ENERGY STORAGE SYSTEMS (ESS) AND MICROGRIDS IN BRITTANY ISLANDS

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ABSTRACT

Sein Island (French Brittany) has an isolated and autonomous network (Figure 1) that is not connected to the continental electricity grid. From the system operator point of view, the challenge is therefore to ensure, with the highest possible degree of robustness, the quality-of-service required by the French regulatory framework in this territory especially vulnerable to unexpected events such as generation means failures. Currently, power is provided almost solely by Diesel Generators (gensets) resulting in a high kWh cost and greenhouse gas emissions. Raising the share of renewable energies (RE) in the mix could be an interesting way to both limit the electricity generation cost and environmental impact. Thus, 90 kW_c of PV will be installed in the beginning of 2017. However, because of RE intermittency and lack of inertia, and gensets features, the deployment of RE may endanger the stability of the power system. To maintain the security of the grid without curtailing PV, Electricité De France (EDF) has decided to install in 2017 an Energy Storage System (ESS).

Based on the results obtained on a specific simulation tool developed at EDF R&D, presented in this paper, the control algorithms were elaborated and the associated sizing of the ESS was determined. In particular, the interest was shown, in certain conditions of PV generation and consumption, of completely switching off the gensets and therefore operating the grid solely with the PV and the ESS. The associated issues especially in terms of (i) operation of the ESS Power Conversion System (PCS) and (ii) protection plan are discussed.

As a prospect, these different elements will be validated experimentally, before being installed in Sein Island, by being tested on our EDF R&D facility of Concept Grid [1].

INTRODUCTION

In France, the Energy transition law of 2015 have set objectives for Renewable Energy (RE) development. One of the key objectives of this law is to reduce dependency on fossils fuels, and to prevent global warming by reducing greenhouse gas emissions. French homeland electricity generation is essentially based on nuclear (76.3 %) and hydroelectric (10.8 %) power plants [2]. However, the French territory includes several other areas which are not connected to the continent. Hence, there are several French “electric islands”, including:

- The oversea departments and Corsica, with an associated power capacity greater than 100 MW;
- Some of the Brittany islands, with capacities closer to a few hundred kilowatt; thus, they can be considered as microgrids. There are also microgrids in the internal area of French Guyana.

In these territories, electricity is typically generated from oil energy. This energy vector, in addition of generating greenhouse gases, is expensive and subject to high price volatility. For these reasons, an ambitious objective has been set for these islands: 50% of RE by 2023 and 100% by 2030.

The major issue associated to this goal is the RE intermittency. Unlike the continental network, a microgrid, such as a small island, has no resiliency to supply/demand equilibrium variations. To reach such a high intermittent energies penetration, it is then mandatory to use an Energy Storage System (ESS) coupled with an Energy Management System (EMS).

This paper focuses on one of these microgrids: Sein Island where such a system will be implemented in 2017.

