Towards a New Energy Model

Challenges and solutions to enable large RES penetration in the Canary Islands' isolated power systems

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***Abstract*— A strong commitment has been agreed between authorities at the Canary Islands – Spain, to make a transition from the current energy model, to a cleaner, cheaper and more autonomous energy ecosystem. This paper describes the basics of this proposal, a strategy defined to make this envisaged future possible.**

A huge amount of new renewable generation facilities, which are planned for the coming years, will totally reshape the generation mix of the six isolated electrical systems at the Canary archipelago. This new scenario will lead to significant changes, especially from the system's stability point of view, as the number of synchronous connected generation units decrease, in favor of new power electronics connected plants, reducing system's natural inertial capabilities. Furthermore, the primary energy source will transition from oil based fuels to wind and solar, whose non-controllable nature will introduce additional challenges for the system operator.

The main driver of change, large RES penetration, will definitely force the system to adapt. The new energy model pretends to make it possible by means of network infrastructure development and innovative R&D initiatives, which will help to maximize renewable integration while keeping system parameters within security margins.

The challenge, which is going to be described throughout the paper, is quite huge, as there is a rather small set of experiences worldwide regarding large non-controllable renewable integration in isolated power systems.

Isolated systems, TSO, frequency, stability, RES, wind, solar, variability, system security, storage, pumped hydro, interconnectors

I. Introduction

The Canary Islands, located at the Atlantic Ocean, off the west coast of Africa, are part of Spain and one of the outermost regions of the EU. The archipelago, which comprises six isolated power systems distributed over seven islands, are energized mainly from thermal power plants that comprise combined cycles, diesel and steam generators, all of them using oil based fuels as the primary energy source, thus making the power production quite polluting. There is a number of renewable production plants, mainly windfarms and photovoltaic plants, whose year production cover around a 7-8 % of the total annual demand of the islands.

Due to the fact that the power generation heavily relies on imported fuel, and power units are mostly small, generation costs are high. This reason, together with the need of reducing pollution, has led to a strong commitment of authorities in supporting the development of new renewable energy generation facilities that will increase the current production capacity.

As a result, a large amount of newly installed renewable power plants are planned in the near future. Those new facilities, which will translate into a significant increase in renewable power capacity with respect to 2017, are expected to be in operation by year 2025. Meanwhile, there is a short term scenario, within the scope of year 2018, where there is already an important amount of committed infrastructures.

This paper describes the main challenges that arise as a result of combining large non-controllable RES production within small, weak, non-interconnected electrical power systems, as well as the solutions that have been planned to minimize the adverse effect in system reliability and stability.

First of all, the future scenario will be depicted. The description will cover, among other aspects, the characteristics of new installed capacity, as well as the geographical concentration of facilities.

Secondly, there will be a brief explanation of the most common issues that will occur and how some of them are already arising, even with current relatively small RES penetration levels.

Finally, the envisaged solutions are described. Those solutions address the identified issues from various points of view: network development, interconnectors between islands, small energy storages systems, large pumped hydro facilities, as well as smart grid tools. This set of solutions will serve as valuable tools for the system operator in order to allow maximum integration of RES without compromising system security.

II. Current vs Near Future Scenario

Current RES contribution to the Canary Islands energy mix is rather small. Figure 1 depicts total RES contribution to electricity generation during year 2017.

As shown, the overall contribution is between 0 and 11%, with the exception of El Hierro Island, a special case that will be briefly described later on.

Furthermore, the current installed facilities were commissioned before year 2004 and, as a matter of fact, their technology is rather old. This implies limitations on how the generation units respond to severe incidents on the network.

By horizon 2025 a huge amount of RES plants are expected to be installed all over the Canary Islands. In the short term, within the scope of year 2018, there is an important amount of committed infrastructures which are already being built.

Figure 2 shows actual and expected RES installed capacity in the Canary Islands, both by the end of 2018 [1] and by year 2025 [2].

This strong development has a set of characteristics, being the most important ones:

- Size: the total amount of installed power will be, in most of the cases, close to or even greater than the maximum demand of the system.
- Primary source: the vast majority of the planned facilities are wind and photovoltaic power plants.
- Location: within each of the islands, RES generation plants are geographically concentrated, as territory is limited and the best performing zones, in terms of capacity factor, are in certain specific areas, mainly located at the south-east shore of the islands.

