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RENEWABLE HYDRO-WIND POWER SYSTEM FOR SMALL ISLANDS: THE EL HIERRO CASE

F. Cabrera Quintero [1] **J.F. Medina Padron** [1] **E.J. Medina Dominguez** [2] **M.A. Artiles Santana** [1]

1. University Institute of SIANI, University of Las Palmas de Gran Canaria (ULPGC), Las Palmas G.C., Spain
fidel.cabrera@ulpgc.es, josef.medina@ulpgc.es, miguel.artiles101@alu.ulpgc.es
2. Canary Islands Institute of Technology (ITC), Spain, ejmedina@itccanarias.org

Abstract- El Hierro Island is a world biosphere reserve since 2001 and has an electric power system with a high percentage of renewable energy capacity installed, based on a hydro-wind power plant. Some of its 20 kV distribution overhead power lines have been buried to avoid visual impact. In this paper, the system frequency behavior is analyzed for the case of the maximum renewable energy penetration, including a 100% scenario. The impact of undergrounding all the overhead lines on the power system operation is also investigated. This power system was modeled for steady-state analysis in several scenarios to find the impact of undergrounding overhead lines on network voltages and on the operation of generators. Results suggest a negative impact on the generating units, which are forced to absorb a high amount of reactive power.

Keywords: Renewable Energy, Sustainability, Modeling, Power System Analysis, Distribution Power Lines, Stability.

I. INTRODUCTION

El Hierro is the smallest of the Canary Islands, with 278m^2 of surface area and a population of about 10,000 inhabitants. Since the year 1997 there is a plan for a sustainable development, which last revision was performed in 2006 [1]. Due to its environmental values and the political willing to sustainability, the island was declared a Biosphere global reserve by UNESCO in January 2001 and in September 2014 has also been declared as part of the European Geoparks Network, being the tenth Spanish territory in obtaining such distinction [2].

The main action concerning energy infrastructure is the implementation of a hydro-wind power generation system energy [1], with the aim of achieving the highest possible penetration of renewable energy in the power system of the island. There is some literature about this new system from economic, technical feasibility and stability points of view [3-7].

However, following the commitments made by its declaration as a Biosphere Reserve in 2001, a program for burying many of the 20 kV overhead power lines was performed. New underground lines were installed closing the ring and providing a higher security of supply [8]. Some issues have been reported about reactive power and distribution networks [9, 10].

It is estimated that 36% of current lines are underground and operative. The aim of this paper is to analyze the behavior of the electrical system by these lines and simulate the operation for 100% of underground lines. The work was performed using PowerWorld software. Measured values of the system frequency at different scenarios of energy sources are also analyzed.

II. EL HIERRO POWER SYSTEM

The power system consists of a single thermal station, a wind farm, two water reservoirs linked by two pipelines, a hydroelectric power plant, a pumping station and a medium voltage distribution network. Figure 1 shows the main elements of the system [11].

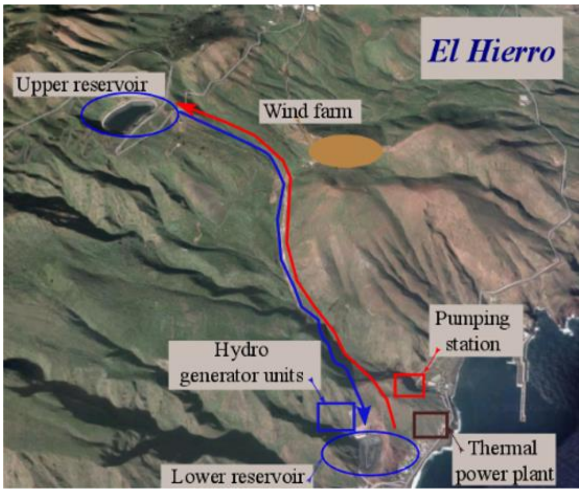

Figure 1. Main elements of the hydro-wind power system

The annual demand of energy for recent years slightly exceeded 67 GWh, having a power peak of about 7.6 MW and a power off-peak of about 3.6 MW. At present the hydroelectric plant is still a trial version. Because of that, the power system demand of load is still mainly provided by diesel units. Nevertheless, some new operating scenarios are progressively tested, looking for a massive renewable energy penetration with a minimum conventional participation.

