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Analysis of System Stability in Developing and Emerging Countries

Country Chapter: Senegal

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1 Senegal's Power Sector

1.1 Overview

Senegal's Power Sector is operated by the public company SENELEC, which is a vertically integrated power company that generates, transmits, distributes and sales electric energy to the customers. Besides this, SENELEC identifies and finances new projects and has to maintain an autonomous self-financing system.

The "Ministère de l'Energie" controls the power sector and defines its regulatory framework. Besides generation owned and operated by SENELEC, the current framework also permits private generation regulated by an IPP and a self-supplier scheme. [1]

1.2 Demand and Generation

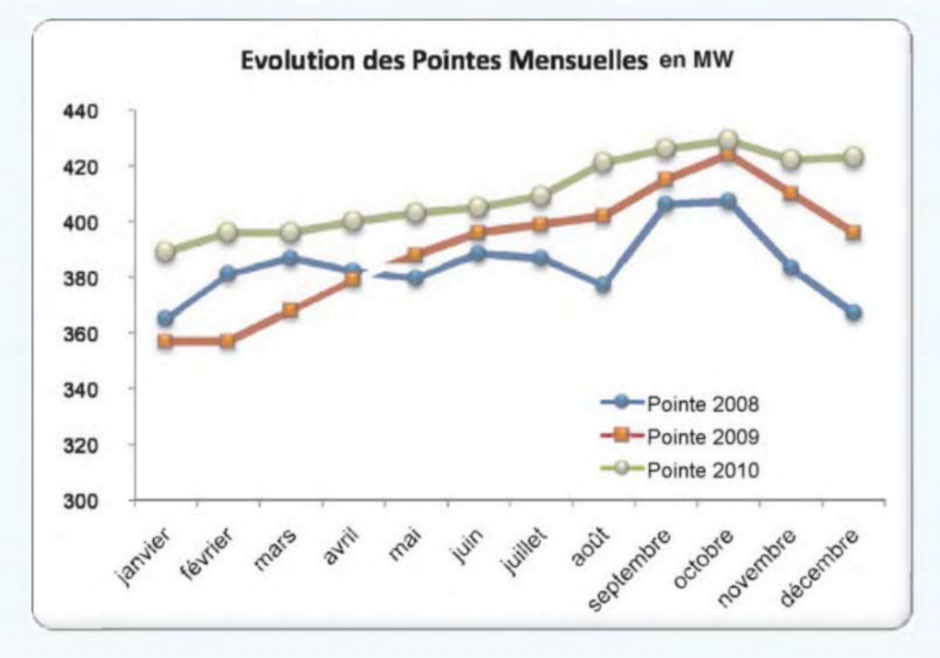

Figure 1 - Monthly peak load evolution 2008 – 2010 [1]

In 2010 the peak demand of Senegal reached around 430 MW on October 5th in the late evening and minimum demand of 175 MW at February 23rd in the early morning.

In 2010 the total electricity production reached around 2,6 GWh generated by a total installed capacity of around 690MW, out of which around 520MW is actually available. The difference can mainly be explained by aging effects.

Out of these 690MW, around 26MW are connected to the isolated regional centres of Ziguinchor and Tambacounda, which are not connected to the main national grid.

Another 15MW of installed capacity supply 26 very small, autonomous systems in the East and South of Senegal.

The generation mix is dominated by thermal power stations, most of them diesel power stations (see Figure 2), followed by steam turbines, gas turbines and the hydro power station of Manantali in Mali.

