SPORE MULTIFLUID MICROGRID TESTS AND RESULTS IN THE TROPICS

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ABSTRACT

The present paper describes the largest innovative multifluid microgrid pilot in South East Asia and the associated use cases enabling safe control of DERs through µEMS – Power Control: Power Management System and optimal operation through µEMS – Optimization multifluid: Energy Management System. The first batch of testing in the pilot was started in the summer of 2018, and several use cases were defined.

INTRODUCTION

Global electricity demand is expected to increase dramatically in the coming years. Global electrical infrastructures for the production, transportation and distribution of energy are facing different challenges such as weak, aging or missing networks, growing number of users, energy dependence and high cost of energy.To further complicate this equation, the world has to march ahead in its resolve for a carbon-free future. In this context, microgrids allowimplementation of decentralized systems with increased renewable penetration. Supported by energy digitization that enables development of smarter control and optimization features, microgrids reinforce local power safety, reliability and quality.

In a giant leap towards this goal, Economic Development Board of Singapore launched the Renewable Energy Integration Demonstration-Singapore (REIDS) initiative, the world's largest microgrid demonstrator in a tropical environment. NTU, ENGIE and Schneider Electric have made a partnership within this huge program to set up a state-of-the-art multifluid microgrid solution under the Project Sustainable Powering of Off-grid REgions (SPORE).

DISTRIBUTED ENERGY RESOURCES (DERS) IMPLEMENTATION

The SPORE multifluid microgrid was built on SEMAKAU island with various DERs, enabling control for stability and efficient use of energy with optimization.

The SPORE microgrid SLD is represented in Figure 1 as follows:

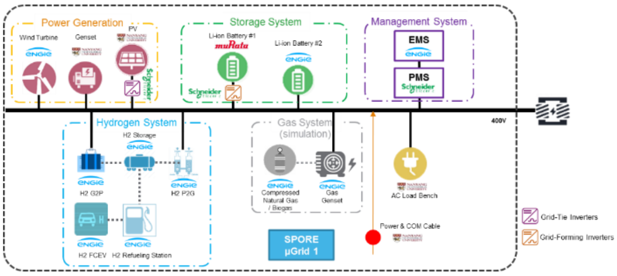

Figure 1: SPORE microgrid SLD

The microgrid system is composed of the following DERs:

- A wind turbine of 100 kW built by Xant and provided by ENGIE. This wind turbine technology uses guyed tower with all components coming in a single 40ft container for easy deployment, easy installation and erection. This technology is particularly well adapted to tropical conditions since it can withstand CAT4 and CAT5 hurricanes.

Figure 2: erection of XANT wind turbine in SPORE

- 2 gensets of 50 kVA and 1 of 100 kVA provided by NTU. The ultimate goal of SPORE is to demonstrate that 100% renewable microgrid is possible. But gensets were set up in order to demonstrate the scalability of the solution for brown field situations. Part of the use cases consist to switch from pure genset (which is the most common way of producing electricity today in South East Asia and Pacific islands) to progressively

100% of renewable energy.

- Grid-tie PV string inverters built and provided by Schneider Electric were designed for tropical humidity and heat conditions. These inverters are not able to act as voltage sources i.e. grid-forming DER for the grid. However, combined with the PMS algorithms and other grid-forming entities, they are able to maximize PV penetration within the microgrid up to 100%.

- Grid-forming storage units powered by virtual synchronous generator (VSG)_controls. This new generation of inverters developed by Schneider Electric is a true grid-forming inverter, which is capable of maintaining the voltage and frequency irrespective of whether it is operating as the sole voltage source or as a voltage source in parallel with other grid-forming inverters or traditional generators.
  AVSG inverter is the combination of:
  - An advanced control called virtual synchronous machine (VSM) that emulates the physical behaviour of a synchronous machine to benefit from its natural grid-forming characteristics, and avoid paralleling issues;
  - An energy source (power storage), to decouple the instantaneous renewable power from the load demand and thus smoothen the variations of the renewable sources production. This enables the VSG inverter to provide "spinning" reserve for grid stability.

