# Control of a Microgrid based on Virtual Synchronous Machine Technology

***Supervisor:*** Dr. Fabio MANDRILE ***Advisor:*** Vincenzo MALLEMACI ***Candidate:*** Federico CAMPANELLI

***Abstract*—This thesis deals with the control of power electronics for grid applications. The high penetration of energy generation from renewables interfaced through power electronics creates concerns on the ability of the grid to remain stable as the static converters do not behave as the conventional synchronous generators. Therefore, this thesis focuses on control strategies for grid-connected power converters able to provide ancillary services and grid support, such as voltage and frequency regulation, mimicking the behavior of the conventional synchronous generators using the concept of the Virtual Synchronous Machine (VSM). Among the possible VSM solutions, this thesis implemented the S-VSC (Simplified Virtual Synchronous Compensator) solution to ensure the stability of a 45 kVA microgrid with three static converters.**

## I. INTRODUCTION

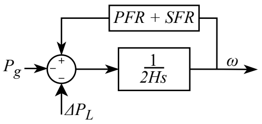
The VSM is a control strategy for grid interfaced converters, which emulates the behavior of traditional Synchronous Generators (SGs) through the electromagnetic and mechanical dynamic model of the machine. This model imposes the virtual machine currents into the grid through the inverter. Therefore, it enables static converters to provide ancillary services, such as inertial active power injection, by generating proper current references for the inverter [1].

The S-VSC has been so far tested on a setup made up of a single inverter and a grid emulator, which actuates the open loop voltage references coming from a real-time controller, independently of the effect of the connected converters, i.e., static grid model. However, to evaluate the support provided by the inverters, it would be beneficial to implement the grid emulator in closed-loop fashion, leveraging a power feedback from the system and running a grid model in the real-time computer to drive the grid emulator, i.e., dynamic grid model.

Therefore, the goal of the thesis is to implement a dynamic grid model with active power feedback from the system and test it together with a microgrid composed of 3 inverters.

## II. DYNAMIC GRID MODEL

The grid model I implemented uses the swing equation and active power balance of Fig. 1 to model the grid's frequency.



*PFR : Primary Frequency Regulation*
*SFR : Secondary Frequency Regulation*
*$P_g$ : Microgrid interface power*
*$\Delta P_L$ : Load variation within the grid*
*H :Grid's inertial constant*

Fig. 1. Swing equation control block diagram.

The electric power feedback $P_g$ is calculated from the measured current $i_g$ and the reference grid voltage $v_g^*$ generated by the grid emulator. In this thesis I assembled the current sensing circuit and interfaced it to the real-time controller (Plexim RT Box) as shown in Fig. 2.

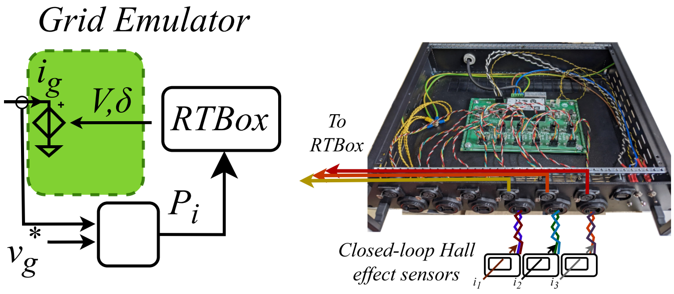


Fig. 2. (left) Dynamic grid emulator schematic (right) Current sensing closed loop and real time processing setup.

## III. EXPERIMENTAL RESULTS

The dynamic grid model was validated experimentally on the setup shown in Fig. 3. The tests consisted in simulating a contingency – $\Delta P_L$ of Fig. 1 – and observing the results with and without VSM control on the inverters. A picture of the testbench is shown in Fig. 4.

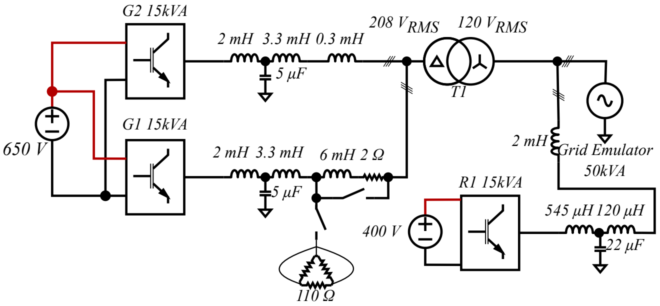


Fig. 3. Microgrid layout.

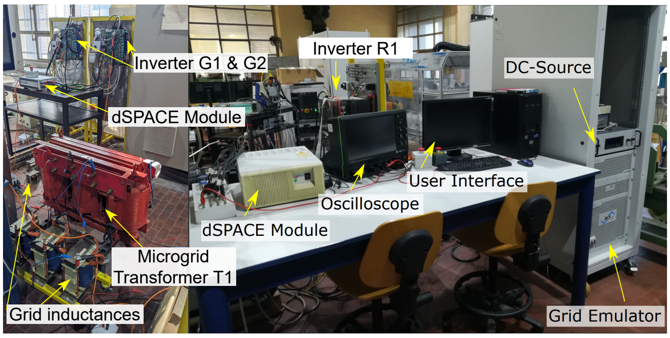


Fig. 4. Laboratory setup.