The only existing thermal power station consists of ten diesel units, with a total capacity of 14.98 MW. On the other side, the hydro pumped storage power plant includes an upper water reservoir with a capacity of about 380 m^3, and a lower reservoir with a capacity of 150 m^3.

The reservoirs are joined together by a discharge pipe 3015 m long and 0.8 m diameter, with a suction pipe 188 m long and 1 m diameter. The penstock is 2350 m long and 1 m in diameter. There are eight individual pump drives, with six pumps of 500 kW rated power and two pumps of 1500 kW rated power.

Hydro-wind power plant are also equipped with four Pelton turbines with a rated capacity of 2.83MW, giving a total output of 11.32 MW. Every Pelton unit is equipped with a flywheel for a better dynamic performance.

Adding a flywheel increases significantly the inertia constant of the hydraulic generator units, improving their dynamic response under load variation as indicated by the swing equation of the synchronous machine as Equation (1).

$$\frac{d\omega}{dt}=\frac{1}{2H}\left(P_m-P_e\right) \tag{1}$$

Five 2.3 MW Enercon E70 wind turbines give a total rated wind power output of 11.5 MW. Being a small island, El Hierro has not a transmission network and electricity flows through a 20 kV Medium Voltage (MV) distribution network. There are about 40 buses at that MV distribution level. Most of the underground cables are aluminum cable 150 mm^2 size, whereas overhead lines are copper 50 mm^2 size.

The one line diagram of the power system can be observed in Figure 2, as modeled using PowerWorld, the software selected for the analysis.

III. SYSTEM PERFORMANCE

Figures 3, 4 and 5 are examples of the power system performance [12]. Power generation is based on diesel units in the case of Figure 3. Hydroelectric generation by means of the Pelton turbines was tested during a few hours, limited to a power output about 1.33 MW. Wind generation was also tested at two different periods, limiting its output to 0.4 MW.

Figure 4 shows a similar operational scenario, although the 6 MW wind power generation is used for pumping water to the upper reservoir and also for partially supplying the island demand. Hydroelectric production from the Pelton units can also be seen when the wind farm is out of service.