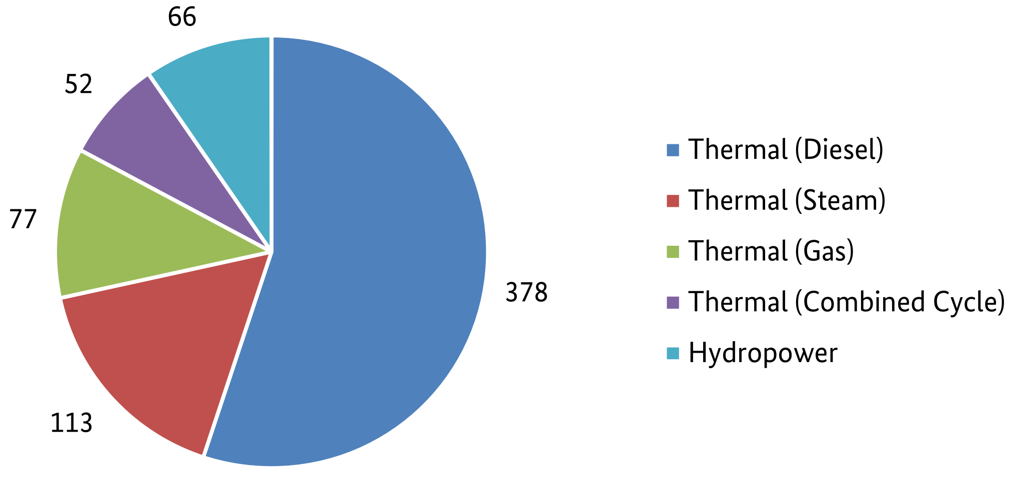

Figure 2 - Installed capacity per technology in MW (2010) [1]

1.3 System Expansion

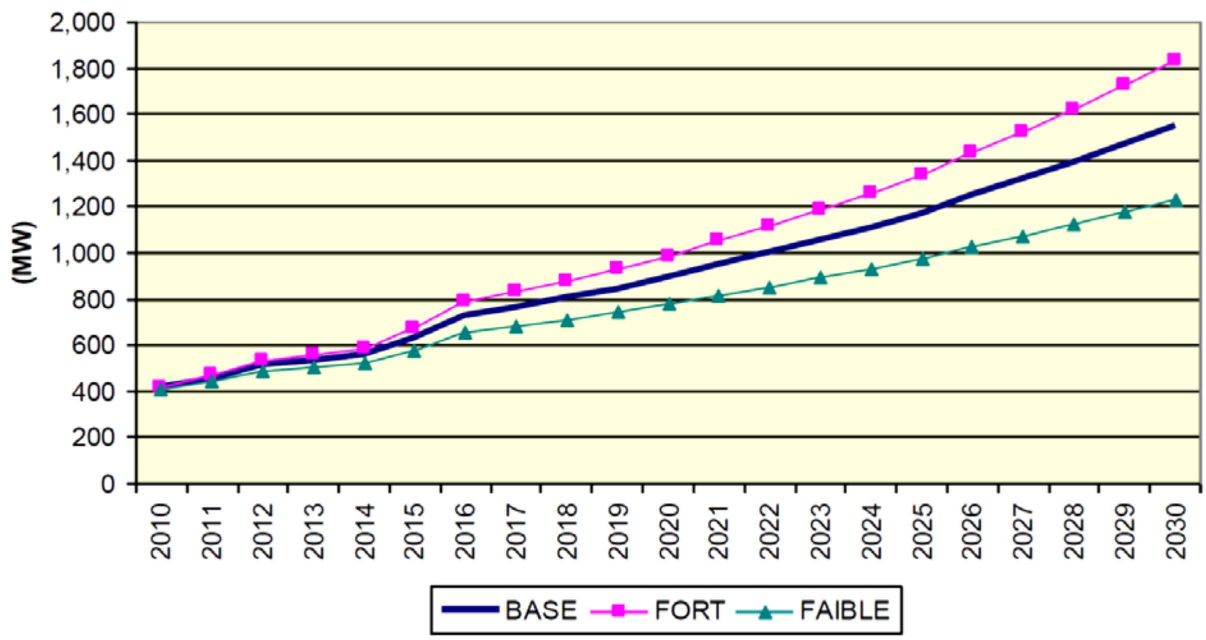

Figure 3 - Demand forecast (MW) [2]

Like most emerging countries, Senegal expects a considerable load growth over the next years. In 2030, peak load is expected to be around three times higher than in 2010 (see Figure 3).

