Gorona del Viento Wind-Hydro Power Plant

Results, Improvement Actuations and Next Steps

Agustín Marrero Quevedo
Elías J. Medina Domínguez
Jesús M. de León Izquier
Renewable Energies Department
Technological Institute of the Canary Islands (ITC)
Santa Lucía, Gran Canaria, Spain
agustin.marrero@ree.es
ejmedina@itccanarias.org
jdeleon@itccanarias.org

Rubén Corujo de León
Pablo Santos Arozarena
Isolated Systems Department
Red Eléctrica de España, S.A.U. (REE)
Alcobendas, Spain
rcorujo@ree.es
pasantos@ree.es

Juan Gil Moreno
Alberto Castañeda Quintero
Departamento Técnico
Gorona del Viento El Hierro, S.A.
Valverde, El Hierro, Spain
jgil@goronadelviento.es
acastaneda@goronadelviento.es

Jaime González Hernández
Departamento de Ingeniería en Electrónica y Automática
Universidad de Las Palmas de Gran Canaria (ULPGC)
jaime.gonzalez@ulpgc.es

***Abstract*—This article presents the Gorona del Viento Wind-Hydro power plant, located in El Hierro Island (Spain), its initial results during first years of operation, some improvement actuations done at the end of 2017 and next steps planned in order to improve the performance of the power plant.**

The power plant includes an 11.5 MW wind farm, that supplies the primary energy, and a pumped hydro energy storage system (PHES) that operates as storage and regulation system. The PHES is powered by an 11.3 MW Pelton turbines station and includes a 6.5 MW pump station.

Operation results show that Gorona del Viento Wind-Hydro power plant has increased significantly the energy generation and its integration into the El Hierro power system.

Improvement actuations have been carried out in order to enhance the power plant performance and reduce pump units shedding. These actuations described in the article are a revision of the speed governor logic of the hydraulic turbines and a revision of the processing of the wind farm active power setting. Both were carried out in order to smooth wind power ramps and its effects due to wind gusts, avoiding the pump units shedding.

Next steps for enhancing the plant performance are presented.

Wind Power, Renewable Energies, Pump-Hydro Energy Storage, Isolated Power Systems.

I. INTRODUCTION

High penetration of renewable sources into power systems can be a challenge due to its own characteristics. These renewable sources characteristics, including intermittency and variability, can limit the integration. Besides, the integration into small isolated power systems, such as those found on small islands like El Hierro, can be more difficult due to low system inertia, the grid topology or geographical concentration of wind farms.

Different actions can be taken into account in order to obtain higher levels of renewable energies such as the use of energy storage systems. Gorona del Viento Wind-Hydro Power Plant represents a real and successfully solution to achieve a high penetration of renewable energy. This power plant integrates a wind farm and a pumped hydro energy storage system (PHES).

Gorona del Viento Wind-Hydro power plant is on El Hierro island, one of the Canary Islands, Spain. El Hierro Island is located in the Atlantic Ocean, at the west of Africa coast. The island has an area of about 268 km^2 [1].

Nowadays, due to the Wind-Hydro power plant, El Hierro Island presents one of the greatest renewable integration in the world, taken into account the islands that have about 10700 registered inhabitants [2] and fulfill the EN 50160 or similar standard.

Annual consumption of electricity in El Hierro power system is around 43 GWh [3], with a peak demand about 7 MW and a valley demand of 3.5 MW [4].

Gorona del Viento Wind-Hydro power plant belongs to Gorona del Viento El Hierro, S. A. (GVEH), enterprise participated by the Cabildo de El Hierro (Island Government), Endesa, Technological Institute of the Canary Islands and Canary Islands Government [1, 5-8]. After the required initial technical tests of the power plant, which took about a year, the commissioning was in July 2015.

The power plant represents a part of the actions planned by the Cabildo de El Hierro in order to become an island self-sufficient in energy [1, 9]. Other actions are:

- Improvements in energy efficiency.

- Load management – desalination plants and pump drinking water systems working during surplus wind conditions.
- Electric vehicle implantation.

GVEH and the transmission system operator (TSO), Red Eléctrica de España (REE) [4] are enhancing the operation of the Wind-Hydro power plant with the aim to increase the amount of electric energy that is supplied from the renewable source.

In this article is presented a description of the Gorona del Viento Wind-Hydro power plant and a description of the frequency control in the El Hierro power system. It can be seen in section II and section III respectively.

In section IV, the principal results of the Gorona del Viento power plant in the first years of operation as wind-hydro energy generation are shown.

An enhancement of the performance and efficiency of the Gorona del Viento power plant and a higher level of power system stability can be achieved with a reduction of pump unit shedding in this power plant. Some improvement actuations have been done in order to achieve these enhancements. The improvement actuations are a revision in the speed governor logic of the hydraulic turbines and a revision of the processing of the wind farm active power setting. They are presented in section V.

Results and next steps with the aim to enhance the power plant performance are finally presented in section VI.

This paper and a part of the tasks were carried out within the ENERMAC project - Renewable Energies and Energy Efficiency - Sustainable Development of Western Africa and Macaronesian Islands [10], belonging to INTERREG VA España-Portugal (Madeira-Açores-Canarias) MAC 2014-2020 cooperation program and it is funded by European Union through European Regional Development Fund (ERDF).

Tasks and actuations presented in this paper were developed in a collaborative environment between GVEH and REE.

II. Description of Gorona del Viento Wind-Hydro Power Plant

As described before, Gorona del Viento Wind-Hydro power plant includes a wind farm and a PHES.

The wind farm converts the primary energy into electricity. The PHES is used for energy storage and its capabilities allow collaborate in the stability of the El Hierro power system.

In Fig. 1 can be seen a subsystems diagram of the power plant.

