Active grid management of SAL island with medium/high level of renewable penetration
Technical solutions to optimize the rate of penetration

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ELECTRA (Member of Executive Board)
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   - Renewable Energy Increase Strategy
   - Renewable Energy Management Strategy Medium Penetration up to 50%
• Cape Verde is composed by 9 inhabited islands
• ELECTRA operates 9 independent and isolated electric systems
• Boa Vista Island is managed through a sub-concession to the company AEB
• In Sal Island, besides ELECTRA, there is APP, an independent producer.
• Electricity production managed by ELECTRA is based on:
  – 3 Diesel Power Plants (LFO e HFO)
  – 6 Diesel Power Plants (GO)
  – 5 Wind Farms
  – 2 Solar Power Plants
• Water production by ELECTRA is based on:
  – 3 Desalination Plants (RO) in São Vicente and Sal islands and in Praia
COMPANY PRESENTATION
COMPANY HISTORY
MAIN MILESTONES

1982
Launch
• ELECTRA was launched in April 17th 1982

2000
Privatization
• Sale of 51% of the share capital. Private management on January 18th 2000.

2006
Corporate Restructuring
• EDP/AdP transferred all its shares to the State of Cape Verde, which started to hold full control of the company with 85% stake, and the remaining 15% kept being held by the municipalities of Cape Verde - August 31st 2006.

2013
3 Companies separation
• Entry into operation of 3 companies from July 1st, 2013:
  ELECTRA SARL
  ELECTRA Sul
  ELECTRA Norte
• ELECTRA SARL owns all assets
  • ELECTRA Sul (Maio, Santiago, Fogo e Brava) and ELECTRA Norte (Sto. Antão, S. Vicente, S. Nicolau e Sal) are operating companies.
ELECTRA ACTIVITY AREAS:

- Electricity transmission and distribution across the country, on an exclusive basis (except Boa Vista island)
- Water transport and distribution on S. Vicente, Sal and Praia, on an exclusive basis
- Electricity Production nationwide (except Boa Vista island)
- Desalinated water production on S. Vicente, Sal and Praia
- Wastewater collection and treatment for reuse in Praia, on an exclusive basis
In recent years, Cape Verde has invested in renewable energy making use of its endogenous resources, mainly wind and solar resources.

Presently ELECTRA manages **26,9 MW** of renewable capacity (independent power producers and state owned renewable power plants represents **24%** of the total installed capacity of **140 MW**).
At the end of 2015 ELECTRA had about **181 161 clients (130 641 electricity and 50 520 water)** and employs **782 workers**
Energy and Water is **strongly dependent** on fuel and diesel power plants.

**High cost of energy (fuel and electricity)** leads to high cost of electricity and water production.

**Fuel Cost per kWh**

- 2014: 16.4 ECV/kWh
- 2015: 11.8 ECV/kWh

**Energy Cost per m3 of Water Production**

- 2014: 130.1 ECV/m3
- 2015: 124.9 ECV/m3

**Fuel and Diesel Consumption (10^3 Ton)**

- FO180: 2014
- FO380: 2014
- GO: 2014
Electricity and Water is strongly dependent on fuel and diesel power plants. Fuel represented in 2015 54% of electricity production cost. Electricity represented 50% of water production cost. Low cost of energy (fuel and electricity) leads to low cost of electricity and water production.

**Fuel Cost per kWh**
- 2014: 16.4 ECV/kWh
- 2015: 11.8 ECV/kWh

**Energy Cost per m3 of Water Production**
- 2014: 130.1 ECV/m3
- 2015: 124.9 ECV/m3

**Fuel and Diesel Consumption (10³ Ton)**
- FO180: 2014: 50,0 T
  - 2015: 40,0 T
- FO380: 2014: 10,0 T
  - 2015: 10,0 T
- GO: 2014: 10,0 T
  - 2015: 10,0 T
High cost of electricity and water production leads to the need of more renewable power in Cape Verde.
**Lower cost of fuel** has an impact on economic and financial viability of projects aiming to increase the renewable penetration rate to medium/high levels in Cape Verde.
ENERGY DISTRIBUTION
CURRENT GRID (2015)

