TEST AND OPERATION OF A HYBRID MICROGRID IN THE FRENCH ISLAND OF SEIN

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ABSTRACT

Eight kilometers off the French west coast, Sein Island is a small territory with its own electrical system, totally disconnected from the mainland. Until last year, diesel generators covered almost 100% of the electric load, resulting in a high kWh cost and high greenhouse gas emissions. In 2017, "Electricité De France", with the help of other partners such as local communities and renewables projects developers, set a target of a new electrical system based on renewable energies and a storage system. 90kWp of photovoltaic modules were installed at the same time with a 180kWh/200kW Li-ion energy storage system. This new energy mix involves a complete change in the grid operation and its control. The present paper details two major stages of the microgrid development: first, a test sequence aimed to validate the dynamic behaviour of the energy storage system on the grid; second, a synthesis of the first few months of operation.

INTRODUCTION

Eight kilometers off the French west coast, Sein Island is a small territory with its own electrical system, totally disconnected from the mainland. This type of isolated electrical network is known as a Non-Interconnected Area (NIA) or in French 'Zone Non Interconnectée' (ZNI). During winter, the number of permanent inhabitants doesn't exceed 200 and the average power is around 160 kW over a full year. Energy transition has long been a major issue in Sein Island. Until mid-2017, the energy needs were covered almost exclusively by one fuel-oil thermal power plant. In addition to significant greenhouse gas emissions, the electricity generation cost was very high estimated to 250€/MWh in 2014 [1]. To start the energy transition, since 2007, multiple actions managed by lots of different partners (local communities, ADEME, SDEF, ENEDIS, EDF, *etc.*), are in progress. In particular, Sein Island was the first French municipality to be fully equipped with LED public lighting, resulting in a 80% decrease in public lighting consumption. In 2016, the French department of environment and energy transition set some very ambitious objectives for all Non-Interconnected Areas (NIA): renewables shall cover 100% of the electricity needed by 2030, with an intermediary target of 50% in 2023, making this territory a pioneer and a reference for the rest of the French electrical systems.

However, in such a small microgrid, the combination of the renewable energy intermittency and rapid load fluctuation is a real challenge to the stability of the system and makes renewables integration difficult. In such conditions, an electrical energy storage system (ESS) is essential to provide flexibility in order to match power generation with consumption at every single moment.

In summer 2017, 75kWp of photovoltaic (PV) were connected to the grid (SDEF), in addition to an already existing 9kWp PV rooftop (SDEF) and a building self-consuming its own PV and wind generation (Finistère Habitat). This new architecture based on distributed energy resources involves a complete change in the operation and the control of the microgrid. To inject this renewable generation into the grid while maintaining quality of supply and grid safety, 'Electricité De France' (EDF) installed a 180 kWh/200 kW Li-ion Energy Storage System (ESS). Besides, an intelligent Energy Management System (EMS) was developed to control all the generation and storage assets: the ESS, the PV units and the diesel generators (gensets). More renewable systems, like wind turbines, are expected on the island to fulfill the 2030 100% renewables energy goal.

One of the most important features is that the grid can be formed either by the gensets or the ESS. In the second configuration, the gensets are turned off and the ESS forms the grid and is responsible of its stability. This islanding ability allows the microgrid to operate a couple of hours a day with diesels turned off. To make sure that a power electronics based system would work properly on the grid, the ESS was first tested in the "Concept Grid", one of EDF's smartgrid test platforms.

This successful experimentation was helpful for securing the installation and the operation of the ESS in the microgrid. In the current situation, diesel generation is still dominant compared to PV. The ESS is used to minimize renewable curtailment, minimize fuel consumption and support the gensets aiming to optimizing their efficiency.

The first section of the document is dedicated to the sizing analysis of the storage system, necessary for a good comprehension of the overall paper. Then the details of the test sequence are exposed. In the last part of the paper, we discuss the first operational results.