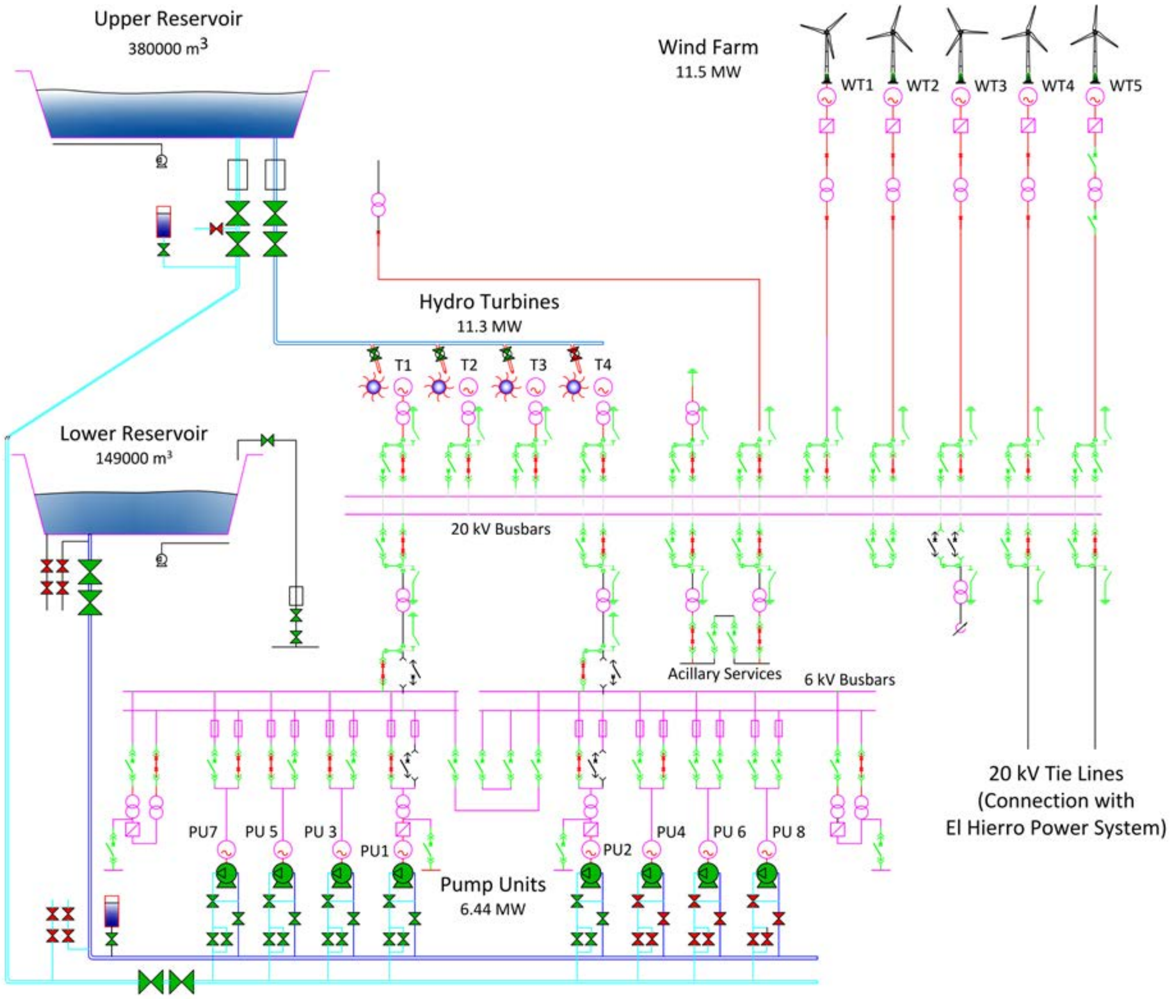


Figure 1. Diagram of Gorona del Viento Wind-Hydro power plant.

Principal elements and its characteristics of power plant are described below:

- Wind Farm. Wind farm is formed by 5 full converter wind turbines. Rated power of each wind turbine is 2.3 MW.
- Water reservoirs. There are a higher reservoir and a lower reservoir. Capacities of the higher and lower reservoirs are around 380000 m^3 and 149000 m^3 respectively. These water reservoirs are lined with waterproof high density polyethylene geomembrane.
- Penstocks. A hydro turbine pipe of 2.3 km and 1 m of diameter and a pump pipe of 3 km and 0.8 m of diameter.
- Hydro turbine station. Hydro turbine station is composed by 4 Pelton turbine generation units. Capacity of each unit is 2.83 MW. Hydro turbine rated flow is 0.5 m^3/s.
- Pump Station. There are 8 centrifugal pump units in the pump station. The pump units are:
  - 2 pump units of 1.6 MW rated power. Each pump unit has a rated flow of 0.178 m^3/s. Pump units controlled by frequency converters drivers.
  - 6 pump units of 0.54 MW rated power. Each pump unit has a rated flow of 0.058 m^3/s. Pump units started by 2 frequency converters drivers.

These principal elements and others are depicted in Fig. 2.

Another description of the Gorona del Viento Wind-Hydro power plant can be found in [11].