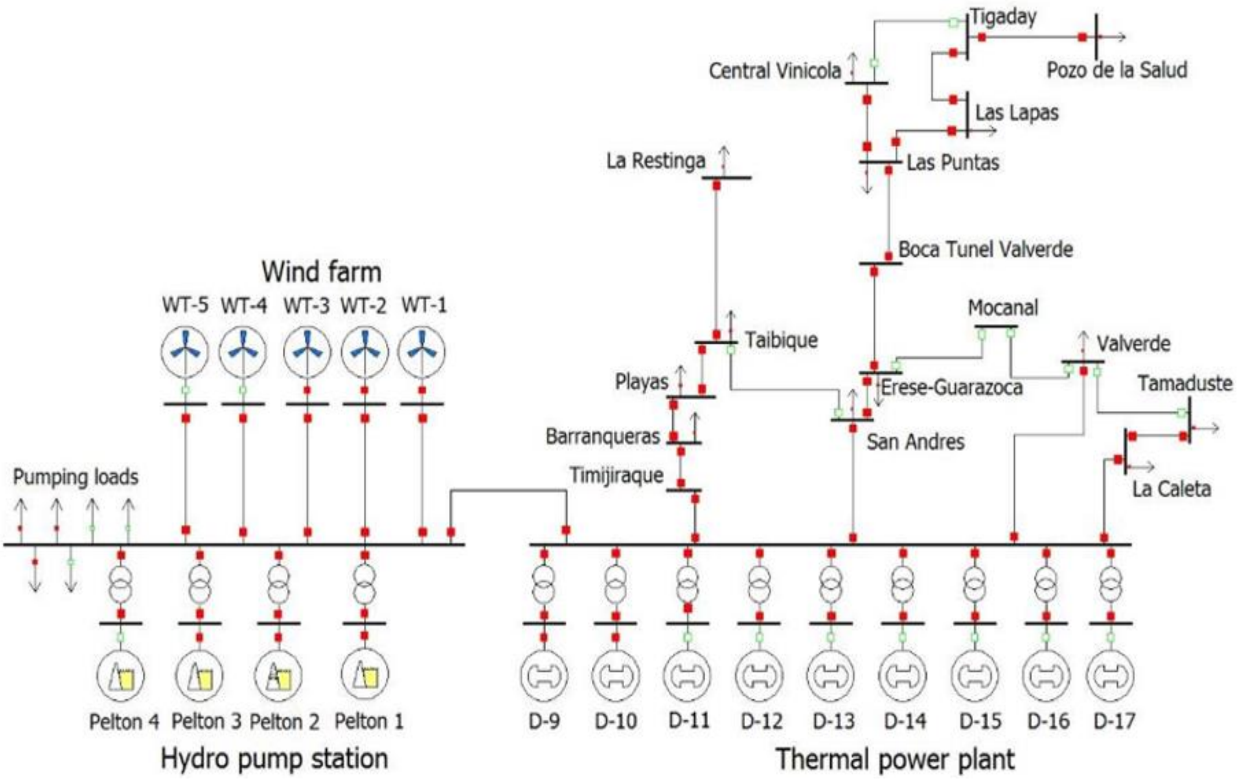

Figure 2. One line diagram of El Hierro power system

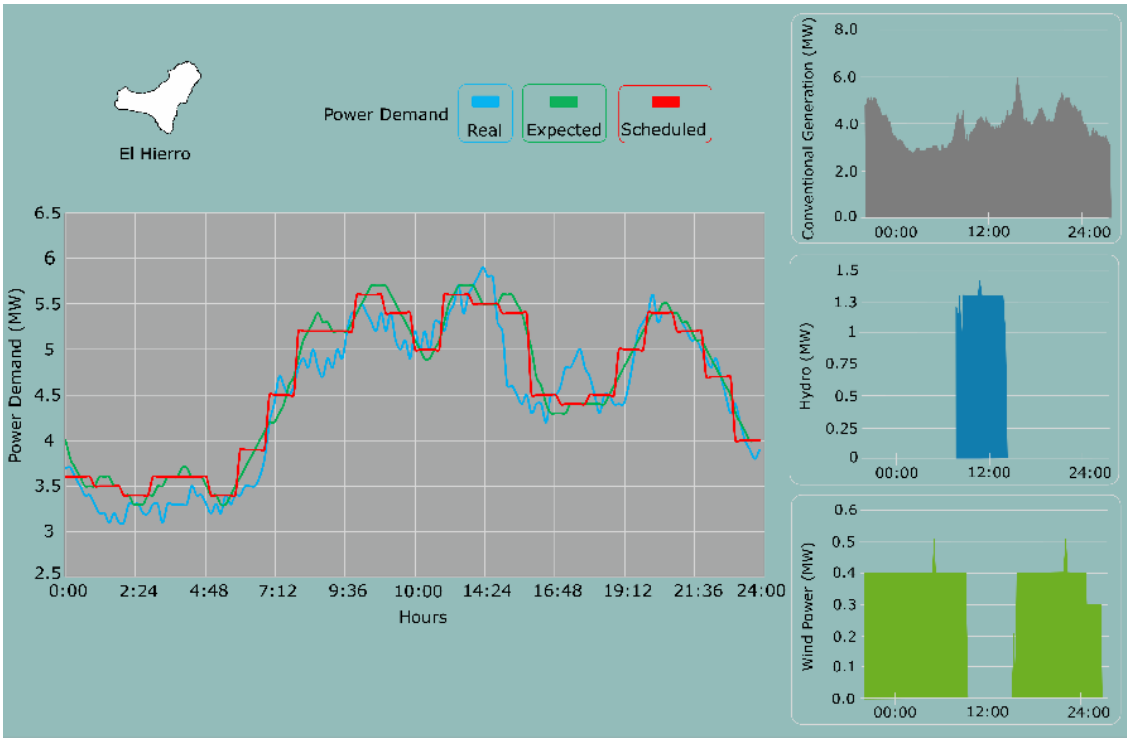

Figure 3. Example of operation 1. Hydraulic system operating as a generator

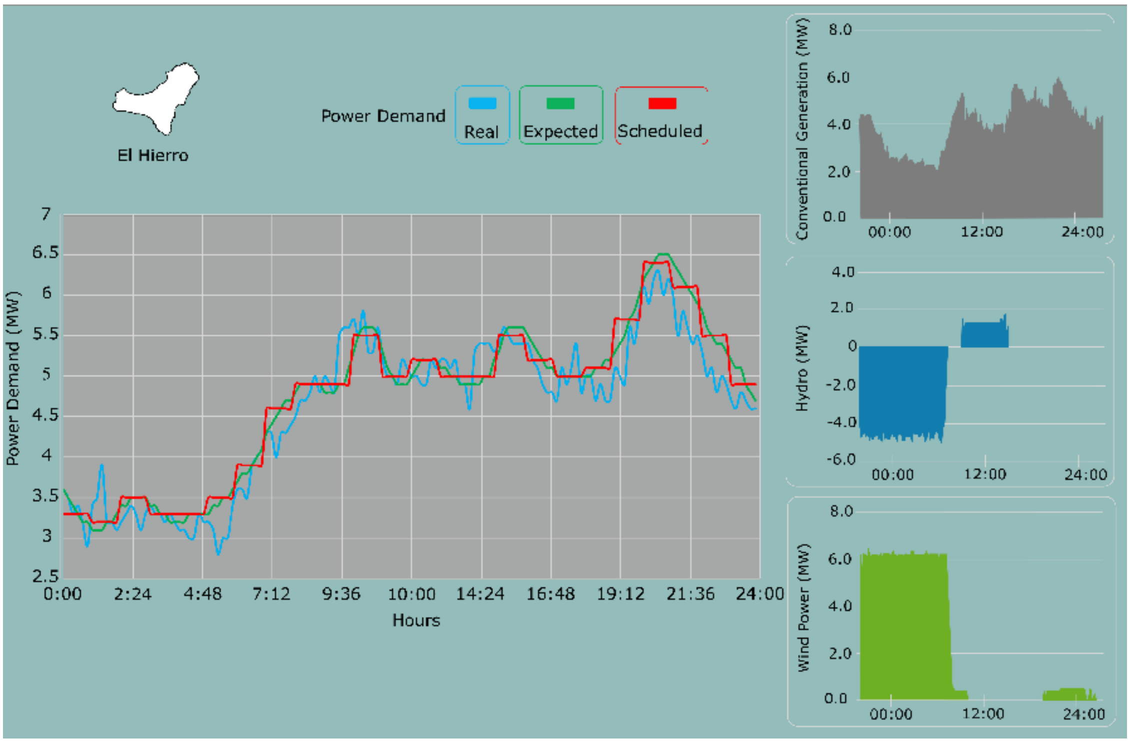

Figure 4. Example of operation 2. Hydraulic system operating as a pump

At this point we must highlight favorable evolution of the operation of the hydro-wind power station towards a generation that is close to be able to cover the electric power demand with 100% renewable energy.

In Figure 5, which corresponds to the 9th April 2016, during a continuous period of 24 hours, a generation based exclusively on wind energy and on the hydraulic system balance was archived. On one side Pelton turbines were used for generation and, on the other side, the lower reservoir to the upper reservoir pumping system was used as a variable load.

