Off-Grid and Grid-Tied Microgrid Operation

Seamless transitions at the MASERA microgrid testbed.

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***Abstract*—This article presents the EDF MASERA microgrid testbed, conducted in partnership with NTU (Nanyang Technical University) on Semakau Island (Singapore) for which one of the research objectives is to implement a fully optimized solution to maximize the share of renewable in its energy mix. Seamless transitions between islanded and grid-connected modes have been successfully tested thanks to EDF Energy Management System LiteDERMS and Socomec SUNSYS PCS² BESS power converter.**

Keywords-component: Microgrid – Smartgrid – Sustainable energy – Storage – Isolated area –Load management – Flexibility - Distributed Energy Resources Management System – Energy Management System – Demonstrator - Singapore.

I. Introduction

The MASERA (Microgrid for Affordable and Sustainable Electricity in Remote Areas) project is part of REIDS (Renewable Energy Integration Demonstrator – Singapore) cluster project.

Launched in 2016, REIDS is a research project led by Nanyang Technological University (NTU) and backed by the Economic Development Board (EDB) and the National Environment Agency (NEA) in Singapore. It primarily consists in designing, demonstrating and testing solutions for sustainable multi-activity off-grid communities in Southeast Asia. In October 2017, EDF, has signed a four-year Research Collaboration Agreement with NTU to benefit from this largest in the world hybrid interconnected multi-vendor microgrids testbed and research platform in an equatorial harsh environment.

Figure 1 MASERA within REIDS environment (Source: NTU)

The reason for this project is that around 1.2 billion people on earth do not have access to electricity and an even higher number do not have access to proper sanitation, including drinking water. Most of this population live in Africa, in Southeast Asia and in South America. It is unrealistic to imagine on the short term that the solution to provide this access will be through interconnected transmission systems with upgrade or additional grid connection lines. Therefore, the solution that enables a faster access to 24/7 greener energy seems to be localised, decentralised networks: off-grid hybrid microgrids.

II. Masera project

Innovative technologies leveraging the potential of renewable energies as well as digital grid solutions offer new perspectives for microgrids development in isolated areas typically facing a lack of grid infrastructures, reliability issues and CO_2 emissions regarding electricity supply and growing needs towards affordable energy supply to ensure local economic growth.

In the recent years, EDF has developed multiple innovative microgrid solutions including a 100 percent renewable energy system on La Réunion island, the Nice Grid demonstrator in Carros near Nice, hybrid microgrids in Toucan and Kaw in French Guyana, also on Ile de Sein to become a fully renewable island. EDF has then an extensive experience designing, developing and operating microgrids in various environment and areas of the world.

In October 2018, EDF commissioned the MASERA demonstrator (Microgrid for Affordable and Sustainable Electricity in Remote Areas) on Semakau island located in the Singapore strait. Designed, built and deployed in only one year, this innovative microgrid testbed aims at demonstrating EDF expertise, skillset, technologies, research and references in microgrids and smart grid development. Supporting EDF microgrid industrial solutions, MASERA is a combination of a pre-commercial solution and a R&D project with innovative hardware/software and objectives.

Figure 2 Semakau Island (Source: NTU)

MASERA aims to design, develop, test and promote an innovative and affordable microgrid solution based on three key objectives:

- Affordable: containerized, remote control and monitoring, optimized design and components.
- Sustainable: maximization of renewable energy, limited environmental footprint.
- Reliable: industrial grade solutions, standardized, cyber secured and smart controls improving resiliency.

Combining EDF unique expertise, know-how and innovative technologies, MASERA aimed to be EDF leading project for isolated and remote areas electrification. One of the partner of EDF for this project is Socomec, a French manufacturer specialist in conversion, including storage converters. This company is supplying the lithium-ion battery energy storage system. Both companies have been in touch through the French professional association Think Smartgrids, of which both of them are members. This association aims to develop the smart grid sector in France and to promote French solutions in Europe and around the world. https://www.thinksmartgrids.fr/en

III. Sizing of the Installation

MASERA is a demonstrator installed on a site were no electric grid or installations were present, meaning that the entire sizing has been done by EDF from scratch. Since this is a R&D testbed, no customers are connected to MASERA, load curves representative from EDF commercial projects in South-East Asia were used to size the generation assets accordingly.