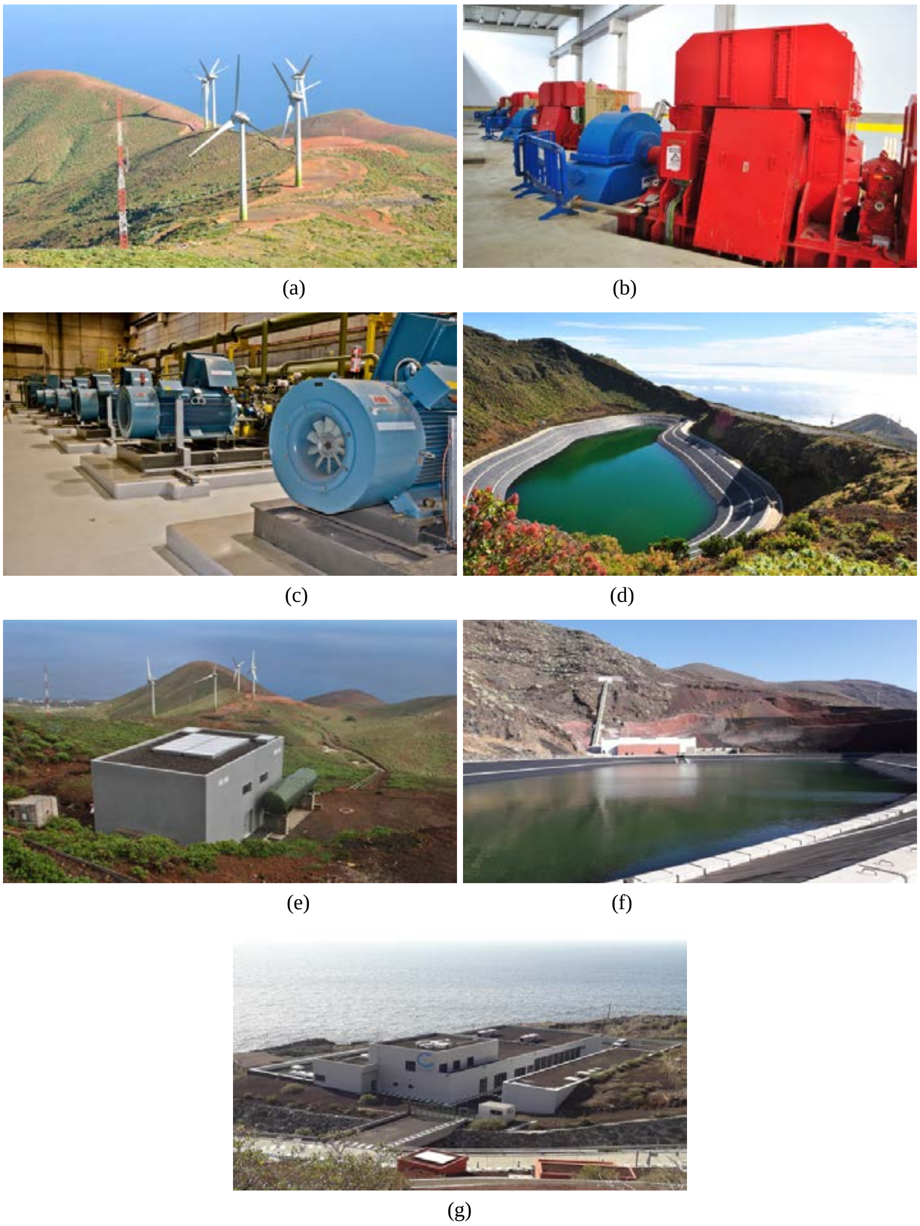


Figure 2. Gorona del Viento Wind-Hydro power plant: (a) Wind farm; (b) Hydro turbine station; (c) Pump station; (d) Upper reservoir; (e) Valve room of upper reservoir; (f) Lower reservoir; (g) Control, subestation and pump station building.

III. Description of Frequency Control in El Hierro Power System

The ancillary service of active power-frequency control is organized in several levels on the electrical power system of the El Hierro Island. These levels are:

- Tertiary regulation.
- Secondary regulation.
- Primary regulation.
- Pump shedding scheme.

REE, as TSO, provides a weekly/daily/hourly power dispatch which takes into account system stability and security as well as economic criteria. As a result a generator/pump unit schedule is obtained. The power dispatch is modified according to the real time situation and the actual wind resource.

The secondary regulation is done through an automatic generation control device.

The hydro turbine generation units and the pump units of the Gorona del Viento Wind-Hydro power plant receive the active power setting in their speed governors and in the frequency converter controllers (case of pump units driven by converters) respectively. The TSO active power setting for wind farm is received in the automatic generation control device of the power plant.

The El Hierro power system has several devices able to provide primary regulation. These devices are:

- Hydro turbines of Gorona del Viento power plant and diesel generators of another power plant, through its speed governors.
- Pump units. Both 1.6 MW pump units and two 0.54 MW pump units regulate frequency using the frequency converters.
- Wind farm. The wind farm has an active power-frequency regulation capability using the farm control unit.

The last level of frequency control is a pump shedding and it takes action if the others levels cannot restore the system frequency. This consists in pump units disconnection when the frequency system or the rate of change of frequency (ROCOF) reaches certain values.

IV. Power Plant Performance

General results of the Gorona del Viento Wind-Hydro power plant are presented in this section. Besides, performance of pump units shedding in the power plant is also discussed.

A. *General Results*

Gorona del Viento Wind-Hydro power plant has increasing its results over the years. The energy injected into El Hierro power system by the power plant was 20234 MWh in the last year. This produced energy represents the 46.4 % of El Hierro power system demand and it is highest annual value since the commissioning of the power plant.

Higher produced energy results in a reduction of diesel consumption and a reduction of CO_2 emission. Gorona del Viento Wind-Hydro power plant has avoided the emission of 29133 tons of CO_2 since its commissioning. Its related values and the rate of integration of the Gorona del Viento Wind-Hydro power plant into power system is presented in Table I.

TABLE I. Saved Diesel, CO_2 Reduction and Integration into Power System

Year	Saved Diesel (tons)	CO_2 reduction (tons)	Integration into power system (%)
2015 (From July up to the end of the year)	2099	4352.57	19.4
2016	5366	11629.56	40.7
2017	6070	13150.87	46.4

Others milestones reached by the power plant are:

- 79 % of renewable integration into power system in July 2017.
- 8 consecutive days covering 100 % of the Island demand in June 2017.
- 18 consecutive days covering 100 % of the Island demand in January-February 2018.

Energy generated by the power plant that it is injected into the El Hierro power system has been increasing as described above. Fig. 3 shows wind resource available from July 2015 to December 2017. It can be seen that most of 2017 months have fewer wind resource than 2016 and 2015, except for January, March and October. Nevertheless the Wind-Hydro energy injected into the power system is greater in 2017. In Fig. 4. it can be seen that the rate of energy integration of the Gorona del Viento power plant in the overall generation mix is higher in 2017.

