THE BENEFITS OF LARGE-SCALE ENERGY STORAGE SYSTEMS (ESS) IN FRENCH ISLANDS

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ABSTRACT

This paper presents the benefits obtained with large-scale Energy Storage Systems (ESS) in French islands. We focus on two projects:
- **PEGASE** demonstrator project (territory of la Réunion)

  By (i) setting-up a dedicated information system, (ii) elaborating innovative generation forecast methods, and (iii) developing Energy Management Systems (EMS), we combine successfully a large-scale 1MW battery-type storage system and Renewable Energy (RE) farms in order to smooth an intermittent generation and inject into the grid a controlled power. The efficiency score obtained on dozens of days, close to 90%, for PV and wind smoothing, demonstrates the relevance of the developments carried out during the project;
- “Non-Interconnected Zones (NIZ) Frequency Containment Reserve (FCR) storage” project (territories of Martinique, Guadeloupe, and la Réunion)

We present the interest of using 5MW ESS as FCR in several French islands. The results obtained with dedicated simulation tools developed by EDF R&D show that centralized ESS, installed on dedicated feeders that cannot be shed, efficiently provide power in case of frequency drops. Benefits from a quality of supply and economical point of view are generated. Finally, the possibility of increasing the RE share in the electricity generation mixes is discussed.

I. INTRODUCTION

There are several French “electric islands”, amongst them are the oversea departments and Corsica (with an associated power capacity greater than 100MW) and some of the Brittany islands (with capacities closer to a few hundred kilowatts). These territories, also called Non-Interconnected Zones (NIZ), have isolated grids that are not connected to the continental electricity network.

From the system operator point of view, the challenge is therefore to ensure the quality-of-service required by the French regulatory framework in these areas especially vulnerable to unexpected events such as generation means failures. The associated electricity mixes are largely based on thermal facilities resulting in high kWh cost and greenhouse gas emissions. In order to reduce the electricity generation cost as well as its environmental impact, Electricité De France, which manages the NIZ electric power systems, has been thoroughly investigating the interest of using Energy Storage Systems (ESS) for several years. In this paper, we present two projects involving large-scale ESS with different use cases:

- “PEGASE” demonstrator project which aims at demonstrating the possibility of smoothing a Renewable Energy (RE) generation by using a 1MW sodium-sulfur (NaS) ESS on the territory of la Réunion island (near Madagascar);
- “NIZ Frequency Containment Reserve (FCR) storage” project which has the goal of installing and operating in Martinique, Guadeloupe (both located in the West Indies), and la Réunion three 5MW Li-ion ESS to support grid frequency and thus contribute to maintain the electricity generation – consumption balance.

II. “PEGASE” DEMONSTRATOR PROJECT

Thanks to the current decrease of the cost of photovoltaic (PV) and wind generation, raising the share of these renewable energies (RE) in the mix could be an interesting way to both limit the electricity generation cost and environmental impact. Thus, in the recent years, wind and PV capacities have quickly grown in French NIZ. However, because of their intermittency, their behavior during network faults and lack of inertia, the rapid and massive deployment of these energies endangers the stability of the grid. To maintain the security of the power system while enabling the development of wind and PV energies, Electricité De France (EDF), Météo France and the Laboratoire de Météorologie Dynamique – Ecole Polytechnique, thanks to the financial support of the Agence De l’Environnement et de la Maîtrise de l’Energie (ADEME), launched, in 2011, the PEGASE demonstration project on la Réunion island. The aim of this project is to combine PV/wind farms with a large-scale energy storage system in order to smooth the intermittent generation and inject into the grid a
controlled power. In particular, “PEGASE” requires (i) the setting up of a dedicated information system, (ii) the elaboration of new generation forecast methods, and (iii) the development of innovative controllers, or Energy Management Systems (EMS), to manage the different systems involved (Figure 1).

**Figure 1. Building blocks of the coordinated system “PEGASE”**

**Experimental section**

The following section describes the different blocks represented Figure 1.

**PV and wind farms**

During the “PEGASE” project, 3 RE farms were involved (Figure 2):
- PV farm of La Star (peak power: 2MW; operator: ALBIOMA);
- PV farm of La Roseraye (peak power: 10MW; operator: EDF EN);
- Wind farm of La Perrière (peak power: 11MW; operator: QUADRAN).

**Storage system**

The storage system used in “PEGASE” is a large-scale sodium-sulphur (or NaS) battery manufactured by NGK®. This system, installed in 2009, is connected to the grid at Saint-André substation (Figure 2). The total energy of the battery is 7.2MWh for a maximum power of 1MW in discharge and 1.2MW in charge.

**Generation forecast methods**

During “PEGASE”, specific studies were carried out to forecast PV and wind generation. The collection and deep analyses of several years of data allowed us to:
- Better understand the clouds formation/movement on la Réunion island;
- Adapt the METEO FRANCE AROME meteorological model to la Réunion island;
- Develop generation forecast methods based on satellite images;
- Combine several generation forecast methods and optimize the weight of each method depending on the time horizon;
- Develop specific operational tools to forecast RE generation in la Réunion island (Figure 3).