The resulting scenario will originate mainly two new issues to address: on one hand, a set of improvements and development of current network infrastructure will need to be faced, in order to evacuate the amount of new generation planned. On the other hand, a number of operational challenges will arise, mainly related to the increase of non-synchronous generation in the power mix, as well as to the variable, non-controllable nature of their primary resource.

Next section will introduce those foreseen issues in more detail.

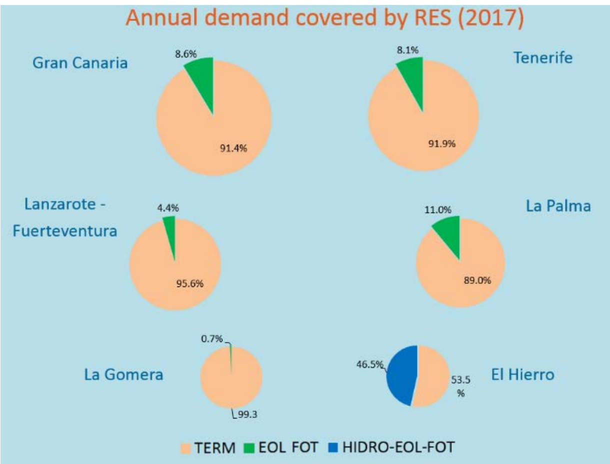

Figure 1. Canary Islands' Annual demand in 2017

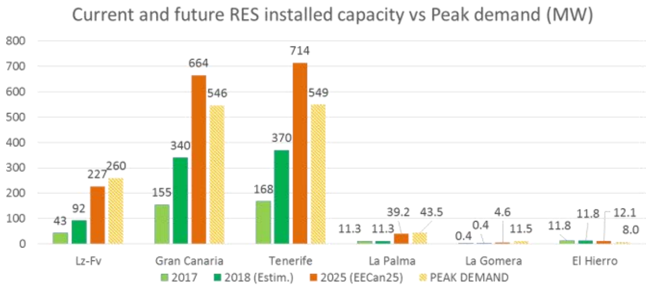

Figure 2. Current and future RES installed capacity

III. Foreseen Issues

A. *Transmission related*

Most of the existing and planned RES generation plants are geographically close together:

- Despite solar radiation is spread all over the islands, its volcanic nature leaves only a few areas suitable for photovoltaic power plants development as they usually cover large flat zones.
- Trend winds, present at the canaries nearly all over the year, blow generally from the north-east. This fact sets a specific area of the islands having an optimum capacity factor for the wind farms, which is usually the south-east coast line.

This geographically concentrated development of new RES facilities sets a big stress into specific points of the existing transmission network, mainly into substations and power lines at the south of the islands, whose capacity won't be enough to transport the expected RES generation in the coming years.

The network development plan must cover those future needs. Building the necessary infrastructures on time is considered a huge challenge, as there is a long administrative process involved, were national, regional and local authorities take active part.

B. *Operation related*

Large penetration of RES translates into moving from a generation mix mainly composed by synchronous generators, towards a scenario where most of them have been displaced by power electronic connected plants. This directly reduces the system inertia, as rotating masses are removed from the power generation mix, and changes the behaviour pattern of the generation as a whole. Therefore, the nature of wind and solar generation, are likely to trigger changes in the operation of the power system, mainly driven by their non-synchronous connection and non-manageable nature.

From the operational point of view, the main issues identified by the Spanish System Operator are the following:

- Frequency stability. In a small and isolated system there are few generators, which leads to low inertia and therefore to high frequency excursions as a response of demand or generation variations. This fact, together with the small and isolated nature of the system, makes frequency stability as the main issue to monitor, and also magnifies all the operational challenges that normally RES generation introduce.

