IElectrix Project – Results and lessons learned from the Indian demonstration in Delhi

Pierre-Jacques Le Quellec
Project Director
Smart Grid Program, Enedis
Paris La Défense, France
pierre-jacques.le-quellec@enedis.fr

David Pampliega
Project Manager
Schneider Electric
Seville, Spain
david.pampliega@se.com

Abhinav Pal
CEO Cell
Tata Power Delhi Distribution Limited
Delhi, India
abhinav.pal@tatapower-ddl.com

Tanguy Choné
Project Manager
Odit-e
Meylan, France
tanguy.chone@odit-e.com

Chloé Lucas
Data Analytics Engineer
Odit-e
Meylan, France
chloe.lucas@odit-e.com

Robin Croutz
Site Coordinator
Smart Grid Program, Enedis
Delhi, India
robin-externe.croutz@enedis.fr

Abstract

IElectrix is a response to the Horizon 2020 Call of the European Commission: "Integrated local energy systems", which experiments 1 demonstration in India and 4 demonstrations in Europe. "Local energy systems" is a mix of locally generated power and consumption, thereby addressing the challenges of Renewable Energy Sources penetration and network associated challenges in case of reverse power flow back to the grid.

The Indian demonstration is the first pilot project co-financed by the European Commission to physically implement an urban Low Voltage (LV) Microgrid in Delhi.

Most of the equipment and software have been designed and manufactured in Europe. Therefore, after having shipped the configuration to Delhi, all the different equipment and systems have been installed and commissioned in March 2022 at the demonstration site, which is the St. Xavier Sr. Secondary School substation in Delhi operated by Tata Power-DDL.

After resolving several technical issues encountered during the summer period, the experimental phase of the Indian demonstration was carried out in the second half of 2022. The objective of this phase was to test the microgrid with its islanding capability in order to assess the potential improvements in terms of quality and continuity of the LV distribution power supply at the secondary substation of St. Xavier School.

The paper presents a technical description of the results obtained as well as the lessons learnt from this smart grid project.

I. Introduction

The Shakti demonstration, located in Delhi, implements a microgrid solution being deployed in the St. Xavier secondary substation and its associated low voltage (LV) grid.

This document begins with a brief presentation of the final configuration of the microgrid installed on the site.

Then, the main results obtained during the experimentation period are presented in the following domains:

- Local monitoring
- Improvement of the resilience of the local energy system
- Frequency management
- Voltage management

Eventually, the main challenges met during the testing phase of the demonstrator are presented along with the associated lessons learnt.

II. Microgrid final configuration

Shakti Microgrid demonstration is connected to a Tata Power-DDL distribution network through 3 LV feeders, with existing 3 PhotoVoltaic (PV) fields. A set of equipment including a smart MV/LV transformer with on load tap changer to enhance the community's electricity quality and renewable hosting capacity, an Energy Control Center which enables electrical safety and cybersecurity, a Battery Energy Storage System (BESS) allowing the electrical back-up in case of a Medium Voltage (MV) grid loss, were installed in order to transform the classical secondary substation into a smart and more resilient one, as represented in Fig. 1. This configuration is managed by a Supervisory Control And Data Acquisition System (SCADA) and an Energy Management system (EMS).

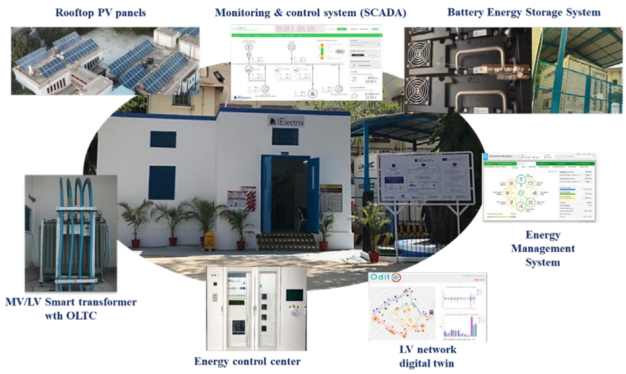

Fig. 1. Shakti on site final set-up

III. MAIN RESULTS OF THE DEMONSTRATION

A. Local monitoring

A.1. Local monitoring through the SCADA system

The system that has been deployed includes a detailed logging of the status of the main components of the demonstrator, as well as the value of the main electrical parameters of the LV distribution grid. Hundreds of signals have been configured to be continuously monitored and sent to the SCADA system, so the operators could know at every moment the status of the installation and have the right information to operate it in a proper way. Those signals are also stored in the SCADA database, to show a greater insight about past events on the installation.