1.4 Voltage levels and grid layout

1.4.1 Main Transmission grid

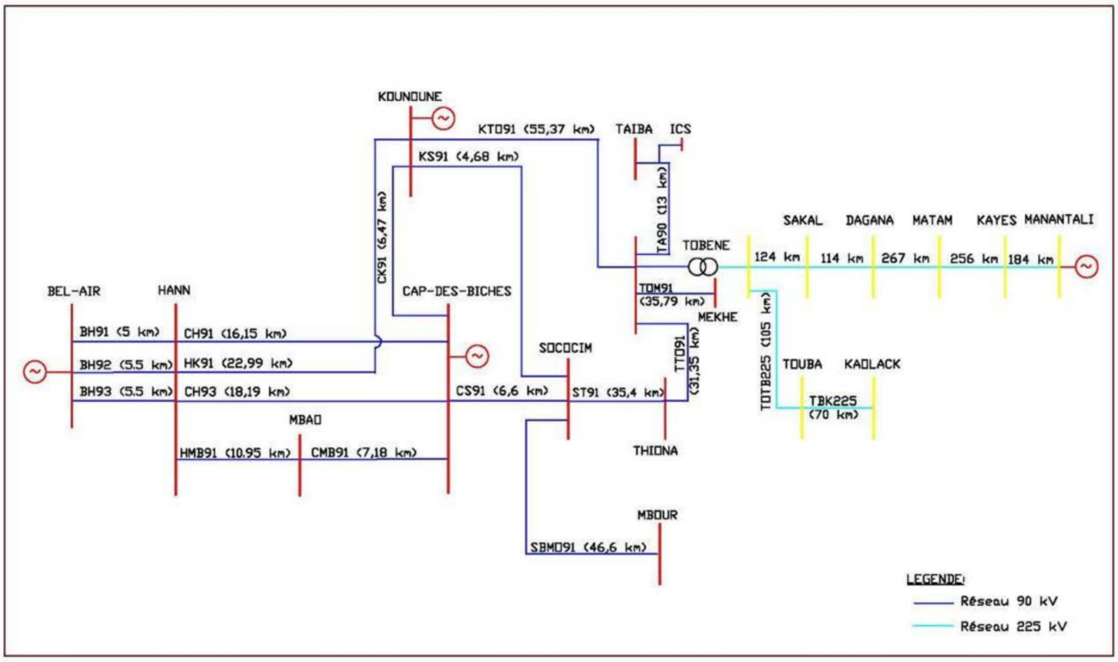

Figure 4 - Single line diagram of Senegal's transmission grid [2]

The main transmission grid is built by a 90 kV national and a 225 kV transmission line connecting the hydro power plant Manantali, which is located in Mali (see Figure 4).

In 2010 the combined length of all 90 kV transmission lines was around 328 km. There are nine 90kV/30 kV substations with a total installed capacity of 1127 MVA (see Table 1)

Table 1 – 90kV/30 kV Substations [3]

Substation	Capacity [MVA]
Bel Air	362 MVA
Hann	240 MVA
Mbao	80 MVA
Cap des Biches	25 MVA
Thiès Thiona	80 MVA
Mbour	40 MVA
Tobène	20 MVA
Touba	80 MVA
Kaolack	80 MVA

The 225 kV interregional grid (Manantali – Matam – Dagana – Sakal – Tobène) has a total line length of 945 km [3]. The 225 kV/90 kV Tobène (2x75 MVA) substation and three other 225kV/30 kV substations are connected to this line (see also Table 2).

The planned transmission expansions for 2010 are depicted in Table 3

Table 2 - 225/30 kV Substation [3]

Substation	Capacity [MVA]
Matam	1x20 MVA
Dagana	1x20 MVA
Sakal	1x50 MVA

Table 3 - Planned transmission grid enhancements (2010) [1]

