ISLANDING TESTS WITH LI-ION STORAGE SYSTEM ON THE EDF CONCEPT GRID

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ABSTRACT

Concept Grid is a laboratory dedicated to the test and validation of smart grid equipment, systems and functions. It has been set-up by EDF R&D and has now been in operation for more than two years. It allows full-scale tests on complex topologies with high disturbances. That is why it has been used by Nice Grid consortium.
Nice Grid is the first smart solar-energy district demonstration project to be conducted in France. The objective is to develop a smart electricity grid that harmoniously integrates a high proportion of solar panels, energy storage systems and intelligent meters installed in the homes of volunteer participants.
Prior to field experiments, storage systems have been installed on Concept Grid to reproduce what should be the real situation on the grid, allowing to perform islanding, black-start, LV short-circuits, unbalanced networks, etc. Thanks to Concept Grid, the Nice Grid consortium could de-risk the installation, fasten development and tune command laws that have been implemented three months later in the field.

CONTEXT

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.
To understand the global challenge of this experiment, it is important to keep in mind some information about:

- *Nice Grid, a French demonstrator dedicated to the integration of PV energy, storage systems* and intelligent meters;
- Concept Grid, a test platform developed by EDF to answer needs raised by customers such as Nice Grid.

Nice Grid

Nice Grid is the first **smart solar-energy district demonstration project** to be conducted in France. This project is located in the municipality of Carros and brings together a broad range of stakeholders.

The objective is to develop a smart electricity grid that harmoniously integrates a high proportion of solar panels, energy storage systems and intelligent meters installed in the homes of volunteer participants.
This demonstrator allows interesting feedback on integration of new uses, but previous tests needed to be performed to de-risk this solution and validate the storage system in disturbed conditions.

Within the Nice Grid, islanding of a district is a use case respecting the following sequence:

- Consecutive to the **disconnection of the district from the main grid** (manually or automatically, scheduled or unforeseen)
- During which the district is supplied for **a limited duration of time** by a **storage system** and **local PV generation**
- Involving the maintaining of **frequency** and **voltage** by the storage system
- Ending with the **resynchronization** to the main grid **without any interruption of service** (when the upstream grid is back or at the end of a set period).

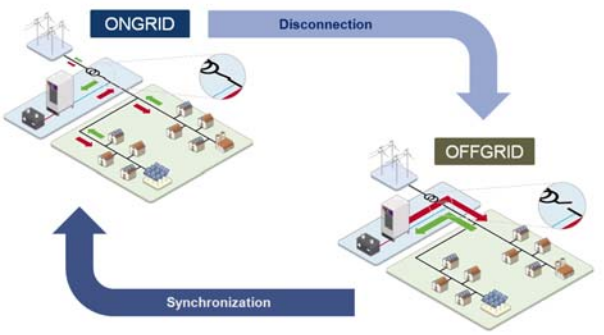

Figure 1 – Islanding principles

For furthermore information, see paper 414: Islanding of a commercial district: NICE GRID project.

Concept Grid

Located on EDF Les Renardières site, 70 km south of Paris, Concept Grid is an **experimental platform enabling to safely conduct complex testing campaigns** that would be impossible to perform on a real grid. Its very core is composed with:

- A **control centre** to operate the network and monitor the tests,
- A **primary substation** supplying MV and LV grids,
- A reduced scale **residential area**,
- A protection and control system based on **IEC 61-850** standard,

- A powerful **four-quadrant amplifier** (120 kVA source / 60 kVA load) coupled with real time simulation to perform complex **PHIL experiments**, even in disturbed conditions.

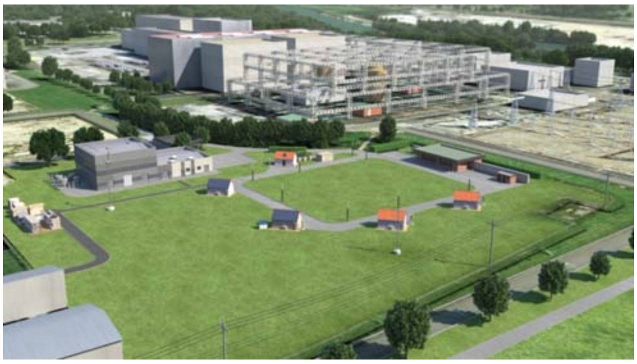

Figure 2 – Concept Grid overview

All these elements are linked by real **overhead lines** and **underground cables** (both LV and MV), in order to be completely representative from what exists in the field. **Fiber optics** are also installed all over Concept Grid to ensure ICT and advanced smart grids functions.

This infrastructure thus allows **fast developing** and **de-risking** on smart grids issues. Indeed, it becomes easy, thanks to Concept Grid, to reproduce microgrids, islanded systems, and to change the topology according to users' needs.
Once done, these configurations can be challenged, performing huge and accurate disturbances:

- MV and LV short-circuits,
- Voltage dips,
- Overcurrent,
- Complex harmonic distorsions,
- IT issue,
- Etc.

GENERAL DESCRIPTION OF THE EXPERIMENT

Two containers from Nice Grid have been installed on Concept grid. The first one contains Saft **Li-ion battery** modules, with a total capacity of **106 kWh**.

