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EXPERIMENTAL EVALUATION OF MICROGRIDS AS AN ALTERNATIVE FOR THE IMPROVEMENT OF POWER SUPPLY CONTINUITY IN SECONDARY DISTRIBUTION SYSTEMS

Summary

This paper presents proof of concept for non-isolated low-voltage microgrids, through tests using commercially available devices in an experimental microgrid at the *Universidade de São Paulo* (USP). The key objective is to evaluate how microgrids can be used to improve power distribution reliability by guaranteeing power supply continuity during power outages of the main distribution grid. Different topologies for microgrid integration were tested, including both static-converter and diesel genset based microgrids. Furthermore, different scenarios of penetration of distributed photovoltaic generation were evaluated, to test the system's capabilities of voltage and frequency regulation during stressful conditions. The results indicate that commercially available grid-forming devices are capable of maintaining stable microgrid operation during power outages, even during stressful system conditions such as high photovoltaic penetration.

Keywords: Power distribution planning, Low-voltage microgrids, Experimental evaluation

1. Introduction

The USP laboratory has an infrastructure for operational testing of AC and DC microgrid systems. The infrastructure includes photovoltaic generation systems, battery storage systems of different technologies, static grid-forming and grid-following power converters, and their peripherals from different manufacturers, a diesel generator set (GGD), and measurement and control systems. The laboratory has been continuously expanded in terms of capacity and equipment availability, and focuses on supporting the group's research activities, including the development of academic works, and R&D projects. The implementation of the microgrid infrastructure is detailed in Souza (2018), and Torres *et al*. (2024) presents a practical manual for microgrid operation. Furthermore, in Torres *et al.* (2021), practical insights for microgrid operation using this laboratory structure are presented. Furthermore, an improved dynamic model for a diesel genset operating as the microgrid power supply was proposed in Martinez-Bolanos (2025) using this infrastructure. For the tests presented in this paper, an AC microgrid infrastructure was used, which is described in the following section.

2. The laboratory testbed for microgrid experiments

The microgrid illustrated in Figure 1 was designed to allow different operational configurations, based on the sectioning of the circuit breakers (DJ) in the Microgrid Central Controller Distribution Panel (QDMGCC). The four subsystems formed from bidirectional DC-AC converters (SM1, SM2, ST1 and ST2) represent prosumers and/or generators, with local energy storage capacity, through battery banks (BB), and with distributed photovoltaic generation. The microgrid loads are distributed among the prosumers, in addition to an adjustable resistive load bank of up to 3 kW, connected to the central busbar of the QDMGCC, which represents a consumer without storage and generation resources. The main busbar of the microgrid, located in the QDMGCC, can be energized from three configurations:

(1) Grid-connected configuration, with automatic transfer to islanded mode via GGD: under normal operating conditions, the automatic transfer switch (QTA) is in position 1, DJ_{QTA} closed, DJ_{T} and $DJ_{ST1,S}$ open. The subsystems are supplied directly from the QDMGCC central busbar (circuit breakers $DJ_{ST1,E}$, DJ_{ST2}, DJ_{SM1} and DJ_{SM2} closed), in addition to the DJ_{C} closed. In the event of an interruption in the medium voltage (MV) grid (emulated from the opening of DJ_{REDE}), the QTA switch automatically switches to position 2, and the GGD starts to supply the system after a short interruption;

(2) Grid-connected configuration, with manual transfer to islanded mode via ST1: under normal operating conditions, the QTA switch is in position 1, DJ_{QTA} closed, DJ_{T} and $DJ_{ST1,S}$ open. The subsystems are

supplied directly from the QDMGCC central busbar (circuit breakers $DJ_{ST1,E}$, DJ_{ST2}, DJ_{SM1} and DJ_{SM2} closed), in addition to the DJ_C closed. In this configuration, the GGD is disabled. In the event of an interruption in the MV grid (emulated from the opening of DJ_{REDE}), the operator must manually transfer the power supply to the ST1 output port (port 2), by opening the circuit breakers DJ_{QTA} and $DJ_{ST1,E}$ and closing the circuit breaker $DJ_{ST1,S}$. The connection of the other subsystems and the load remains unchanged. The ST1 operates as a grid former, from its battery bank (BB1), and starts supplying the system after an interruption of duration corresponding to the manual transfer time after the fault;