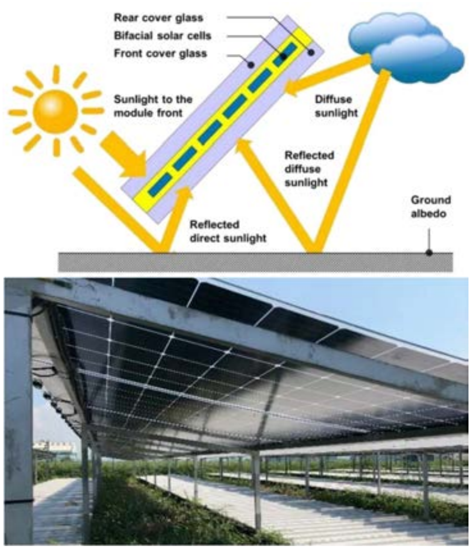

Figure 3 Bi-facial PV panels principle and installation in MASERA

A. Generation Assets

Most of remote areas are powered by diesel gensets, which are typically costly, noisy and polluting. The idea of MASERA project was first to demonstrate that the solution was able to adapt to existing facilities, with a diesel genset and photovoltaic bi-facial panels, and then, to get rid of the genset, in order to increase the renewable energy penetration up to 100%, inducing reducing the operation and maintenance costs (fuel, transportation,…) and the pollution.

Bi-facial dual-glass PV panels – as shown in figure 3 - are very suitable for tropical context as weather and climate: diffuse irradiance, constant all over the year, saline pollution etc. allowing producing up to 20% more electricity in comparison with classical PV panels, at an equivalent cost. In MASERA in order to increase the benefit of the rear face, reflecting white corrugated steel panels (very low cost) have been disposed between PV arrays.

A diesel generator – figure 4 - equipped with an advanced controller is as well part of the generation assets. The main objective of the MASERA microgrid is to minimize the use of this fossil-based generation but it was mandatory to support the innovative use cases developed during the R&D operation run and to keep it in order to ensure minimal generation in some very specific situations.

Figure 4 Diesel Generator and advanced controller to enable microgrid support for innovative R&D use cases

B. Load Assets

MASERA is taking advantage of the Semakau Island testbed particularity to demonstrate different patterns of innovative loads in terms of characteristics, electrical needs and functionalities. Despite the fact that MASERA is a demonstrator, the loads have been designed and chosen in order to be as representative as possible to the market and to show the versatility of the solution, addressing key objectives such as sustainability and electric mobility.

1) V2G integration

Electric vehicles tends to be one of the most promising global markets, with many stakeholders. MASERA hosts an EV (Nissan Leaf) allowing to test breakthrough features: flexibility, vehicles to grid (V2G), smart charging…

Combined with the Nuvve charging station, V2G capability brings more energy flexibility and is a lever for grid optimization. This secondary storage is able to answer to peak demand and can do system services such as frequency regulation.

In addition, the EV completes our idea of circular economy, as the battery, at the end of its first life could be upcycled as a second-life energy storage system.

2) Load Simulation

MASERA targets various remote territories and applications: from remote villages with energy access improvement, to more sophisticated cases such as resorts or military application. This means the solution needs to meet local expectations in terms of sizing and power generation as well as the criteria to support socio-economic development.

Thus, the programmable load banks on MASERA allow simulating a large number of use cases and consumption curves in order to fit the solution at the closest to the reality.

Figure 5 Electric Vehicle with V2G charging station

Figure 6 Load Bank

Those load banks are operated with a differentiated status: one is considered a critical load while the other is non-critical. This allows EDF to test advanced load management for microgrids thanks to smart algorithm in its in-house EMS called "LiteDERMS".

C. Storage Assets

MASERA hosts two technologies of batteries, with different technical characteristics, both innovative.

1) Lithium-Ion based Battery Energy Storage Systems

The first energy storage system is composed of a power converter, a lithium-ion NMC battery and a microgrid control cabinet supplied by Socomec, able to ensure grid availability for several hours (according to the load) as well as absorbing production peaks (from photovoltaic panels). Thanks to its advanced inverter, the system allows to maintain grid frequency and voltage (i.e. "Grid-Forming" mode) in order to rely on 100% renewable energy.

2) Zinc-Air a breakthrough eco-friendly technology

EDF believes that the batteries of the future will be efficient, affordable, safer and environmentally friendly. The zinc-air technology is a promising technology that fully meets these expectations. The zinc-air technology relies on an anode, made of zinc, and a cathode using the ambient air, more precisely its oxygen, to allow the chemical reactions within the cell. The air electrode is a complex membrane, permeable to air, but impermeable to the aqueous solution which constitutes the electrolyte of the battery.