1. SIZING ANALYSIS

The ESS is the keystone of the microgrid. Understanding its role and how it has been sized is key to grasp the operation of the overall system. The sizing analysis has already been detailed in a previous paper, "Energy storage systems (ESS) and microgrids in Brittany Islands" [2]; the main lines are indicated below.

The need for islanding ability, which in this case means powering the grid only through renewables and storage system, dictates the sizing of the power part of the ESS. With around 200 permanent inhabitants and a maximum of 1500 tourists, the electrical load is 160kW on average and varies all over the year between 50kW and 500kW (figure 1; freely accessible data at https://opendata-iles-ponant.edf.fr/pages/home/). In the case of islanding, the ESS shall ensure the security of power supply: if a renewable unit fails down, the ESS shall provide enough power to maintain the balance of supply and demand. Therefore, islanding is authorized only when the electrical load is below 90% of the maximum power that the ESS can deliver at any moment. Based on this load profile and on these electrical security rules, a power rating of 200kW was chosen for the ESS. Furthermore, the chosen inverter is equipped with overload capability for a few seconds, which allows covering load spikes, waiting for the gensets to take over. This sizing enables many islandings all year long, which are key to renewable energy insertion, as discussed in section 3.

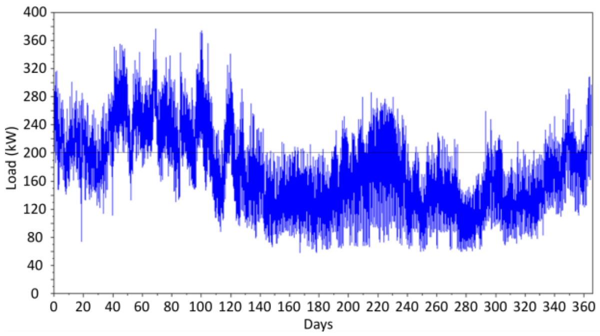

Figure 1 - Annual electrical load

Regarding the sizing of the energy part of the ESS, it is mainly driven by renewable energy insertion targets. The ESS shall enable a rate of 50% renewables in the medium term, with a 250kW wind turbine and a total of 150kW PV. Simulations showed that an energy capacity of 100kWh for the ESS is enough to reach this target. EDF finally chose a 180kWh battery on the market, an energy capacity which allows having sufficient margin at end of battery life.

2. REAL-SCALE TESTING

Prior to installation on the grid, the ESS was tested at Concept Grid, EDF. It helped to validate the dynamic behaviour of the power electronics on the grid: the operator needed to make sure that the performance of the ESS in grid forming mode are at least as good as the performance of the diesel plant, and that the ESS would always guarantee the electrical security of supply.

The entire architecture of the island's grid (Figure 2) was reconstituted in the real scale testing platform. In particular, we were able to check the capability of the battery inverter to magnetize two transformers in a row (a step-up transformer for the connection to the medium-voltage grid, and a step-down to feed the low-voltage loads), by implementing a simple voltage ramp.

One of the main advantages of Concept Grid is its ability to perform short-circuits of all kinds at any place on the grid. We could therefore observe the behaviour of the ESS when a fault arises, which is a major point of concern: unlike synchronous machines, an inverter has a relatively limited contribution to current faults. For that reason, before considering relying entirely on the ESS, it is essential to validate that the protection plan is fully efficient and selective.

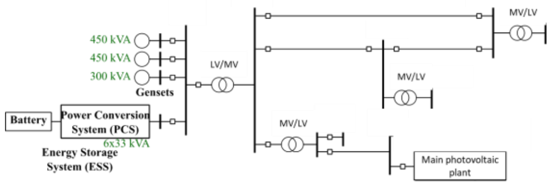

Figure 2 - Single Line Diagram of the island's grid

An interesting output of this test sequence was the measurement of frequency. We could compare, on the same load profile, the quality of frequency when the grid is formed by the gensets or by the ESS (Figure 3). The load curve used for this test was taken from measurements of active and reactive power in the island before the installation of the ESS. A sequence of 20 minutes with strong frequency variations was chosen and played with the ESS at Concept Grid which was operated in grid forming mode, at a step of 40ms so that we could grasp all frequency fluctuations. We showed that the frequency is more stable when the grid is generated by the ESS than by the gensets. Nevertheless, the local distribution grid code is fulfilled with both power sources.