Fig. 2. Trend of the frequency of the electric grid as collected in the SCADA.

Besides the usual electric parameters (voltage, currents, power, frequency), and the status of the breakers (open/close), other parameters like temperature and humidity are also collected, to be used for condition monitoring purposes and to anticipate the need for maintenance of the monitored installation.

Finally, and to support the local monitoring of the installation, detailed system and alarm logs are available to shed light about specific situations affecting the demonstrator. For instance, they are useful to identify communication instability, availability of power on the main grid, status of the battery energy storage system, and so on.

A.2. Local monitoring through the Odit-e software

A LV Grid Observability software developed by Odit-e within the IElectrix project allows Tata Power-DDL to monitor its LV grid.

The analysis has been built based only on the data coming from the smart meters connected to the St. Xavier secondary substation.

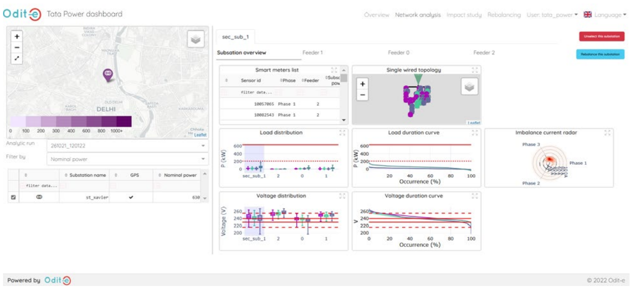

Fig. 3. Network Analysis through the Odit-e software

It displays to the user different widgets that have different applications for the Distribution System Operator (DSO).

The two first widgets show the retrieved topology of the LV grid, meaning that only with smart meters data and Machine Learning (ML) algorithms, Odit-e was able to find the meter-to-phase and the meter-to-feeder associations. This information was crucial for Tata Power-DDL in order to confirm or correct Geographic Information System (GIS) data that is often unreliable.

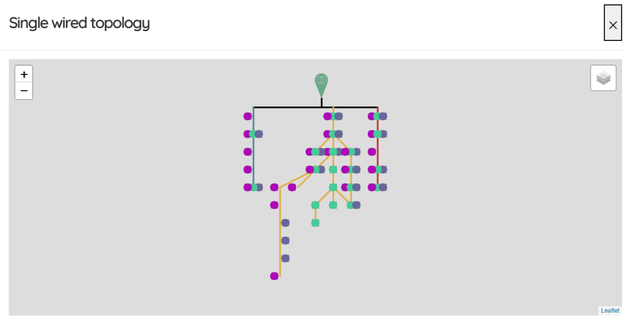

Fig. 4. Graphical representation of the retrieved topology in the Odit-e software

The following widgets provide a statistical overview of the condition under which the St. Xavier secondary substation is operating, with views such as duration curves (voltage and load), distribution boxplots (voltage and load), and a radar of imbalance.

All these tools enable Tata Power-DDL to monitor the LV grid and take corrective actions if necessary. Concretely, such actions consist of rebalancing plans or changing the taps of a distribution transformer to mitigate voltage excursions and high neutral current issues.

This software tool showed overall that the substation studied during the IElectrix project was not overloaded and was not too imbalanced. However, many voltage excursions have been identified, mainly over voltages happening during the nights when consumption is low.

On one hand, voltage plan happens to be set at a high level to compensate the important drops during the day. PV production on another hand allows to mitigate voltage drops drop during the day, which occur mainly in the mornings and evenings (see Fig. 5).