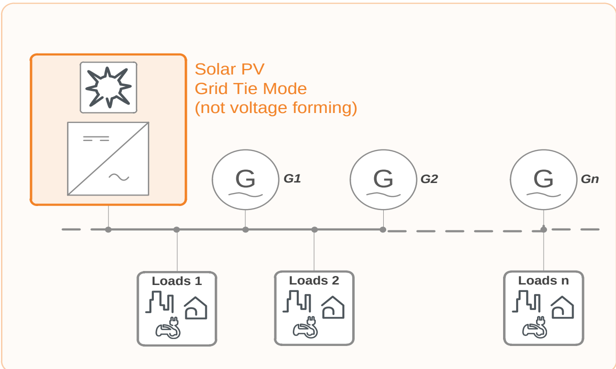

Figure 3: Grid-tie inverters enabling 30% renewable penetration

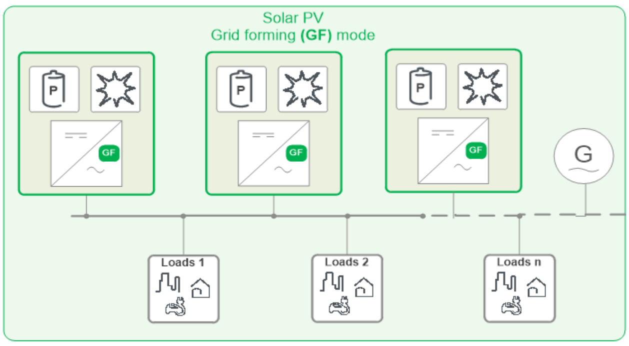

Figure 4: Grid-forming inverters with VSG technology, enabling 100% renewable penetration

- An H2 chain which consists of a H2 power-to-power (P2P) system, a H2 refueling station (HRS) and a fuel cell electric vehicle (FCEV). The H2 P2P system serves as an energy storage system (ESS) similar to a traditional battery ESS. Energy can be stored through electrolysis process in the form of H2 in a H2 storage tank. Energy can then be reused through a fuel cell by converting H2 into electricity. The HRS further compresses the H2 stored in the P2P system to be used by the FCEV.
  The H2 chain of the SPORE microgrid aims to demonstrate the use of H2 in a distributed manner, and offering various additional services rather than energy storage only.

- A grid-tie storage unit built and provided by ENGIE with the capability of grid supporting activities such as active and reactive power delivery within 4 quadrants in order to participate to the load sharing and microgrid global balance and stability.

- A simulated biogas system through mathematical model and emulation through one of the diesel genset. In order to further study the multifluid aspect of the SPORE microgrid, ENGIE will model an entire biogas system using anaerobic digestion. The model will be integrated in the system operation, while the output electrical power of the biogas system to the microgrid will be emulated by a diesel genset.

MICROGID EMS AND PMS DEVELOPMENT AND IMPLEMENTATION

The global control of the microgrid is provided by 3 key elements:

1) A µEMS – Multifluid Optimization Module provided by ENGIE. The objective of the µEMS is to optimize the usage of different assets in the microgrid with the goal to provide affordable, reliable energy with a low environmental impact. This objective is reflected in the different key performance indicators (KPIs) defined in the module. The module is composed of two optimization layers, respectively on a mid-term and short-term basis.
The mid-term layer, from one day to one month ahead, aims at optimizing the use of all assets with a view to maximize their lifetime and thus reduce the total equipment cost, but also to provide maintenance and replacement schedules as well as a fuel supply schedule. Therefore, the mid-term layer is basically a general planning for a relatively long time. It provides the necessary information for the short term layer to ensure a comprehensive optimization.
The short term layer, also called intraday layer, focuses on intraday optimization. It aims at providing set points for all controllable assets to the Power Management Module as well as the operating reserve dispatch for the Power

Management Module. The goal is to be able to deal with real time fluctuations in the microgrid maintaining its voltage magnitude and frequency.
To determine those set points, several elements are taken into account:

Firstly, forecast is included using predictive algorithm to have a prevision as accurate as possible n
ot only for intermittent renewable energy sources (PV and Wind power) but also for the load. Those predictions are based on weather forecast as well as on historical data of previous behaviour, consumption and production profiles.
Secondly, the optimization includes demand side management (DSM) for flexible loads. In the tropics, typical load such as water treatment or cold production (e.g. ice factory) are very appropriate for DSM: an ice factory typically has to run 8 hours a day, and those 8 hours can be dispatched whenever it's best for the microgrid.
Production and storage systems are also optimized, including H2 storage, with a view to minimize operating cost, environmental impact and to have the highest quality of supply for customers.
H2 vehicles are also part of the solution, enabling to address mobility needs and also to increase the proportion of renewable energy in the microgrid.