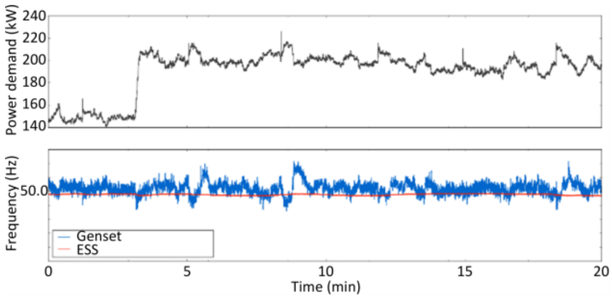

***Figure 3** - Comparison of the quality of frequency generated by the gensets* and *the ESS*

This difference in frequency stability is visible in operation today. Figure 4 shows a sequence in which the gensets were turned off, then the ESS takes over and generate both voltage and frequency of the grid.

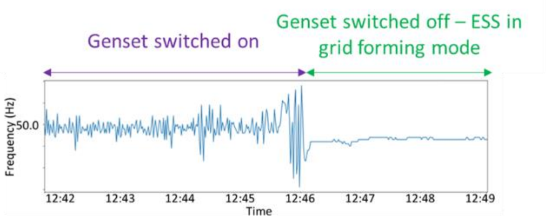

Figure 4 - Stability of frequency in operation

The quality of voltage was also measured during the tests at Concept Grid. Again, the local distribution grid code is fulfilled with both power sources but voltage and current showed lower harmonic distortion with the ESS than with the gensets.

3. SYNTHESIS OF THE FIRST FEW MONTHS OF OPERATION

Working principles

An energy management system was installed on the microgrid together with the ESS to centrally dispatch the distributed energy resources. Taking as input the measurements of power generation of all units, the EMS computes and sends active and reactive power setpoints to the ESS, power generation authorizations to the PV units, and start and stop orders to the gensets.

The main objective of the EMS control is to use the ESS to integrate as many renewables as possible on the grid and to lower the fuel consumption. In practice, this means controlling the ESS according to the gensets' constraints. Indeed, the renewable generation is curtailed when the production is so high that it would make the gensets work at very low power, a condition in which they might be damaged. Setting as a target for the ESS to maintain the gensets in an optimal power range will automatically serve to inject renewables on the grid: the ESS will absorb all excess PV within its energy capacity.

Three gensets are used in Sein Island, two 240kW and one 360kW power rated. Thanks to the ESS, the operator can avoid running them below 30% of their nominal power: when the difference between the load and the renewables is lower than 72kW, the ESS charges, maintaining the genset in proper working conditions.
In situations where the renewable production is high or the load is low, this logic can lead the ESS to saturate quickly stopping the possibility of absorbing excess renewables or maintaining the gensets in good operating conditions. In this case, the EMS will automatically turn the gensets off and pass the ESS in islanding mode without any interruption. Figure 5 shows such a sequence: the genset (in green) stops and the ESS (in blue) takes over while maintaining the continuity of supply. The ESS is then responsible for generating the voltage and frequency of the grid and for balancing the electrical generation and consumption. During the islanding sequence, the PV generation (in purple and in brown) is injected on the grid without curtailment.