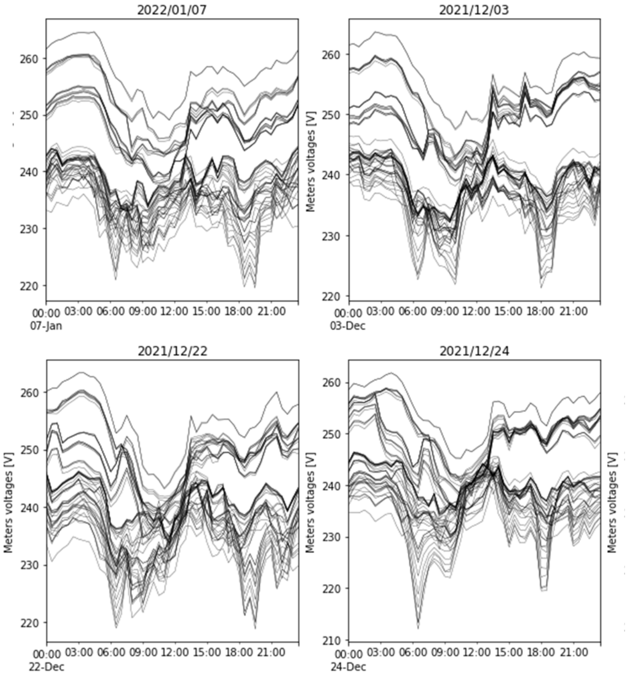

Fig. 5. Voltage time series for all meters and all phases on 4 random days

B. *Improvement of the resilience of the local energy system*

For the India demonstrator, the type of customers obliges the DSO to maintain a high level of power continuity.

Firstly, feeder 1 of the switchboard is connected to St. Xavier's School which has over 4,000 students and many teachers and staff. A power cut during an examination period or simply during teaching days must be avoided. Secondly, feeder 2 supplies critical government establishments and associated area where Tata Power-DDL is committed to providing the highest quality of supply.

An issue on the grid, like under/over voltage and under/over frequency is detected by a MiCOM P923 relay acting on the under voltage release coil of the main breaker.

For the Shakti demo, the conditions to switch to islanding mode have been set as unavailability of the main utility grid for a maintained number of seconds, and while the BESS is in good condition without presenting operating alarms.

In November 2022, an islanding test was performed with the St. Xavier School.

The goal was to simulate a loss of the grid and analyze the complete cycle:

- Sequence of operation from ON grid to OFF grid.
- Capability of the BESS to supply the customers.
- Sequence of Operation from OFF grid to ON grid mode.

During 30 minutes, Schneider Electric, Enedis and Tata Power-DDL teams monitored the state of the system through a remote session access to the SCADA system. As shown on the following figure, the main CB was opened and the BESS was power supplying the school.

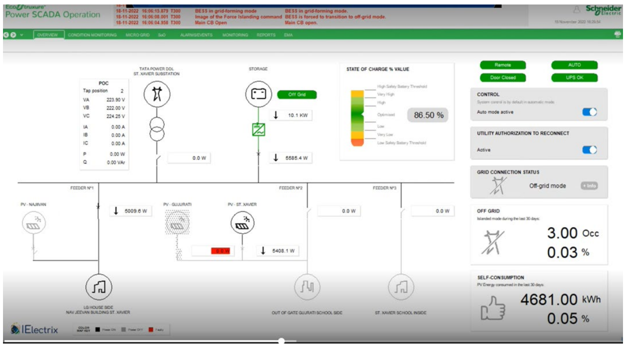

Fig. 6. Main screen of the SCADA system during the islanding test on November 2022.

The total consumption of the school was around 10 kW, having 5 kW supplied by the PV production and 5.5 kW by the BESS.

In parallel, the battery cells delivered 10 kW of power and only 5.5 kW were injected on the network. Indeed, the HVAC system to cool the container consumes in average 4 kW of power.

Fig. 7 highlights the islanding process from a voltage point of view.

The first drop corresponds to the loss of the grid and then, the feeder voltage is maintained at 230V during the test until the reconnection to the grid, marked in this case by a slight increase of the voltage.

Fig. 7. Trend of voltage during the islanding test on November 2022.

