ENEL GI&N RURAL ELECTRIFICATION SOLUTIONS AND IMPLEMENTATIONS

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ABSTRACT

Enel Global Infrastructure and Networks (Enel GI&N), a business division of Enel group, is managing, through local distribution system operators (DSOs), more than 25 million customers in Argentina, Brazil, Chile, Colombia and Peru. Moreover, Enel GI&N is facing the challenge of bringing access to electricity to the 100% of the population; for that reason, it is working on microgrid (MG) solutions for the sites that are not connected or hard to connect to an electricity network. These solutions are having or are expected to have an important impact in the DSO engineering also because they requires additional and innovative components, traditionally non-present in the DSO catalogue. In this paper the Enel GI&N solutions for rural electrifications are described also by presenting some field implementations.

INTRODUCTION

Electric power is the corner stone for economic development, better healthcare, increased safety, education as well as efficiency gains in agriculture and manufacturing. Unfortunately, an estimated 1.2 billion people have no electricity connection. Another estimated 2.7 billion people have only very limited access to electricity. In total they represent 53% of the world's population [1].

Access to energy can be viewed as the golden thread that supports the attainment of most of the 17 United Nations sustainable development goals (SDGs) and their sustainability once met [2]. In particular SDG 7: Ensure access to affordable, reliable, sustainable and modern energy for all.

Enel GI&N is facing the challenge of bringing access to electricity to the 100% of the population, in the area of competence of all the DSOs of Enel group; particularly in Argentina, Brazil, Chile, Colombia and Peru where some areas are still not served by electricity grid.

By according to [1], when developing a policy of electrification, it is necessary to consider the medium (10 years) as well as the long term (20 to 30 years) outcomes.

Such a plan needs to include both the extension of existing electricity grids, as well as individual or collective autonomous electrification systems. Optimal results depend on the ability to interconnect decentralized electricity systems at a later time. This requires that the same technical rules are applied for all projects that later need to be interconnected.

For that reason, Enel GI&N is working on:

- the extension of current grid, to reach the closer clusters of population;
- decentralized rural electrification systems (DRESs) able to be interconnected plug&play in case of main grid arrival.

In all cases, the required characteristics of electricity at the user interface must be compliant to the applicable international, national and regional standards, laws or regulations, for example IEC TS 62749 and EN 50160 (only for Europe).

By according to the IEC 62257 series, DRESs are designed to supply electric power for sites which are not connected to an electricity network.

They provide basic electricity access for household, community services (public lighting, pumping, health centers, administrative buildings, places of worship, cultural activities) and for economic activities in the form of micro-industry, workshops or agriculture.

DRES fall into three basic categories:

- Process electrification systems (PES), for example for irrigation and the pumping of ground water.
- Individual electrification systems (IES) for sparsely populated regions or isolated individual households.
- Collective electrification systems (CES) for more densely populated areas, for example a village.

Process and individual electrification systems comprise a relatively simple electricity generation system combined with a single electrical installation.

Collective electrification systems also include a distribution system, becoming a full MG, and interface equipment that links the individual electrical installation of each user to the MG.

In this paper, Enel GI&N solutions for CES and IES will be presented; they were based to the latest evolution of the international standardization and to the state of the technology.

The paper is organized such that the collective electrification system is presented at first. This is followed by the section describing the individual electrification system. Then, a section describes some examples of integrations and tests performed in the Enel smart grid laboratories. Finally, a field implementation will be introduced. Conclusions and future works are presented in the final section.

