INTEGRATION OF DISTRIBUTED PV GENERATION: THE NICE GRID PROJECT

ABSTRACT

The NICE GRID project deals with PV integration in low voltage networks. It relies on a local flexibility mechanism which allows for solving grid constraints due to PV generation. Grid and residential flexibilities have been installed on the distribution grid: residential flexibilities have been activated during summer 2013 and 2014, and preliminary results are available.

INTRODUCTION

The research leading to these results has received funding from the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement n°268206. The project is also funded by the French Environmental Agency ADEME.

NICE GRID is a smart grid demonstration project led by ERDF and developed with nine partners: EDF, ALSTOM Grid, SAFT, RTE, ARMINES, SOCOMEC, NKE, NETSEENERGY and DAIKIN.

Located in Carros (Southern France), NICE GRID deals with the integration of massive decentralized photovoltaic (PV) generation. Within this 10,000-inhabitant city are installed around 2 MWp of PV, including 110 residential installations.

Distributed PV plants along radial and long low voltage feeders in suburban areas lead to grid constraints. Such constraints can be of two types: current constraints appear when a line is overloaded and voltage constraints appear when there is too much local injection versus consumption. These constraints require grid reinforcement to guarantee the quality of supplied power to the end customer.

Reinforcing the distribution grid is a direct and costly solution to mitigate such constraints. Another approach consists in using “flexibilities”, i.e. means to activate in order to locally adapt the load curve to the generation curve, and thus to avoid grid constraints.

Experimentations are occurring during summer. First experimentation was done during summer 2013, the second one in 2014 and the last one during summer 2015, when all the flexibilities are going to be operational.

This paper explains the principles of the demonstrator, describes the different flexibilities and presents the first results of the effects of residential flexibilities.

1. DEMONSTRATOR PRINCIPLES

1.1 Solar district

The city of Carros is supplied by two primary substations, and there are 88 secondary substations supplying the low voltage clients.

In order to proceed the experimentation, seven ‘solar districts’ have been selected (Figure 1). These districts correspond to the clients connected to the same secondary substation, where there is an important solar capacity installed. For six of them, the clients are mostly residential clients with rooftop installations and long and radial low voltage network. The 7th one is located in the industrial area, with around 430 kWp of solar PV capacity within 3 industrial plants.

1.2 Smart metering

1.2.1 LINKY

The LINKY smart meter is a communicating meter that is going to be rolled out in France. These smart meters will provide much more details regarding the consumption and the quality of electricity than the current meters (such as the consumption at a 10-minute step or the voltage).

All the consumption data are encrypted at the meter level as ERDF has to ensure the privacy of the customer’s data. The permanent connection of the meter to the information system and its capacity to measure multiple variables regarding electricity will allow for:

- A calculation of the bills based on real rather than estimated consumptions;
- Next-day interventions for simple tasks such as the modification of the contracted power instead of the current five days delay, thanks to remote access;
- A better knowledge and control of their electricity consumption by customers as they will be able to visualise it on their electronic devices (computer, smart phones, tablets...)
- Easier diagnostics of the problems in case of a power outage thus a reduction of the ‘Critère’ B’ (average yearly outage time per customer).

In the case of the NICE GRID project, one of the most valuable measures is the voltage.

The roll out of LINKY meters in Carros started...
in June 2012 and two years later, there are now over 2300 meters installed. The meters were installed in selected districts that correspond to the seven solar districts of the project as well as some neighbourhoods with a high penetration of electric heating.

So as to obtain more accurate measurements and a clearer picture of the evolution of voltage during the day, a few key meters were modified to record all voltage values. Indeed, LINKY meters can be used as real voltage meters and record the average voltage every 10 minutes on one phase or on the three phases depending on type of meter. In order not to use too much storage space, each low-voltage feeder that was monitored had up to three meters with a full voltage measurement. As the project’s objective is to mitigate increases in voltage on the network, the modified meters were selected so that they would provide us with an overview of the voltage over the entire length of their feeder – meaning that measurements had to be taken close to the substation, in the middle of the network and at the end of the line.