C. *Frequency management*

The deployed solution includes a feature for automatically regulating the frequency of the low voltage grid of the demonstrator. Thanks to the real-time monitoring of the frequency of the installation, and to the thresholds that have been defined, the system is able to automatically charge/discharge the BESS when any of the thresholds are crossed, in order to restore the frequency measurements to the desired values.

This feature was tested during March 2022, and it is displayed in Fig. 8. The figure shows in green the frequency measurements of the main circuit breaker of the substation, and in black the charging/discharging of the BESS. A positive slope in the black line means that the BESS would be charging, consuming energy from the grid. On the other hand, a negative slope would mean a discharging of the BESS.

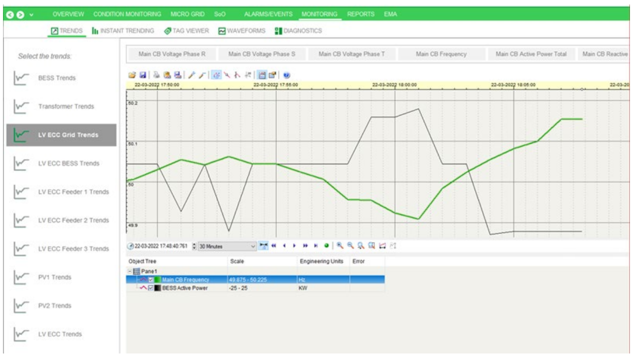

Fig. 8. Frequency regulation test on March 2022

In the test illustrated in the figure, it is possible to observe that when the frequency went down beyond a specific threshold, a command was given to the BESS to inject energy to the grid, and as such, provoke an increase of its frequency.

D. Voltage management

As shown by the Odit-e LV Grid Observability software based on smart meters data (previously described in section III, A.2), the demonstration site faces network instabilities due to weak infrastructure, especially voltage drops and peaks which pose a challenge for stable and reliable grid operation.

Because of that, voltage management is another aspect addressed by the solution deployed in Shakti demonstrator. It relies on a Minera transformer able to be remotely regulated, on an Easergy T300 regulation algorithm implementation, and also on the optional inputs that may come from the LV Grid Observability software developed by Odit-e. The ambition is to regulate the voltage level of the energy community, to provide to the users of such community a stabilized voltage supply.

Minera transformer provides on-load tap changers that can be remotely commanded to adjust in real-time the voltage level of an electrical installation. That regulation is commanded by an algorithm embedded in Easergy T300 Remote Terminal Unit (RTU), and takes into account the voltage values in the Shakti secondary substation. Based on several thresholds that have been defined, the RTU is able to identify which is the right voltage setting for the mentioned on-load tap changers of the transformer.

Complementary to the regulation algorithm executed in the RTU, it is possible to combine the regulation with the outputs of the LV Grid Observability software, a digital twin of the LV grid based only on smart meters data. Odit-e grid observability software, as in [2], estimates and predicts voltage values for the LV side of the substation. The use case consists here in sending those voltage estimations to the RTU, as an input to regulate the On-Load Tap Changer positions which manage the voltage plan of the local grid.

The following graph sums up the voltage management process:

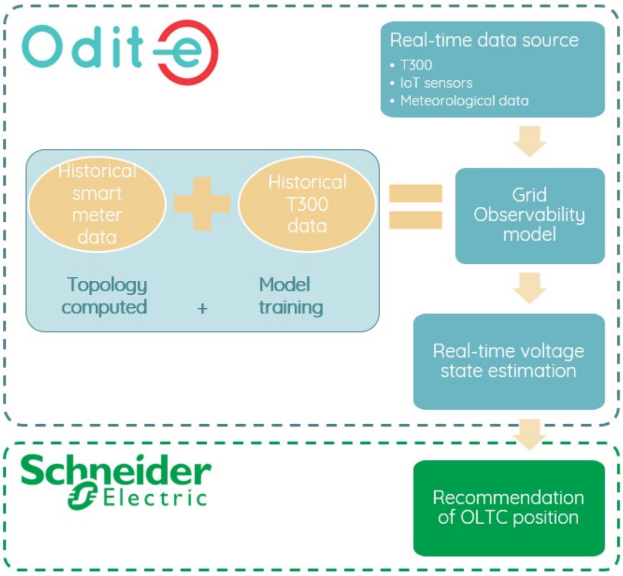

Fig. 9. Summary of the voltage management by Odit-e with integration of historical smart meter data and real-time data from Easergy T300

This regulation by using inputs from the LV Grid Observability software is an optional one, as in the event that the communication with such a system was not available, the regulation of the MV/LV transformer could still be performed by using the local regulation algorithm implemented in the RTU.