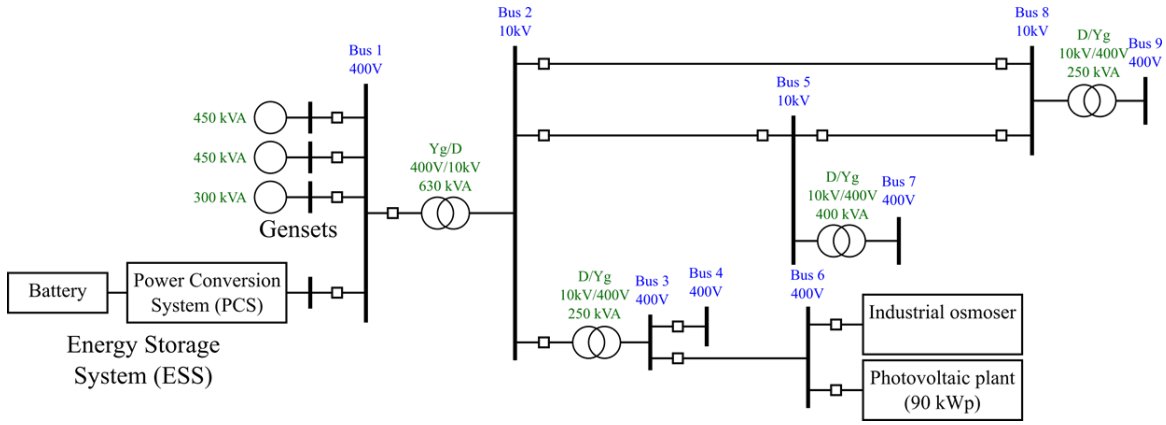

Figure 1 : Single line diagram of Sein Island

SEIN ELECTRICAL GRID

Sein Island is located in the Atlantic Ocean, at 8 km of the continent without any electrical connection to the continental grid. The territory is 0,58 km², and the permanent population is about 100 inhabitants.

In most situations, microgrids can be connected to a continental distribution network or islanded. Once a microgrid is connected to a grid, it can exchange active and reactive power with the main grid. The supply/demand equilibrium is not necessary at all times.

In the case of Sein Island, the microgrid is totally isolated from the French main grid, therefore the whole generation has to be consumed locally and the supply/demand equilibrium is necessary at each moment.

During the summer, tourism can increase the island population up to 1500 persons. During the winter, the electrical heating and water heating strongly increases the electrical load. In addition, the freshwater is produced locally by an osmoser whose operation is intermittent. These particularities lead to large variations of the electrical load over time, a real challenge for the electric system operator. It varies between 50 kW and 450 kW (Figure 2), with an average value of 170 kW.

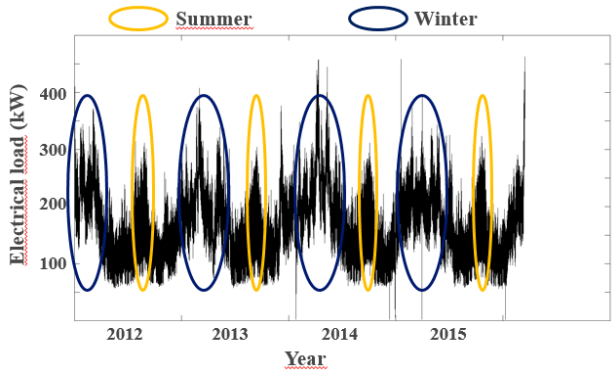

Figure 2 : Variations of the electrical load, 2012-2015

Until now, the electricity is almost exclusively generated by three gensets, with a total 1050 kVA power. Depending on the electrical load, one or two gensets can be operated at the same time and generate the electrical network. When the electrical load is low, typically less than 70 kW, the main genset is forced to operate under 30 % of its nominal power. These conditions generate bore glazing which degrades the gensets efficiency and has impact on lifetime and safety [3].

As a start, 90 kW_c of PV will be installed in 2017. When PV arrays are added, they mainly produce electricity in the middle of the day, mostly in warmer periods, when electrical load is low resulting either in increasing the glazing phenomenon of the gensets, or PV curtailment. Furthermore, the addition of intermittent energies requires a reserve of power to be able to maintain permanently the power supply/demand balance.

Consequently, an ESS is required at Sein Island to achieve the energetic transition. The goal of this ESS is both to:

- negate renewables curtailment ;
- and to optimize the functioning of the gensets, *e.g.*, reducing the fuel consumption, the number of starts and stops and improving their lifetime,

while maintaining quality of electricity supply and grid safety. The operation of this ESS requires an Energy Management System (EMS) to be installed as well, mostly to ensure communication and control of the power generated by the distributed energies. The control algorithms of this EMS, and the sizing of the ESS were optimized by modelling the electrical network of Sein Island using Matlab-Simulink.

THE NEW MICROGRID DESIGN

Description of the Matlab-Simulink model

A model of the microgrid was developed by EDF R&D on Matlab-Simulink software. This model is made of distinct modular blocs for the gensets, the RE, the ESS and the EMS (Figure 3).