All the elements mentioned above are included in the multifluid optimization process in the µEMS – Multifluid Optimization Module. With this module, different systems that are providing different services can operate cooperatively in an optimal way, at the same time, providing the customers the best services.

2) A µPMS – Power Control Module provided by Schneider Electric. This real-time power control module in the solution enables to orchestrate the decentralized energy resources, and to take care of the spinning reserve in order to ensure stability of the microgrid. The key functions of the PMS are the following ones:
- Ensure the stability of the microgrid through a balance of active powers for the frequency stabilization and reactive powers for the voltage.
- Apply a power sharing strategy which promotes usage of renewable energy within the microgrid without making gensets work at a too low capacity in order to enable a good efficiency.
- Accommodate optimization set-points from the EMS module without compromising on the system stability
- Respect operational constraints around each DER to ensure longevity of the assets

3) A SCADA – Supervisory Control And Data Acquisition provided by Schneider Electric and implemented by ENGIE. This tool enables to visualize, interact and monitor the good performance of the microgrid.

The following KPIs are monitored through the SCADA, among other data:

- Voltage frequency with respect to its boundaries;
- Voltage level with respect to its boundaries;
- Power Quality (harmonics, unbalance, etc.);
- Renewable penetration.

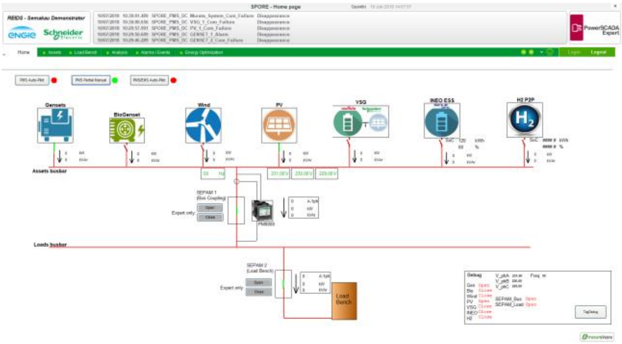

Figure 5: SPORE microgrid SCADA.

TECHNICAL USE CASES

The following Technical Use Cases (TUCs) are designed in order to study the behaviour of the microgrid, to assess its technical limits, and to validate the µEMS optimization. For all the TUCs below, all the possible combinations of assets and all possible loads are to be tested to give an overview of the impact of each test on the grid stability and different KPIs. This will ultimately enable to extrapolate general trends for any similar microgrid.

TUC 1 - Black-Start

Black start is the process of restoring the electric power of the microgrid without relying on any external electric power transmission network. This is usually done with gensets that natively have this capability. Without gensets, the virtual synchronous generators could enable to form the grid and to connect other renewable grid-tied DERs such as the wind turbine.

TUC 2 – Synchronization

Synchronisation of the DERs is tested within the microgrid between grid-tied and/or grid-forming DERs. A further step would be to test the synchronisation of the SPORE whole microgrid with other microgrids that will be built on the SEMAKAU island illustrating the concept of "lateral electrification". [1]

TUC 3 - Step load

Step loads can be tested using the load bench of 400 kW set-up on the island. This enables us to analyse the performance of the microgrid PMS to ensure the stability of the frequency and voltages following a load impact on the microgrid.

TUC 4 - N-1 situations

This TUC is to validate the stability of the microgrid. The sudden loss of an asset can occur during the microgrid operations and will have an impact on the grid stability. Depending on the conditions (assets configuration, load level and type, etc.), the microgrid might not return to steady-state operation and a blackout could thus occur.

TUC 5 - Production fluctuations

This TUC is to study the characteristics of different DERs, and their impact on the entire microgrid. Due to the unpredictable nature of renewable energy resources, unforeseen power fluctuations can occur in the microgrid, which in turn challenge the grid stability. The most significant example of this are the wind gusts that the wind turbine would endure and transmit as power to the microgrid.

TUC 6 - Energizing the MV matrix

In order to interconnect the different microgrids, a MV matrix has to be used. Energizing the MV/LV transformer will require a sudden high demand of reactive energy (transformer inrush current). Not all assets are able to deliver this current almost instantaneously.