**Figure 3. Example of a day from PVSCOPE – operational tool developed during the “PEGASE” project to forecast PV generation**

**Power profile specification**

The power profile specifications we used during the “PEGASE” project come from calls for tenders emitted by the French ERC (Energy Regulation Committee). As an example, concerning the PV profile, the profile is made of three steps:
- Ramp-up step: the injected power needs to increase or remain stable (1);
- Constant power step: power level ≤ 40% P_{peak} (2);
- Ramp-down step: the injected power needs to decrease or remain stable (3);

This profile comes with (i) mandatory notifications to the power system operator (1 hr before the end of the ramp-up phase and 1hr before the beginning of the ramp-down phase) and (ii) financial penalties if:
- Ramping rates are out of the limits during steps (1) and (3): 0% P_{peak-min} \leq |rate| \leq 0,6% P_{peak-min}^{-1}
- During the constant power phase (2), the injected power must remain inside an interval around the power level +/- 2.5% of P_{peak}.

**Information System**

A dedicated information system was set up during the project to:
- Collect the data from (i) the RE farms and (ii) the storage system (power, State Of Charge – SOC);
- Transmit the instructions emitted from the EMS to the different involved systems;
Note that all data (generation, set points, generation forecasts, battery SOC, etc.) are saved: in addition to the real-time management of the systems, it is possible to replay the scenarii and assess the impact of various parameters (for instance the generation forecast method) on the performance of the smoothing.

**Energy Management System (EMS)**

In order to coordinate the RE farms and storage system and inject into the grid a smooth power, two versions of an innovative EMS were developed during the project (for wind and PV), with identical structure but different optimization parameters.

As an example, Figure 4 describes the EMS to smooth PV generation. Its building blocks are:

- **an optimizer**: based on the SOC of the storage system and the generation forecasts, it calculates every 30 min optimized set points for the storage system and the RE inverters;
- **a regulator/controller**: by using the set points computed by the optimizer and taking into account the real-time situation, the controller sends definitive set points to the storage system and the RE inverters every 5 s.

**Figure 4.** Description of the Energy Management System to smooth PV generation.

**Results**

Real-time management of the RE farms and the storage system were carried out over dozens of days. As an example, Figure 5 shows the results obtained for one day in 2015 to smooth the PV generation of *La Roseraye* farm.

**Figure 5.** One day of PV generation smoothing. A positive battery power corresponds to power injected into the grid (thus to a discharge of the storage system) and a negative battery power is associated to power injected from the grid in the storage system (thus to a charge of the battery).

One finds, during this day, the following steps:

- (1) 06:40 → beginning of PV generation;
- (2) 07:02 → power is injected into the grid;
- (3) 07:22 → the storage system is used to maintain a positive rate during the ramp-up step;
- (4) 08:30 → the power of the constant step is reached; the supplemental PV generation is injected into the storage system;
- (5) 11:10 → very strong decrease of PV generation; thus the battery is used to maintain the power;
- (6) 14:00 → beginning of the ramp-down step;
- (7) 15:00 → power stabilization to take advantage of the sun in the afternoon;
- (8) 18:16 → the battery reaches the targeted SOC of 25%.

With $\Delta$SOC referring to the variation of the storage system SOC, efficiency is defined as:

$$Efficiency = \frac{\text{compliant energy injected into the grid} + \Delta \text{SOC}}{\text{Total PV generation}}$$

On this day, efficiency reached almost 95%.

**Conclusions**

During “PEGASE” project, by (i) setting-up a dedicated information system, (ii) elaborating innovative generation forecast methods, and (iii) developing EMS, we combine successfully a large-scale battery-type storage system and RE farms in order to smooth an intermittent generation and inject into the grid a controlled power.

The efficiency score obtained on dozens of days, close to 90%, demonstrates the relevance of the developments carried out during the project. Note that a company called *EDF Store & Forecast* was created to commercialize these tools.

The next step is to connect simultaneously several RE farms to the storage system in order to smooth their combined power fluctuation. The first results are very promising and show that the size of the storage system can be greatly reduced for the same efficiency if several RE farms are connected (vs only one connected farm).

**III. “NIZ FCR STORAGE” PROJECT**

In parallel to RE smoothing, EDF investigates other ways to use storage systems to promote the integration of RE and/or decrease the cost of the electricity generation mix. The “NIZ FCR storage” project, started in 2016, focuses on large-scale centralized ESS. The aim of the project is to install on dedicated feeders and operate, in the most efficient way, in Martinique, Guadeloupe, and La Réunion, three 5MW Li-ion ESS (one system per territory) to support grid frequency and thus contribute to maintain the electricity supply – consumption balance.
Both technical and economical aspects are studied in the project. The first part of the following section describes the technical features of these 5MW Li-ion ESS: the second and the third parts present the expected benefits from a quality of supply and an economical perspective obtained by simulations; finally the possibility of increasing the RE share in the mix is discussed.