INDIVIDUAL ELECTRIFICATION SYSTEM

Photovoltaic individual electrification system (PV-IES) are adopted by Enel GI&N.
By according to the IEC 62257 series, the PV-IES is a micropower plant system that supplies electricity to one consumption point with a single photovoltaic (PV) energy resource point, but hybridization with an additional source may be also possible.
In order to reduce the complexity of the engineering process, it was decided to harmonize the PV-IES by defining a common set of specifications, which are fully described in a first global standard (Enel code GSTE103). A summary of this specifications is presented in this section.
The main characteristics of this system are:

- PV-IES user daily consumption, that is a design value of the electrical energy averagely requested at all the user interface of the PV-IES (GSTE103 specifies different configurations in the range 435 ÷ 5000 Wh).
- PV-IES autonomy (at PV-IES user daily consumption), that is a design of the minimum time for which the PV-IES must offer electrical energy to the user in case of no insolation (GSTE103 specifies 48 h).
- PV-IES user min power, that is the max power to assure at the user interfaces in case of absence of PV subsystem generation (GSTE103 specifies different configuration in the range 250 ÷ 2000 W).
- PV-IES user max power, that is the max power to assure at the user interfaces in case of presence of PV subsystem generation (GSTE103 specifies different configuration in the range 250 ÷ 2000 W).
- The PV-IES VRLA capacity, that is the sum of the batteries rated capacity (GSTE103 specifies different configuration in the range 2 ÷ 40 kWh).
- The PV-IES PV peak power, that is according to the peak power definition from IEC TS 61836 applied to the PV subsystem (GSTE103 specifies different configuration in the range 0.15 ÷ 4.5 kW).

The PV-IES operating conditions are showed in table 1.

Table 1 – PV-IES operating conditions

PV-IES type	Nominal operating range	On storage and transport
Temperature	-15 °C ÷ 50 °C	-40 °C ÷ 80 °C
Humidity	0 % ÷ 95% RH, non condensing	
Atmospheric pressure	860 hPa ÷ 1060 hPa	
Altitude	0 m ÷ 2700 m	
Pollution degree (IEC TS 60815-1)	Heavy	
Mechanical impact (IEC 62262)	IK05	
Protection against dust, water and foreign bodies (IEC 60529)	IP65 for type G IP20 for type R	IP20
Shipping vibration (IEC 62093)		10 Hz to 11,8 Hz 11,9 Hz to 150 Hz Amplitude: 3,5 mm Acceleration: 2 g, 1 octave/min Duration on each axis: 2 h Overall: 6 h

PV-IES architecture

PV-IES is made from different components with different scope, Enel GI&N technical specifications organize them in several subsystems (figure 1):

a. primary subsystem;
   i. accumulation subsystem;
   ii. power conversion subsystem;
   iii. PV subsystem;
b. second source;
c. auxiliary subsystem;
d. control subsystem;
   i. communication subsystem;
   ii. management subsystem;
   iii. protection subsystem.

The second source and the DC user interface are generally not required in the most part of the implementations.

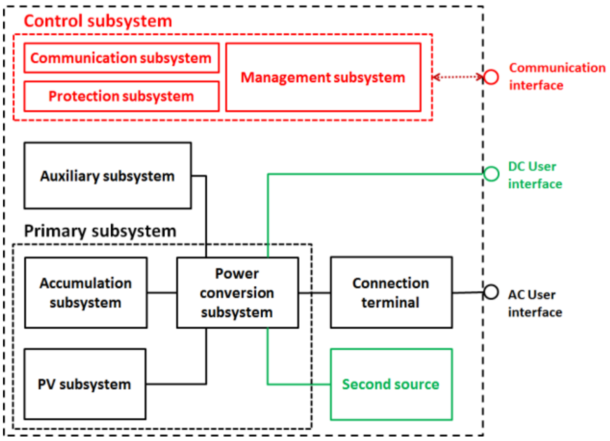

Figure 1 – PV-IES architecture

PV subsystem

The PV subsystem is made by a summarization of PV panels (same model) and accessories in order to create an equivalent DC generator (nominal voltage less than 600 V), with a bipolar terminal to be connected to the power conversion subsystem.
PV panels and accessories must be compliant to the IEC

61215 series, IEC 61730 series, IEC 61853 series, IEC 61730 series, IEC 62790 and IEC 62941.
PV panels efficiency must be at least 15%.