TUC 7 – Protections

A new protection function was set up to ensure fault discrimination in all microgrid operating modes, in particular with the lowest short-circuit currents. This new protection function is based on local current and voltage measurements, without real time communication between protection devices. This new function could already be performed in some modern multifunctional protection relays with a customized logic between conventional functions. But in the future, this function could become a “ready to use” function, as the other conventional functions (overcurrent, directional …). [2]
Furthermore, one of the goals of this TUC is to assess the actual fault current that can be reached with a high penetration of power electronics-connected assets.

TUC 8 - Power Quality

Short circuit power is very low within a microgrid. Therefore, any harmonic current absorption by non-linear loads will have a great impact on the voltage since the source impedance is very high compared to a traditional distribution grid. This aspect of power quality was measured and monitored within SPORE in order to emulate all kinds of scenarios and be ready to prepare answers depending on the configuration of future customer microgrids and non-linear loads connected.
Furthermore, other Power Quality parameters such as unbalance or flicker are also measured.

TUC 10 – Optimization

The objective of this TUC is to assess the optimization performed by the µEMS by letting the microgrid run on its own for several weeks.

PRELIMINARY TESTING RESULTS

TUC 3 was among the first tests performed, with various step loads applied under various circumstances.
Figure 6 and Figure 7 illustrates two examples of such tests. The first one shows the results of the application of a step load of 15 kVAr (inductive) to a microgrid formed by a 50 kVA genset, while the second one displays the results of a step load of 40 kW and 30 kVAr (inductive) to a microgrid formed by two 50 kVA gensets and 1 PV string of 25 kW$_p$.

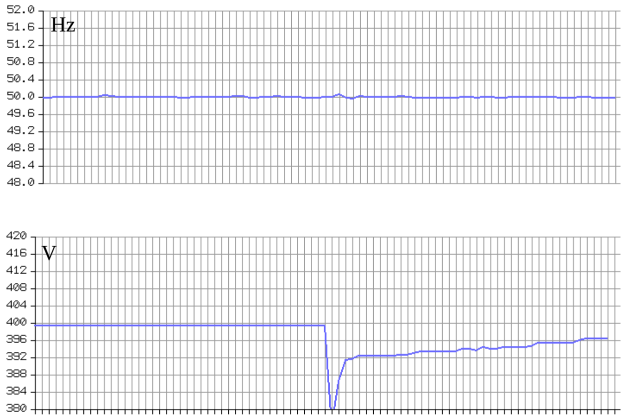

Figure 6: TUC3 - Step load of 15 kVAr (ind)

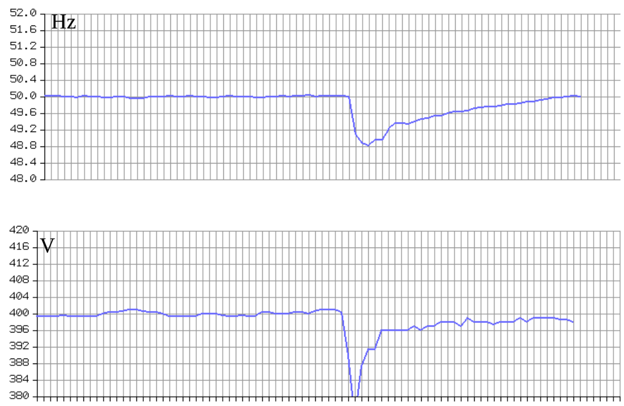

Figure 7: TUC3 - Step load of 40 kW and 30 kVAr (ind)

One of the key take-aways from this research initiative is to assess and test the capability of the system to work in no-genset mode supported by a VSG inverter. A grid formed by the VSG was subjected to fluctuations in load and renewable production and the behaviour captured. Figures 8, 9, 10 and 11 illustrate these responses

