Resiliency in Case of Power Outages for Rural Zones with an Energy Storage System

Correze Resilient Grid: An innovative rural microgrid

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***Abstract*—This article presents the Corrèze Resilient Grid project, that aims at testing a new business model adding an energy storage system in the power sub-stations to use the customers PV production during loss of the mains grids.**

Keywords-component: Microgrid – Rural Smartgrid – Storage – Demonstrator.

I. Introduction

Corrèze Resilient Grid is a project led by Enedis (French public service Company, grid operator) and the Syndicat de la Diège (in charge of the electricity distribution over 65 municipalities in its perimeter). It is part of the Corrèze Ecological Transition program. Its aim is to guarantee that the Nespoux hamlet (Lestard municipality) gets electricity supply even in case of grid loss. Therefore, the idea is to take advantage of the installed photovoltaic (PV) production in order to repower the hamlet during the day – in case of problem on the main grid – by creating a low voltage microgrid able to operate islanded.

Some key figures about this project:

- The project consists in repowering: 5 houses, 1 fire department antenna and 1 drinking water pumping station
- The global cost of the project is 323 000€ shared between the Syndicat de la Diège and Enedis
- It is the result of a 3 years research and development program.

Figure 1 Nespoux hamlet

II. What is "Corrèze Resilient Grid"

A. Origin of the project

In Corrèze, the Nespoux hamlet is located in an isolated and mountainous rural area that cannot benefit of burial of power lines.

However, this region is subject to lots of climatic risks that can led to issues on the electricity grid, such as trees falls on medium voltage lines. When such issues occur, the electricity is off. As the hamlet is isolated and with a difficult access, in case of bad weather, technical interventions can sometimes take several hours, even days. This is all the more difficult to understand for the inhabitants as they have photovoltaic (PV) panels installed on some rooftops.

After a 3-year study and several exchanges on the subject, Enedis, the Syndicat de la Diège and the Department of Corrèze have decided to start the experiment of an innovative solution in 2019. This project is part of a global territory approach to develop smartgrids in rural zones.

The projects has several targets:

- Experiment the repower of houses using the inhabitants PV installations
- Test, in real situation, a smartgrids architecture in a rural environment
- Show that it is possible to get people work on a disruptive concept in a mutating electric grid.

B. What are the components of Corrèze Resilient Grid?

To be functional the grid needs three main elements that will be detailed after: a PV plant, Linky metering devices and an energy storage system.

1) Photovoltaïc power plant

There are three PV generation installations within the hamlet that are installed on the roof of some stables, hangar: two 9kVA PV installations and one 159kVA installation - 1200m² of rooftop.

2) *Linky meters*

The stable and the hamlet inhabitants have been equipped with Linky that enable:

- To follow and master the consumptions in order to do energy savings
- To manage the contract remotely (move, change of power, new tariff)
- To invoice real consumptions
- To measure the electricity powered by the PV panels and the electricity consumed.

It is a key element to enable the balance between consumption and production.

3) *Energy storage system (ESS)*

A battery energy storage system of 66 kVA / 91 kWh has been installed to enable storing the surplus PV production and consume it later in the day as well as working in islanding mode in case of loss of the grid. The details of operation of the ESS will be given later in this document.

C. Short introduction to the microgrid operation

Corrèze Resilient Grid guarantees an electricity power supply continuity, even during bad weather, to the Nespoux hamlet where some critical sites are located: one telephone network, one fire department antenna and one drinking water pumping station. Indeed, when there is an issue on the public grid, such as a tree fall, that damages the power lines, the Corrèze Resilient Grid takes over.

Three minutes after the event the grid circuit breaker (CBG) opens and separates the public distribution grid from the Nespoux microgrid. At that moment, the ESS and the PV enable the power supply of the microgrid, so inhabitants and critical installations are secured with electricity. The microgrid is operating in islanding mode.

At the same time, Enedis teams join forces in order to repair as soon as possible.

Once the intervention is over, the public grid again powers the Nespoux hamlet. The details of those operations will be detailed in the rest of the document.