This higher energy integration is due to some improvements in the power plant control and the operation scheme with the aim of increase the energy production realised by GVEH and REE.

These improvements in the power plant operation involve the increase of the wind power injection directly to the power system as well as a reduction of the wind power consumed by pump station when possible.

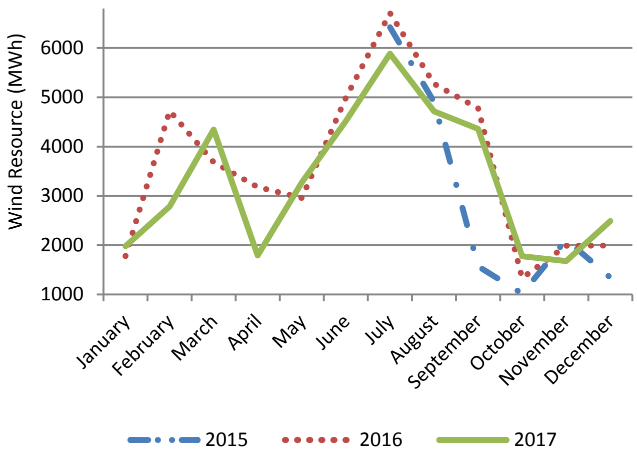


Figure 3. Wind Resource available.

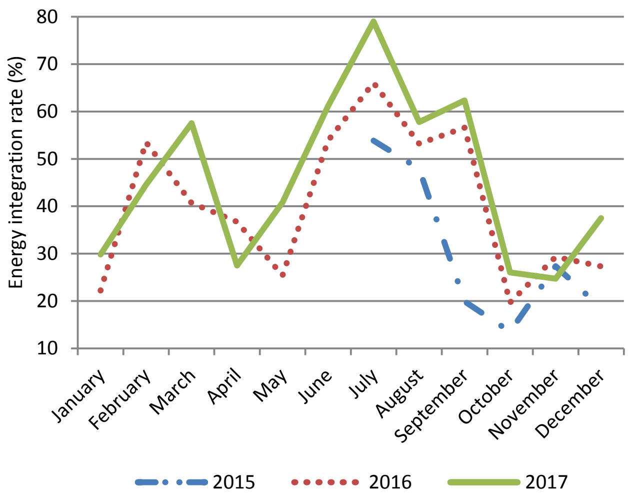


Figure 4. Energy integration rate of the Gorona del Viento wind-hydro power plant into El Hierro power system.

An increase of the Wind-Hydro energy integration into power system can be obtained by the reduction of the wind power consumed by pump station because per each wind energy unit that is pumped up to upper reservoir, only about half is recovered. This rate is associated to the efficiency of whole equipment of the PHES. As a result, the wind resource used in 2017 is higher than previous years.

These positive results prompt more changes in power plant operation to continue the increase of the injection of wind power into the power system and the reduction of pump station consumption.

Another possible way to increase the energy generated by the power plant that is injected into the power system is to enhance the efficiency of the PHES. However, it is not feasible task or, at least, not easy. The installed equipment of the PHES has its own characteristics and it is made up by hydro turbine station, pump station, penstocks and reservoirs. The improvement of the efficiency can involve the modification of these characteristics. At today, the performance of the PHES has efficiencies of around 50 %.

B. *Shedding of Pump Units*

Gorona del Viento Wind-Hydro power plant has implemented a shedding scheme of pump units as a method of active power-frequency control. A pump unit shedding occurs when frequency falls and it is activated by an under frequency value or a ROCOF value. The pump units shedding occurs mainly during wind ramps.

A case of pump units shedding took place on July, 27th, 2016, around 14:10 hours. It is shown in Fig. 5 and it includes the time evolution of some power plant parameters. In this case, there are two hydro turbine units connected. Both generators are producing a total active power of 1.5 MW. There are also connected pump units with a total active power of 6 MW and the wind farm is generating around 7.8 MW. The power plant injects into the power system about 3.3 MW. The power plant is covering around 70 % of the power system demand. The rest active power consumed in the power system is produced by a diesel generator belonging to another power plant. This diesel generator injects 1.7 MW.

When the wind power ramps occur due to wind gusts, the primary power-frequency control of hydro turbines units (speed governors) and the pump frequency converters help to maintain the balance between generation and consumption. As Fig. 5 shows, these control actions are not enough to maintain the system frequency in this case. Therefore, it is necessary a shedding of two 0.54 MW pump units at 14:20 h. Power frequency decreases until 49.2 Hz during the wind power ramps.

After the wind ramps, the generated active power of the wind farm is reduced, and the TSO commands the disconnection of a 1.6 MW pump unit at 14:25 h. in order to maintain the exported active power to the power system.

GVEH and REE have worked on the reduction of these pump units shedding. A reduction of number of pump units shedding leads to lower number of operating pump units dispatched as a protection mechanism against wind ramps, and therefore it leads to an enhancement of the power plant efficiency. In addition to this, a reduction of pump units shedding increases the power system stability.