TRANSPORT	Puissances installé (MVA)	Coût du projet (10p9 CFA)	Date mise en service
Réalisation et alimentation postes 225/30 kVX40 Saint Louis	40 MVA	13,96	
Réalisation et alimentation postes 225/30 kVx40 SAPCO	40 MVA	12,17	
Boucle 90 kV Dakar Phase 1	90kV	18,09	2012
Boucle 225 kV Phase 1 Mbour-Kounoun-Tobène	225kV	20	2011
Boucle 90kV à coupure sur la SF6 à Cap de Biches		9,91	
TELECOMMANDE (RCVD des régions, réabilitation réseau radiocom)		8,85	
Alimentation terminal minéraliers de Sendou		2,66	
Réhabilitation et renforcement réseau de transport		4	
Réhabilitation des lignes de transport 90kV		10,11	2011

1.4.2 Distribution grids

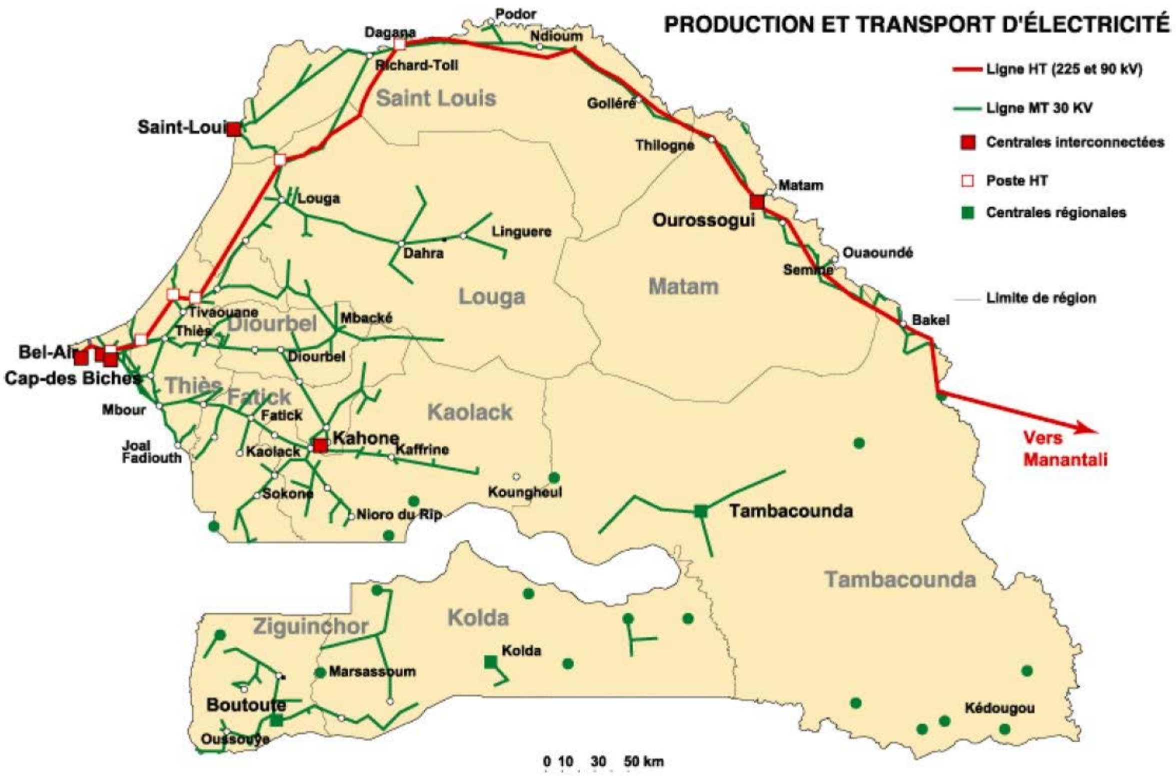

Figure 5 - Map of the transmission grid and the distribution grids (30 kV) of Senegal [4]

The distribution network consists of [5]:

- 30kV/6.6kV substations
- 7627 km of MV lines (6.6kV and 30 kV)
- 6761 km of LV lines
- 3511 MV/LV transformers

The regional centres around Ziguinchor and Tambaccounda are 30kV distribution grids that are not connected to the main transmission grid.