This technology is addressing other load needs than the traditional Li-Ion battery, focusing on more diffuse energy request. Zinc-Air battery has a similar energy mass density as Li-Ion and can store large amount of energy but with limited power output making it a good match with residential load.

This MASERA initiative is the perfect testbed to optimize the complementary behavior of those two different storage technologies.

Figure 8 Socomec NMC ESS (converter on the left, battery on the right)

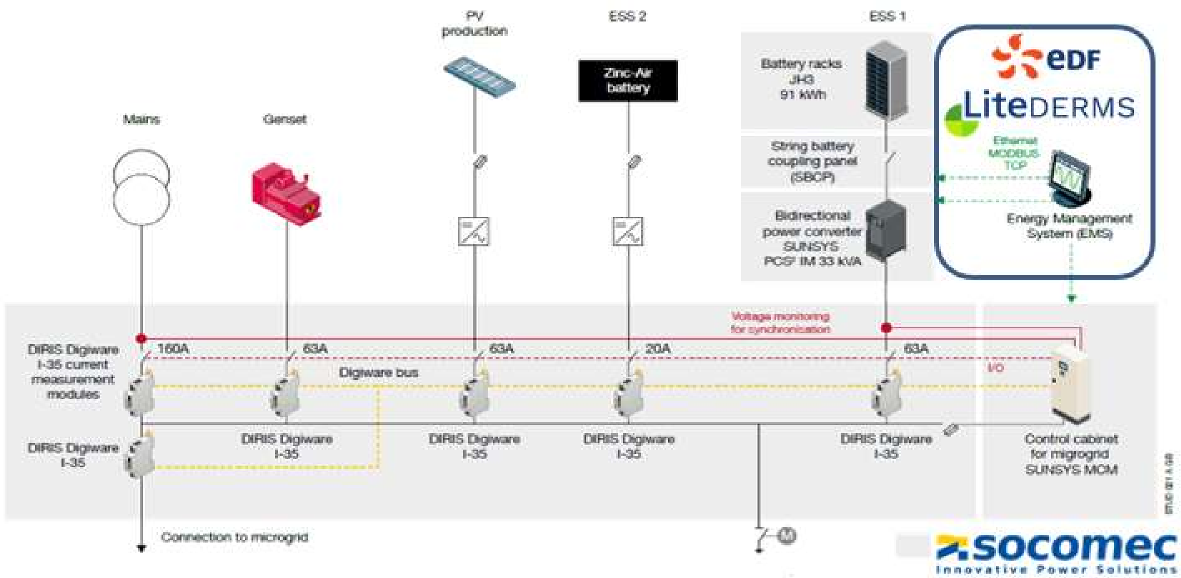

Figure 9 MASERA Single Line Diagram and scope

Zinium is a young French innovative company established in 2016, spun off EDF R&D research laboratories to develop innovative products based on zinc-air batteries.

The single line drawing – figure 9 - presents all the above-mentioned elements. In grey, can be found what is under SOCOMEC scope of supply..

IV. Microgrid Seamless Transitions

Energy Management System (EMS) constitutes a key element for the optimal design and operation of microgrids. They can help maximize renewable energies in the mix considering the demand (load curve) and forecasted generation. Their functionalities, sometimes included in smart inverters directly provided in the suppliers' equipment, will depend on the microgrid, tis capacity and its specific needs. They shall also rely on communication standards to ensure inter-operability between microgrid equipment. In that regard, IEC61850 is becoming a worldwide reference. Microgrid communication channels, software and hardware components should be carefully secured from a cyber-perspective.

EDF R&D has developed in-house a dedicated EMS called LiteDERMS to operate microgrid for rural electrification. It is a simple to configure and to commission, affordable and highly evolutive control solution for remote areas. This LiteDERMS solution leverages EDF R&D expertise in microgrid control and software architecture.

MASERA is equipped with two grid-forming generation assets: the diesel Genset and the Socomec Lithium-Ion battery. The grid of microgrids when MASERA is operating in grid-tied mode is providing a third "grid-forming" source.

Several transition use cases between those grid-forming sources were tested using LiteDERMS EMS and Socomec ESS, they are detailed here after. The first transition tests were conducted with MASERA in islanded mode in 2019 and the transition tests with MASERA in grid-tied mode in 2020.