<table>
<thead>
<tr>
<th>Island</th>
<th>HV Overhead</th>
<th>MV Overhead</th>
<th>MV Underground</th>
<th>LV Overhead</th>
<th>LV Underground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Santiago</td>
<td>70</td>
<td>135</td>
<td>145</td>
<td>352</td>
<td>39</td>
</tr>
<tr>
<td>S. Vicente</td>
<td>-</td>
<td>16</td>
<td>117</td>
<td>214</td>
<td>17</td>
</tr>
<tr>
<td>Sal</td>
<td>-</td>
<td>0</td>
<td>135</td>
<td>36</td>
<td>32</td>
</tr>
<tr>
<td>Other islands</td>
<td>-</td>
<td>125</td>
<td>172</td>
<td>574</td>
<td>24</td>
</tr>
<tr>
<td><strong>Total (km)</strong></td>
<td><strong>70</strong></td>
<td><strong>276</strong></td>
<td><strong>569</strong></td>
<td><strong>1176</strong></td>
<td><strong>112</strong></td>
</tr>
</tbody>
</table>
RENEWABLES IN CAPE VERDE
Presently ELECTRA manages **29,68 MW** of renewable capacity (independent power producers and state owned) in Santiago, São Vicente, Sal and Santo Antão.

<table>
<thead>
<tr>
<th>Installed Capacity</th>
<th>Santiago</th>
<th>São Vicente</th>
<th>Sal</th>
<th>Santo Antão</th>
<th>S.Nicolau</th>
<th>Fogo</th>
<th>Brava</th>
<th>Maio</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal (MW)</td>
<td>81,32</td>
<td>29,35</td>
<td>11,36</td>
<td>8,60</td>
<td>4,22</td>
<td>6,80</td>
<td>1,06</td>
<td>1,38</td>
<td>144,08</td>
</tr>
<tr>
<td>Wind (MW)</td>
<td>9,30</td>
<td>5,90</td>
<td>7,20</td>
<td>0,50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>22,90</td>
</tr>
<tr>
<td>Solar (MW)</td>
<td>4,28</td>
<td>2,50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6,78</td>
</tr>
<tr>
<td>TOTAL (MW)</td>
<td>94,90</td>
<td>35,25</td>
<td>21,06</td>
<td>9,10</td>
<td>4,22</td>
<td>6,80</td>
<td>1,06</td>
<td>1,38</td>
<td>173,76</td>
</tr>
<tr>
<td>RE/TE Ratio</td>
<td>16,7%</td>
<td>20,1%</td>
<td>63,4%</td>
<td>5,8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20,6%</td>
</tr>
</tbody>
</table>

---

**Bar Chart:**
- Solar (MW)
- Wind (MW)
- Thermal (MW)
In 2015 Santiago, São Vicente, Sal and Santo Antão islands registered relevant renewable energy penetration levels...
Currently, 20.5% of the energy produced in Cape Verde comes from renewable resources!!!
In a moderate load growth scenario, it is expected that consumption in Cape Verde reaches **525 GWh** in 2020 with a total installed capacity of approximately **250 MW**.

Source: Cape Verde 50%Renewable - Energy Master Plan 2010-2020 – Load Forecast Study (GESTO Energy 2010)
Given the dependence on petroleum products, ELECTRA intends to:

- Increase the penetration of renewable energy
- Reduce the diesel portion in the production mix
- Reduce the pollution emission gases
Cape Verde Renewable Energy Masterplan establishes a target of 50% Renewables penetration until 2020!!

Source: Cape Verde 50%Renewable - Energy Master Plan 2010-2020 (GESTO Energy 2010)
Cape Verde Renewable Energy Masterplan establishes different targets for each island in order to reach the 50% Renewables.

Source: Cape Verde 50%Renewable - Energy Master Plan 2010-2020 (GESTO Energy 2010)
RENEWABLE ENERGY MEDIUM PENETRATION CHALLENGES...

GOAL
maximize the penetration of renewables ensuring the system stability and sustainability

CHALLENGE
Instability caused by a high penetration of renewable energy in isolated systems, small and weak

Large power variations in seconds
CONCLUSION

• ELECTRA is focused on the objective of maximizing the penetration of renewable. Therefore, when with medium/high level of penetration problems such as electric quantity and quality arise. Thus, it is important to manage challenges in term of the quantity (surplus electricity and thermal capacity) and quality (voltage and frequency) of electricity.

• ELECTRA is conducting various technical and economical studies in order to achieve this objective, while maintaining system stability and quality of power supply:
  
  ▪ Use of energy storage in some islands:
    ▪ Flywheels
    ▪ Batteries
  ▪ Brava Island 100% Renewable;
  ▪ ...

THE GOAL
RENEWABLE ENERGY MEDIUM/HIGH PENETRATION
SAL ISLAND CURRENT STATUS AND ISSUES
ELECTRA has been conducting studies in order to find optimum technical and economical solutions to optimize the increase of the penetration level of renewable energy on Sal island.