Thanks to Corrèze Resilient Grid, the inhabitants can benefit from a green grid that can be islanded.

III. General System Description

The energy storage system installed in the Corrèze Resilient Grid that is of Socomec supply is composed among others of a storage converter, a lithium-ion battery, a control-command cabinet and a grid connection cabinet. What's more, it is piloted by an EMS of the LiteDERMS type supplied by EDF R&D. More details on the operations and the components will be given in the next chapters of this document.

The ESS objective, within this project, is to generate the microgrid voltage and frequency references in case of loss of main high voltage grid, so that the customers stay powered.

The single line drawing – figure 2 – shows the interconnection between the different elements.

Physically, the elements are present in the two rooms of the electricity sub-station (public distribution room and storage room).

A. Bidirectional power converter (PCS)

The power converter used in this project is a 66kVA with 2x33kVA power modules, each hot swappable. It enables to charge the batteries by taking the energy from the grid or the PV producers and discharges the batteries on the electric grid.

The PCS enables two modes of operation:

- On-grid Mode = connected to the grid. In this mode, the PCS is piloted through active power P and reactive power Q orders.
- Off-grid Mode = islanded (disconnected from the grid). In this mode the PCS ensures voltage and frequency regulation.

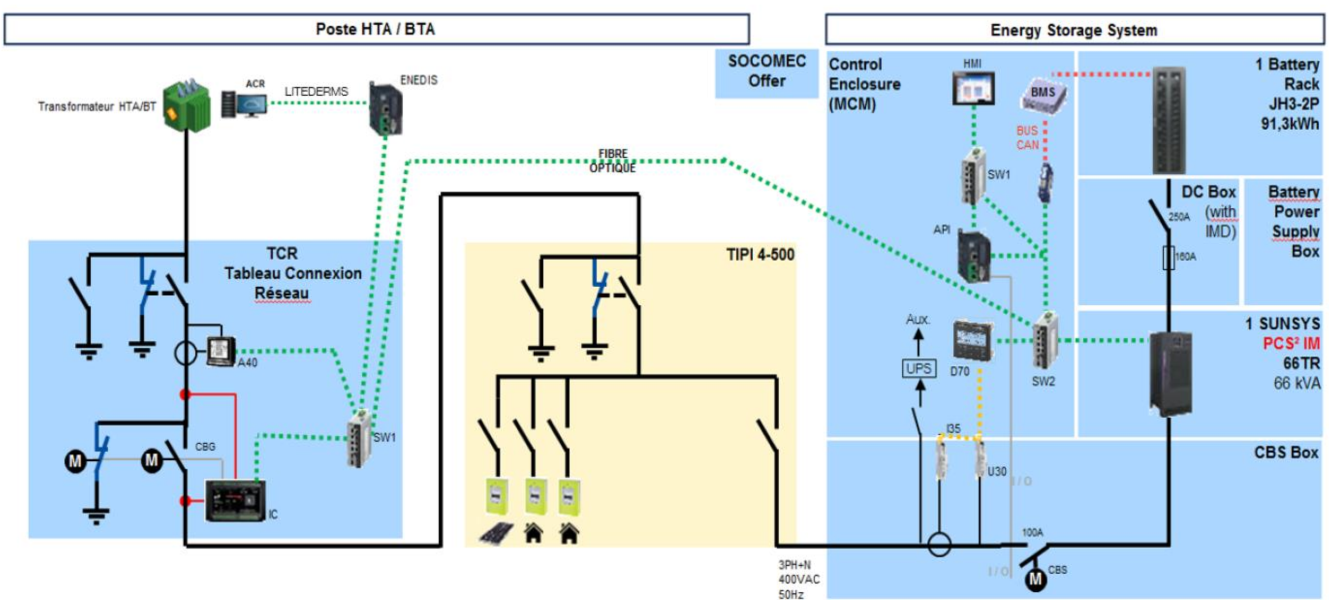

Figure 2 Project single line diagram

During a programmed islanding, as long as the battery state of charge (SoC) level is high enough, the PCS ensures the transition between the two operating modes without any impact on the quality of the power supply. This is a no-black islanding.