Accumulation subsystem

The accumulation subsystem must be designed to meet the following characteristics:

- high energy efficiency;
- very long life (highest EUROBAT classification);
- maintenance free;
- robust construction;
- high reliability and less self-discharge;
- wide operating temperature;
- low ventilation requirement according to EN 50272-2 and IEC 62485-2.

Accumulation subsystem based on lead acid batteries is requested as basilar requirement; therefore it will be made by several batteries in series-parallel connection. Different storage technologies (mainly NaNiCl and Li-ion) are admitted, but adopted only in specific cases (this topic is better approached in the next section about the collective electrification system).
The IEC 61427-1 describe the general requirement for PV-IES application, moreover additional requirements are provided in the GSTE103, for example:

- type of batteries: sealed maintenance free VRLA type batteries by according to IEC 61056 series and IEC 60896 series.
- tested according to IEC 60896-21 and compliant to defined requirements of IEC 60896-22;
- admissible DC nominal voltages: 12 V or 24 V or 36 V or 48 V or 60 V;
- Ah efficiency: 90%;
- Self-discharge: <2% months at 20°C;
- 1500 aggregate cycles by according to IEC 61427-1 cycling endurance test in photovoltaic applications (extreme conditions), by according to this standard one set of 150 aggregate cycles is approximately equivalent to 1 year service.

Power conversion subsystem

The IEC 62109 series and IEC 62509 describe the general requirement for PV-IES application, moreover additional clarifications are provided in the GSTE103, for example:

- Accumulation subsystem voltage operating range: 0 V ÷ 80 V;
- PV subsystem voltage operating range: 0 V ÷ 230 V;
- transfer time (AC to DC and DC to AC): < 20 ms;
- optimal efficiency: 85%;
- dead battery charge function;
- PV curtailment function;
- MPPT function defined in the IEC 62116.

By according to IEC 62509 battery lifetime protection must be adopted. The IEC 62509 Table A.1 gives suggested battery voltage set-points also for the operation where such information is unavailable from battery manufacturer.

Protection subsystem

IEC TS 62257-5, IEC 61140, IEC 62305 series provides applicable PV-IES protection guidelines, moreover additional clarifications are provided in this section.
The protection subsystem includes one or more protection equipment, instrument transformer(s), transducers, wiring, tripping circuit(s), auxiliary supply(ies). Depending upon the principle(s) of the protection subsystem, it may include one end or all ends of the protected section and, possibly, automatic reclosing equipment. Breakers must be adopted as much as possible, the adoption of fuses is allowed where no alternatives.
The principle associated with PV-IES protection can be described as “3S":

- selectivity (whether to trip or not);
- sensitivity (whether a fault can be detected);
- speed (the trip time).

In particular, the PV-IES must work also in case only one subsystem is available between the accumulation subsystem, PV subsystem and second source.
In the PV-IES high current detection protections are not allowed, current differential and voltage drop must be used (see IEC 60255 series).

Communication and management subsystems

Because of possible unavailability of communication networks in rural area, the PV-IES operate mainly in stand-alone mode without interoperability with external links.
The PV-IES must be equipped with Human-Machine Interface (HMI) based on web server. Security policy based on username and password must be implemented in order to avoid not desirable accesses.
The HMI must allow:

- to visualize all the measurement performed by the PV-IES in real time;
- to manage all the data stored in the PV-IES internal data storage;
- to manage the data exchange and communication issues;
- to perform all possible settings (including the first installation settings);
- to manage PV-IES alarms and warnings.

Configuration settings must be also uploaded as a single file.
The PV-IES management subsystem must optimize the energy management in order to assure the maximum usage of the PV source when available. The energy management must adopt countermeasures against deep discharge more than a predefined threshold (that depend from the adopted storage technology).
The energy management strategy is approached in the next section about the collective electrification system.