The localisations of these sample meters in the seven secondary substations are presented on Figure 2[1].

![Figure 2 - Localization of sample meters within a solar district](image)

### 1.2.2 PME-PMI

The PME-PMI meters are traditionally used as equivalent to LINKY meters for customers contracting a power superior to 36 kVA. In NICE GRID, these meters are indeed used for large customers but eight additional meters have also been included and are used to monitor each of the seven substations corresponding to the ‘solar districts’, as well as one of the main PV producers.

Retrieving some aggregated data every ten minutes is necessary to the real time management of the network as a daily retrieval is only good enough for billings, post-event analysis and predictions regarding the next day. Thus, fitting PME-PMI meters in the most interesting secondary substations is a good way of gaining information that can be collected more easily and used closer to real time.

A PME PMI meter equips a 200 kWp solar producer, which is the ‘reference PV producer’. This meter is used to quickly assess the level of PV production of the seven solar districts. Indeed, the project calculated in 2013 the ratio between the production of each district and the production of this installation. For instance, all the PV producers downstream of the Caillietiers substation represent about 12% of this reference producer. This approximation is made possible by the fact that Carros is a relatively small city and that we measure the average production over 10 minute. Both these factors combined lead to the conclusion that any change in weather can be considered as affecting simultaneously all the different producers. Eventually, this meter and its 10-minute step data will allow the project to recalibrate its production predictions on the day by simply checking whether the sun is shining as much as predicted [1].

### 1.3 Network Energy Manager

Power flow calculations run on a day-ahead basis and rely on historical metering data, meteorological data and forecast, as well as load and generation forecast. These calculations allow the project to predict grid constraints and associate them with a zone, called a ‘commercial location’, and a certain period of time. The Network Energy Manager (NEM) is the platform responsible for these calculations; it is also operating a mechanism which enables ERDF to activate the flexibilities required to mitigate these constraints. Aggregators are bidding flexibilities on this mechanism represented on Figure 3, and the NEM is in charge of reserving and activating them, after having processed technical and economical optimisations. This mechanism and the flexibilities are deployed over the seven solar districts described above.

![Figure 3 - Demonstrator principles](image)

For more information, see [2]

### 2. FLEXIBILITIES

#### 2.1 Residential flexibilities

To engage the customers who live in areas where PV production could be a problem, EDF has put in place several offers that all rely on the idea of ‘solar off-peak periods’. Every summer, forty days are selected as ‘solar days’ and on these days, the customers taking part in the project benefit from four additional off-peak hours between 12 PM and 4 PM. Depending on the customer’s level of involvement in the project, these hours are used differently:

- Some customers will only be urged to increase their consumption during that time (thanks to the lower prices): ‘solar bonus’ offer (SBO)
- Some customers will have their electric water heater turned on remotely: ‘smart water tank’ offer (SWT)
- Customers with PV production and a residential battery will have their battery charging: residential battery offer.

##### 2.1.1 ‘Solar bonus’ offer

In France, there are two regulated offers for residential clients: base and on-peak hours/off-peak hours. For the first offer, the electricity price is 0.1440€/kWh, whereas for the second offer, the price is differentiated according to off-peak (mostly during the
night) and on-peak hours: 0.1572 €/kWh (On) and 0.1096€/kWh (Off) [3].

The clients who subscribe to the ‘solar bonus’ (SBO) offer have four additional off-peak hours between 12 PM and 4 PM on 40 sunny days each summer. For example, the on-off/peak hours structure is shown on Figure 4 for an “on-peak hours/off-peak hours” client.

Clients receive a SMS and/or an email one day ahead of a so-called ‘solar day’.

![Figure 4 - New tariff structure with the SBO](image)

### 2.1.2 Smart water tank

The clients taking part into the ‘smart water tank’ (SWT) offer have the solar bonus (SBO) and also a remotely controlled water heater. The water tank is charged from 2 PM onwards, when the PV installations are the most productive. Water heaters are switched on through dry contact with the LINKY meter.

The water tank is used as a storage asset as it can absorb the excess of PV generation within the distribution grid. These clients can act also on a voluntary basis using the solar bonus as they are advised with a SMS and/or an email the day before.