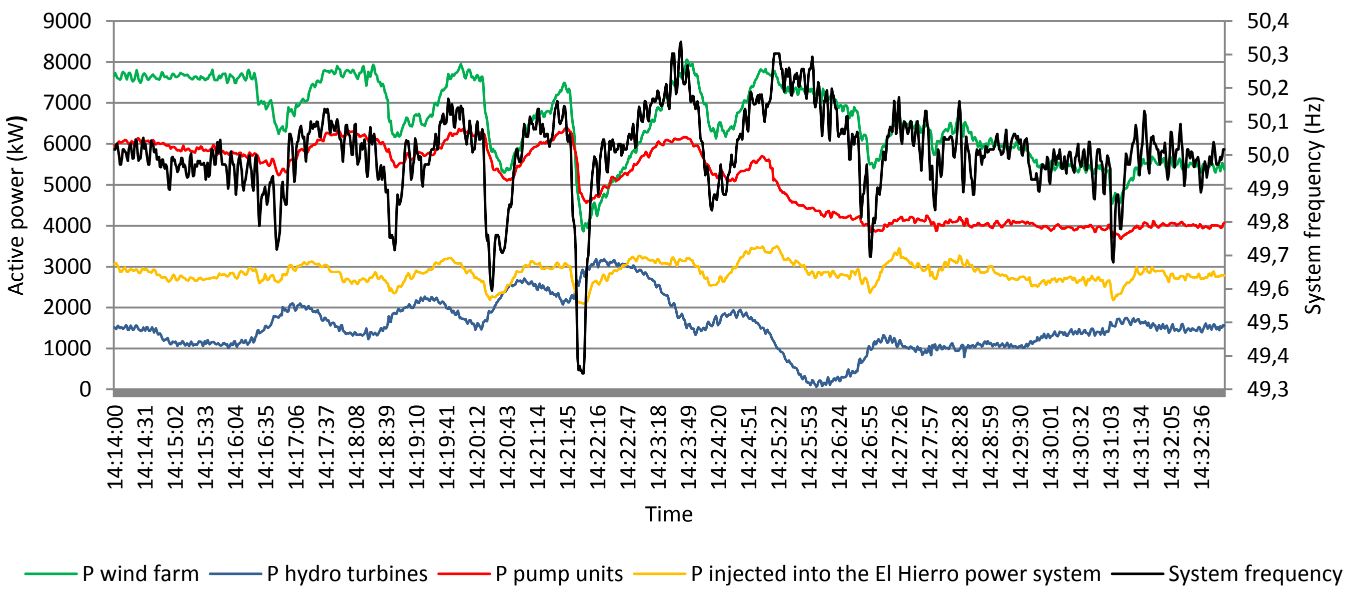


Figure 5. Performance of Gorona del Viento wind-hydro power plant. (Date: July, 27th, 2016).

Measures to improve the power plant operation and the control of the power system were implemented, by the end of November 2017, with the aim of reducing the high number of pump units shedding.

V. Reducing of Pump Units Shedding

As it is commented in section B. Shedding of Pump Units, GVEH and REE carried out actuations related to the reduction in the number of pump units shedding, from 2015 to midyear of 2017. It led to the enhancement of both the power plant efficiency and the power system stability.

Some other improvement actuations have been taken at the end of 2017 year to reduce the pump units shedding. An improvement actuation is a revision in the speed governor logic of the hydro turbine generator units. Another one is the revision of the processing of the wind farm active power setting. Both improvement actuations try to smooth the wind power ramps and its effects which can cause the pump units shedding. These improvement actuations are described in this section.

A. Speed Governor Logic of the Hydro Turbine Generator Units

A revision of the speed governor logic of the hydro turbines was carried out, with the aim to enhance the response of the hydro turbine units during wind ramps. This enhance could avoid pump units shedding. The revision included the following tasks which were done:

- Design and implementation of a damper to mitigate the pressure waves in the turbines penstock.
- Retuning of the PID gains of the hydro turbine speed governor, that allows a better hydro turbine response when a wind ramp or outage of others generators occur.
- New setting of the hydro turbine deflector in order to improve the hydro generator response during an over frequency event as well as the performance of the damper.

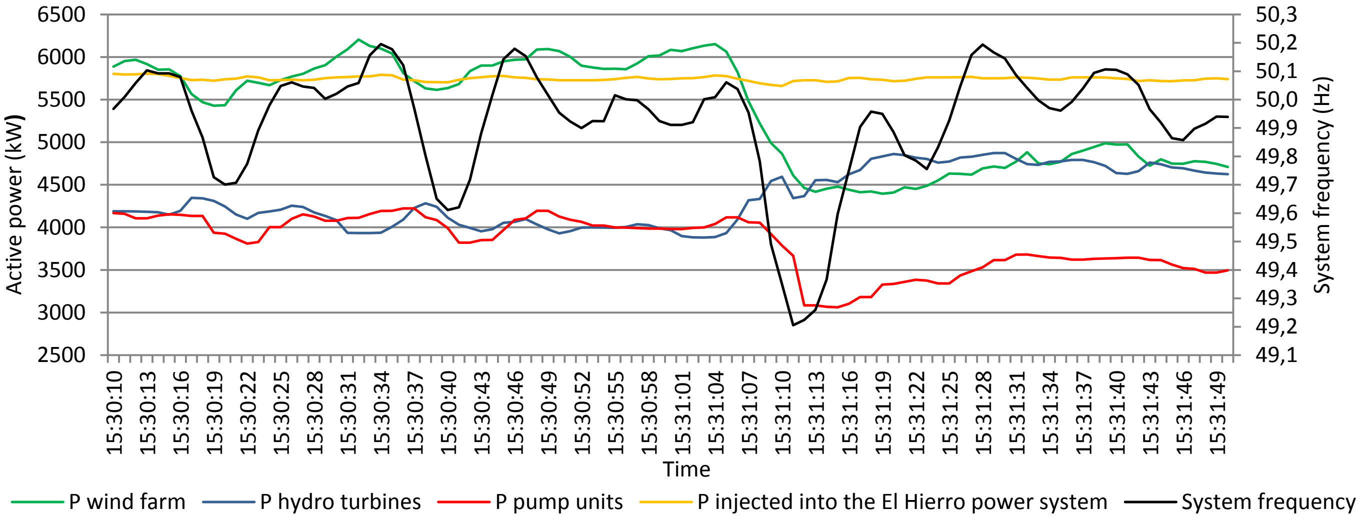
During a frequency control action, the hydraulic turbine units open or close its nozzles to change the water flow through the machine and control its active power.

