108	VICABO1G
IKOTAB06	132	NI	no line connected	---	---	---			
AFAM__02	330	NI	ALAOJI02-AFAM__02-1	123	127	BUSHR2G2/3/4	119	123	KENIE_1/2/3G
ALAOJI02	330	NI	OWERRI02-ALAOJI02-1	104	108	BUSHR2G2/3/4	100	104	KENIE_1/2/3G
CALABA02	330	NI	IKOTEK02-CALABA02-1	166	170	CALABGT3/4/5	174	178	KENIE_1/2/3G
KWALE_02	330	NI	KWALE_02-ONITSH02-1	190	194	BUSHR2G2/3/4	213	217	KENIE_1/2/3G
EGBEMA02	330	NI	OWERRI02-EGBEMA02-1	123	127	BUSHR2G2/3/4	115	119	KENIE_1/2/3G
OMOKU_02	330	NI	EGBEMA02-OMOKU_02-1	174	178	BUSHR2G2/3/4	166	170	KENIE_1/2/3G
IKOTAB02	330	NI	IKOTEK02-IKOTAB02-1	174	178	IBOMGT03	182	186	IBOMGT03
OMOKU_06	132	NI	no line connected	---	---	---			
GBARAN06	132	NI	no line connected	---	---	---			
EGBIN_06	132	NI	no line connected	---	---	---			
EGBIN_02	330	NI	ERUNKA02-EGBIN_02-1	104	108	BUSHR2G2/3/4	104	108	MANAN14/5A+FELOU1/2_G+KENIE_1/2/3G
IKEJAW02	330	NI	IKEJAW02-ERUNKA02-1	104	108	BUSHR2G2/3/4	100	104	KENIE_1/2/3G
ERUNKA02	330	NI	ERUNKA02-EGBIN_02-1	104	108	BUSHR2G2/3/4	100	104	KENIE_1/2/3G
PAPALA02	330	NI	IKEJAW02-PAPALA02-1	135	139	BUSHR2G2/3/4	127	131	KENIE_1/2/3G
JEBBAP02	330	NI	JEBBAP02-JEBBA_02-1	213	217	BUSHR2G2/3/4	229	233	KENIE_1/2/3G
KAINJI02	330	NI	KAINJI02-JEBBA_02-1	323	326	KAING12	303	307	KAING12
SHIROR02	330	NI	JEBBA_02-SHIROR02-2	170	174	BUSHR2G2/3/4	162	166	KENIE_1/2/3G

Table 140 - Critical clearing times for Base case and Scenario 2 off peak load situation, with line tripping (2/2)

6. APPENDIX: NOTE FOR THE HARMONIZATION OF THE UNDER FREQUENCY LOAD SHEDDING SCHEME IN GHANA, IVORY COAST, BURKINA FASO, TOGO AND BENIN

6.1. Introduction

High imbalance in active power/frequency domain can be corrected by suitable automatic load shedding. The Under Frequency Load Shedding (UFLS) of the different power systems which are synchronously interconnected have to be coherent. This coordination is required in order to maximize the chance, to avoid a complete or partial frequency collapse in the system and to fairly share the load shedding among all systems making the interconnected system. A coordinated load shedding plan could limit the shed load in each system by applying the "solidarity" principle: the load is shed not only in the area where the imbalance occurs but also in the interconnected systems.

The objective of this report is to review and to analyze the existing UFLS schemes of the WAPP interconnected system and to present some guidelines to harmonize them. Before this analysis, the international practices and especially the ENTSOE rules are presented.

6.2. International Practice for UFLS scheme

6.2.1. General Guidelines

Concerning the definition of the Under-frequency Load Shedding (UFLS) scheme, the following main rules are recommended internationally:

- The frequency range of load shedding results from the power-frequency control policy of the network. It has to be defined between the frequency range kept for primary frequency control and the frequency threshold to disconnect the generating units.
- The shedding thresholds have to be uniformly distributed in a common frequency range for the whole power system. If this criterion is not fulfilled, the area with the highest frequency threshold will be penalized by more frequent load shedding and this area could be the unique area concerned by the load shedding for most of the situations.
- The higher the number of the frequency steps, the better will be the self adjustment of the load shedding plan (ability to catch most situations with the minimum possible load shedding).
- The global amount of load shedding is limited due to the over-voltage problems arising during and after the frequency restoration.