### 2.1.3 Residential batteries

The third offer for the residential clients is the residential battery offer. The clients receive a financial support to install PV panels and receive a 4 kWh residential battery to host in their garden for the duration of the project. The battery is connected as another consumption appliance, and is remotely controlled by the residential aggregator.

Up to now, four residential batteries have been installed. The first one was installed and commissioned on October 15th 2014. Such an installation is among others composed of:

- An outdoor battery cabinet with two SAFT SYNERGYON battery modules (2 kWh for each module), and Battery Management Module (BMM)
- A battery inverter SUNNY ISLAND 6.0H (4.6 kW nominal power)

![Figure 5 - Residential battery](image)

### 2.2 Grid flexibilities

Grid flexibilities are managed by the Network Battery Aggregator. Grid flexibilities involved in PV integration are the On Load Tap Changer (OLTC) transformer and three grid batteries. Up to now, they have not been yet tested for PV integration; they will be involved during summer 2015.

#### 2.2.1 On Load Tap Changer Transformer (OLTC)

The OLTC transformer’s objective is to maintain the voltage within the +/- 10% range at all time by adapting its primary to secondary voltage ratio. The NICE GRID projects aims to replace a classic 20kV/400V transformer by a 20kV/400V OLTC transformer.

The OLTC transformer can be an asset to a distribution network with a high penetration of PV production as it can provide a constant secondary voltage by adapting its turns ratio to the variations of the primary voltage. On a distribution network fitted with a classic transformer, the +/-10% range has to cater for both medium and low voltage variations. This can prove difficult as the MV network voltage can vary up to +/-5%, thus leaving only a small range of acceptable variations for the LV network. The objective of the OLTC transformer is to compensate these medium voltage variations in order to leave the complete +/-10% range for the variations on the low voltage network.

The provision of a constant secondary voltage is where the OLTC transformer is required. Indeed, it is able to dynamically adjust its primary to secondary ratio depending on the variations of the primary voltage. The French voltage plan of 2011 plans for variations at different levels: the primary substation, the medium voltage network and the secondary substation – extreme variations are given in the table below.

<table>
<thead>
<tr>
<th>Voltage variations (extreme)</th>
<th>Summer</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary substation</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Medium voltage network</td>
<td>5%</td>
<td>-5%</td>
</tr>
<tr>
<td>Secondary substation</td>
<td>2%</td>
<td>-2%</td>
</tr>
<tr>
<td>Total primary voltage variation</td>
<td>9%</td>
<td>-5%</td>
</tr>
</tbody>
</table>

This table means that the primary voltage of the transformer could vary between 20kV - 5% and 20kV +9%. Thus, to ensure that it can provide a constant 400V +1% secondary voltage, the OLTC transformer should be able to operate in the -8%/+6% range around the 20kV/400V transformation ratio or +/-7% range around the 20kV/404V transformation ratio.

There will be two parallel regulations for this OLTC:

- A distant control, provided by the Network Energy Manager, which will give a voltage set point (see figure 6, "consigne" NEM)
- A local control, provided by the light measurement of a light sensor (see below)

A light sensitive sensor, located at the roof of the substation, is connected to the controller and gives an estimation of the PV production downstream the substation. Then it automatically modifies the voltage.
reference used for the regulation.
- In the sunlight, the regulation is done with a low voltage reference (404V) to increase the possibility of PV deployment without risk of overvoltage.
- When the light drops, the regulation is progressively set to a higher reference, up to + 4% (420V), to avoid risk of under voltage during peak periods (mostly at evening and in winter in residential areas which are the main kind of networks interested by this light sensor regulation).