In this case, an adaptation of the power system load is done by adjusting the load of the pumping system, as can be seen in Figure 5, while the wind energy generation remains constant.

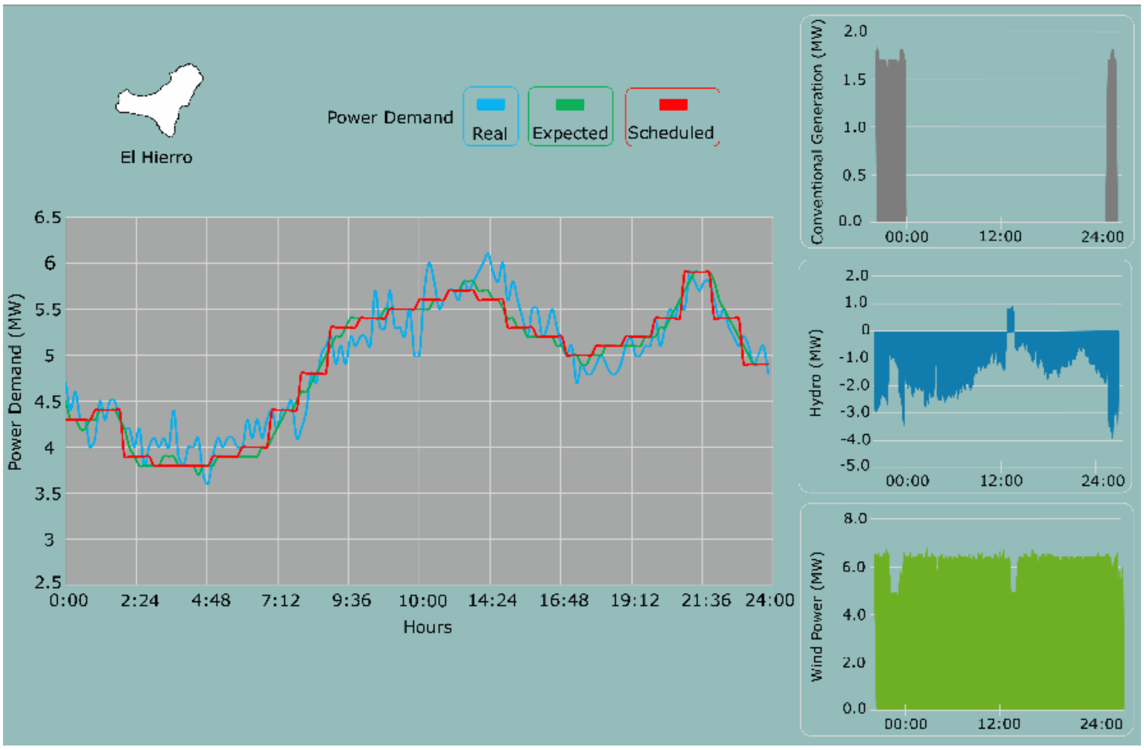

Figure 5. Example of operation 3. 24 hours only by hydro-wind power system

IV. FREQUENCY BEHAVIOR

During the daylight hours of the day April 9, 2016, the frequency of the power system was measured (Figure 6). Lower frequency deviations are found in comparison to the periods in which the power-frequency control systems of the diesel units were used to adjust power generation to the system load, as usual in every conventional power system (Figure 7). Therefore it can be concluded that there is a good response of the hydraulic power system equipped with flywheels, using the combined action of the power-frequency control system of the Pelton units and the adjustment of the power load demanded by the pumping system.

V. THE IMPACT OF BURYING MV NETWORK

To avoid visual impact caused by the overhead MV power lines, new underground MV lines are being introduced in the network. Several scenarios have been set up for studying how undergrounding overhead distribution lines influences the power system operation, on the basis of peak load and minimum load demands. Relevant cases are:

- Case 1. Most of the distribution power lines are overhead.
- Case 2. Most of the distribution power lines are underground.
- Case 3. All distribution power lines are underground.