When a wind ramp takes place, the wind power can decrease and the frequency of the power system drops. The connected hydro turbine units respond by the opening of the nozzle to replace with hydro power the amount of wind power that is ramped down. Because of this, a water pressure wave is produced in the hydro turbines penstock. This water pressure wave travels through the hydro turbine penstock and it is reflected in the upper reservoir and reaches again the hydro turbine units. When the water pressure wave reaches the hydro turbine units, it is reflected once again. Thereby, this phenomenon starts again [12]. The reflections cause oscillations in both water pressure and mechanical power into hydro turbine units. Therefore, the reflections have a significant influence on the performance of the hydro turbine units.

The bigger nozzle rate of opening of a hydro turbine unit is, the bigger oscillations are caused. So, if the response of a hydro turbine unit is big enough, the travelling water pressure wave could cause instability in the hydraulic system of the power plant and in the whole power system. As a part of the revision, the damper was designed and implemented in order to mitigate the pressure waves allowing the turbines to give a greater response. This higher response can prevent higher frequency deviations and therefore, avoid pump units shedding.

Fig. 6 (a) shows the behavior of the power plant during a wind power ramp on June, 7th 2017. It can be seen that wind power diminishes 1.6 MW in 5 s at around 15:31 h. The system frequency drops and the 3 hydro turbine generator units increase their active power. It can be seen that this power increase in not enough to maintain the previous value of the system frequency. Therefore, system frequency falls to 49.2 Hz and shedding of a pump unit takes place. It can be seen the same event in Fig. 6 (b), but including the nozzle position, deflector position, active power and water pressure in the hydro turbine 3.

Fig. 7 (a) includes a similar event during December, 12th 2017, in which the new speed governor logic is in operation. In this case, the response of the hydro turbine units is faster due to the action of new speed governor logic. The system frequency reaches 49.59 Hz at around 19:42 h., its oscillation is lower and there are not pump units shedding.



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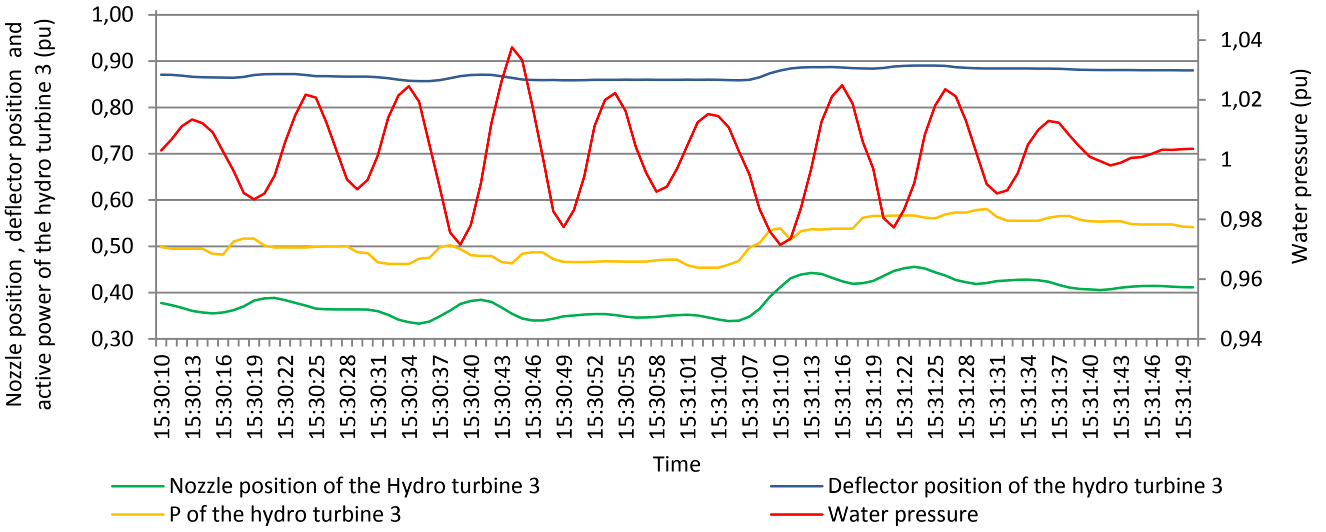
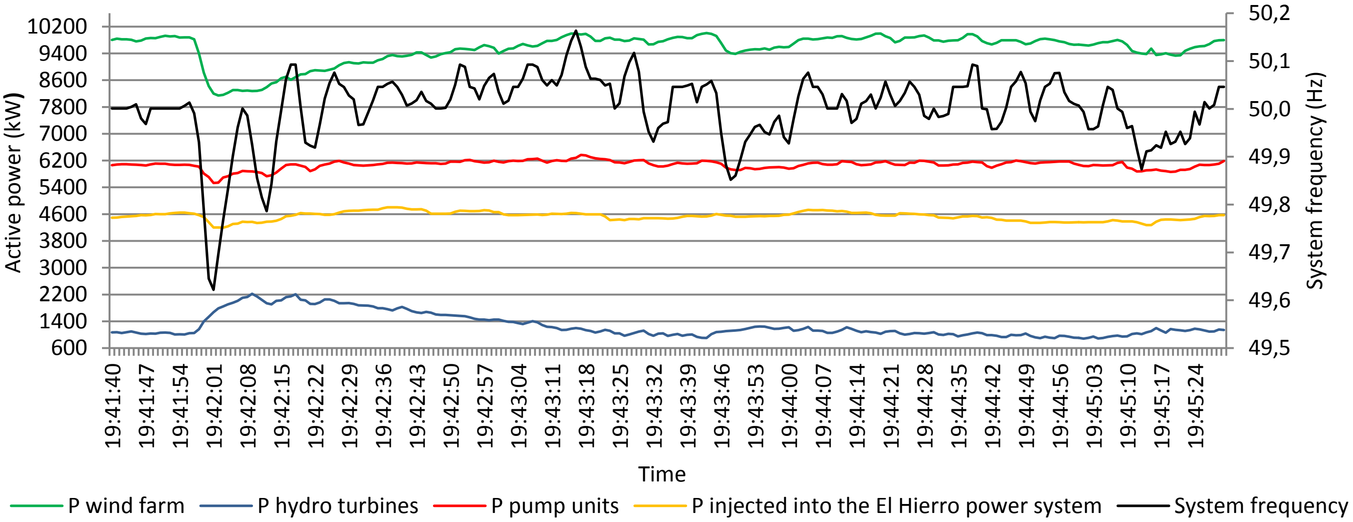
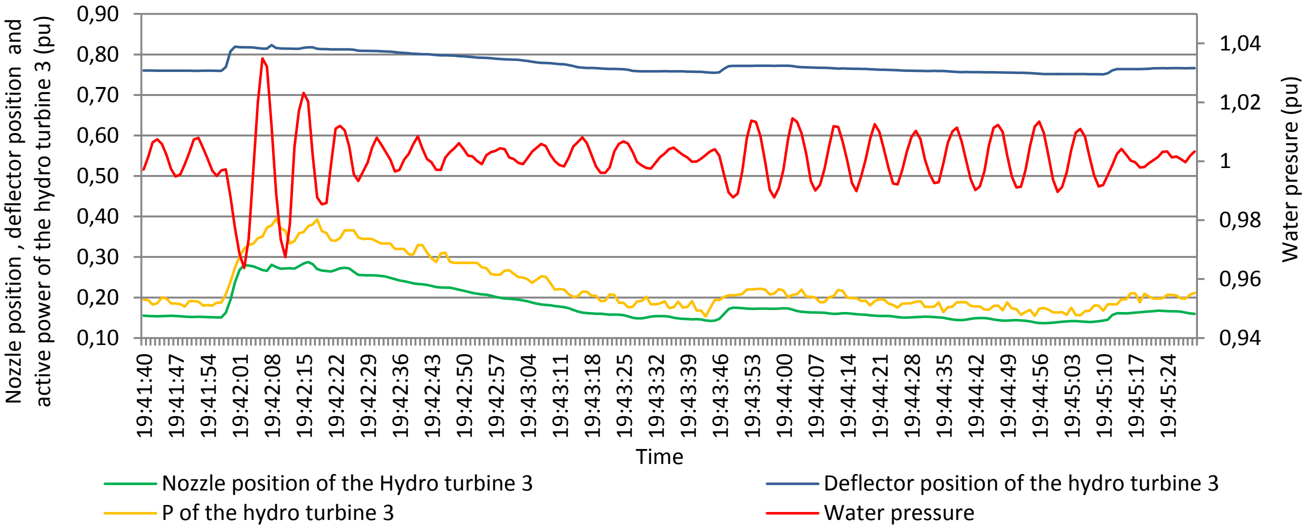