![Figure 6 - Secondary voltage regulation by the OLTC: distant (NEM) and local (light sensors) management](image)

For more information, please report to [5]

### 2.2.2 Grid storage assets

Three grid storage assets are involved in PV integration. They are located in three different solar districts. The following table gives the main features of these storage assets:

<table>
<thead>
<tr>
<th>District</th>
<th>Power</th>
<th>Energy</th>
<th>Location</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cailletiers</td>
<td>33 kW</td>
<td>106 kWh</td>
<td>400 m away from the secondary substation</td>
<td>Integrated 10 ft container with SOCOMEC converter and SAFT battery modules</td>
</tr>
<tr>
<td>Colombie</td>
<td>33 kW</td>
<td>106 kWh</td>
<td>400 m away from the secondary substation</td>
<td>Integrated 10 ft container with SOCOMEC converter and SAFT battery modules</td>
</tr>
<tr>
<td>Dock Trachel</td>
<td>250 kW</td>
<td>620 kWh</td>
<td>Connected to a direct feeder of the secondary substation</td>
<td>20 ft battery container located outside and 466 kW SOCOMEC converter located in the secondary substation building</td>
</tr>
</tbody>
</table>

![Figure 7 - Main characteristics of the grid storage assets](image)

The two first storage assets (33 kW) are installed where the constraints are more likely to be present, 400 m away from the corresponding secondary substation. The storage assets will charge energy between 12:00 and 16:00 on sunny days in order to avoid overvoltage occurrences.

For the third one (250 kW) the PV excess energy at secondary substation level will be stored. The secondary substation often has an excess of PV energy: a threshold will be chosen [6]. For example, if the chosen threshold for backfeed energy is 100 kW, the storage asset will start to charge, as shown in the next figure:

![Figure 9 - Resulting load curve at “Dock Trachel” secondary substation](image)

### 3. FIRST RESULTS

Up to now, results are available for residential flexibilities involved during summer 2013 and 2014. It is important to notice that these are preliminary results of an ongoing experimentation. The evaluation works were led by EDF R&D.

#### 3.1 Summer 2013

The first experimentation was done during summer 2013, enabling a test of ‘solar off-peak hours’ offers. This “solar off-peak hours” offer is different from the SBO presented above (which has been tested in 2014, see 3.2). From June 21” to September 21st, 21 participants with remotely controlled water tanks saw four of their eight off-peak hours at night shifted during the day from 12 PM to 4 PM. This test allowed the customers to consume 22% more from the locally generated PV energy compared to the baseline scenario without flexibilities (Figure 10).

![Figure 10 – Average power consumption and generated PV energy](image)

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1 Benoit Chazottes, Jonathan Reynaud, Maxime Cassat, Charlotte Paquet, Kévin Guillaumé
3.2 Summer 2014

From May 1st to September 17th 2014, there were 32 ‘solar days’. 28 clients took part into the ‘solar bonus offer’ (SBO) and 23 clients to the ‘smart water tank offer’ (SWT). This section presents the average results for these two types of clients.

3.2.1 “Solar bonus” (SBO) offer

Figure 11 presents the effect of the solar bonus on average for a residential client. Overconsumption on a “solar day” is displayed in green. The ‘solar bonus’ represents a potential of 0.4 kWh per client between 12 PM and 4 PM, i.e. a shift of 12% compared to a reference day.

3.2.2 Smart water tank (SWT) offer

Figure 12 presents the effect of smart water tank (SWT) management on average for a residential client. Overconsumption on a “solar day” is displayed in red. SWT represents a potential of 2.4 kWh per client between 12 PM and 4 PM, i.e. a shift of 57% compared to a reference day.

3.2.3 Conclusion

Figure 13 displays the average shift potential of the SBO and SWT. Although it is lower than the average PV generation, this relevant flexibility can be activated in order to absorb the PV excess generation within the solar district between 12 PM and 4 PM [7].

CONCLUSION

The first results show that residential flexibilities could be relevant to shift electricity consumption during high PV generation periods. These flexibilities will be completed during summer 2015 by 20 residential and 3 grid batteries, as well as the operation of the OLTC transformer.

GLOSSARY

ekWp – kilowatt peak
NBA – Network Battery Aggregator
NEM – Network Energy Manager
OLTC – On Load Tap Changer
PV – Photovoltaic
SBO – Solar Bonus
SWT – Smart Water Tank

REFERENCES

[1] Desgranges, Lebossé, 2014, Section 3 of dD 3.1.10 Halfway assessment of the smart solar district, deliverable to the European Commission