- Primary resource variability. RES development in the Canary Islands is mainly based on wind and photovoltaic, whose primary resource is variable, uncontrollable and in certain conditions difficult to predict. Therefore, dealing with high power production variability is expected to be one of the main issues to be faced from an operational point of view. Besides, this issue would get magnified by the geographical concentration of the power plants, as a local variation in the primary resource will affect to a large amount of generators. As a reference, RES production variability has been already observed in the recent years. Figure 3 shows real power curves of both wind and solar generation during different days. A clear difference can be observed between stable and variable scenarios, within the same system. The availability of accurate prediction tools and models will be key to anticipate the required mitigating actions, whenever those situations arise.

- RES curtailments. The amount of RES installed capacity will likely lead to situations where system demand is not enough to absorb it. In such a situation, the exceeding power production coming from RES will be lost. With the considered values, and in absence of any tool for the System Operator to cope with these situations, curtailments are expected to be quite common, as the gap to be covered by RES generation is limited by the technical minimum of a set of "must-run" units, a group of synchronous generators that need to be online at all time, in order to guarantee demand coverage and power reserves at any given hour.

- Non-synchronous generation different features. Photovoltaic and some wind generation technologies are not synchronously connected to the network because they are connected through a power electronics converter, and this fact leads to different technical features compared to synchronous generation. Just as examples: in principle, unless inertial response or frequency sensitive modes are implemented within the plant control system, power production will not notice network frequency deviations; besides, short circuit power is likely to be dramatically reduced, which can have an effect for instance on the protection system, and also in the behavior of other electronic devices.

Given the future expected issues in the context of the energy transition at the Canary Islands, the Spanish System Operator is already tackling the abovementioned challenges, identifying a set of solutions so as to successfully manage the RES integration objectives, by means of maximizing RES production while guaranteeing system security and security of supply.

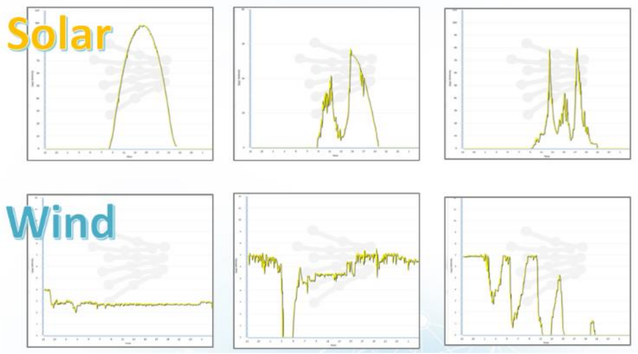

Figure 3. Wind and photovoltaic production curves showing variability

To maximize RES integration, and to minimize RES curtailments, it has been identified as essential to act on several fronts. The set of foreseen solutions we have been working on are described next.

IV. THE ENVISAGED SOLUTIONS

A. Network developments

The 2015-2020 network development plan [3], currently into execution, address the identified transmission network capacity needs, and will end up with an expanded electrical network that will allow to integrate large amounts of RES generation.

The main figures of the plan, which is approved by the Spanish national government (and compulsory for the TSO), comprises the construction of 340 new substations switching positions and more than 560 km of new power lines, aimed at securing energy supply and evacuating RES generation from the planned facilities, with a total budget of around 991 M€. [4] Figure 4 depicts the scope of the main actuations.

Despite most of the energy evacuation needs will be covered, the most recent access inquiries from RES plants promoters have putted into evidence that even the planned network development won't be enough. The current approved network development plan was designed back in year 2014, where the considered scenarios were slightly different. This has led to a situation where, on some specific points of the network, the total capacity of already requested accesses surpass the actual node energy evacuation capacity.

New solutions are being analyzed to cope with this situation in the short-term, mainly the use of energy storage to alleviate network congestions at critical points.

B. Interconnectors

One of the main problems of the Canary Islands electrical systems is their isolated nature, which translates into weak, low meshed, non-interconnected power networks. This sort of systems suffer from scarcities in terms of capacity to cope with severe incidents, and a lack of flexibility at every aspect of system operation, even during daily scheduled maintenance works, some of which need to be carried out while the power equipment is energized and in service.