Concerning the implementation of the under-frequency load shedding scheme, the following general guidelines should be followed:

- The shed load has to be evenly distributed geographically. This allows limiting power flows resulting form the load shedding and facing frequency collapse in possible islands which could appear.
- The load shedding program should follow the actual overall load evolution in time so as to maintain the percentage of shed load. The effective load corresponding to the under-frequency relays has to be regularly checked (mainly if the total load shedding amount is fairly limited).
- The time delays of the frequency relays have to be limited (no addition delay is recommended), but an unavoidable delay exists for insuring "stable" frequency measurements. The typical global time delay is between 100 ms to 200 ms. Using longer delays is not recommendable because self adjustment of the scheme can get lost.
- A frequency margin is kept between the lowest frequency threshold of the UFLS and the frequency threshold of the under-frequency protection of the generating units (preferably a single uniform value for all units).

6.2.2. ENTSOE Practices

ENTSOE (European Organization of TSO merging the former UCTE, Nordel, ETSO,…) is generally considered as a worldwide reference in terms of interconnected system and harmonization rules and recommendations. This European TSO organization reviewed recently the basic rules to be followed by each member in terms of Under Frequency Load Shedding. Those rules are summarized here-below.

UFLS of ENTSOE solidarity range

The automatic load shedding of consumption due to the large drop of frequency for the UCTE solidarity range is designed as follows:

- *Beginning of the solidarity range at 49,2 Hz,*
- *End of the solidarity range at 48.5 Hz with the sum of shed consumption reaching minimum 25% of the initial total consumption before load shedding.*
- *Trigger of load shedding are as follows:*
- *At 49 Hz at least 5% of total consumption*
- *At 48.8 Hz at least 10% - with a maximum of 20% - of total consumption*
- *At 48.6 Hz at least 15% of total consumption*

25% of the total load should be operated under load shedding relays in the range from 48.6 to 49,2 Hz, with an inaccuracy of 100 mHz for old relays.

Load shedding relays (modern type) should be triggered in the range from 48.6 to 49.2 Hz in steps smaller or equal than 200 mHz (old relays type: larger frequency steps are acceptable with an inaccuracy of 100 mHz)

In each step not more than 10% of the load should be disconnected, except for radial regions or other local/regional risk assessment.

Individual ranges of load shedding

Additional 25% or more of the total load could be operated under load shedding relays in the range from 48.6 to 48.0 Hz (regional/individual solution), even till 47.5 Hz based on the individual appreciation of TSOs.