A. Transition in islanded mode

1) Blackstart

The 'blackstart' function; commonly referred to as "coupling on shutdown" in the world of gensets, involves the gradual restoration of the supply voltage on the microgrid to avoid an excessive inrush of current (e.g. magnetizing spikes in transformers). Two ways of performing blackstart have been tested and are detailed just after.

Step N°	Diesel Genset	SOCOMEC Battery System	UPS	Critical Load (EMS, HVAC...)	PV	Load Bank	Others(EV...)
Step 0	Blackstart from only UPS and critical load operating status.						
	OFF	OFF	ON	ON	OFF	OFF	OFF
Step 1	Energy in Li-ion battery is not enough, so firstly switch on genset as power source.						
	ON **(Grid forming)**	OFF	ON	ON	OFF	OFF	OFF
Step 2	ON **(Grid forming)**	ON (Charging) **(Grid following)**	ON	ON	OFF	OFF	OFF
Step 3	ON **(Grid forming)**	ON (Charging) **(Grid following)**	ON (Fully-charged)	ON	OFF	OFF	OFF

Figure 10 Asset status during Blackstart with genset as Grid-Forming

a) Blackstart with genset in Grid-Forming

The initial state is the following: the microgrid UPS supplies the critical loads apart from this all equipment are off and all breakers are open; the battery state of charge of is too low to sustain the microgrid.

From this situation, what happens is that the diesel genset is started, as the battery charge level is too low, and he is the master of the microgrid, acting as grid-former.

The next step is the startup of the energy storage system (ESS) that will be working as current generator, following the master – genset. In this way of operation there is no issue, the ESS follows the P, Q set points given to it.

b) Blackstart with battery energy storage system in Grid-Forming

The initial state is the following: the UPS discharges to supply critical loads; apart from this all equipment are off and all breakers are open; the battery state of charge of is high enough to sustain the microgrid.

From this situation, the ESS is started and he works as a voltage generator to be the master of the microgrid. Once voltage and frequency are in the right ranges, the other sources and loads can be started. The status of the assests during this process is presented in the table – figure 12.

If the state of charge level of the battery gets too low the diesel genset is started to recharge the battery and supply the microgrid.

c) Conclusion

Both tests had positive outcomes, which means that an energy storage system is perfectly able to replace a diesel generator to supply a microgrid.

2) Transition of Grid-forming assets

Once we know that both diesel genset and energy storage system are able to act as grid former, the point is to check if it is possible to go from one master to the other seamlessly without any perturbation on the load.

a) Genset grid forming to battery grid forming

At the beginning both systems are on and operating in parallel.

When the ESS start-up is requested, the Energy Management System (EMS) asks for the power ramp up of the PCS; through the Power Management System (PMS), thus doing a ramp down of the genset's power, in order to erase the current flow on the genset circuit breaker.

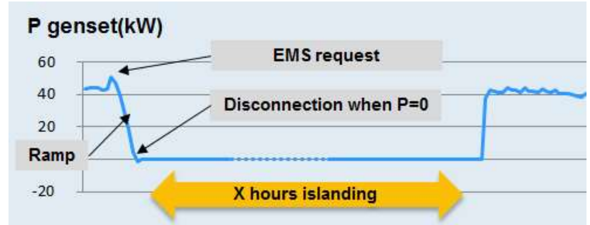

Figure 11 Representation of genset power when ESS/PV can supply the microgrid loads

The ESS is in discharge mode to supply the load. Once this current and power at the genset circuit breaker level are close to 0, the genset circuit breaker is opened, without any disturbances on the load. After that the ESS switches automatically from slave voltage generator to master voltage generator.

In this situation, the ESS ensures autonomously the balance between the local production & consumption, while the state of charge and the power of the PCS are within the operating ranges.

The power sharing between the PCS is ensured by hyper droop algorithm, without any communication link for robustness.

b) Battery grid forming to genset grid forming

In some cases, for example, when the EMS forecasts or detects a lack of PV production, or when the battery state of charge is too low, it asks for the genset reconnection.

From this situation, the genset is started and once the nominal speed and voltage are reached, the EMS can ask for the synchronization sequence. The target of this sequence is to ensure the perfect alignment between genset and ESS voltages, frequencies and phases. When these 3 parameters are aligned, the controller gives the authorization to close the open circuit breaker. The microgrid is paired again.

The PMS gets the info to work as grid-follower and thus changes the operation mode of the PCS.

c) Conclusion

The change of one mode to another happens without any perturbation on the load.