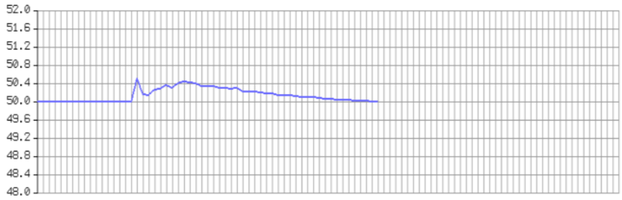

Figure 8 TUC5 - PV fluctuations on a grid formed by VSG

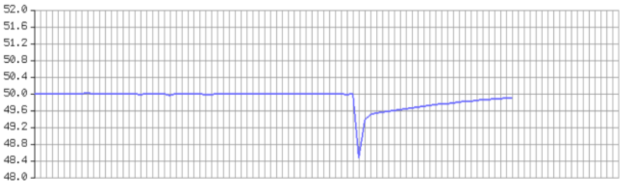

Figure 9 TUC4 - PV disconnection from a grid formed by VSG

On comparing the curves in Figure 9 and Figure 6 one can notice the similarities in the frequency responses. Just as is the case in a rotating synchronous machine, the VSG also has an inertia behaviour (characterized by negative slope or rate of change of frequency), a droop behaviour (characterized by a positive slope immediately after the zenith of the negative slope region) and a secondary control response restores the frequency back to the nominal value.

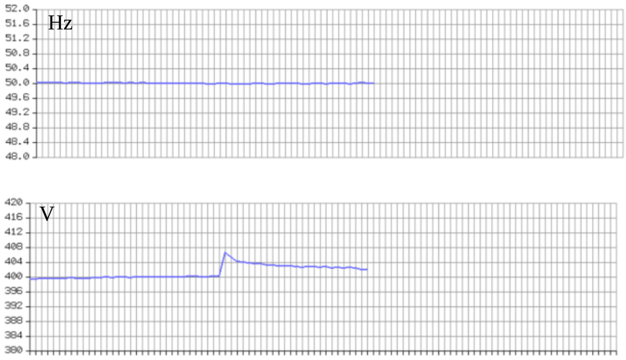

Figure 10 TUC 3 - Step load of 15 kVAR on grid formed by VSG

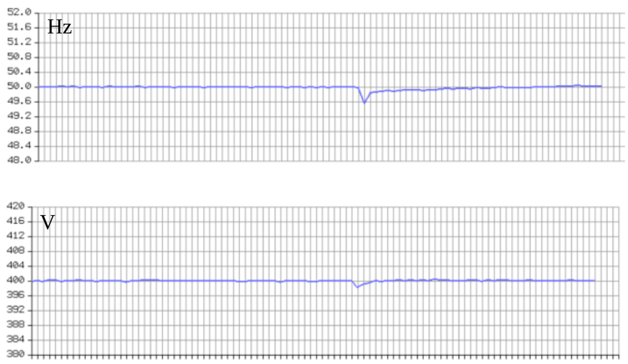

Figure 11 TUC 3 - Step load of 15 kW on grid formed by VSG

FUTURE WORKS

Renewable Energy Integration Demonstration-Singapore (REIDS) initiative is a huge program led by NTU that will host several microgrids connected between them through a distribution MV network.

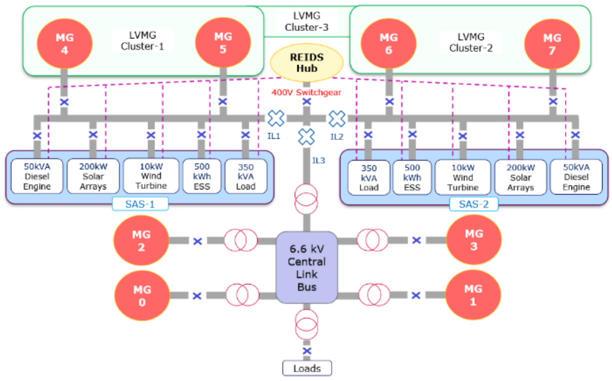

Figure 12: REIDS Future extension

SPORE is referenced as MG1 in Figure 12. Once the program will be achieved, one of the use case will be to interconnect and make the microgrids work together.
Nowadays, a new electrification model which is more realistic and more ambitious is generally requested. The limitations of current electrification approaches among different power grid solutions are the main causes.
This approach is based on a process of progressive building of decentralized electrical infrastructures and gradual integration of these bricks into larger balancing electrical networks. This would be performed in order to economically monitor the natural increase in the density of electrical demand and serve new uses such as productive needs [1].
The interconnections of the future microgrids in REIDS including existing SPORE will enable to test and fine-tune interconnections capabilities and required standards.

REFERENCES

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[2] Philippe Alibert, Jean Wild, 2018, " PROTECTION SYSTEMS FOR MICROGRIDS WITH HIGH RATE OF INVERTER-BASED-GENERATORS", *CIRED workshop*, Paper 0316