Off-stream Pumped Storage Hydropower plant to increase renewable energy penetration in Santiago Island, Cape Verde

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Introduction

In order to reduce the high dependence on imported fuels and to meet the ongoing growth of electricity demand, Cape Verde government set the goal to increase renewable energy penetration in Santiago Island until 2020. To maximize renewable energy penetration (wind, solar and waste), one of the selected projects is a 2x10 MW rated off-stream Pumped Storage Hydropower (PSH) plant. A technical, economical and environmental feasibility study carried out by Gesto Energy pointed out three potential geographical locations for the PSH plant: Chã Gonçalves, Mato Sancho and Ribeira dos Picos. The subject of this work came from the need to overcome the integration challenges of the PSH plant in 2020 Santiago's electricity network. The main goal is to find the best location and connection point of the PSH plant, assessing the impact of this energy storage system, in each location, on power system stability. The main contribution of this work is to help the integration of renewable energy in Santiago Island.

Methodology

The grid case study was dimensioned in PSS/E 33 of Siemens to represent all branches, generating units and consumption points of the current island electricity grid together with the new 2020 projects.

Load and renewable resources scenarios were created so that grid performance could be studied with the PSH plant in both pumping and generating modes.

For power flow purposes, all grid components were sized according to Electra's data set. To study the dynamic performance of the grid, it was associated a dynamic model for the different generating technologies so their specific response to a grid disturbance could be accounted for. The models were properly sized to best represent the generating technologies in Santiago Island. Frequency and voltage relays were also modeled.

Concerning the PSH plant, each hydro unit was modeled as an adjustable speed reversible turbine employing a DFIM. According to the PSH plant location, it is made the connection to the grid. For Chã Gonçalves and Mato Sancho it is studied two possible connection points. The water column time constant is the only parameter that differs in the dynamic modeling of the PSH plant for each geographical location.

Results

Steady-state simulations

The main results of the steady-state simulations are summarized in Table 1.

Ribeira dos Picos	Mato Sancho	Chã Gonçalves
• No overloaded branches. • No voltage limits violation. • 83% renewable energy penetration.	• Overloaded branches with connection 2. No overloads with connection 1. • No voltage limits violation. • 75% renewable energy penetration.	• No overloaded branches. • Need of a 3.6 Mvar capacitor bank. • 82% renewable energy penetration.

Table 1 Steady-state simulation results.

Dynamic simulations

For dynamic studies two types of grid disturbances were applied: **(1)** simulation of a 3-phase fault on an important operating thermal unit transformer - the fault is cleared tripping the transformer; and **(2)** simulation of the loss of one of the three 60 kV transmission lines. Table 2 summarizes the main results obtained.

	Ribeira dos Picos	Mato Sancho	Chã Gonçalves
(1)	• PSH plant trips in both operating modes.	• PSH plant trips in generating mode.	• Acceptable steady-state operation point.
(2)	• Overloaded branches – PSH plant in pumping mode.	• Overloaded branches – PSH plant in pumping mode.	• No overloads. • No voltage limits violation.

Table 2 Dynamic simulation results.

Figures 1 to 4 illustrate the fundamental simulation results when the 3-phase fault is applied.