1.5 Renewable Energy Sources in Senegal

The government expects to reach a renewable energy penetration level of 20% by 2020. At the moment there exists only very little PV capacity at SENELEC's grid, which is mainly concentrated in solar power plants [2]:

- Solar thermal power plant of Diakhao (25 kVA);
- Solar-wind power plant de Niaga Wolof (5 kWp+4 kVA);
- Photovoltaik systems de Notto (7,5 kWp), Diawoulé (21,5 kWp) et Ndiebel (18,7 kWp);
- PV-Diesel hybrid power plant: Dionewar (100 kWp+250 kVA), Bassoul (80 kWp +100kVA) et Djirnda (10 kWp+10 kVA).

1.5.1 RES Potential

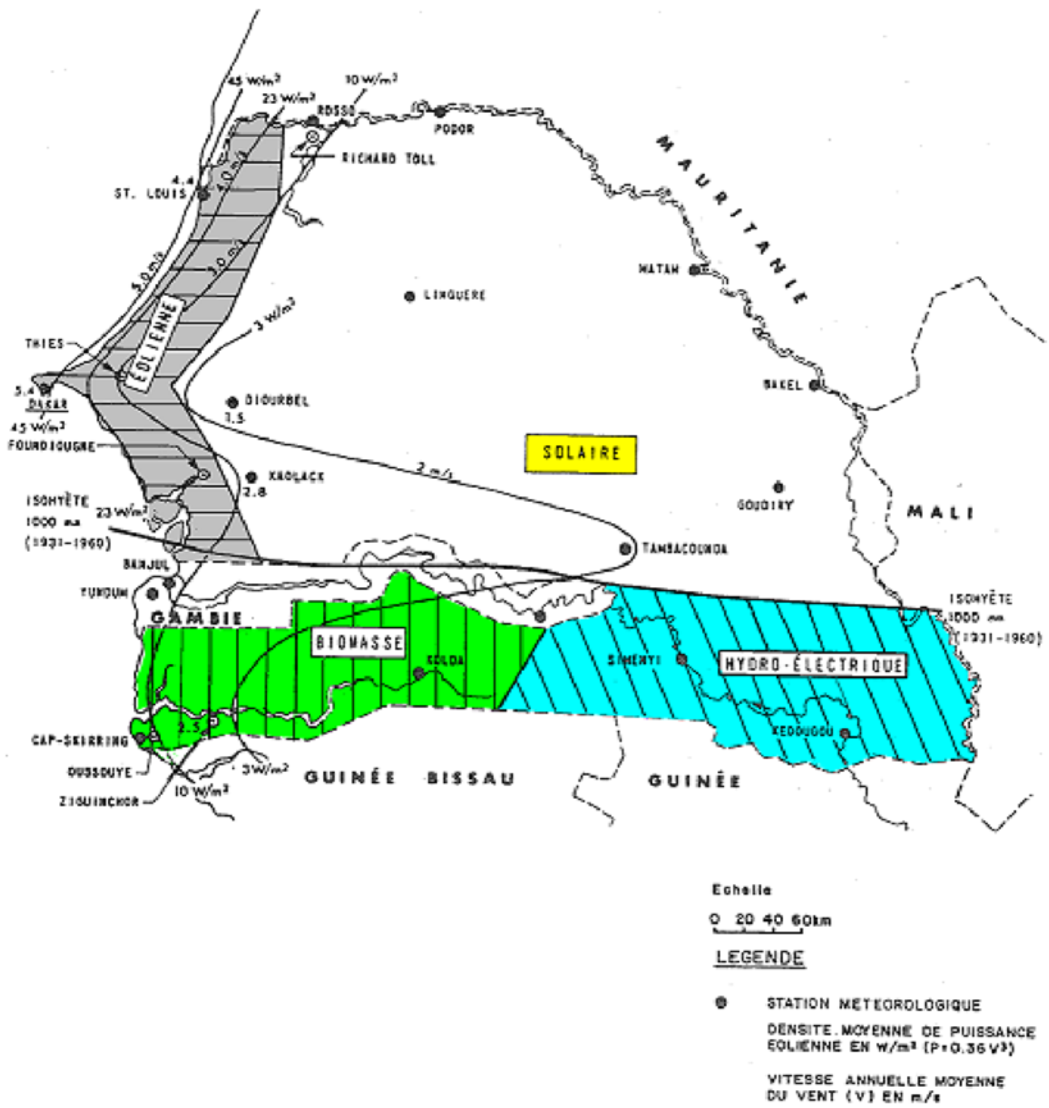

Figure 6 - RES Potential map [2]