Main results of the analysis are shown as the following.

A. Peak Period

Figure 8 shows total real and reactive power generated by the generation units for the three cases. We can see that real power can remains almost constant.

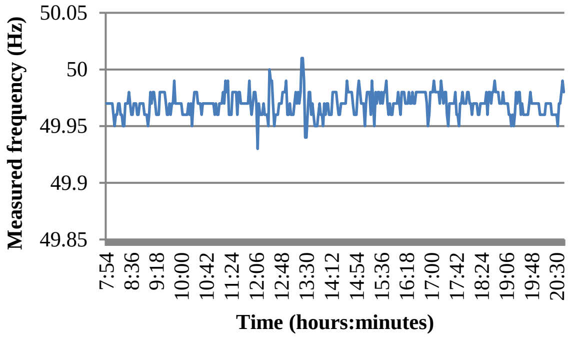

Figure 6. Measured system frequency April 9, 2016

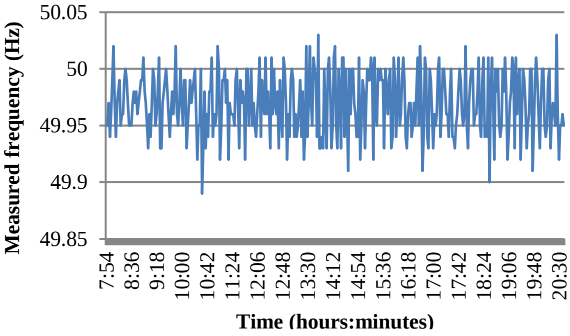

Figure 7. Measured system frequency variation April 14, 2016

On the contrary, the total reactive power generation from those units is lower for a higher number of MV lines being buried. This is due to the higher reactive power generated by the higher number of undergrounded MV lines. Therefore, generation units does not need to generate all the reactive power for a given reactive load and can reduce their reactive power output.

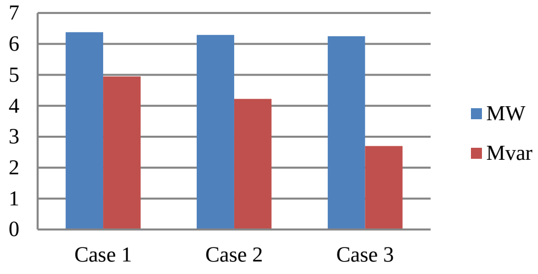

Figure 8. Total power generation in peak period

Figure 9 shows that the power losses in the MV network are reduced when the number of underground lines grows. This due to a decrease in the value of the currents through the lines caused by the above mentioned lower production of reactive power by the generators. When most of MV lines are overhead there is a global consumption of reactive power (case 1). In cases 2 and 3 the production of reactive power in the buried MV lines forces to the generator units to absorb reactive power.

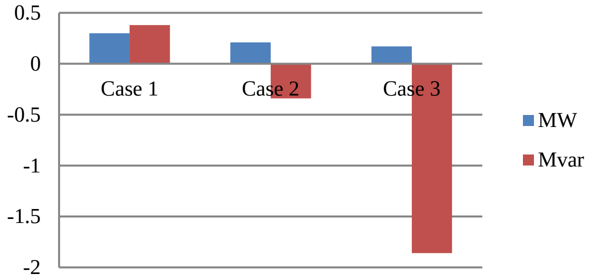

Figure 9. Network losses in peak period

Voltages are influenced by undergrounding power distribution lines, as can be seen in Figure 10. Since the reactive power generation is distributed along the MV distribution network and not only concentrated on the power plant, it is not necessary a high value in the voltage output of the generator units. As a consequence, voltages at the MV network buses have the lower values in Case 3. Figure 11 shows these lower values of voltage in terminals of the generator units.