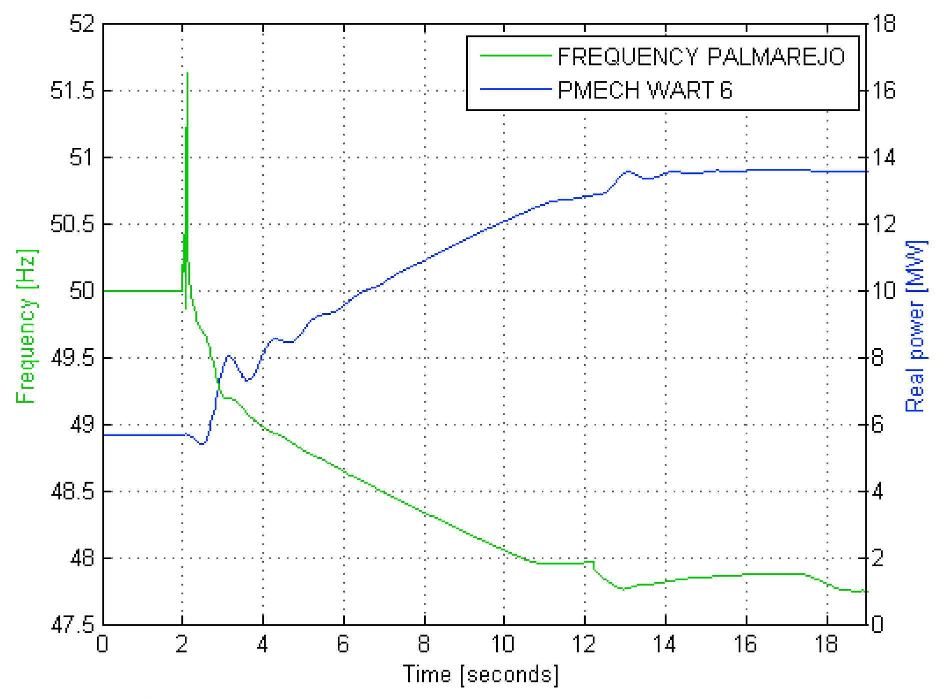

Figure 1 Ribeira dos Picos, generating mode.

Major active and reactive power deficiency. Under voltage relays start disconnecting wind turbines at t= 12.1 sec. System collapses at t= 22 sec.

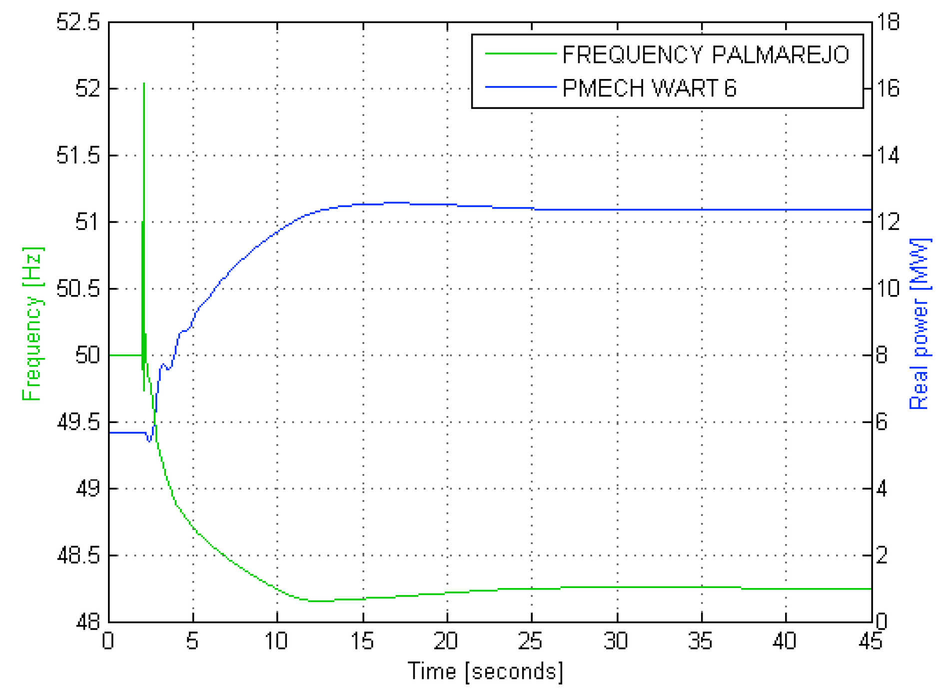

Figure 2 Mato Sancho, generating mode.

Unacceptable steady-state operation point reached after the involuntary tripping of the PSH plant, due to the short-circuit.