Source: Report «Projet de renforcement et d’optimisation du système d’énergie électrique de l’île de Sal»
Sal Island

Installed Capacity 2000 - 2015 (MW)

- Diesel
- Solar PV
- Wind

Fuel Consumption Change 2000 - 2015 (LT)

- Gas Oil
- HFO
It is expected that the consumption on the island of Sal reaches **86 GWh** in 2020, strongly driven by the Tourism sector.

Source: Cape Verde 50%Renewable - Energy Master Plan 2010-2020 – Load Forecast Study (GESTO Energy 2010)
Sal Island currently has a renewable installed capacity of **9.7 MW** (7.2 MW wind and 2.5 MWp Solar) and reached a penetration of renewable energy of approximately **36.8%** in 2015.

### Energy Mix

![Energy Mix Chart]

### Installed Capacity

![Installed Capacity Chart]

### Sal 2015

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind MWh</td>
<td>2.206</td>
<td>1.611</td>
<td>2.026</td>
<td>2.045</td>
<td>1.880</td>
<td>1.829</td>
<td>757</td>
<td>981</td>
<td>964</td>
<td>1.049</td>
<td>1.946</td>
<td>1.483</td>
<td>18.776</td>
</tr>
<tr>
<td>Solar MWh</td>
<td>89</td>
<td>74</td>
<td>170</td>
<td>277</td>
<td>280</td>
<td>173</td>
<td>254</td>
<td>184</td>
<td>146</td>
<td>174</td>
<td>166</td>
<td>185</td>
<td>2.173</td>
</tr>
</tbody>
</table>

### Penetration Ratio

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind penetration ratio</td>
<td>54,9%</td>
<td>40,5%</td>
<td>38,2%</td>
<td>39,8%</td>
<td>38,9%</td>
<td>40,8%</td>
<td>14,0%</td>
<td>17,2%</td>
<td>23,4%</td>
<td>22,8%</td>
<td>41,4%</td>
<td>32,3%</td>
<td>33,0%</td>
</tr>
<tr>
<td>Solar penetration ratio</td>
<td>2,2%</td>
<td>1,9%</td>
<td>3,2%</td>
<td>5,4%</td>
<td>5,8%</td>
<td>3,9%</td>
<td>4,7%</td>
<td>3,2%</td>
<td>3,6%</td>
<td>3,8%</td>
<td>3,5%</td>
<td>4,0%</td>
<td>3,8%</td>
</tr>
<tr>
<td>Total penetration ratio</td>
<td>57,1%</td>
<td>42,3%</td>
<td>41,4%</td>
<td>45,2%</td>
<td>44,7%</td>
<td>44,7%</td>
<td>18,7%</td>
<td>20,4%</td>
<td>26,9%</td>
<td>26,5%</td>
<td>45,0%</td>
<td>36,3%</td>
<td>36,8%</td>
</tr>
</tbody>
</table>
Currently the spinning reserve is managed manually by imposing **remote limitation set points** to the Windfarm turbines.

**Spinning Reserve 50%**
(50% of the renewable power supplied)
Unit Commitment

- Unit commitment solves the problem of determining which generation units should be running in each period so as to satisfy a predictably varying demand for electricity, considering the minimum technical unit output limited in 50% of the nominal unit capacity.
- Period of optimization is variable (up to 10 days)
RENEWABLE ENERGY MANAGEMENT STRATEGY
MEDIUM PENETRATION (20% - 40%)

Load Forecast And Renewables Forecast

- Forecast based on history, day type, weather and current system state
- Short-term forecast – 7 days with one hour granularity
- Bottom-up approach
- Support for solar and wind generation forecast
- Forecast based on history, weather (current and forecasted) and current system state
- Near-term forecast – 24h with one hour granularity
- Short-term forecast – 7 days with one hour granularity
RENEWABLE ENERGY MANAGEMENT STRATEGY
MEDIUM PENETRATION (20% - 40%)

Load Shedding

- 10 levels of consumer priorities
- Fast response time
RENEWABLE ENERGY MANAGEMENT STRATEGY
MEDIUM PENETRATION UP TO 50%

ELECTRA is working in a medium term Renewable Energy Penetration Strategy (50%) for Sal Island based on 4 drivers:

- Grid Management
- Security
- Renewable Energy High Penetration Strategy
- Fuel Generation Efficiency
- Power Quality
- Renewable Energy Optimization

![Map of Sal Island](image)
Grid Studies

Selectivity and protections coordination studies, complemented with steady state and dynamic grid studies, in order to ensure the stability of the grid in different contingency scenarios:

• Building the static model of each network.

• Building of dynamic models and preparation of the scenarios for dynamic stability simulations.