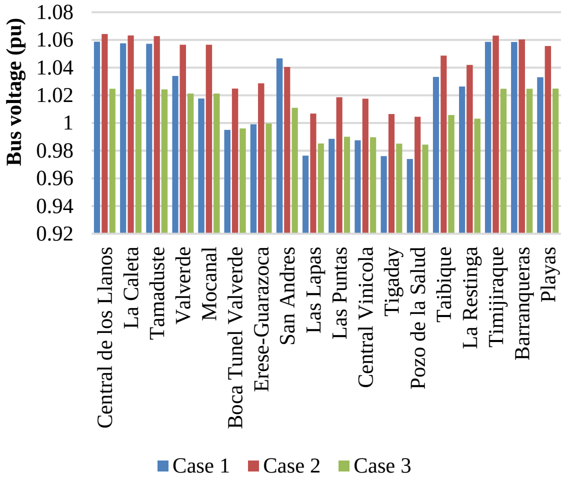

Figure 10. Distribution network voltages in peak period

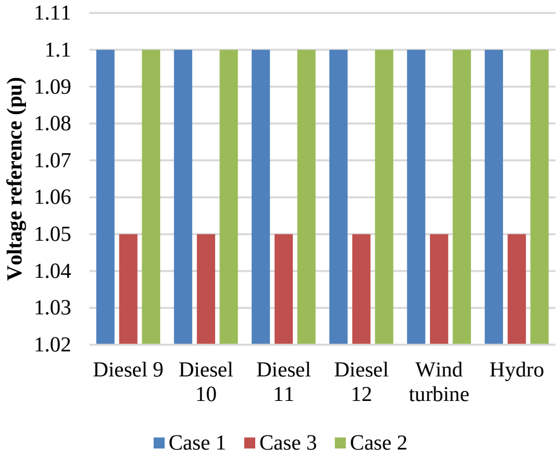

Figure 11. Voltage in terminal of generators in peak period

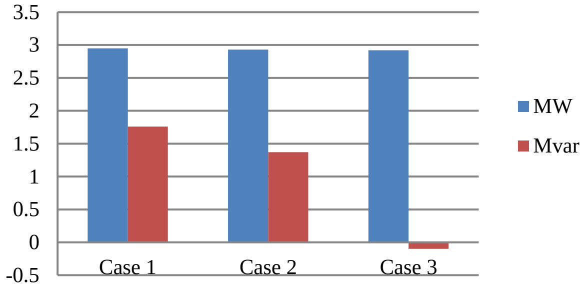

Figure 12. Total power generation in valley period

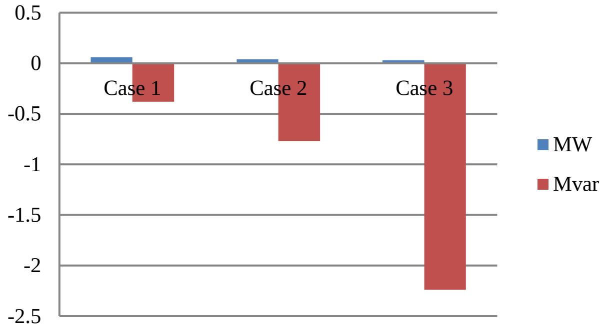

Figure 13. Distribution network losses in valley period

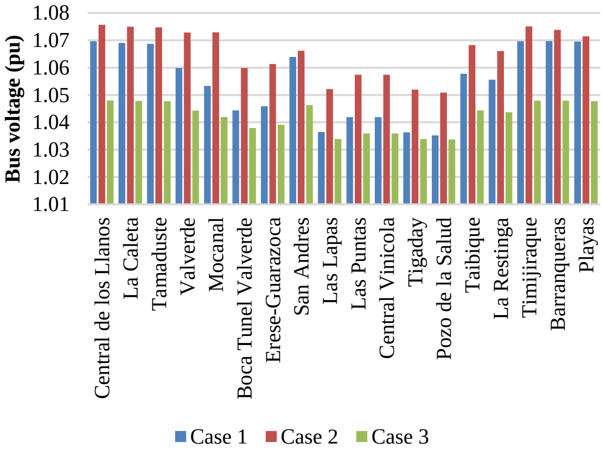

Figure 14. Network voltages in valley period

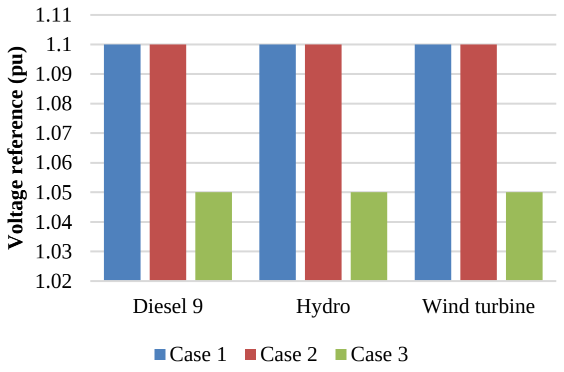

Figure 15. Voltage in terminal of generators in valley period

B. Valley Period

The results obtained for valley period are similar to the above mentioned values for the peak period and can be seen in Figures 12 to 15. Since in valley period the currents through the MV lines are lower, the reactive power 3I2X consumed in the inductance parameter of every line is also lower. Therefore, the overall production of reactive power by the line and MV network increases.

VI. CONCLUSIONS

Due to its environmental values and the political willing towards sustainability, the small power system of El Hierro Island has a singular goal of operation, based on a hydro-wind power plant. The installed generation capacity is about three times power demand and a suitable generation management is required in the way towards a 100% renewable system operation.

As a consequence of political willing to sustainability, the island was declared a Biosphere global reserve by UNESCO in January 2001 and in September 2014 has also been declared part of the European Geoparks Network. So, overhead power lines conversion to an underground network is seen as a natural step.

Such kind of distribution network leads to a high generation of reactive power because of the capacitive parameters of underground cables, influencing the power system operation. This paper addresses the impact of a whole underground distribution network on network voltages and the secure operation of generators, in the El Hierro power system. Several cases have been analyzed.