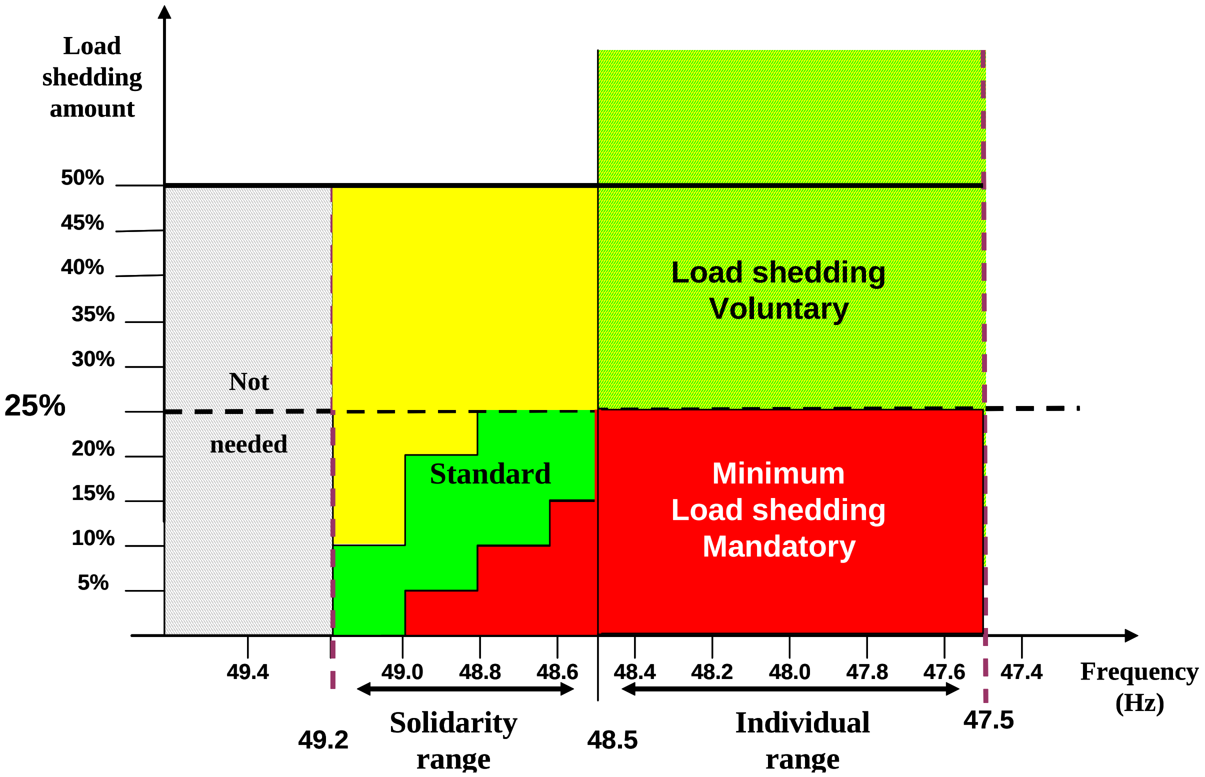
Load shedding geographical distribution

Load shedding should be implemented in a regionally evenly distributed way.

Time delay of relays

The reaction time should be realized as short as possible under consideration of the required time constant respectively time delay of the measuring element. The operational time of relays should not be longer than 200 ms (without time of opening of breakers).

The recommended UFLS scheme can be summarized by the following graph.



A large numbers of international utilities follow those European guidelines to define their under-frequency load shedding.

6.3. Analysis of Existing UFLS of Ghana

The collected data are the following (2010 data). The given percentages are referring to peak load situation.

	Threshold (Hz)	Threshold df/dt	Time delay	Load (%)
1	49.5	-0.35	150 ms	9.5
2	49.5	-0.6	150 ms	9.5
4	49.		150 ms	9.8
5	48.5		150 ms	7.9
6	48.3		150 ms	10
TOT				**46.7**

This analysis of the existing UFLS of Ghana is split into the following parts: the features respecting the international practices and the ones not following these practices.

6.3.1. Features respecting international practices

The existing global UFLS scheme of Ghana follows the international recommendations for the following aspects:

- Similar load amount per threshold with maximum 10% per threshold;
- Identical and low time delay (<200 ms) for all UFLS thresholds;
- Acceptable first frequency threshold of 49Hz.

6.3.2. Features not according to international practices

The following characteristics of UFLS of Ghana are not following the international recommendations:

- Few substations are equipped with UFLS relays (not geographically distributed), sometimes only one or two substations. The UFLS relays should be uniformly distributed geographically in the Ghana power system as each subarea includes global load shedding threshold which is almost proportional to the size of this subarea.
- Insufficient number of UFLS thresholds (only 3 frequency thresholds). A minimum of 5 thresholds is recommended (for example adding two thresholds at 48.8 Hz and 48.1 Hz).
- The use of df/dt criteria for UFLS activation is not usual and questionable for the Ghana system. As demonstrated by simulations, it provokes sometimes load shedding in situations for which it is not needed. These criteria are generally used when incidents happen that provoke a huge power deficit and force a rapid decrease of the frequency. Due to the size of the interconnected system and the characteristics of Ghana (size of unit, no massive importation), they should not be required. Moreover, such criteria are more sensitive than classical frequency threshold and they should be reviewed and checked regularly.
- If the df/dt thresholds are maintained, they should be coupled with a classical frequency threshold (OR logic) to ensure a sufficient total load shedding amount in case of frequency drop with a decrease rate lower than df/dt thresholds (for example multiple loss of generators with some seconds between each loss).

6.4. Analysis of Existing UFLS of Burkina Faso

The following data are coming from the report « Etude du couplage des réseaux CIE-SONABEL à la mise en service de la ligne Bobo-Ouaga » (novembre 2009).