(3) Grid-connected configuration, with automatic transfer to islanded mode via ST1: under normal operating conditions, the QTA switch is in position 1, DJ_T and $DJ_{ST1,S}$ closed, and DJ_{QTA} and $DJ_{ST1,E}$ open. The subsystems, with the exception of ST1, are supplied directly from the QDMGCC central busbar (circuit breakers DJ_{ST2}, DJ_{SM1} and DJ_{SM2} closed), in addition to the DJ_C closed. In this configuration, the GGD is disabled. The QDMGCC central busbar is supplied from the ST1 output port (port 2), which, under normal operating conditions, is in bypass mode, *i.e.* connected to port 1 and connected to the grid via DJ_T. In the event of an interruption in the MV grid (emulated from the opening of DJ_{REDE}), there is an automatic transfer in ST1 from bypass mode to grid-forming mode, starting to supply the system after a transient.

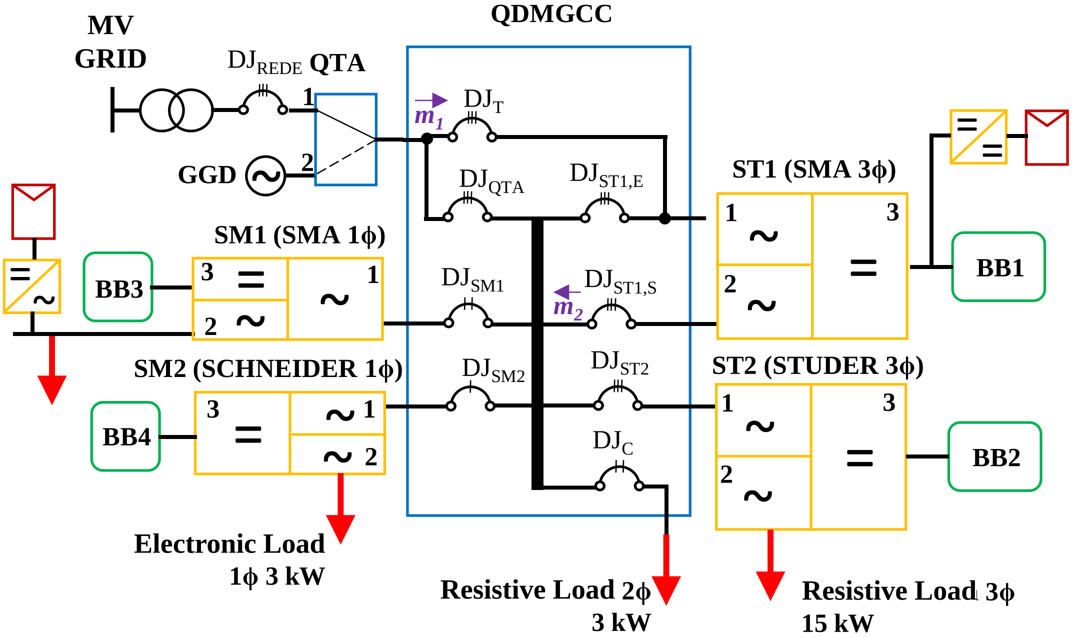

Figure 1. Simplified diagram of laboratory microgrid testbed.