COLLECTIVE ELECTRIFICATION SYSTEM

Collective electrification system based on hybrid photovoltaic (HPS-CES) are adopted by Enel GI&N.
By according to [4], the HPS-CES combines two or more sources of renewable energy as one or more conventional energy sources. The renewable energy sources do not deliver a constant power, but due to their complementarities and the hybridization with conventional sources, this combination provides a more continuous electrical output. The purpose of a HPS-CES is to produce as much energy from renewable energy sources to ensure the load demand. HPS-CES includes a full MG, therefore a grid design is needed.
The PV-IES may be used to introduce the HPS-CES; in fact, the architecture in figure 1 is completely applicable with the following clarifications:

- the second source of energy is generally present and it is a diesel generator;
- instead of a single AC user interface, a distribution grid is present;
- the communication interface with external links (DSO SCADA) is needed by using the Enel standard RTU.

The HPS-CES operating conditions are showed in table 1.
With reference to the other main characteristics (user daily consumption, autonomy etc.), the HPS-CES is a system that must be planned case by case; the approach used for the PV-IES to define several configurations is not pertinent. Nevertheless several specifications for the PV-IES subsystems are fully applicable.
For that reason this section will emphasize only the main differences between the two systems.

Accumulation subsystem

The bus voltage is standardized to 48 Vdc and the interoperability trough MODBUS with the conversion subsystem is required (except for lead acid batteries).
In addition to lead acid batteries NaNiCl and Li-ion batteries are integrated.
This new storage options are needed mainly in the geographic areas with severe climatic conditions, where the lead acid batteries health may decrease rapidly, or with logistic constraints, where the weight and the replacement needs must be reduced.

Protection subsystem

The adoption of overcurrent protection is enough only in case of diesel generation. Anyway, the presence of different voltage levels (and therefore neutral point earthing status) may strongly influence the fault detection.
Advanced fault ride through (aFRT) is assured at for PV and storage. FRT is the capability to stay connected in short periods of abnormal electric network voltage; with aFRT during that period the power conversion subsystem also inject at least its rated current to the MG.
Thanks to aFRT, voltage measurements may be used for fault detection and current measurement for fault location.

Management subsystem

As discussed before, the purpose of a HPS-CES is to produce as much energy from renewable energy sources to ensure the load demand.
Therefore an automatic management routine is implemented, an illustrative example (figure 2) facilitate the explanation:

- the PV is used as a preferential source, it is shaved only with load fully covered and storage fully charged;
- the diesel generator is used as integrative source and in its efficiency range, only in case of no alternative, the diesel generator is used at very low powers;
- the storage is dimensioned in order to have a trade off between operational and capital costs, it is mainly used at low power, to avoid inefficient diesel generation operation.

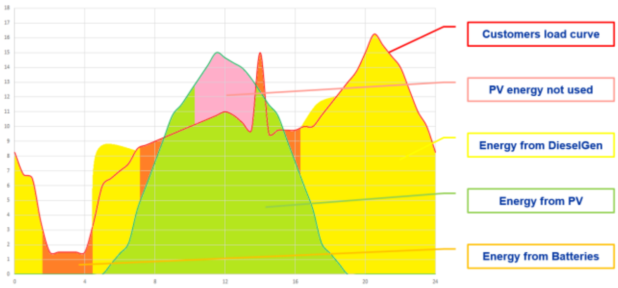

Figure 2 – Illustrative example of energy management

TESTS AND INTEGRATIONS

Tests and integrations activities are performed in Enel laboratories first by replicating the field configuration by using both real devices and emulator.
As an example, a current HPS-CES configuration (figure 3) and the replica in the Enel laboratory (figure 4) are represented.
Generally only diesel generator, PV, batteries and loads are emulated thanks to load/generation emulator, the rest of the devices are real.
The main integration tests are related to:

- interoperability between the subsystems and within the Enel RTU (UP);
- energy management and protection strategies.

These tests are very important because the HPS-CES and PV-IES are multibrand systems integrated by Enel GI&N, so is Enel GI&N the responsible of system integration. As an example, the HPS-CES in figure 3 is a Schneider Electric Conext platform [5] customized for Enel GI&N, integrated with FZSonick 48TL200 batteries [6] and Enel UP.
Enel laboratory in Bari (Italy) is entrusted for HPS-CES and Enel laboratory in Sao Paulo (Brazil) for PV-IES.