Solar resource

Solar resources are quite equally distributed across the whole territory. The average solar irradiation is around 5.5 kWh/m²/day, out of which there is direct irradiation of 65%. [2]

Wind resource

The main wind resources can be found along the Atlantic coast [2].

1.5.2 Planned RES Projects

Both SENELEC and private investors are planning further installation of wind, solar and biomass plants.

Table 4 shows the planned SENELEC projects and Table 5 shows projects proposed by IPPs.

Table 4 - Planned RES projects by SENELEC (status 2010) [2]

Name	Resource	Capacity / Expected Generation	Interconnection
Saint-Louis	Wind	50 MW / 97 GWh/year	HV / Sakal
Taïba Ndiaye	Wind	50 (125) MW / 120 GWh/year	---
Ziguinchor	Solar (PV)	7.5 MWp / ---	---
Béthio	Biomass (aquatic grass)	30 MW / 236 GWh/year	HV / Dagana + Sakal

Table 5 - Planned RES projects by other investors (status 2010) [2]

Deveoloper / Location	Resource	Capacity
Énergie Solaire & Biomasse Distribution (ESBD) / Sakal	solar	250 MWp (1st phase 50 MW)
Technical Cooperation Senegal - China / Ranérou	solar	300 MWp
INFRACO / Littoral du Sénégal	wind	30 and 60 MW

2 Potential Issues and Recommendations for System Impact Studies

2.1 Potential Issues and High Level Recommendation

Different methodologies have to be performed when looking at potential issues relating to the grid integration of renewable generation in Senegal. The renewable generation, which feeds the main interconnected grid, and the renewable generation, which feeds the distribution grid or even one of the 26 so-called secondary grids, have to be analysed independently from each other.

2.1.1 Main Grid

The main grid of Senegal has an installed overall capacity of slightly more than 600MW. The main grid is not supported by any other grids outside Senegal (except from the connection to the hydro power station of Manantali in Mal), which means that all active power balancing tasks have to be executed by this system, without any support from outside.

Most of the planned projects according to Table 4 and Table 5 are large wind or PV projects having a connection to the HV grid. When adding the proposed installed capacity of the renewable generation projects, capacity penetration levels of close to 100% (in terms of installed capacity) do not seem to be unrealistic, even if the status of most of the cited projects is quite uncertain.

Because there is a long 225kV line connecting the hydro power station of Manantali to the main grid of Senegal and a relatively long 90kV overhead line system along the north and north-west of Senegal, transient and voltage stability issues can be expected and should be studied.

However, because the planning status of most renewable energy projects is quite vague at this stage and because the system of Senegal is an isolated system being prone to frequency stability, it is recommended to carry out studies relating to active power balancing and system flexibility in the first place. Those studies would help at identifying potential limitations to the overall penetration level of renewable generation of different technologies in the main grid of Senegal, without requiring precise location of these projects.

Grid studies, which require precise locations and connection points of the various renewable generation plants, could be carried out at a slightly later stage, when some of the projects will be in a more detailed planning phase.

2.1.2 Regional Grids, “Secondary” Grids

In Senegal, there are several regions with small island networks without any connection to the main grid. These small networks (regional networks and “secondary” networks) are entirely supplied by diesel power stations of various sizes.

Since electricity generation by diesel is very expensive, there may be purely economic reasons supporting the installation of renewable energy power plants in these areas with the purpose of saving as much diesel fuel as possible.

In these areas, high penetration projects, either on basis of wind-diesel, PV-diesel or a combination of wind, PV and diesel generation could help to reduce the cost of electricity production.