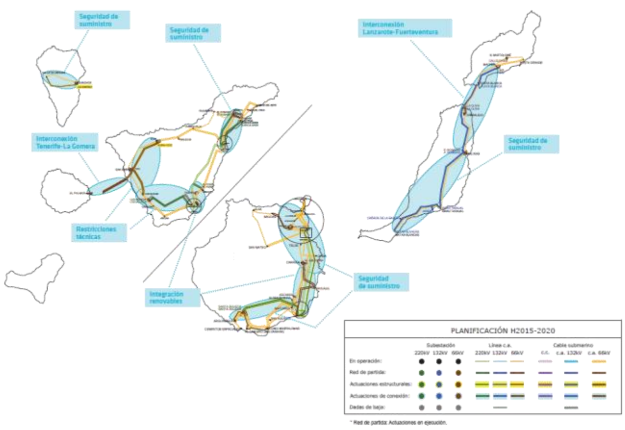

Figure 4. Current network development plan: areas of actuation

Problems become bigger at the time RES integration increases, as it implies reducing synchronous generation and therefore limiting the natural inertial capacity of the system to positively contribute during a sudden loss of generation or load.

Size therefore matters, and having bigger, more interconnected networks will add robustness as well as flexibility, both characteristics considered as basic to increase RES integration while keeping system security.

As a result, there are several initiatives in the form of interconnector´s development. The current network development plan contemplates the reinforcement of the existing interconnector between Lanzarote and Fuerteventura. This 66kV power link, the only already in service between islands at the archipelago, will be upgraded with an extra 132kV submarine line.

The second planned interconnector will link Tenerife and La Gomera power systems. This interconnector, a dual line at 66kV will allow La Gomera to benefit from the energy generation from Tenerife, were RES development is expected to be huge, and a more diverse generation mix is available in terms of generation technologies, if we compare it with generation in La Gomera, which comes out of a single diesel power plant.

Finally, there is an additional infrastructure that is being studied, included in the network development plan as a non-binding long-term infrastructure: an interconnector between Gran Canaria and Fuerteventura, an island with great wind power potential. This underwater link, once in service, will connect the electrical networks of three islands (Gran Canaria with the already interconnected Lanzarote-Fuerteventura subsystem), leading to a bigger electrical subsystem that will allow to integrate more RES generation as well as to reduce generation costs by optimizing generation dispatch.

Figure 5 shows where the mentioned interconnectors fit within the Canary Islands geography.

C. *Large Energy storage*

Figure 2 shows how RES installed capacity is expected to be close to the islands peak demand, in most of the cases. This scenario will lead to many situations where there will be an excess of production. This will happen mainly for two reasons: the first one, islands demand is quite lower than peak demand for the most part of the day, hence the difference between generation capacity and the capability of the system to absorb it is even bigger. The second one, in order to keep system security and guarantee of supply during the whole day, a certain number of controllable "must-run" units must be online at any time. The technical minimum of those units reduces therefore the capacity of the actual power demand to absorb RES generation.

The only feasible solution in order to avoid RES curtailment is to store the surplus by means of large energy storage infrastructure. In this context, the Spanish TSO has been given the authorization to develop pumped storage energy plants at the islands, when the main driver is system security and renewable energy integration [5].

1) The Soria-Chira project

The very first of those planned facilities will be the Soria-Chira Pumped hydro storage plant in Gran Canaria [6]. The infrastructure will store the RES production that cannot be integrated in the real time operation, and will permit recovering such power whenever best suits to the system itself. This facility will be designed also to cope with the rest of the operational challenges, i.e. it will be designed to be a tool for the System Operator to cope with situations that, in the absence of a pumped storage hydro plant, will lead to preventive curtailment of RES generation.

Figure 6 shows an infographic of the main plant elements, together with some relevant figures.

The Soria - Chira plant consists of a 3625 MWh capacity pump storage plant, located in the municipality of San Bartolomé de Tirajana, which will connect two existing dams located in the central zone of the Island of Gran Canaria: the dam of Soria (132 m high and 32,30 hm3), which will be used as the lower reservoir, and the dam of Chira (38 m high and 5,64 hm3), which is the upper reservoir. Both reservoirs will be connected by means of a main hydraulic circuit.

Except the water intakes, which are located under the water level of the reservoirs, all the elements of the main hydraulic circuit will be underground. The power plant and substation will be installed in two caverns to minimize the environmental and visual impact of these elements.

The plant comprises six units rated each one at 33 MW in generating mode and approximately 37 MW in pumping mode.