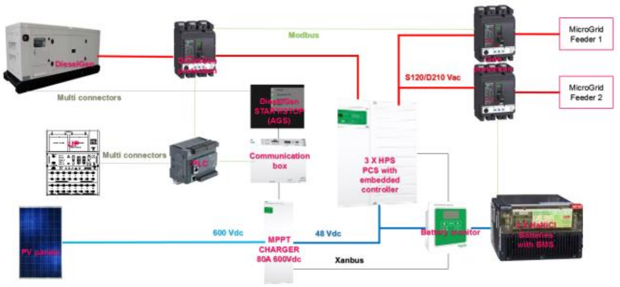

Figure 3 – One of the current HPS-CES configurations

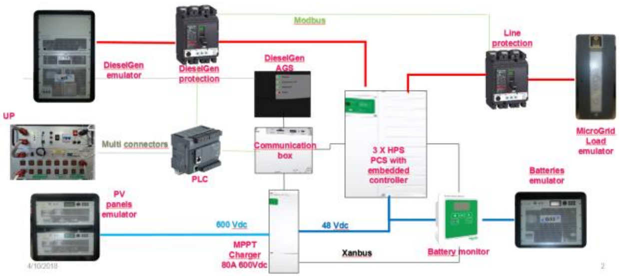

Figure 4 – The HPS-CES configuration in the Enel laboratory

PARATEBUENO PILOT PROJECT

The Paratebueno area is located in Colombia as an non-interconnected areas (ZNI in Spanish), that are defined in Colombia as areas "where it is not provided the electric public service through the National Interconnected System (SIN – Sistema Interconectado Nacional)" [7].

Figure 5 – Drone picture of the Paratebueno MG

The Paratebueno MG pilot (fully operating from the 1Q 2018) is the first HPS-CES implementation of Enel GI&N, the main characteristics are (figure 5):

- 18 houses, 1 grocery store, 1 church, 1 school and public lighting (19 LED lights) served with around 156 kWh/day consumption;
- 22 kWp PV, 20.5 kVA diesel generator, 225 Ah VRLA batteries;
- MV (13.2 kV) and LV (208 V) grid with 1 step-up transformer (45 kVA, 3 phases, 208 V / 13.2 kV), 2 step-down transformers (15 kVA, 3 phases, 13.2 kV / 208 V) and 3 step-down transformers (5 kVA, single phase, 13.2 kV / 208 V).

Each users signed an agreement with Codensa (local Enel DSO) for the service provision and payment. One meter per end user is installed for statistics purposes and data collection; invoicing is done through flat rate tariff.

CONCLUSIONS AND FUTURE WORKS

This paper presented the Enel GI&N rural electrification solutions and a consequent field implementation.
Enel GI&N specified a collective electrification system based on an enhanced and modular hybrid diesel/photovoltaic/storage system (HPS-CES), able to be interconnected plug&play in case of main grid arrival.
The prototype version of the system has been assembled and tested at the Enel Smart Grid Laboratory in Bari (Italy). After these performing tests, first implementation has been activated in a Colombian village, around 300 additional sites are expected.
Enel GI&N specified a photovoltaic individual electrification system (PV-IES) based on an enhanced and modular hybrid photovoltaic/storage system.
Large area implementation (around 100 PV-IES) is under deployment in Brazil, around 4000 new sites expected.
The idea to combine traditional Enel GI&N approach (in-house design through technical specifications) with the innovation by vendor from commercial solution has the following reasons:

- turned key commercial solutions with specific design are expensive for such number of installations;
- commercial solutions did not include the features Enel GI&N needed and they rarely integrate storage solutions not dependent to temperature.

Future works will also deal about:

- enhanced protection scheme;
- enhance energy management;
- new storage options.

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