These projects require very careful planning and design, especially with regard to an optimized coordinated control of wind, PV and diesel generation that allows maximizing the use of wind and PV generation.

2.2 Objectives and Contents of Proposed Studies

2.2.1 Objectives

The main objectives of studies proposed for Senegal could be the following:

1. Calculate the capacity credit of different renewable technologies for considering RE power plants in the generation expansion plan of Senegal.
2. On basis of realistic scenarios with regard to future PV, wind and other on-grid renewable energy plants, execute system flexibility studies with the aim of determining the maximum installed RE-capacity that could be integrated into the system of Senegal.
3. Carry out steady state and dynamic grid studies for identifying the potential RE capacity that could be integrated into the power system of Senegal without major network upgrades.
4. Carry out steady state and dynamic studies for identifying required grid reinforcements for accommodating planned renewable generation plants that go beyond the limits identified by the studies mentioned under item 3.

2.2.2 Contents

2.2.2.1 Capacity Credit Studies (Generation Adequacy)

On basis of credible scenarios for future growth of wind, PV and other renewable generation and under consideration of the existing grid expansion plan, calculate the contribution of RE plants to the equivalent firm capacity of the system of Senegal (capacity credit) and work out a concept for integrating renewables (considering their contribution to capacity and energy) into the generation expansion plan of Senegal.

2.2.2.2 System Flexibility Studies

Based on scenarios being worked out on basis of:

- Potential of wind, PV and biomass electricity
- Planned projects
- Capacity credit studies according to section 2.2.2.1.

Execute studies relating to active power balancing tasks in the network of Senegal, which

- Calculate the residual load for various RE scenarios.
- Compare various parameters (variability, predictability, rate of change) of the residual load with the actual load.
- Identify the required additional reserve power under various operating conditions for various RE scenarios.
- Work out concepts for wind and solar forecast for minimizing additional reserve requirements.

Additionally, carry out short-term frequency stability studies, looking at

- The impact of increasing penetration of wind and PV generation on system inertia and frequency rate of change caused by major generator outages.
- The impact on primary frequency control
- The performance requirements for RE-plants and conventional power plants with regard to their short-term performance (inertia) and with regard to their impact on primary frequency control.

2.2.2.3 Grid Studies

For each larger RE project (>10MW) and for complete RE scenarios looking at several planned RE projects connected to the main grid of Senegal, execute various steady state and dynamic grid studies, including:

- Load flow studies for relevant operational scenarios.
- Contingency analysis studies for relevant worst-case operational scenarios:

  Contingency analysis will focus on a list of credible contingencies (N-1 line outages, credible N-2 outages, generator outages, reactive compensation plant outages).
  The results of contingency analysis studies will be verified against maximum permitted line loadings and voltage bands under contingency situations and will help identifying required network reinforcements.
- Voltage stability studies:

  The impact of planned RE plants on voltage stability limits of critical network corridors, especially on the import from Manantali hydro power station, should be assessed using load variation studies. Voltage stability studies will consider critical line and generator outages.
- Transient stability studies:

  Dynamic simulation studies will be carried out for assessing the impact of the planned RE plants on critical fault clearing times and transient stability constraints transfer limits on critical transmission corridors.

For all studies, relevant operational scenarios and study years have to be defined on basis of typical planning horizons of RE projects and grid expansions in Senegal.

3 Summary and Overall Recommendations

The main grid of Senegal is built by a transmission grid having an installed capacity of around 600MW and no connections to the power grids of neighbouring countries.

Besides the main grid, there are two very small regional grids and 26 so-called “secondary grids” with only a few MW of installed capacity and peak load.

There is potential and there exist already exploration plans for implementing power generation from renewable energies (mainly based on PV, wind and biomass)

Because of the relative small size of the overall system, even a moderate use of the available RE potential for electricity production would lead to fairly high RE penetration levels, not only at regional but at system-wide level.

Therefore, studies relating to active power balancing and frequency stability issues will be very important.

Besides this, there are long transmission corridors in the main transmission grid of Senegal requiring stability studies, especially transient and voltage stability studies that will have to be carried out as soon as the first projects will be planned.

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