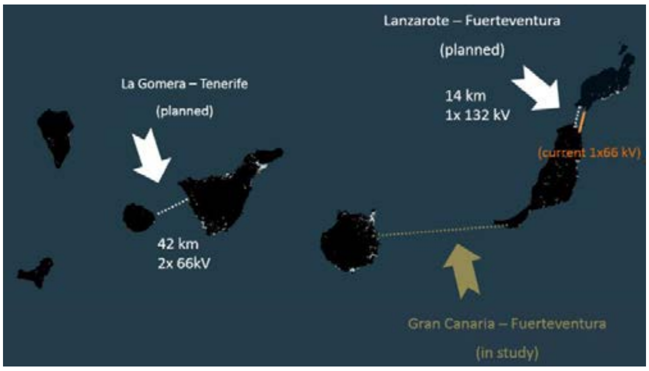

Figure 5. Current and planned interconnectors

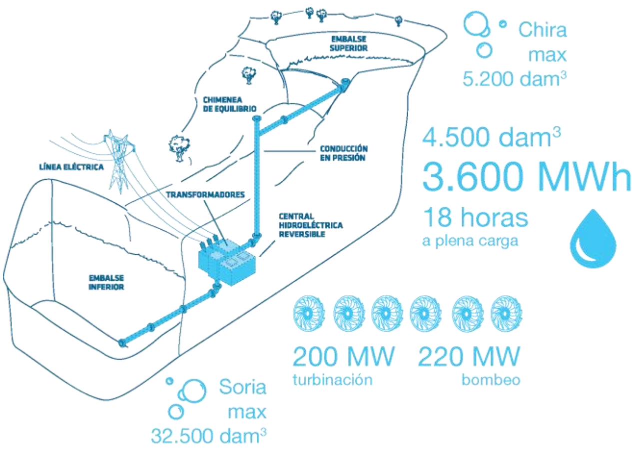

Figure 6. Soria-Chira project: main figures

Once in operation this pumped storage hydro plant will contribute to increase the RES penetration in the Gran Canaria island power grid, reducing curtailed energy significantly, with respect to a scenario with no storage facilities available.

Other pumped storage facilities are being studied, in order to incorporate similar solutions in the islands of Tenerife and La Palma.

2) *El Hierro Island experience*

A first experience on using a pumped storage hydro facility for the purpose of system security and large scale RES integration has already been carried out at El Hierro Island. As it can be seen from figure 2, El Hierro Island covered its annual demand with a 46,5% of energy coming from RES in year 2017. This achievement was possible because of the contribution of another pumped storage hydro facility, named Central Hidroeólica de El Hierro (CHE) [7].

CHE is a unique plant composed by a wind farm linked to a pumped hydro storage system, designed to feed the island demand with wind power when available, storing excess of production by means of water moved to an upper reservoir that will be used to generate electricity on demand.

Figure 7 shows a schematic view of CHE.

There were no references worldwide on managing power systems in such a scenario: a wind farm tied to a pumped storage hydro system whose total installed capacity doubles the islands peak demand.

The infrastructure, which is operated (but not owned) by REE as the TSO, is exploited in order to maximize the amount of renewable energy into El Hierro power system in a system-safe way, minimizing the risks associated with unpredictability of wind-power, which could trigger important incidents in the power grid.

The experience have been highly positive since the starts of operations, back in the summer of 2015. Since then, a great knowledge have been gathered both from the daily operation tasks of the plant as well as from the constant dialog with the owners.

As a result, a new record have been stablished in early 2018, where the CHE system covered the complete island's demand during 18 consecutive days, more than two weeks, where the diesel power plant was completely off and the island was therefore 100% renewable.

The experiences gained in El Hierro Island are expected to be of great value for the operation of the new pumped storage hydro plants already planned.

D. *Small Energy storage*

Finally, there is another set of operational challenges that need to be faced, mainly related with system stability.

One of the tools that can help to mitigate the effects of the lack of natural inertia in a power system is, again, energy storage. Batteries are gaining worldwide momentum as a valuable tool to provide system services, especially in isolated systems, but there are not the only feasible solution. Other technologies such as flywheels and ultracapacitors have been used for frequency regulation to some extent.