In case of unforeseen islanding, the PCS also needs to be able to re-establish the microgrid voltage; therefore, it needs to be able to operate a blackstart.

B. Battery rack

The characteristics of the used batteries are as follows:

- Technology: lithium-ion
- Type 1C
- Energy: 1 rack composed of 14 modules to reach a total of 91.3kWh nameplate.

C. Control-command cabinet MCM

This cabinet is there to enable different functions of the ESS, depending on the operating mode. Therefore, it integrates a Power Management System (PMS).

1) On-Grid mode

At the time being, within the Corrèze Resilient Grid project, the storage system is used in on-grid mode only to charge the battery, no complementary services are operated yet.

2) Islanding mode

In this mode, in addition to the on-grid functions, the following ones can be done:

- Grid-forming – microgrid powering with voltage and frequency references generated respectful of the EN 50 160
- Management of the power supply of the loads connected to the microgrid
- Programmed islanding => Power ramp
- Unforeseen islanding / Fault detection => Blackstart
- Grid synchronisation and reconnection
- Consumption / production balance: ENR production is regulated using P(f).

D. Grid connection cabinet - TCR

One of the main constraints imposed by Enedis for this project is that the circuit breakers aiming at coupling the main grid with the microgrid is integrated in order to keep the electric distribution panel as known by Enedis operatives. This means that it needs to be based on the TIPI architecture.

This panel main objective is to enable the transitions between On-Grid and Off-Grid modes. During such transitions, the grid must be disconnected from the microgrid then reconnected following a synchronisation phase between both grids. To do that the TCR must also integrate elements enabling to pilot the main elements, to send some elements to the controllers and to control the voltage and frequency of the grids.

E. LiteDERMS

EDF R&D developed a complete solution that enables to ensure the microgrid islanding management and monitoring from the Agence de Conduite Régionale (ACR). This solution will make it possible to communicate information and orders to perform the islanding and then the grid reconnection. The solution is known as LiteDERMS.

LiteDERMS system interfaces with:

- the PMS: it is the only entry point for the LiteDERMS to the storage system. It will be part of the piloting of the CBG and the storage circuit breaker (CBS).
- the Agence de Conduite Régionale (ACR): LiteDERMS ensures microgrid monitoring in relation with the ACR. Its role is to periodically transmit, to the ACR, information of system measurement, states, alerts and alarms.
- elements of the electricity sub-station:
    - LiteDERMS directly pilots the opening of the CBG and the CBS.
    - LiteDERMS provides indicator lights, push buttons and voltage relays management. Thanks to that, the operative people can monitor the Enedis cabinet that is inside the sub-station.
- LiteDERMS issues alarms that are a major fault indicator of the microgrid. The alarms are provided to the ACR and the energy storage system or even the entire microgrid are stopped. A RESET order is then necessary to restart the system.

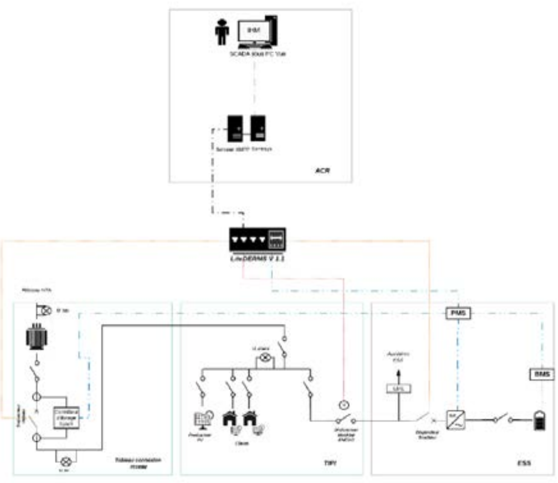

Figure 3 LiteDERMS interfaces

IV. MICROGRID SPECIFIC OPERATION DESCRIPTION

The operation of the microgrid are presented in details in the following chapters.