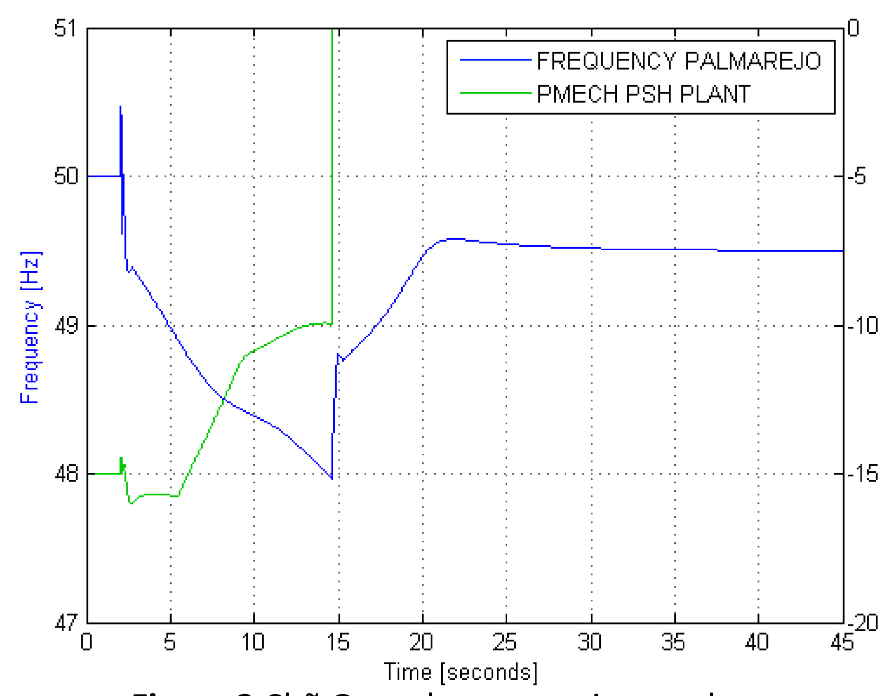

Figure 3 Chã Gonçalves, pumping mode.

PSH plant supplies primary frequency regulation in pumping mode. However, frequency reaches 48 Hz. The tripping of the PSH plant is performed.

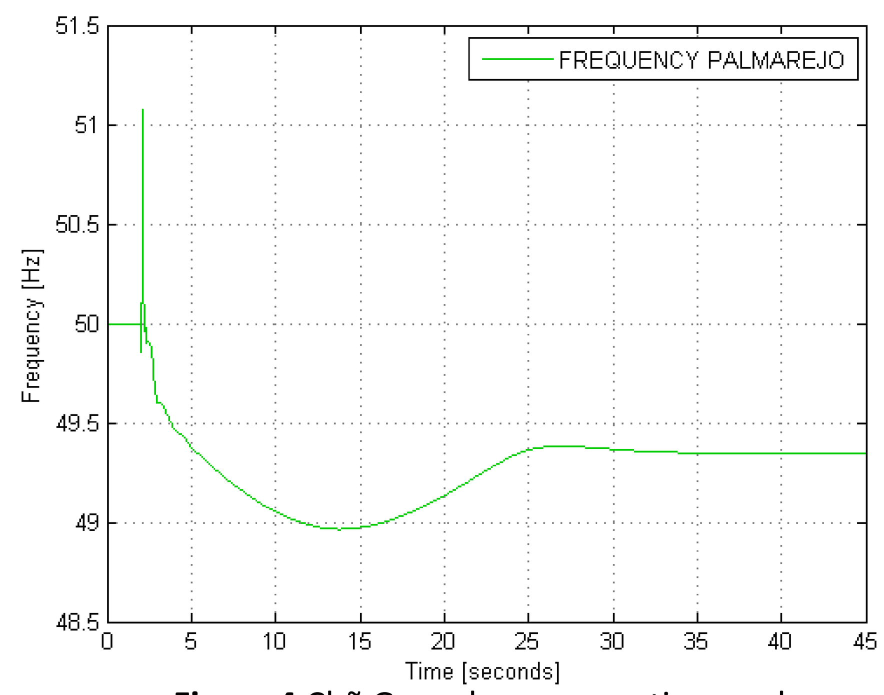

Figure 4 Chã Gonçalves, generating mode.

The frequency decay is arrested by the response of the governors of the PSH plant hydro units and remaining thermal units.

Conclusions

The results of the steady-state and dynamic studies show that 2020 Santiago's grid with the PSH plant in Chã Gonçalves is the one that has the best performance. The PSH plant in Ribeira dos Picos or Mato Sancho revealed clear disadvantages in dynamic simulations, such as the involuntary plant tripping and the failure to assure the n-1 security criteria in a grid disturbance likely to happen. The grid with the PSH plant in Chã Gonçalves has an average of 82% of renewable energy penetration. An average of 3% of injected active power and 9% of injected reactive power are losses. It is necessary to install a capacitor bank of 3.6 Mvar to keep bus voltages above 0.95 p.u. in peak hour.