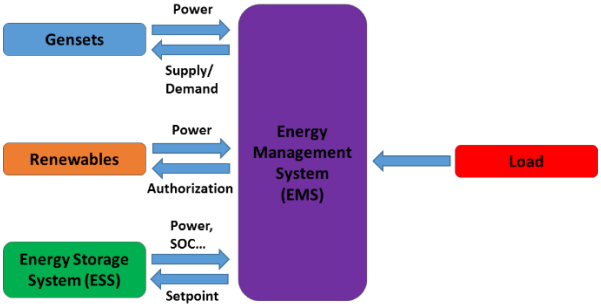

Figure 3 : Scheme of the Matlab-Simulink model

In this model, the supply/demand equilibrium is calculated at every time step. The EMS decides an optimum in terms of ESS set point, renewables curtailment and gensets starting. This model was tested to simulate the current electrical grid of Sein Island. The results were well aligned with reality, particularly in terms of fuel consumption with a disparity under 5%. After this validation, simulations were carried out to develop and optimize the control algorithms of the EMS. The model was used for the sizing of the ESS as well.

Input data

The input of the model are active power data. The typical time step is 10 minutes. The input vectors are:

- The electrical active power load. The data come from on-site measurements made from 2012 to 2015;
- The PV producible (Figure 4). It is estimated from operating PV arrays at Saint Nicolas des Glénan, another Brittany Island located at 80 km from Sein island.

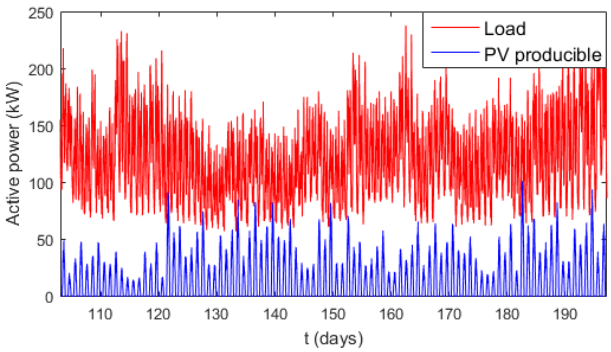

Figure 4 : Determination of the PV producible

Other parameters include battery capacity and efficiency, inverter efficiency, self-discharge and nominal charge/discharge power for the ESS, as well as fuel consumption and nominal power for the gensets.

EMS optimization

The control laws of the EMS aims at:

- Avoiding renewables curtailment;
- Injecting renewables into the grid without degrading the gensets by bore glazing;
- Optimizing the operation of the gensets in terms of operating power range, fuel consumption and number of starts/stops;
- Operating safely the ESS and maximizing its lifetime;
- Ensuring the security and quality of the electrical supply, especially when the genset are switched off and the ESS inverter is used as voltage source (V/f mode, detailed hereafter).

Some non-exhaustive examples of the use of the ESS are explained below.

First, the start and stop will degrade the gensets and increase maintenance costs [4]. This can be avoided by discharging the ESS when the electrical load increases (Figure 5).

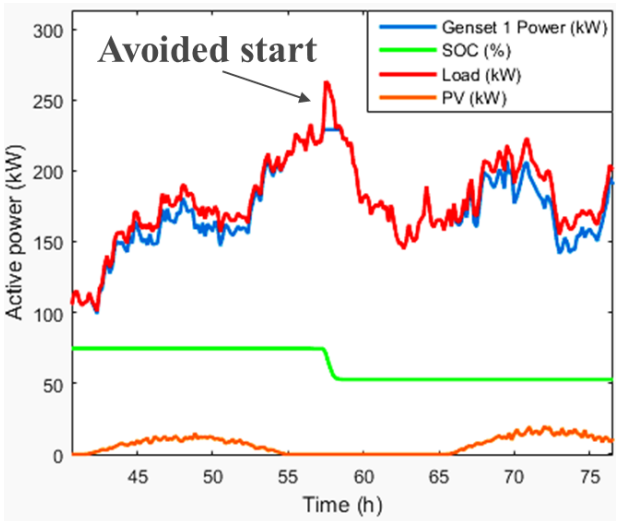

Figure 5 : Avoided genset start by discharging the ESS

When the part of RE injected into the grid increases, and the electrical load is low, the genset may operate below 30 % of its nominal power. To avoid this situation and the bore glazing phenomenon, the ESS is first charged to maintain the genset at 30 % of its nominal power. When the State of Charge (SoC) of the battery reaches 100%, the genset stops. The network is then only generated by the ESS inverter (Figure 6). It is important to note that in this mode, the ESS can both charge or discharge, depending on the renewable producible and the electrical load.