• Load Flow and Short Circuit studies.
1st STAGE

Grid Studies

• Dynamic stability simulations: calculation of critical clearing times and Frequency response at Loss of largest diesel generator, largest wind farm/aero generators, Loss of major load, up to 10 contingency scenarios, e.g. three-phase short circuit followed by outage of line or bus bar.

• Identification of limitation and actual problems that can affect the system stability.

• Analysis of weaknesses in the protection system and recommendations to its improvement.
Standard Dispatch System

installation of a national standard dispatch system (to be commissioned within the next 18 months) to efficiently manage the existing power plants and grids in safety conditions
Advanced Dispatch System and Energy Storage Systems

• To integrate the simulation software and grid models developed in Stage 1 with the Dispatch System, in order to ensure the stability of the grid on contingency scenarios with relevant fluctuation of renewable power;

• Study the use of complementary systems with the purpose of creating conditions to safely integrate more renewable energy power into the grid (Flywheels systems, Battery Systems, Energy Storage Control Systems, etc.).
Advanced Dispatch System and Energy Storage Systems

• Upgrade the Standard Dispatch System with advanced and specific modules configured to manage massive amounts of Renewable Power, based on algorithms specially dedicated to the management of high renewables penetration grids, optimizing the use of Renewable Energy, ensuring grid stability and safety conditions including, namely:
  - Master control system configuration to control the renewable’s power output smoothing and grid operation stability;
  - Monitoring system configuration to meet monitoring and management needs of network operation;
Advanced Dispatch System and Energy Storage Systems

• Refurbishment of the protection systems based on the recommendations of the result of the selectivity and coordination of protection systems studies, accomplished in Stage 1;

• Development of the terms of reference for a pilot-project in Sal island containing:
  - Overall Design of Energy Storage (Energy storage system should include at least three dimensions: energy storage stack design, battery management systems and energy storage inverter).
  - Energy storage system configuration
Necessity for Power Storage

- For stable expansion of renewable energy power storage is indispensable.
Objectives of Power Storage

1. Short cycle

- To maintain frequency,

50±2Hz is adopted, but need to maintain frequency may be low
2. Long cycle

- To maintain minimum diesel output (50%),

- *Store surplus power generated over and above demand, and discharge stored power at peak demand times

Suppress diesel output → fuel cost reduction
Effective use of potential renewable energy

*Need to consider associated costs and charging/discharging losses
RENEWABLE ENERGY MANAGEMENT STRATEGY
MEDIUM PENETRATION UP TO 50%

Perspective of Secondary Battery for Power Grid

- **Secondary Battery**
  - Present Situation (2012)
  - 2020
  - 2030

- **Control use for Long-period variation**
  - Life cycle: 10-15 yrs.
  - Cost: US$500-1,000/kWh
  - 20 yrs.
  - US$230/kWh
  - 20 yrs.
  - Further cost reduction
  - Implementation for feasible operation use

- **Control use for Short-period variation**
  - Life cycle: 10-15 yrs.
  - Cost: US$2,000/kWh
  - 20 yrs.
  - US$850/kWh
  - 20 yrs.
  - Further cost reduction
  - Implementation for feasible operation use

Source: “Battery Road Map 2013” by New Energy and Industrial Technology Development Organization, JAPAN
Solution Measures for Sal Island

- Calculate the amount of renewable that can be connected ensuring the system stability without using batteries.
- Suppression of wind power output is being carried and storage batteries is required to make more effective use of installed renewable plants.
- Make use of storage batteries at peak times.
- For introduction of batteries the optimal battery system that would bring economic value in terms of cost reduction should be considered.
- The adopted solution should ensure grid security and stability, reduces diesel fuel consumption, and improves wind turbine and PV power supply ratio.
Solution Measures for Sal Island

- To increase the level of penetration above the current rate (36.8%), namely the following grid configurations should be analysed in order to find the best technical and economic/financial solution.
RENEWABLE ENERGY MANAGEMENT STRATEGY
MEDIUM PENETRATION UP TO 50%

Scenario 1
Scenario 2
RENEWABLE ENERGY MANAGEMENT STRATEGY
MEDIUM PENETRATION UP TO 50%

Scenario 3
Solution Measures for Sal Island

Main points of the solution:

• Energy storage system configuration (battery stack + energy storage inverter), step up transformer connected to the 20kV rated busbar of the windfarm or the public grid.
• Master control system configuration, to control the wind power output and grid operation stability.
• Monitoring system configuration, to meet monitoring and management needs of the network operation.
Solution Measures for Sal Island

Scope of Supply:

- Overall Design of Energy Storage

- Energy storage system includes: energy storage stack design, battery management systems, and energy storage inverter.
Solution Measures for Sal Island

• The optimum solution should bring economic value in term of cost reduction.
Thanks!

Merci!

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