(b)

Figure 6. Performance of Gorona del Viento wind-hydro power plant without new operating speed governor logic of the hydro turbine units. (Date: June, 7th 2017).



(a)



(b)

Figure 7. Performance of Gorona del Viento wind-hydro power plant with new operating speed governor logic of the hydro turbine units in operation. (Date: December 12th, 2017).

The water pressure and nozzle position is showed in Fig. 7 (b).The water pressure drops during the nozzle opening and it produces a pressure wave which has a maximum value around 1.035 pu (65.2 bars) at around 19:42 h. The implemented damper is activated few seconds later and the water pressure amplitude drops to its previous value, 1 pu (63 bars) in 30 s.

As it has been seen, the new speed governor logic has several benefits. The main one is that the turbines response is faster when a wind power ramp takes place, diminishing the pump units shedding and due to the damper, the oscillations of the water pressure during the transients are fewer than before.

B. Active Power Setting of the Wind Farm

Over time, wind farm performance is more stable if the active power setting is slightly lower than the total estimated available power reported by the wind farm control unit.

When the wind farm control unit receives an active power setting value, it sends subsequent specific settings to the wind turbines. Each wind turbine tries to adjust its active power, according to its setting values. Output active power from wind turbines becomes stable when specific wind turbines setting values are slightly lower than the estimated available power from the wind. Therefore, total output active power of the wind farm is also stable. However, if one or more wind turbines receive a setting value near its estimated available power and it is not reached, the wind farm control unit of the wind farm tries to send bigger setting values to the other wind turbines. If these setting values are near their estimated available powers from the wind, the wind farm active power becomes more variable. This could cause instability in the power plant.

This described performance of the wind farm can be seen in Fig. 8. Because active power setting value is below the estimated available power from the wind, active power of the wind turbines is stable between 16:58 h. and 17:03 h. On the other hand, an oscillation of active power from the wind turbines is showed between 17:05 h. and 17:25 h. due to a higher setting value than available power from wind.

This active power oscillation can cause frequency deviations and the activation of pump units shedding.

A review of the processing of the active power setting of the wind farm was carried out in order to obtain more stable system and avoid pump units shedding. As a result, a new processing of the active power setting has been implemented in the wind farm control unit. This new processing consists in a comparison between consigned active power value and a 5 minutes moving average of the estimated available wind farm power. 5 minutes moving average of the estimated available wind farm power is calculated by a statistical method of regression.

The wind farm control unit selects as active power setting this moving average when the consigned active power value is bigger than the moving average. On the contrary, consigned active power value is used.

This improvement actuation has reduced the number of situations shown in Fig. 8. Therefore wind power ramps and its effects are lower with this new active power setting.