To evaluate the capabilities of such power intensive storage systems as a security tool for the system operator, several R&D initiatives are undergoing.

OSMOSE and ALISIOS projects, REE initiatives, will address specific needs identified in Lanzarote-Fuerteventura and Tenerife systems respectively. In the first case, a hybrid STATCOM, ultracapacitor, battery energy storage system is intended to solve, among others, a voltage problem identified at Lanzarote-Fuerteventura system. In the second case, a storage facility is being designed to cope with large RES ramps expected to be present at Tenerife system in the mid-term.

The results of those projects, which are in their early stages, will complement the experienced gained with the first energy storage device connected to the transmission network at the canaries, a 1.6 MW flywheel that REE put into operation at Lanzarote-Fuerteventura system in August 2014 [8], which has provided valuable feedback during more than 30 incidents where it actuated.

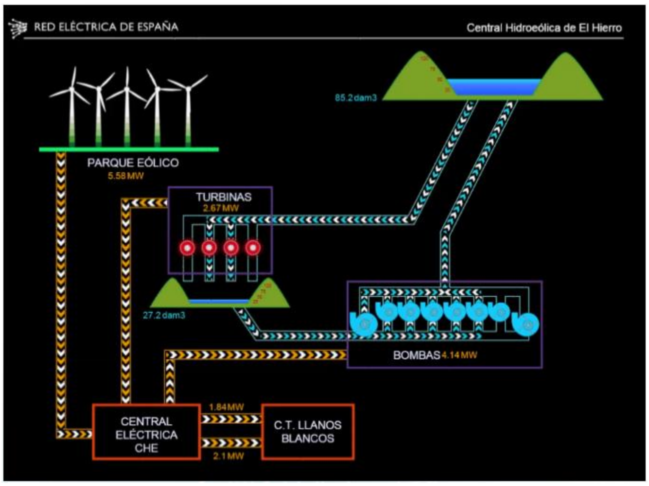

Figure 7. An schematic view of Central Hidroeólica de El Hierro

E. *Smart grids tools*

As it has been described throughout this paper, the presented tools will be key to cover the different challenges that arise in the transition to the new energy model, but an extra integration effort will be needed: going a step further involves efficiently coordinating those tools and activities, with the aim of achieving the expected results in terms of RES integration and system security, at an optimum use of resources. In such a coordination, tools developed under the smarts grid umbrella will play a significant role.

A path have already been walked to some extent, as automation software tools have been developed to serve as an aid to the system operator in the high RES penetration scenario of El Hierro [9].

Further software developments are planned within the scope of the storage R&D projects underway, in order to coordinate joint operation of different technologies and its integration into the existing IT infrastructure.

The accuracy of RES generation prediction tools will also became critical, as margin to react will get narrower in terms of time, so that precise input data is a key element to enrich the decision process.

The above mentioned are three examples on how the availability of smart grid tools will be a must, however, there is a long road ahead, as the complexity and dimensions of the whole activities that embrace this new energy model will require from constant analysis and identification of new automation and coordination needs.

V. Conclusion

A transition to a new energy model is in its way at the Canary Islands. This movement is mainly based on the development of renewables, by means of the construction of a significantly large number of wind and photovoltaic plants all over the archipelago.

This future scenario, were non-controllable renewable generation displaces a number of traditional thermal units currently operating at the power plants, will lead to several challenges for the TSO, as the resulting electrical system will be both more unstable and unpredictable, at the time it will suffer from scarcities in relation to natural inertial response capabilities.

A number of solutions have been put into place in order to guarantee power of supply at the time RES penetration increases. Those actuations involve the development of the network to facilitate RES access to the grid, as well as the provisioning of a set of tools for the system operator. Those tools cover a wide range of needs, ranging from large scale energy storage to avoid curtailments and store energy surplus, to small hybrid storage solutions and software developments that will help to face sudden system events with the necessary guarantee.

Work is under way on each and every aspect of the plan, however we are at a very early stage in this transition process, and there is still a long road ahead.

Only a strong commitment along the coming years from the implied parties: authorities, the different energy sector actors, and the TSO, will lead to the foreseen future energy model of the Canary Islands.

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