### A. *Grid Connected Mode Operation*

The first step before the experiments was to simulate traditional inverter control strategies whose results were then compared to those obtained by the advanced control strategy of the S-VSC using a single converter.

Fig. 5 shows two significant benefits of VSMs controls: the more reduced frequency nadir (49.425 Hz vs 49.345 Hz) and the lower Rate of Change of Frequency (ROCOF) in the first instants of a grid contingency; this support is the result of the VSM inertial active power injection. The injected active power shows the inertial contribution at the beginning of the contingency and, seen that primary and secondary regulations were not activated, it goes back to zero at steady state.

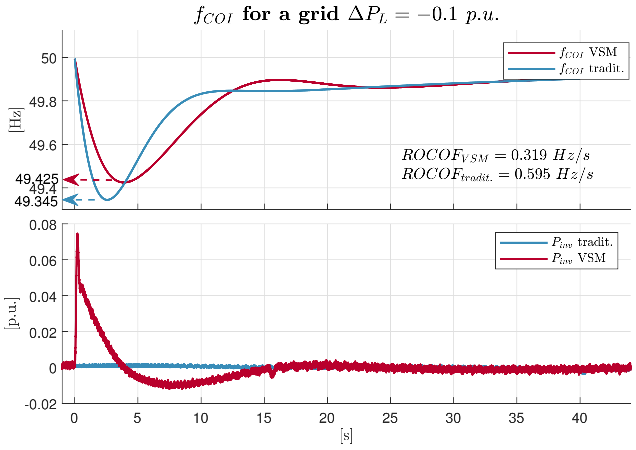


Fig. 5. Comparison of system's frequency and inverter power: inverters with traditional control vs VSM control.

The tests shown in Fig. 6 were then performed using all three inverters and the grid emulator to further validate the results. The tests were performed implementing either traditional or VSM controls on each inverter. They showed how for the same fault, the ROCOF decreased as the number of inverter controlled with VSM increased.

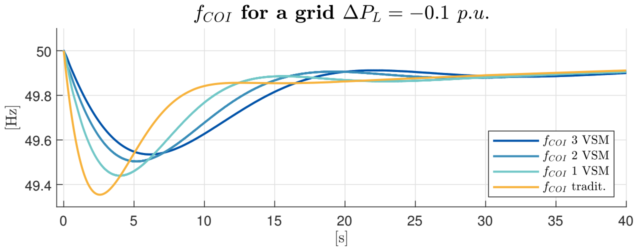


Fig. 6. Tests results for different penetration of VSM controls in the microgrid.

### B. *Islanding*

The tests were carried out to verify the ability of the system to ride through grid disconnection and the steady state condition in islanding configuration.

The results of Fig. 7 show the ability of the system to ride through the disconnection and feed the local loads. The amplitude of the frequency and voltage, being controlled by a purely proportional gain, presented a steady state error; but in any case within the required specifications, i.e., within 10% of the nominal voltage.

A further secondary control could be both implemented on the voltage and frequency control loop to eliminate steady state errors.

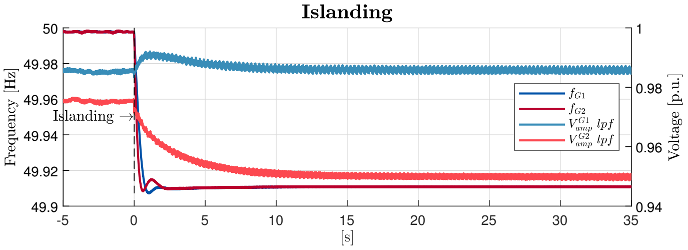


Fig. 7. Microgrid's frequency and voltage at the instant of separation.

## IV. CONCLUSION AND FUTURE WORKS

This thesis dealt with both the theory and the implementation of the S-VSC, carrying out simulation and experimental tests to validate the behavior of virtual machines in microgrids and grids. The results showed improvements in the ROCOF and Nadir as well as the ability of the microgrid to smoothly switch from grid-connected to islanded mode.

During the thesis activity the tests performed necessitated works on the setup, in the months spent in the laboratory I:

- Assembled, tested and operated a sensor conditioning board used for the current Hall effect sensors;
- Renewed the digital and analog cabling of the G1 and G2 inverters;
- Modified the existing C-script and the interface board of the real time dSPACE platform to control two parallel VSMs;
- Assembled the microgrid connecting the grid emulator (Regatron) and the three inverters (R1, G1 and G2);
- Realization and validation of the grid emulator dynamic model.

The assembly of the microgrid and grid emulator opened up numerous tests to be carried out, these include fault ride through, symmetrical and asymmetrical faults, black starts, grid resynchronization, harmonic management and compensation, which will be targeted by future studies.

## REFERENCES

[1] Fabio Mandrile et al. "Grid-Feeding Inverter With Simplified Virtual Synchronous Compensator Providing Grid Services and Grid Support". *IEEE Transactions on Industry Applications* (2021).