**Technical features of the ESS**

In “NIZ FCR storage” project, the ESS will not be used to smooth RE generation; they will provide only an upward FCR service: they follow the static law of primary regulation (Figure 6). Considering the frequency features in Martinique and Guadeloupe, the dead band is set until 49.7 Hz; when the frequency drops below this value because of a generation means failure, the ESS starts to inject power into the grid. If fully charged, they should be able to maintain a discharge power of 5MW during 30 minutes to face two consecutive unit tripings. In addition, the response time of the ESS, which is a critical feature to provide a FCR service, should be below 500 ms. Finally, one must keep in mind that to be efficient, these ESS must not be installed on feeders that can be shed when the grid frequency drops. In “NIZ FCR storage”, the ESS will be installed on dedicated feeders and fully integrated in the global electrical system SCADA in a centralized storage perspective.

![Figure 6](image6.png)

**Figure 6.** Static law of primary regulation implemented in the simulation

**Benefit regarding the quality of supply**

To assess the quality of supply benefit, the ESS model and its control were integrated into a model of Guadeloupe electric power system in order to perform simulations. The parameters of the dynamic responses of the generation units (mainly thermal facilities) are based on on-site measurements. Load frequency auto-adaptation, load and RE shedding, and behavior of RE on frequency dips have been modeled. The ESS model and its control were developed by EDF R&D after several similar R&D or industrial projects.

Figure 7 shows the evolution of the frequency with/without a 5MW Li-ion battery connected to the grid and providing FCR when the frequency drops below 49.7 Hz, after the tripping of a major generation unit. With the 5MW ESS, the grid frequency is maintained over 48.5 Hz (the first load shedding level); without ESS, the FCR provided by the conventional generation units is less reactive: the first load shedding is reached.

![Figure 7](image7.png)

**Figure 7.** Grid frequency and power reserve evolutions and storage response after 30MW tripped (over 140MW of generation)

**Economical value of the ESS**

First, a model to simulate the optimal dispatch for a one-year period with a day-ahead optimization tool looped 365 times was developed. Then, for each of the three territories (Martinique, Guadeloupe, and la Réunion), the program was run with and without considering the insertion of a centralized ESS in the electric system of the island. The ESS use case studied was the provision of upward FCR, and different levels of provision were examined. The results indicate a significant decrease of the cost of the generation dispatch. Indeed, a part of the FCR is carried out by the ESS: the FCR constraint on the conventional generation units is reduced in the unit commitment. As a result, the new generation dispatch shows:

- Less start-ups of generation units which are switched on for the purpose of providing a FCR service;
- A decrease of the energy generated by the combustion turbines; these units present the most expensive generation costs.

Figure 8 shows the evolution of the annual generation dispatch cost (red curve) for different volumes of installed storage. When a certain volume of storage is reached, corresponding to the total FCR, the annual generation dispatch cost stops decreasing. In parallel, the blue curve represents the Net Present Value (NPV) of installing the corresponding volume of storage. It reaches a maximum (Point A); after this value, the NPV decreases and beyond a certain limit (point B), the NPV becomes negative.
As said previously, based on these simulations results, EDF decided to purchase three 5MW ESS dedicated to a FCR service in Martinique, Guadeloupe, and la Réunion. The commissioning is scheduled for beginning of 2018.

**Towards an increase of the RE share in the NIZ electricity generation mixes**

For safety issues, the rate of RE injection into the French grid is permanently limited to 30% of the total generated power. The “NIZ FCR storage” project is part of a larger EDF study which aims to identify the most efficient ways to increase the share of RE in NIZ generation mixes while maintaining quality of supply and grid safety. It appears that coordinated actions conducted by the system operator, the producers, and the regulator are needed to reach that goal.

Those solutions are both technical and regulatory:
- Specifications for the RE inverters: they must remain connected during voltage dips due to HV short-circuit;
- Automatic reconstitution of FCR;
- Modification of the distribution of Distributed RE (DRE) on the different feeders in order to decrease the amount of DRE on the feeders related to the first load shedding steps;

EDF internal studies show that if the solutions listed above are not set, a very large amount of centralized storage will be needed to raise beyond 30% the limitation on instantaneous RE share into the grid.

In addition, other technical aspects still need to be studied in order to integrate more DRE, for example:
- The impact of short circuit power decreases on the protection scheme (modification of thresholds, blinding of protection, improper operation) and on electricity power system stability;
- The voltage plan and reactive power control with less synchronous sources connected to the grid.
- The monitoring of the technical performances of DRE.

**IV. CONCLUSION**

In order to reduce the electricity generation cost as well as its environmental impact, EDF has been thoroughly investigating the interest of using ESS for several years. The results obtained in the PEGASE project demonstrate the possibility of successfully smoothing a RE generation by using a large-scale ESS. The efficiency is greatly improved if several farms are connected to the same ESS. This centralized approach is also crucial to provide a relevant FCR service. The results obtained by simulation show the benefits of using large-scale ESS as FCR both from a quality of supply and economical perspective. Based on the results presented in this paper, EDF decided to purchase and operate as FCR three 5MW ESS in Martinique, Guadeloupe, and la Réunion. The commissioning is scheduled for beginning of 2018.

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