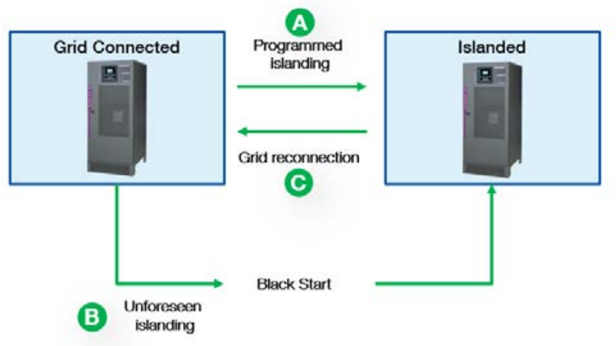

Figure 4 Overview of the ESS transitions

A. Programmed islanding

The no black islanding is possible in case of programmed islanding, which means that the disconnection is voluntary. This function is mainly used for maintenance operations. Its principle is to erase completely the flows between the grid and microgrid powers. The disconnection of the mains grid is operated through a power transfer between the grid and the storage system, which prevents the customer from having a power supply discontinuity.

The process to activate this function, with the Corrèze Resilient Grid is the following:

1) Decision to operate an islanding

The decision to operate an islanding is taken:

- either remotely by the ACR
- or locally from the cabinet front face.

This decision is effective if no emergency stop is activated, if the battery SoC is high enough and the ESS is operational.

2) Power ramp

Once LiteDERMS has transmitted the islanding order to the ESS, the PMS takes over and starts the mains grid disconnection by transferring the power from the grid to the storage system. Concretely the PMS sends the PCS an active power order enabling to reach zero power at the grid point of connection. This is a repetitive process, that depends on the load and PV power variations, up to the objective reach (Pgrid = 0kW). During all this process the power generated by the PCS is adjusted in order to open the CBG as soon as the power delivered by the grid reaches the zero value, this also makes it possible to minimise the perturbations resulting from the transition. The PCS is operating as a current generator during this power ramp.

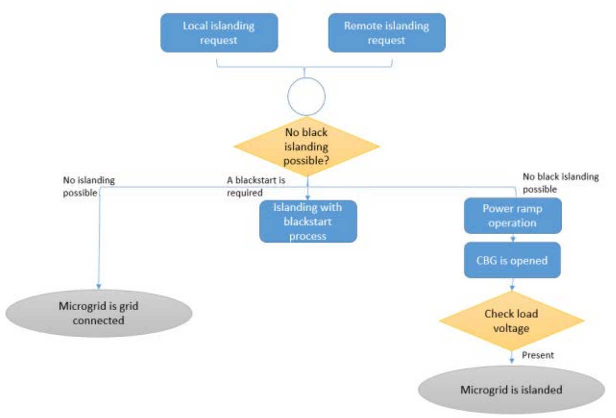

Figure 5 Programmed islanding process

3) Grid disconnection

Once the power flow at the point of connection is close to zero, the PMS gives this information to LiteDERMS.

This one will then give the order to start the islanding. During this phase, the PCS switches to voltage generator mode while operating in parallel to the grid. This makes it understandable why the operating time in this mode shall be as short as possible, so the CBG must be opened in max. 200ms.

When the PV power produced during the islanding process is higher than 66kVA, the process will not be done as a no black, but there will be a blackstart. The next chapter explains this blackstart process.

B. Unforseen islanding

When the disconnection happens automatically following a loss of grid detection; the islanding is called unforeseen. The process is then as follows:

1) Islanding process awareness

In case of loss of the grid voltage, the islanding process can be launched through different means:

- either remotely by the ACR
- or locally from the cabinet front face,
- or automatically after a 5min long loss of voltage.

This decision is effective if no emergency stop is activated, if the battery SoC is high enough and the ESS is operational.

2) Grid disconnection

Once the islanding process is started, LiteDERMS operates the CBG opening in order to island the microgrid. Once the CBG is opened, the PMS will send an islanding order to the ESS.

The PV installations are also disconnected, as the grid is no longer available.