The second one contains 2x66 kVA Socomec SUNSYS PCS² **inverters mounted in parallel and suitable for islanding operation**. The whole system is restrained to **50 kVA** when charging/discharging on Concept Grid network. Once installed:

- **Generation** was ensured by the main grid (ERDF grid), but also with **distributed energy resources**: PV inverters, coupled with DC generators to simulate PV panels, were able to inject up to 20 kVA, with accurate representativeness and reproducibility – mandatory for that kind of test;
- **Consumption** was dealt with real LV active and reactive loads, but also with the amplifier: load curves were recorded in the field, in Carros, and replayed on three-phases on Concept Grid.

This whole configuration composed a **full-scale image** of what exists in Carros. We were then able to perform tests which would have been impossible in the field.

Measurement points have been settled in several places of Concept Grid in order to monitor main values:

- Voltage and Current on three LV phases, in the Secondary Substation linking the storage system to the grid (acquisition bays: Yokogawa and AdLink);
- Voltage and Current on three phases + neutral in the house where was installed the PV generation;
- In the Secondary Substation from where was performed islanding: Voltage, Current, Active and Reactive power, Harmonics…

Figure 3 – Storage system

TESTS PERFORMED & RESULTS

<u>Islanding by opening of the Coupling Circuit Breaker (CCB)</u>

This test aims to monitor the storage system during the **transition** phase between on-grid and **islanded configuration**.

Islanding has been performed with following load / PV configuration:

- 20 kW PV / No load
- 20 kW PV / 50 kW resistor
- 20 kW PV/ 20 kW resistor/ 30 kvar inductance
- 20 kW PV/ 20 kW resistor/ 30 kvar capacitance.

The following sequence is respected:

- The load is carried by PCS (Power Conversion System) until power flow almost reaches zero on the CCB;
- CCB is remotely opened;
- Islanding lasts between 2 and 3 minutes;
- Islanding is stopped and the system goes back to synchronization with the grid.

Transition to islanding has always been successful. PV inverter have never decoupled, and balanced between generation and consumption has always been respected, as shown below.

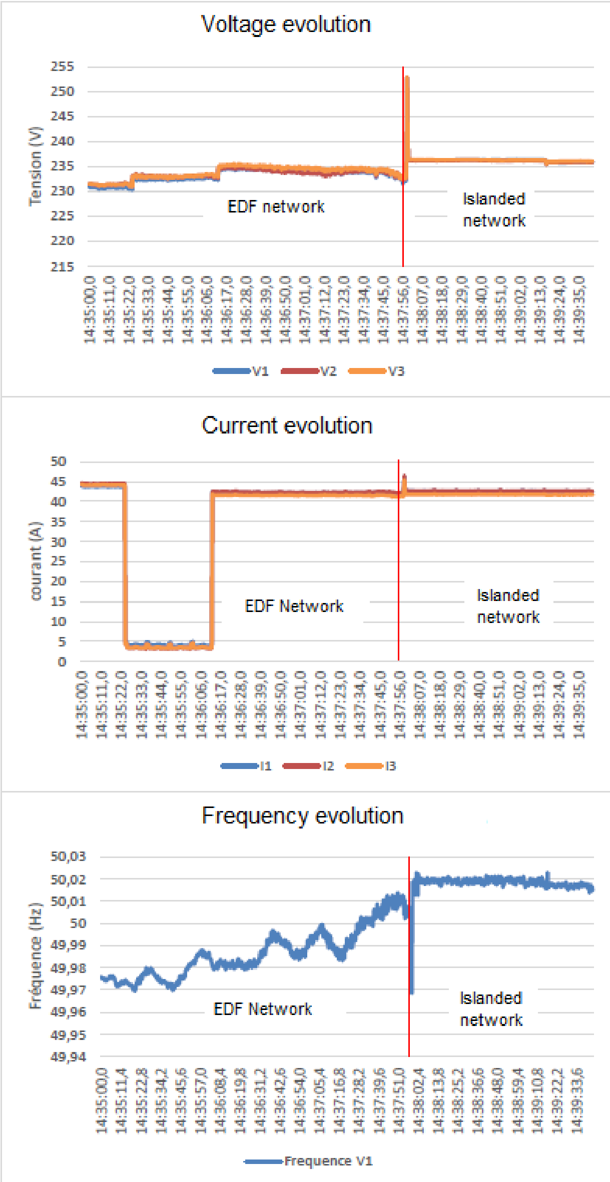

Figure 4 – Evolution of voltage, current and frequency when islanding

Performance tests

These tests aim to assess performances of PCS in islanded mode. They follow the following sequence:

- Variation of active power
- Variation of reactive power
- Variation of both active and reactive power (balanced and unbalanced load)
- Fast variation of LV load
- Power flows recorded in the field
- Behaviour of storage system (high, medium and low SoC)

Five first tests were focused on PCS ability to stabilize voltage and frequency for several values of active and reactive power (produced or consumed). Last tests are focused on the storage system, in particular:

- Frequency management by PCS and PV inverters when SoC is close to order;
- When the system is switching from charge to discharge (and vice-versa).