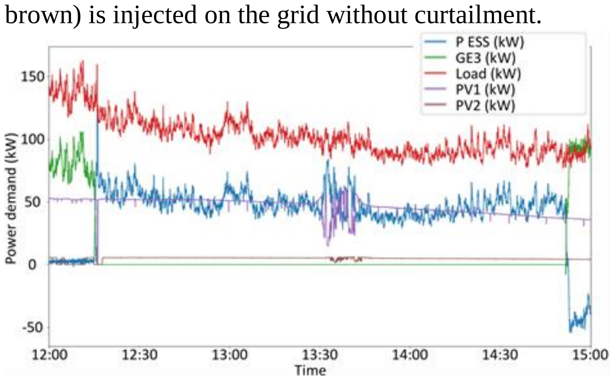

Figure 5 - Islanding mode of the ESS

With the current renewables installations, the system can operate without diesel up to 5 hours a day. This combination of charging to absorb all renewables and then entering an islanding mode enables great rates of renewable insertion. It also cuts the greenhouse gas emissions a few hours a day. The success of these islanding phases prove the technical feasibility of operating the grid without diesel, which is the ultimate goal of this project.

The ESS is used as well to provide support to the gensets at high power. During a load peak, the ESS will discharge, avoiding to start another genset. In most cases, the peak intensity and duration are low enough to avoid discharging the ESS entirely. Thanks to this functionality, the number of gensets' starts was dramatically reduced, as we can see on Figure 6. The majority of starts after June accounts for islanding sequences. Minimizing the number of starts is highly valuable as it avoids stress on the gensets.

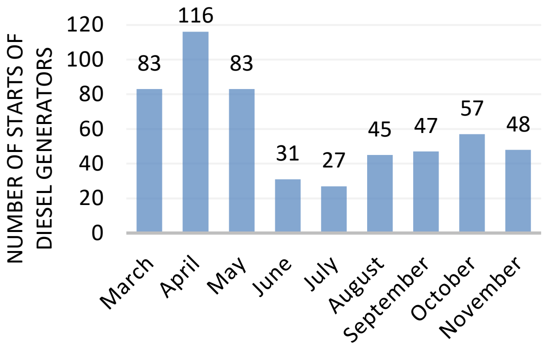

Figure 6 - Number of starts of diesel generators for each month (2017)

Operation of the ESS

During the first months of operation, the ESS performed on average 0.6 full equivalent cycles per day. This value is highly variable according to the period of year (Figure 8), mainly because of the renewable generation pattern. The ESS was intensively used in October due to numerous islanding sequences. During winter, the ESS mainly performs genset support during load peaks; it is therefore less used than in the summertime when PV generation is high.

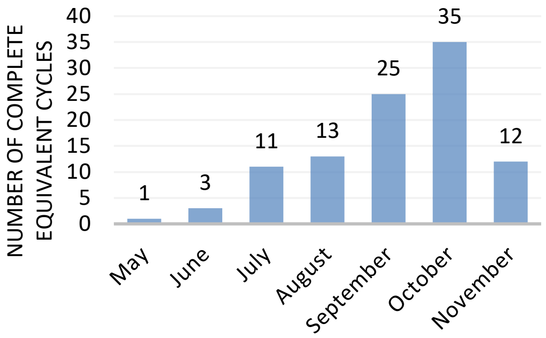

Figure 7 - Number of complete equivalent cycles per month (2017)

Synthesis of the energy mix

Since summer 2017 and the commissioning of the different equipment, the share of renewables in the electricity generation mix is comprised between 5 and 10%. Now that the architecture and the control strategy were successfully validated with satisfying operational results, we are confident that we can reach the 50% target by 2023 when more renewables are installed.

CONCLUSION

The first months of operation of Sein Island's microgrid proved the feasibility and the success of the project. The sizing chosen for the ESS at the early stages of the project turned out to be appropriate for both today's needs and tomorrow's challenges. In the current situation, the ESS can efficiently integrate the renewable generation on the grid, with almost no curtailment, while providing a highly valuable support to the diesel generators. The gensets run in better conditions, resulting in less stress and reduced greenhouse gas emissions.

The test sequence at EDF's test platform Concept Grid enabled a better understanding of the dynamic behaviour of the ESS, essential for a proper installation and operation on the grid.

The technical feasibility of operating the grid without diesel is now proven; the microgrid is ready to welcome more renewables to successively reach the renewable insertion targets of 50% and 100% by 2030. In addition, to help reaching this goal, actions regarding the load management by the EMS is under investigation.

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