IV. Challenges and Main Lessons Learnt

A. Impact of domestic electrical installations

As the Shakti demonstrator involves real customers, the amount of testing that could be performed on site is rather limited. Because of that, once the system was deployed, just one of the 3 feeders was connected, and the remaining two ones were fed by a nearby substation, in order to minimize the level of disruption for the customers.

Although the microgrid was tested in a real MV/LV network platform in France before being shipped to India, it was impossible to test the protection scheme with the actual electrical installations of customers in Delhi. After the first feeder was connected to the system, it was found that the protection scheme was not well suited to the electrical installations at the demonstration site. Several protection relays had to be replaced at site with local devices supplied by Tata Power-DDL, as the supply of European equipment was difficult due to the post Covid global supply chain crisis.

Implementing an innovative demonstrator in India using equipment fully designed and supplied in Europe is a challenge, especially after the sanitary crisis. Therefore, it is highly recommended to use as much as possible local sourcing of equipment.

B. Impact of external environment on HVAC system

The Lithium-Ion battery cells required to be maintained at a temperature of around 24°C and in a clean environment.

The harsh environment of Delhi (very high temperatures and extreme air pollution) has impacted the operation of the 2 Heating Ventilation & Air Conditioning (HVAC) units of the Battery Energy Storage System (7 kW cooling capacity).

Indeed, the accumulation of fine particles and dust in the filter stifles airflow and forces the HVAC systems to compensate by increasing its outputs. This in turn results in higher energy consumption and a reduction of filtering capability. Increased air conditioner output means the unit runs at full throttle most of the time. This puts constant stress on the system, which can lead to frequent breakdowns and increase the risk of thermal runaway.

The compressor units of the 2 HVAC were replaced after several interventions of the supplier.

Finding a European HVAC supplier which meets both the thermal performance (50°C) and the sizing (2 units in a 10 ft container) requirements to operate in Delhi is not easy. Furthermore, it is necessary to clean the HVAC filters every month during the pollution period.

V. Conclusion

Implementing a microgrid solution on a LV network raises many technical challenges. Ensuring compliance with electrical protection standards in both grid connected and grid islanded modes, performing the use cases tests while minimizing the disturbances for the consumers or simply limiting the technical problems are complex tasks that need to be thoroughly studied before the implementation begins.

Being in India brings also additional challenges related to the environmental conditions and the lack of local support for the European technologies.

Even though site studies have been performed before designing the demonstrator, several modifications had to be made during the commissioning phase to adapt the system with the domestic electrical installation and the Indian environment. Following these modifications, the islanding test to increase the resilience of the local grid has been tested successfully. In parallel, the microgrid system put in place has provided real-time data and a better understanding of the LV network and of both the consumer consumption and behavior of PV panels.

At the time of writing this paper, the demonstrator is in operation, and it is expected that further testing and tuning activities are performed until the project finalization at the end of February 2023.

Besides the testing constraints faced during the project due to the installation of the demonstrator in a real-substation currently under operation, the results provided in this paper are promising, and are the outcome of the close collaboration between project partners Enedis, Tata Power-DDL, Schneider Electric and Odit-e.

Acknowledgment

The activities described in the paper are relevant for the SHAKTI demonstrator to be implemented in the IElectrix project. IElectrix project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824392.

This paper reflects only the authors' view and the Agency and the Commission are not responsible for any use that may be made of the information it contains.

References

[1] IElectrix deliverable D9.1 Design of solutions – Indian demonstration. Available online: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5ddbfb1f0&appId=PPGMS (accessed on 15 12 2022).

[2] Richaud L., Implementation of a local flexibility market for solving network issues, CIRED 2020, Paper 0367