Most remarkable case is Case 3, in which all conductors are undergrounded. The results obtained from simulations suggest that this configuration can have a negative impact on generating units, forced to abnormally absorb reactive power for balancing reactive power generation from the power lines.

As can be expected, reactive power generation from distribution power lines has been found more severe in periods of minimum demand of power. Setting the Excitation Control Systems of generators at minimum level would not be enough. Results also suggest that installing reactances in the distribution network could be necessary in order to compensate the reactive power from lines, being this a solution for assuring a proper operation of generating units.

On the other hand, measured values of the system frequency during several 24 hour periods have been recorded. The analysis of those measured values leads to conclude that the new power system exhibit a better behavior in the day to day operation, with a smoother frequency evolution and without remarkable stability problems. Therefore, this kind of power system based on hydro-wind generation could be a good choice for systems who are looking for a sustainable future.

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BIOGRAPHIES

Fidel Cabrera Quintero was born in 1968. He received the B.Sc. degree in Telecommunications Technology from University of Las Palmas de Gran Canaria (ULPGC), Spain in 1992. He is currently with Institute SIANI of ULPGC, under the Energy Efficiency master.

Jose F. Medina Padron received M.Sc. and Ph.D. degrees in Industrial Engineering from University of Las Palmas de Gran Canaria (ULPGC), Spain. He is currently with Institute SIANI of ULPGC.

Elias Jesus Medina Dominguez received M.Sc. and Ph.D. degrees in Industrial Engineering from University of Las Palmas de Gran Canaria (ULPGC), Spain. He is currently with Canary Technical Institute (ITC).

Miguel Angel Artiles Santana was born in 1981. He received the B.Sc. and M.Sc. degrees in Industrial Engineering from University of Las Palmas de Gran Canaria (ULPGC), Spain. He is currently with Institute SIANI of ULPGC.