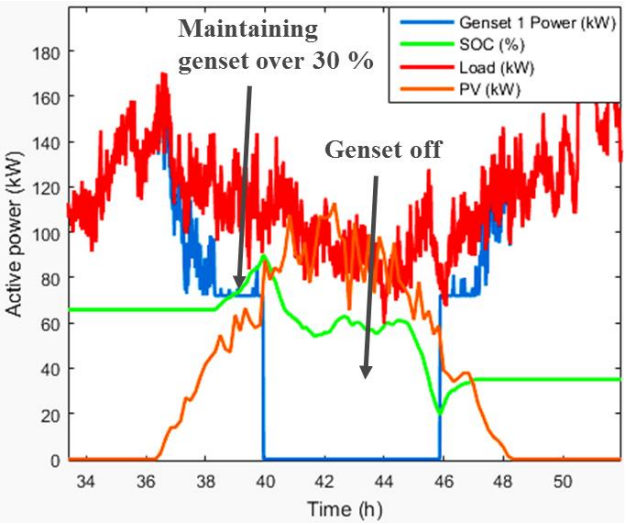

Figure 6 : The genset is maintained over 30 % and then stopped when the ESS SOC is near 100%.

Sizing optimization

Once the control laws were properly defined, the Matlab-Simulink model allowed to define the size required to allows a good penetration of RE on Sein Island. The system was optimized both in terms of power and in terms of energy (Figure 7).

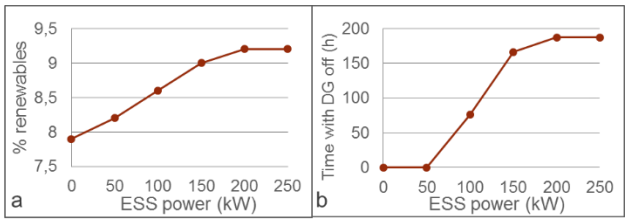

Figure 7 : Power sizing of a 100 kWh ESS, for 150 kW_c of PV installed. a) Effect on the % of renewable energies on the electrical mix. b) Effect on the time spent per year with the gensets off.

For a 200 kW system, the energy has only little impact on the percentage of renewables injected into the grid (Figure 8.a). However, the energy sizing of the ESS has a strong impact on the number of gensets starts and stops (Figure 8.b). This impact can be explained because the ESS can only sustain the network for a shorter duration before the genset need to be restarted.

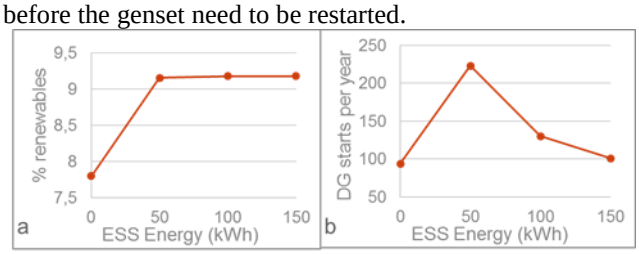

Figure 8 : Energy sizing of a 200 kW ESS, for 150 kW_c of PV installed. a) Effect on the % of RE on the electrical mix. b) Effect on the number of genset starts per year.

ESS INVERTER CONTROL METHODS

As explained, the ESS has to behave as decided by the EMS, and especially:

- in parallel with at least one genset;
- stand alone, as voltage source;

Therefore, three types of Power Conversion System (PCS) control are suitable for different operating conditions of a microgrid: P/Q control, V/f control and droop control.

P/Q control

This control maintains a constant exchange of active and reactive power at a given reference value, assuming that the frequency and voltage are being regulated by another source.

V/f control

The goal of the V/f control is to regulate independently the voltage and the frequency at a respectively given reference values. The V/f control is usually used when the gensets are off.

Droop control

The main objective of the droop control is to adjust the active and the reactive power based on a local measurement of frequency and voltage. This type of control allows the generation and storage units to contribute to the re-establishment of the grid stability. If frequency is decreased, the PCS will increase the active power output to maintain the frequency within acceptable range. Otherwise, the PCS will decrease its active power output. In a similar manner, the reactive power is adapted to maintain voltage within an acceptable range.

