Towards more reliability for renewable energy generation: PEGASE demonstration project in La Réunion island

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ABSTRACT

To maintain the safety of the power system while enabling the development of wind and PV energies, Electricité De France, 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 intermittent generation and inject into the grid a controlled power. In particular, PEGASE required (i) the setting up of a dedicated information system, (ii) the elaboration of new generation forecast methods, and (iii) the development of innovative controllers to manage the different systems involved. At the end of the project, by associating PV/wind farms and storage, we are able to inject into the grid almost 90% of the total PV and wind energy in agreement with the power profile specifications.

INTRODUCTION

La Réunion is one of the France's "electrical islands", *i. e.* the overseas departments and Corsica that have small, isolated grids which are generally not connected with the continental network (these "electrical islands" are also called Non-Interconnected Zones). The associated electricity generation mixes are largely based on thermal facilities resulting in a high kWh cost and greenhouse gas emissions. Thanks in particular 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 on these islands. However, because of their intermittency and lack of inertia, the rapid and massive deployment of these energies may endanger 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, 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. 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).

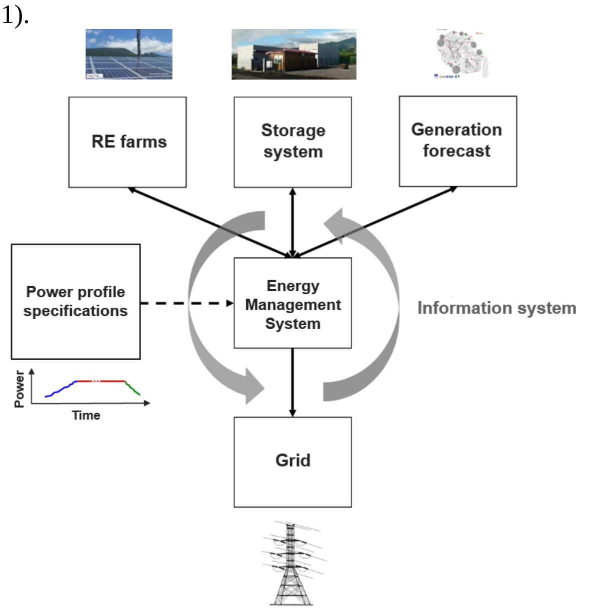

Figure 1. Scheme of the different systems involved in PEGASE

EXPERIMENTAL SECTION

The following section describes the different systems represented Figure 1.

PV and wind farms

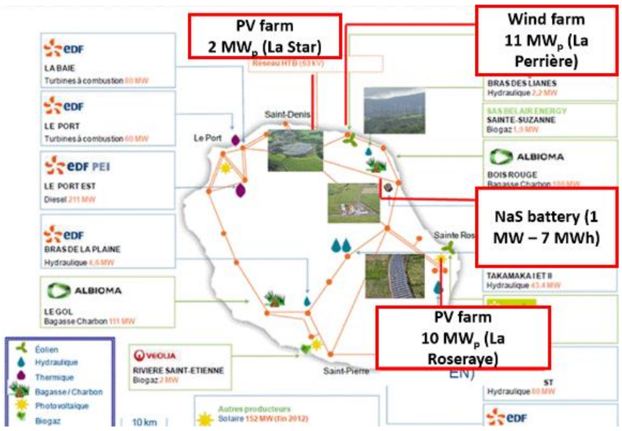

Figure 2. RE farms in the PEGASE project

During the PEGASE project, 3 RE farms were involved:

- PV farm of *La Star* (peak power: 2 MW; operator: ALBIOMA);
- PV farm of *La Roseraye* (peak power: 10 MW; operator: EDF EN);

- Wind farm of *La Perrière* (peak power: 11 MW; operator: QUADRAN).

Storage system

Figure 3. Storage system in the PEGASE project

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. The total energy of the battery is 7.2 MWh for a maximum power of 1 MW in discharge and 1.2 MW in charge.

Generation forecast methods

During PEGASE, specific studies were carried out to forecast RE (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[1,2];
- 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 (Figure 4);

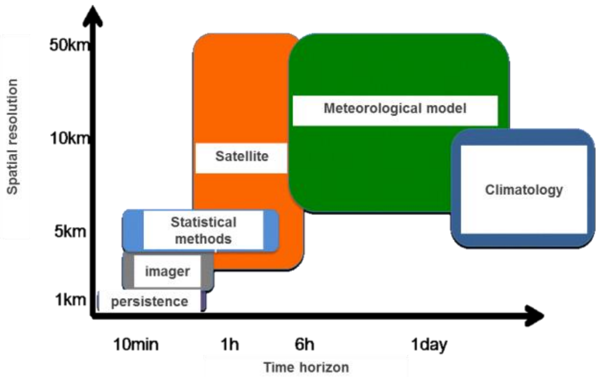

Figure 4. Combination of several generation forecast methods

- Develop specific operational tools to forecast RE generation in La Réunion island (Figure 5).