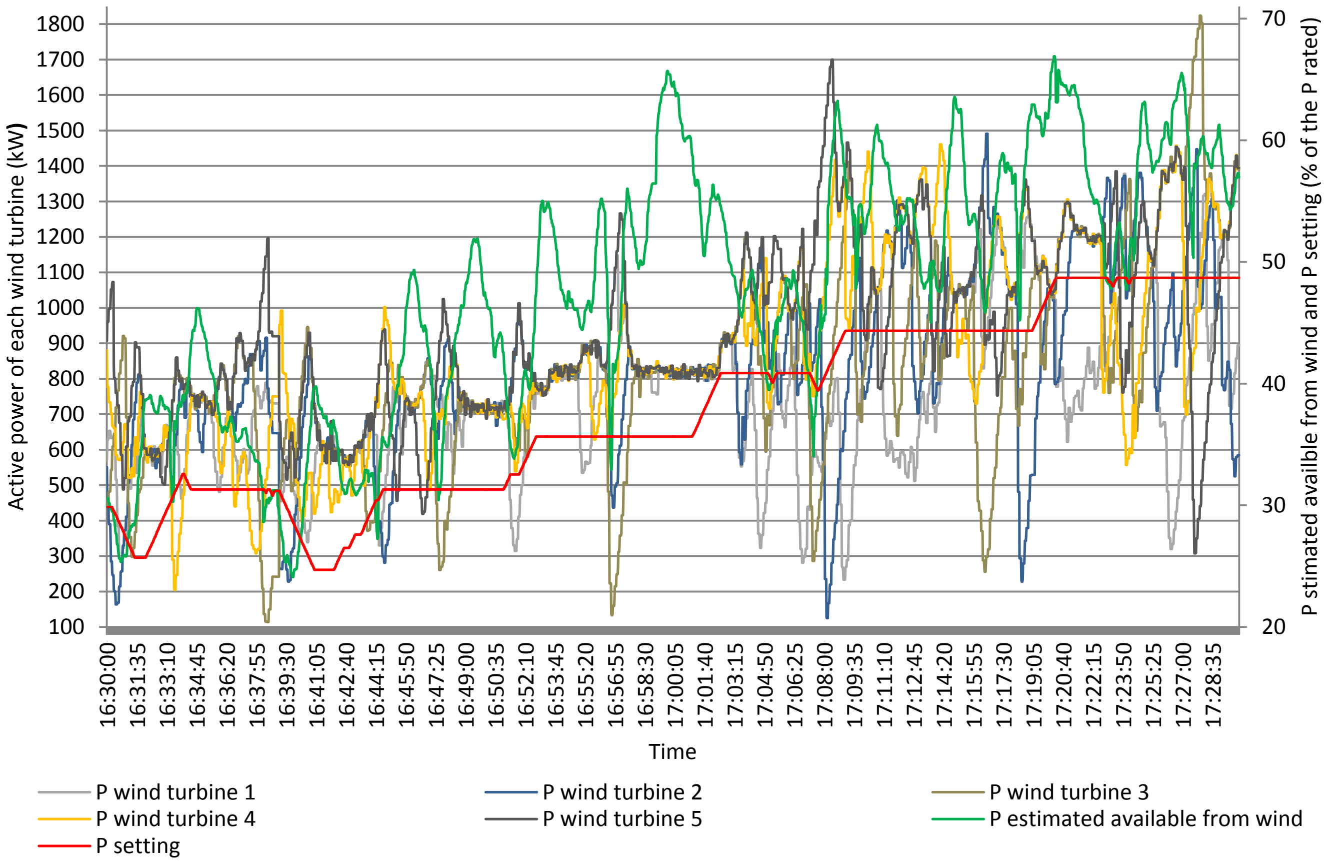


Figure 8. Performance of Gorona del Viento wind-hydro power plant on January, 23th, 2017, around 17:00 hours.

VI. Conclusions – Next Steps

In this paper are presented Gorona del Viento Wind-Hydro power plant general results and improvement actions in order to enhance the performance and the efficiency of the power plant.

Gorona del Viento Wind-Hydro power plant had saved 13535 tons of diesel and it had avoided the emission of 29133 tons of CO_2 since its commissioning in July of 2015.

It can be seen a progressive increase of the energy generated by the power plant that is injected into the El Hierro power system. It is due to that Gorona del Viento El Hierro, S. A. (GVEH) and Red Eléctrica de España, S. A. (REE) are committed to the enhancement of the control of this power plant and operation of the power system. The whole aim is to increase the amount of electric energy that is supplied from renewable energy and to improve the El Hierro power system stability.

As a frequency control method, Gorona del Viento Wind-Hydro power plant has a pump unit shedding scheme and it is usually activated when wind power ramps take place.

A reduction on the number and magnitude of pump units shedding events allows to minimize the number of pump units needed at any given moment for security reasons, which translates into higher efficiency. Therefore, improvement actions related to the reduction of the number of pump unit shedding have carried out at the end of 2017. These improvement actions focus on the smooth the wind power ramps and its effects. Improvement actions were a revision in the speed governor logic of the hydraulic turbines and a revision in the process of transforming the active power setting value of the wind farm to each wind turbine setting value.

A new speed governor logic of the hydraulic turbines was implemented and it consists in a damper to mitigate the pressure waves in the turbines penstock, a retuning of the PID gains and new setting of the hydro turbines deflector.

A new processing of the wind farm active power setting was also implemented. The used value of the active power setting is a 5 minutes moving average of the estimated available wind farm power when the consigned active power value is higher than the moving average. Consigned active power value is used if the moving average is higher.

These improvements actuations have reduced the wind power ramps and its effects, and hence the number of pump unit shedding has been also reduced. As a result, during December 2017 and the first months of 2018, the pump units shedding diminished about 96 %.

Another result is that the dependence of the El Hierro power system stability on pump unit shedding system is lower. Consequently, the Gorona del Viento Wind-Hydro power plant could operate with less connected pump units in order to increase both its efficiency and its renewable energy generation.

GVEH continues to improve the performance of the power plant. Next steps in order to improve the performance are:

- Optimal operation of the hydraulic turbine units as synchronous compensators. These units can work in synchronous compensator mode in order to collaborate on frequency control. It is indicated specially when an underfrequency event occurs due to wind power ramps. Tasks are focused on achieve an optimal transition between synchronous compensator mode and generator mode and the reduction of the consumption of cooling water during synchronous compensator mode.
- Review of the process of the assignment of the active power setting for each wind turbine in order to obtain a more stable wind farm output active power.
- Analysis of enforcement of the wind farm control capabilities such as active power-frequency control or inertia emulation capability. Enforcement of the wind farm control capabilities could help to maintain a more stable active power from wind farm.

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