3) Restart of the microgrid in Blackstart mode

To restart the microgrid it is necessary that the luminosity, detected by a lumandar installed on site, is enough. Once this condition is reached, the microgrid is restarted after a Blackstart. This function aims at re-establishing progressively the microgrid voltage in order to avoid the effects of too high current draws (ex: transformer-magnetizing peak). In a first phase, the battery alone will have to repower the entire hamlet; the PV inverters are disconnected (passive production). After that the PV inverters reconnects progressively.

a) Details of the Blackstart sequence:

As the PCS is able to operate in voltage generator mode, it can be used to perform a blackstart.

Thanks to the PMS, it is possible to start an automatic sequence of microgrid repowering through a slow ramp of voltage increase.

Before starting a blackstart procedure, the microgrid must meet the following conditions:

• the grid must be disconnected,

• the PCS must be disconnected, but the ESS auxiliaries must be supplied thanks to a backup power supply,

• the microgrid PV productions are disconnected.

b) Blackstart sequence:

• The PMS gets an order to start an islanding operation or it detects a loss of grid.

• The PMS send a blackstart starting order to the PCS.

• The PCS initiates a low voltage ramp up (up to 87Vac Ph-Ph) in order to detect possible faults on the microgrids and avoiding any short circuit overload. Once the 87Vac is reached, the CBS is closed and the ESS is connected to the microgrid.

• The PV generators as well as the loads are inactive due to low voltage.

• If there is no fault, the PCS starts the 2nd part of the ramp up to reach the 400Vac within approximately 5s.

• Loads are gradually repowered as soon as the voltage gets to a certain level.

• PV generators are reconnected when the voltage and frequency are back in their operating ranges, after a reconnection time. For this project, the reconnection is not managed by the ESS.

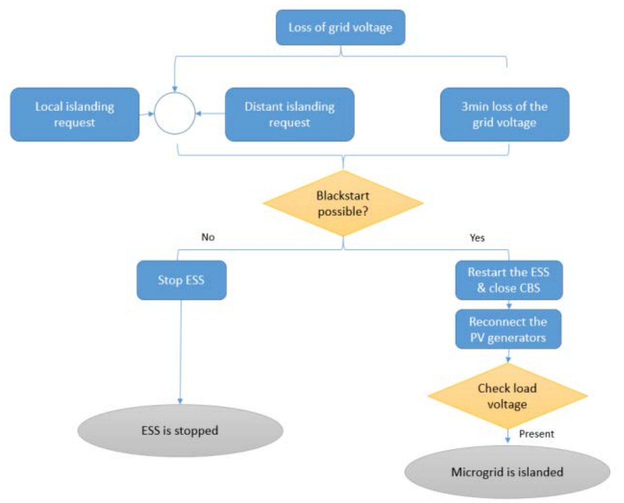

Figure 7 Unforeseen islanding process

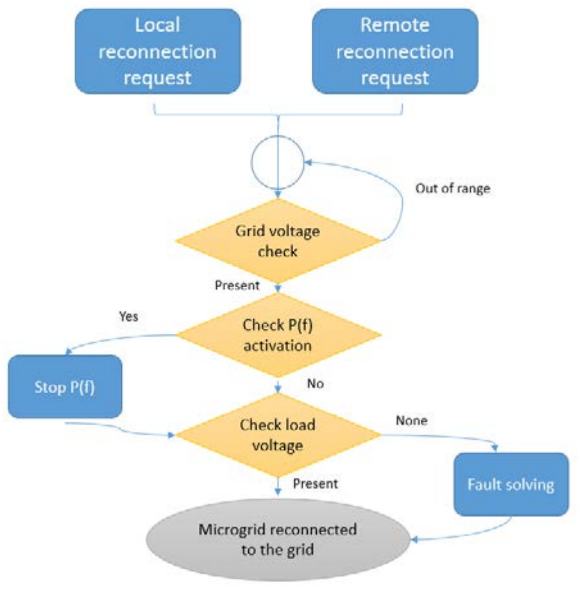

Figure 6 Reconnection to the grid process

C. Grid reconnection

Once the mains grid returns, the recoupling process can be started by two ways:

- either remotely by the ACR
- or locally from the cabinet front face.