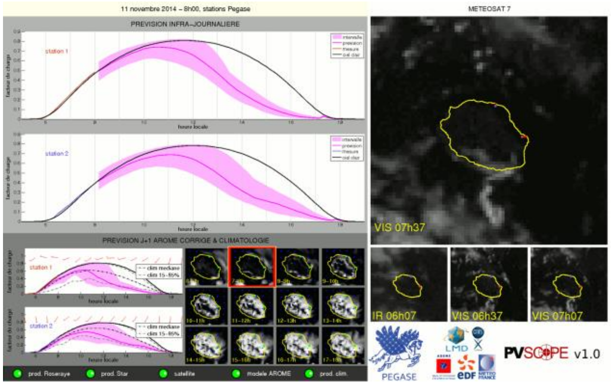

Figure 5. Example of a day from PVSCOPE – operational tool developed during the PEGASE project to forecast PV generation

Power profile specification

The power profile specifications we used during the PEGASE project come from recent calls for tenders emitted by the French ERC (Energy Regulation Committee). As an example, concerning the PV profile (Figure 6), the profile is made of three steps[3]:

- Ramp-up step: the injected power needs to increase or remain stable (**1**);
- Constant power step: power level $\leq$ 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) fines if:

- Ramping rates are out of the limits during steps **(1)** and **(3)**: 0% $P_{peak}.min^{-1} \leq |rate| \leq$ 0,6% $P_{peak}.min^{-1}$
- During the constant power phase **(2)**, the injected power must remained inside an interval around the power level +/- 2.5% of P_{peak};

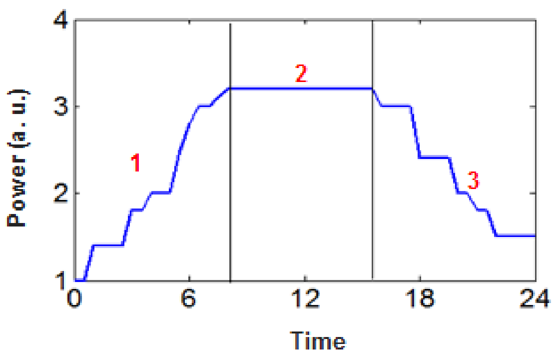

Figure 6. PV power profile specifications

Information System

A dedicated information system was set up during the project. This information system enables, in particular, to:

- Collect the data from (i) the RE farms (PV and wind power) and (ii) the storage system (power, state of charge);
- Transmit the instructions emitted from the Energy Management System (EMS) to the different involved systems;

Note that all data (generation, set points, generation forecasts, battery state of charge, *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)

To manage the different systems (RE farms and storage system) and be able to inject into the grid a smooth power, two specific and innovative EMS were developed during the project (for (i) wind and (ii) PV).
As an example, Figure 7 describes the EMS to smooth PV (the structure is identical for the EMS developed for wind generation smoothing). The PV EMS is made of

- an optimizer: based on the state of charge 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 these optimized set points and taking into account the real-time situation, the controller sends set points to the storage system and the RE inverters every 5 s.

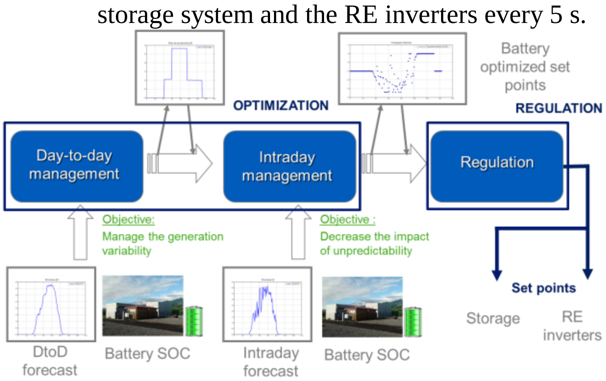

Figure 7. Description of the Energy Management System to smooth PV generation.

RESULTS

Real-time management of the RE farms and the storage system were carried out over dozens of days. As an example, Figure 8 shows the results obtained for one day in 2015 to smooth the PV generation of *La Roseraye* farm.

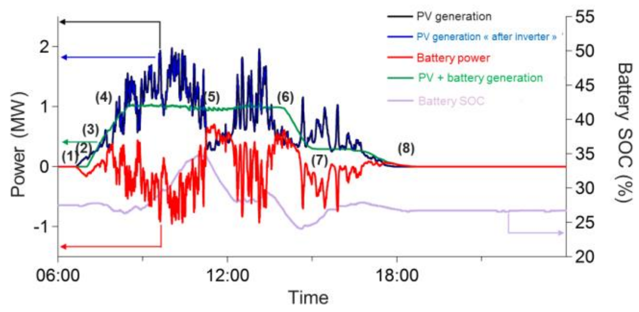

Figure 8. Example of one day of PV generation smoothing. A positive battery power corresponds to power injected into the grid (thus to a discharge of the storage system) and a negative battery power is associated to power injected from the grid in the storage system (thus to a charge of the battery).

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 state of charge target of 25%.

Considering that the efficiency can be defined as (note that ΔSOC refers to the variation of the state of charge of the storage system on the considered period):

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

We obtain for this day an efficiency of almost 95%.

CONCLUSIONS

During PEGASE project, 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 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%, for PV and wind smoothing, demonstrate the

relevance of the tools developed during the project. Note that a company called *EDF Store & Forecast* was created in 2014 to commercialize these tools.

The next step of the project, which is currently under progress, is to connect simultaneously several RE farms to the storage system in order to take advantage of the distributed generation from a RE farm to another. The first results are very encouraging 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).

Note that in parallel to RE smoothing, EDF investigates other ways to use storage systems to promote the integration of RE in the islands' electricity generation mixes. In particular, thanks to a very quick response time, storage systems can be advantageously used as frequency primary reserve and help compensating the lack of inertia of PV and wind facilities.

REFERENCES

[1] J. Badosa *et al*, 2013, "Scales of spatial and temporal variation of solar irradiance on Reunion tropical island", *Solar Energy* vol. 88, 42-56.

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[3] http://www.cre.fr/documents/appels-d-offres/appel-d-offres-portant-sur-la-realisation-et-l-exploitation-d-installations-de-production-d-electricite-a-partir-de-l-energie-solaire-d-une-puissance-superieure-a-250-kwc