Transitory sequences of coupling with network were realized for some tests.

"Unexpected" loss of PV production while islanding

This test aims to monitor the behaviour of the system when **losing two PV inverters in islanded mode**.
The following sequence is respected:

- Storage system feeds the LV network, islanded;
- Both PV inverters inject around 20 kW;
- A 10 kW resistor is connected (storage system is thus loading);
- PV inverter are suddenly disconnected.

Storage system is monitored, as well as transient phenomena (U, I, P, f…) until synchronisation to main grid (when the battery is fully discharged). Everything went as expected.

"Unexpected" loss of a PCS converter

This test aims to monitor the behaviour of the system when **losing a power module or a PCS converter in islanded mode**.
The following scenarios have been tested:

- 20 kW resistor, 30 kvar inductance → PCS is lost during transition to islanding;
- 20 kW resistor, 30 kvar inductance → PCS is lost while islanding;
- 20 kW resistor, 30 kvar inductance → PCS is lost during synchronization with main grid;
- 27 kW PV, 30 kW resistor, 20 kvar inductance → PCS is lost while islanding
- 27 kW PV, 30 kW resistor, 20 kvar inductance → PCS is lost during synchronization with main grid.

Each time a PCS or a power module is suddenly disconnected. Storage system is monitored, as well as transient phenomena (U, I, P, f…) on the islanded grid. Everything went as expected.

Behaviour of microgrid on LV short-circuit

This test aims to monitor the behaviour of the system when **a LV short-circuit occurs in islanded mode**. Protections (switchgear, fuses…) are supposed to act properly in such case.
Passive protection functions (min/max U and f) of decoupling protection must act in case of "non detection"

of fault at the LV feeder level. Short-circuits are created remotely closing a switch.

Five short-circuits have been realised at **the far end of a LV line**, 450m from storage system:

- Single phase (phase-neutral) fault downstream a 60A switchgear
- Two-phases fault downstream a 60A switchgear
- Single phase (phase-earth) fault downstream a 60A switchgear
- Single phase (phase-neutral) fault, no switchgear
- Two-phases fault, no switchgear.

Two short-circuits have been generated at **the very beginning of the LV line**, close to LV feeder:

- Single phase (phase neutral) fault downstream a 250A fuse
- Two phases fault downstream a 250A fuse.

Voltage and current have been measured close to the storage system during these transient phenomena. 60A switchgear always opened on three first faults (third one was so fast and low we could not record any transient curve).

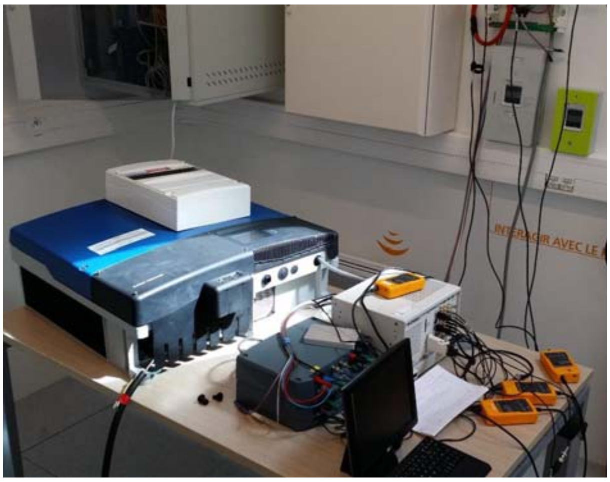

Figure 3 – PV inverter used to reproduce Carros photovoltaic production

<u>Variations of LV load</u>

This test aims to monitor the storage system **when connecting/disconnecting a huge load in black-start mode, until synchronization with the main grid**.

The following scenarios have been tested:

- Brusque variations with resistor (0→20→40 kW)
- Brusque variations with inductance (0→30 kvar) with a 40 kW resistor
- Brusque variation of a unbalanced resistive load (connection/disconnection of a resistor) with a 24 kvar inductance
- Brusque variation with the inductance (0→24 kvar) with an unbalanced resistor.

Transient phenomena are monitored at the loads level, as well as storage system level. Everything went as expected.

<u>Complementary tests</u>

Real home equipment have been monitored during two black-start scenarios:

- with a generation starting directly at 230V;
- with generation starting from 50 V up to 230 V.

Concept Grid houses were equipped with 4 heat pumps, 1 drying machine, 3 washing machines, 2 fridges, 3 convectors and 1 towel radiator.

Tests didn't point out any dysfunction of equipment.

OUTCOMES AND CONCLUSION

In only ten days, Concept Grid allowed a wide range of tests which de-risked and fastened the development of complex configuration for Nice Grid demonstrator.

In particular, more than 150 islanding configurations have been experimented within three days. Command laws have also been validated in safe condition on Concept Grid, before implementing it in the field.

The test reports gave Concept Grid customers a wide overview of the abilities of their systems, in particular for Socomec converters. Accurate measurement reported a comprehensive understanding of islanding mode, from expected to unexpected events, including short-circuits or black-start issue. This allowed, among other results, to earn confidence regarding public acceptance and safety conditions.

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