3. Test results

Several tests considering the three possible configurations described in the previous section were performed and will be presented in the full paper. To illustrate some of the results, Figure 2 presents the voltage at the microgrid point of connection considering the islanded operation supplied by the diesel genset. At 15h40, the microgrid entered in island mode after a fault in the main power distribution system. At 16h03 the microgrid returned to the grid connected mode. In details 1 and 2 it is possible to note the voltage sag during the transition from grid-connected to islanded and vice-versa.

4. Conclusions

The tests that used static converter-based topologies attested to the voltage and frequency regulation capacity of this technology, which is capable of operating in islanded mode, including distributed PV generation. From the point of view of reliability metrics, both the manual transfer configuration to the microgrid and the automatic transfer configuration are suitable for improving reliability, so that interruptions originating external to the microgrid would not be counted, considering the duration of the tested interruptions and demand during islanded operation, which are within the power and energy capacities of the evaluated microgrid supply. In addition, the tests that will be presented in the full paper demonstrate how demand response mechanisms internal to the microgrid can contribute to extending the autonomy time during islanded operation.

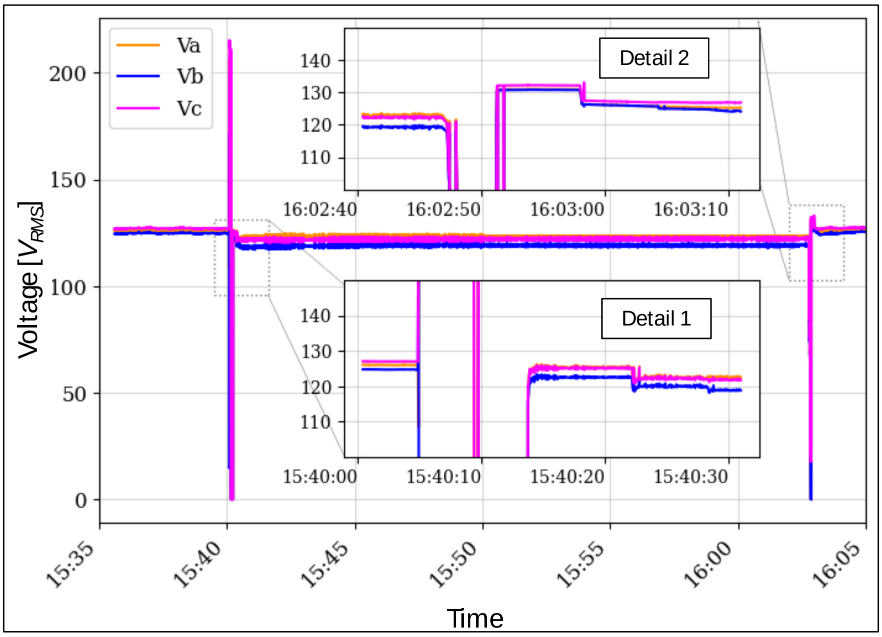

Figure 2. Voltage at the point of connection to the main grid during transition to island mode and recovery to grid-connected mode.

As in the case of static converters, the tests that used microgrid topologies based on the diesel genset showed favorable performance in relation to the ability to mitigate long-term interruptions and, consequently, have the potential to be applied in systems that require reduction interruption metrics (*e.g.* SAIDI and SAIFI). It was also possible to evaluate the possibility of integrating the diesel genset with the other distributed energy resources in the microgrid, specifically with a bidirectional static converter connected to a battery bank and with a grid-tie inverter. In these tests, it was essential to parameterize the system appropriately, to avoid instability conditions caused by the quality of the energy supplied by the diesel genset.

Another point verified during the tests with the diesel genset was the system's operating capacity with high penetration of PV generation. Operational conditions were tested with penetration of approximately 85 % of the load supplied by PV generation, with the remaining 15 % supplied by the diesel genset. In this case, even with the diesel genset operating at a very low-load level and associated with the high penetration of a non-dispatchable source (photovoltaics), no significant impacts were observed on the voltage and frequency levels that would compromise the quality of the energy supplied to the loads.

5. References

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