To avoid any power outage, the recoupling of the microgrid to the mains grid is realised by a synchronisation followed by a coupling of both grids. The islanding controller performs the measures and the PMS performs voltage, frequency and dephasing regulation (ΔU / ΔF / $\Delta\varphi$ parameters can be adjusted). The aim is that the two grids sinusoids are overlapping and when the values are quite stable, the islanding controller will manage a fast piloting of CBG (less than 100ms) to guarantee a seamless transition for users / loads.

When the CBG is closed, the PCS gets back to the current generator mode.

D. Voltage and frequency management in islanding mode

The first interest of the PCS when operating islanded, working as a voltage generator is to stabilise the microgrid frequency and voltage by sharing its power supply with the PV generators.

Staying in the battery operational limits, voltage and frequency are stabilised in the operating ranges defined by the EN 50160 standard. To make this happen P(f) & Q(U) functions are used.

For information, the range defined by the EN 50160 is the following: The nominal frequency of the supply voltage shall be 50 Hz. Under normal operating conditions, the mean value of the fundamental frequency measured over 10 s shall be within a range of; for systems with synchronous connection to an interconnected system:

- 50 Hz ± 1 % during 99,5 % of the year;
- 50 Hz + 4 % / - 6 % during 100 % of the time.

This will result to an inconstant operation point that is always within the limits.

During a load variation, the PCS will automatically and instantaneously adjust the operation point according to the needed power, as shown on figure 8.

Therefore in islanding mode, the P & Q orders coming from an external device will not be followed, they are blocked by the PMS.

Six situations are possible during islanding depending on the battery SoC and the PV production:

	Load > PV production	*PV production > Load*
SoC around 100%	Battery discharge	PV production decrease
In the middle	Battery discharge	Battery charge
SoC around 20%	End of islanding mode	Battery charge

When the PV generators start energy injection on the microgrid, the PCS is subject to a load variation that should have no impact if the start-up of the PV generators is slow enough. This ramp up is specified in some grid codes, for example: $dPdt = 10\%min$ in the ARN4105 (Germany).

E. Single phased or polyphased fault

The system does not react similarly when grid connected or isolated.

1) Grid connected mode:

The ESS, working as a current generator, injects/absorbs the maximum current – 145A at 400Vac. This value us checked and if it is exceeded the ESS will disconnect.

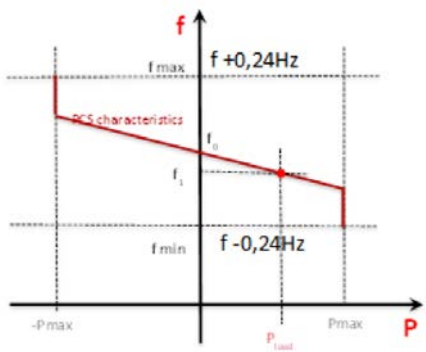

Figure 9 Definition of the P operation point

Figure 8 Example of voltage window

2) Off-grid mode:

When isolated, the main faults are short-circuits. They are maintained during 100ms before disconnection.

The fault detection is done as follows:

- AC phase's voltages are checked during islanding in order to detect a short circuit.

- Phase to neutral and phase-to-phase voltages are checked every 244 µs and compared to a window, as shown in figure 9. If the voltage gets out of the window, an alarm is started (100ms after an under-voltage and 2.5ms after an over-voltage).

F. Conclusion

Corrèze Resilient Grid is a demonstrator proving that it is possible to find a solution for electricity power supply for isolated places with a difficult access.

Using such a system gives a bit of time to Enedis teams to go on-site and do the interventions without the inhabitants noticing that there is an unsolved issue. So it is a possible solution to be put in place in other places.

In the future, it is possible to improve the use of the ESS for example by contracting with the owner of the storage asset – the Syndicat de la Diège – in order to be able to use the system during grid-connected operations. So the ESS could be used for grid services, to provide an EV charging station, for other functionalities such as PV self-consumption maximisation or peak shaving. Nevertheless, a minimum SoC will have to be defined to guarantee that the transition to the islanding mode is still possible, if needed.

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