Step N°	Diesel Genset	SOCOMEC Battery System	UPS	Critical Load (EMS, HVAC…)	PV	Load Bank	Others(EV…)
Step 0	Blackstart from only UPS and critical load operating status.						
	OFF	OFF	ON	ON	OFF	OFF	OFF
Step 1	Energy in Li-ion battery is enough, so firstly switch on battery system as power source.						
	OFF	ON **(Grid forming)**	ON (Charging/Charged)	ON	OFF	OFF	OFF
Step 2	OFF	ON (Discharging) **(Grid forming)**	ON (Fully-charged)	ON	OFF	OFF	OFF

Figure 12 Asset status during Blackstart with ESS as Grid-Forming

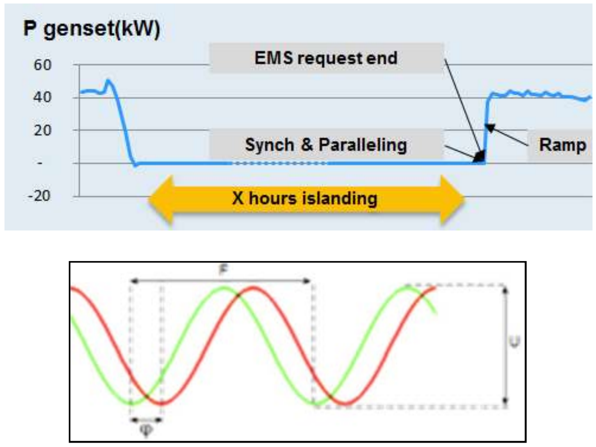

Figure 14 Genset resynchronisation with ESS system

B. Transition in grid-tied mode

As mentioned in the introduction MASERA is part of the REIDS initiative managed by NTU. This grid of microgrids is composed of a 3-phase 400V grid and a 6,6kV grid. It can accommodate up to 8 microgrids coming from different vendors.

Six transition use-cases were successfully tested with MASERA connected to the grid (use-case 1 to 3 and 5), connecting to the grid (use-case 4) or islanding from the grid (use-case 6). In use-cases 4 and 6, MASERA grid-forming source was the Socomec ESS.

Use Case	Grid Genset	Grid load	Grid – MASERA PCC	MASERA Socomec ESS	EDF critical load	EDF load banks	Status
1	30kW Grid forming	20kW	CLOSE	-	~5kW	5kW	Completed
2	25kW Grid forming	20kW	CLOSE	5kW discharging Grid following mode	~5kW	5kW	Completed
3	35kW Grid forming	20kW	CLOSE	5kW Charging Grid following mode	~5kW	5kW	Completed
4	15kW Grid forming	0kW	OPEN to CLOSE	ESS Grid forming Discharging 10kW to ESS Grid following Charging - 5kW	~5kW	5kW	Completed
5	20kW Grid forming	0kW	CLOSE	ESS Grid following Charging - 10kW	~5kW	5kW	Completed
6	0kW Grid forming	0kW	CLOSE to OPEN	ESS Grid following Charging - 10kW to ESS Grid forming Discharging 10kW	~5kW	5kW	Completed

Figure 13 Tested transition use-cases

V. Conclusion

Being both a pre-commercial solution and a R&D testbed with innovative objectives, MASERA aims to present EDF know-how in terms of microgrids.

Benefiting from its expertise and references, EDF thus benefits from the REIDS cluster infrastructure and support, to address technical and commercial ambitions based on innovative and rugged solutions.

With the objectives to enhance the quality of the grid, while reducing the operation, and thus the costs, MASERA equipment and developments are essential to build a complete and integrated offer, preparing EDF future project for local electrical systems.

The EDF MASERA microgrid aims at bringing a better quality of life to local communities, through access to affordable and reliable electricity, leveraging innovative technologies, ensuring enhanced reliability and resiliency. The three next years of the project will allow to focus on the industrial attributes, based on use cases, research projects and:

- Affordable electric supply for isolated territories,
- Green energy helping to reduce the environmental footprint,
- Proven and standardized solutions for a reliable and resilient microgrid.

This project illustrates EDF's drive and unique expertise in designing, developing and executing smart grid and microgrid projects on islands and territories with no access to the grid (off-grid) or facing reliability issues ('bad grid').

MASERA is therefore a unique opportunity to complete technical business challenges, while developing skillsets, serving isolated territories electrification purpose.

Additional high resolution Power Quality (U/f) site measurements will be conducted in 2021 on MASERA to characterize the impact on the quality of electricity during off-grid/grid-tied and Grid-forming assets transitions.

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