	Threshold (Hz)	Time delay	Load (%)
1	49.0	500 ms	3.5
2	48.87	500 ms	8
3	48.87	700 ms	16
4	48.87	1.5 sec	10
5	48.87	2 sec	12.5
TOT			**50**

The existing UFLS should be completely reviewed and is not at all according to international practices. Its main drawbacks are:

- Only two frequency thresholds within a very narrow range 49Hz – 48.87 Hz;
- UFLS having same frequency thresholds with different delays could provoke over-shedding as there is a need for some time to restore the frequency after load shedding;
- Large time delays (> 500ms) could provoke a frequency collapse of the system especially for a country like Burkina Faso which could import a large proportion of its consumption.
- Although this is the only country without df/dt criteria, such df/dt criteria could be justified from Burkina Faso power system to face sudden loss of interconnection in case of massive importation.

6.5. Analysis of Existing UFLS of Ivory Coast

The data are coming from the report “Rapport de collecte de données du réseau Ivoirien” of July 2006.

	Threshold (Hz)	Threshold df/dt	Time delay	Load (%)
1	49.5	-0.4	100 ms	5.5
2	49.5	-0.6	30 ms	5.5
3	49.5	-1.0	10 ms	5.5
4	48.5		1 sec	5.5
5	48.1		300 ms	5.5
6	47.7		0 ms	22
TOT				**47.5**

The main drawbacks of UFLS scheme of Ivory Coast are:

- Not enough number of frequency thresholds. A minimum of 5 steps is recommended;
- Bad frequency load shedding range, the first frequency threshold should be harmonized with neighbouring countries (49Hz) for a fair contribution of all countries and the last threshold of 47.7Hz is too low and probably too close of under-frequency thresholds of generating units.

- The load shedding amount is not well distributed among thresholds; the last threshold corresponding to 22%;
- All time delays should be lower than 200 ms;
- Similarly to Ghana system, it has to be checked if the df/dt criteria are required and correctly tuned;
- If the df/dt thresholds are maintained, they should be coupled with a classical frequency threshold (OR logic) to ensure a sufficient total load shedding amount in case of frequency drop with a decrease rate lower than df/dt thresholds (for example multiple loss of generators with some seconds between each loss).

6.6. Analysis of Existing UFLS of Togo/Benin

No information has been transmitted by GRIDCo concerning the existing UFLS of Togo/Benin system.

6.7. Recommendations

The UFLS schemes of WAPP countries should be in line with the internationally recommended practices. The following guidelines are proposed to update the UFLS scheme of WAPP interconnected system.

- Collect the UFLS settings currently applied in each country with the frequency thresholds, the operation time delay and the corresponding amount of load shed in MW for different network situation (peak and off-peak situation). This information should be centralized and updated regularly.
- Collect the settings of Under-frequency protection of generating units to verify if there is a sufficient margin between the last UFLS thresholds and the first UF protection (at least 200 mHz).
- Perform dedicated studies in order to quantify :
  - The global amount of load that could be shed without facing unacceptable overvoltage problems. As the WAPP interconnected is quite weak and poorly meshed, this maximum % of load shedding should be lower than the classical maximal threshold used in European country (between 40% and 50%). It has to be noticed that some countermeasures could be installed to limit the over-voltages (like automatic disconnection of bank capacitor or automatic connection of bank reactor when the last UFLS are activated.
  - To review the settings and even the need of the thresholds based on the derivative of frequency (see remarks of the previous section).
- Harmonize the UFLS of each country to have a fair and similar contribution of all member states to the load shedding in case of frequency drop. The guidelines for this harmonization are:
  - No harmonization of df/dt criteria is required. These criteria should be additional to the classical frequency thresholds (with OR logic) in order to face possible incident provoking a huge lack of generation (like the loss of the Burkina Faso interconnection);
  - All time delay lower than 200 ms;
  - Identical frequency thresholds and at least 5 thresholds;

- Similar load shedding amount expressed in percentage of the total consumption of each country with a maximum of 10% per threshold;

UFLS relays have to be evenly distributed geographically and installed in a sufficient number of substations.

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