PROTECTION PLAN

The protection plan of the network (Figure 1) includes the protection of the HV and LV feeders, and of the individual LV customers. This section focuses only on LV overcurrent protections. When at least one genset is on, the short circuit power is sufficient to ensure the operation of each of the protections, *i. e.*:

- fuses of the LV feeders;
- fuses and breakers of individual LV customers.

In addition, faults are quickly eliminated and the voltage dips they cause are limited.

When the ESS is used as a voltage source without any genset, it has to be verified that the short circuit (SC) current is important enough to activate the protection and that each generator can ride through the voltage sag.

Calculation of short-circuit currents

An inverter-based source such as the ESS does not behave as a rotating machine and its control is not standardized. Its fault behavior is largely determined by its control and protections [5] [6].

SC calculation methods such as the standard CEI 60909 [7] are not directly applicable.

Then, the SC currents were calculated using the software EMTP. A simulation model of the ESS has been developed. Its control includes a current limiting functionality. In 2017 the results will be compared to experiments to validate the model, as the individual designers have their own preferences on how to operate the inverter under fault circumstances and then design the control.

It should be noticed that the zero sequence impedance of the networks and of the transformers has a strong influence on the value of phase to neutral SC. In addition, the negative sequence behaviour of the inverter has a strong influence on the value of unbalanced SC.

Definition of protection plan

The simulation, which will be validated by tests, has shown that the protection of the LV customers will be activated. The SC current is big enough to trip breakers and melt fuse within the time recommended by the standards.

On the other hand, the ESS cannot ensure the protection of the LV feeders for certain types of faults. Indeed:

- a fault can cause voltage dips on the entire network, which can disconnect the ESS;
- the SC current may be smaller compared to the situation when the grid is feeded by a genset, and then may not be enough to melt the fuse.

Then, to protect the LV feeders, they will be equipped with time overcurrent relays that will be coordinated with the protections of the individual LV customers and with the Fault Ride Through capability of the ESS and the solar inverters.

CONCLUSIONS

A model of microgrid including gensets, REand an ESS, controlled by an EMS, has been developed on the Matlab-Simulink software. It is based on supply/demand of active power at every timestep. This modelling allows to i) validate and optimize the command laws of the EMS and ii) determine the optimal sizing of the ESS. This model has been applied to the Sein Island in French Brittany. The command laws of the EMS, coupled with the ESS, allowed to completely negate the curtailment of renewable energies for the projected 90 kW_c of PV, and the other RE projects coming in 2017. Furthermore, an improvement of the security and quality of electric supply is expected, as well as a better genset operation, guaranteeing a better efficiency and lowering maintenance and fuel consumption. The model will then be used to simulate the integration of wind turbine and submarine tidal turbine in the Brittany islands. Based on these results, as said previously, EDF decided to install and operate an ESS on Sein Island. This ESS will be fully integrated in this innovative advanced microgrid comprising gensets, RE, and storage and managed by a global EMS. The commissioning on site of the ESS and the EMS is scheduled for mid-2017; before this date, these components and their interaction will be tested at Concept Grid, a R&D fully controllable experimental facility [1], beginning of 2017.

Acknowledgments

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REFERENCES

[1] L. Fabien, «Primary Frequency Control by Using a 1 MW Battery : Study at Grid Scale on the Concept Grid EDF Platform,» *CIRED paper 0775*, Lyon, 2015.

[2] EDF, 2015. Available: www.edf.com.

[3] A. Gondal, «Bore polish,» *Materials Science and Technology*, vol. 14, n° %11, 1998.

[4] B. Multon, «Ressources énergétiques et solutions pour l'alimentation en électricité des populations isolées,» *Electrotechnique du Futur*, Belfort, 2011.

[5] Y. Pan, «Impact of inverter interfaced distributed generation on overcurrent protection in distribution systems,» *IEEE Power Engineering and Automation Conference*, 2011.

[6] N. Nimpitiwan, «Fault Current Contribution From Synchronous Machine and Inverter Based Distributed Generators,» *IEEE Transactions on Power Delivery*, vol. 22, n° %11, 2007.

[7] International Standard IEC 60909, Short-Circuit current in three phase. a.c. systems, 2002.