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Addressing LV network power quality issues through the implementation of a microgrid

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Abstract. The results of the implementation of an actual microgrid in the Netherlands are presented. This microgrid has photovoltaic panels as microsources, energy storage, and a flexible AC distribution system (FACDS) that can operate connected to the public grid or autonomously where it regulates the site's voltage and frequency. In this paper, the potential of the microgrid in improving power quality issues of the site, specifically harmonic distortions, is demonstrated. Results show that the system was able to compensate voltage harmonics when the microgrid was operating connected to the public grid and when operating autonomously. Other tests such as short-circuit, synchronization and blackstart were also conducted. The improvement in power quality and positive results of the other tests demonstrate that a self-supporting, reliable and efficient operation of the microgrid can be achieved.

KEYWORDS

Microgrid, power quality, inverters, harmonic compensation.

1. INTRODUCTION

Regulatory changes in the power industry and the development of smaller generating systems (distributed generators) such as PV systems and micro CHPs have introduced possibilities for on-site power generation by consumers. While this opportunity can be considered beneficial for the environment because the distributed generators can be powered by renewable energy sources, it poses a great challenge on the side of the grid operators. Unwanted effects on power quality, equipment, personnel safety and power system protection can occur when these distributed generators in service.

Grouping these generators and loads into smaller power networks called microgrids can address the problems created by the distributed generators upfront. A microgrid is a group of energy sources and loads operating semi-independently of the external grid (or the macrogrid) [1]. The microgrids are seen by the power system as a single, controlled unit either as a load or source. For the customer, the microgrid can be designed to enhance reliability, increase efficiency, improve voltage quality, etc [2].

The structures of microgrids vary depending on the type of loads and sources present. However, every microgrid has the following key components present: the loads, microsources like microturbines, fuel cells, photovoltaic modules and / or other distributed generators, storage and controller/s.

2. MICROGRID TEST SITE

The Bronsbergen low voltage network is made up of all the loads of the houses and facilities in Fort Bronsbergen Holiday Park. The park has 210 cottages, 108 of which have roof-mounted solar panels which can generate a total of 315 kW_{peak}. It is connected to the external grid through a 400kVA 0.4/10kV transformer. A simplified single-line diagram of the network is shown in Fig. 1.

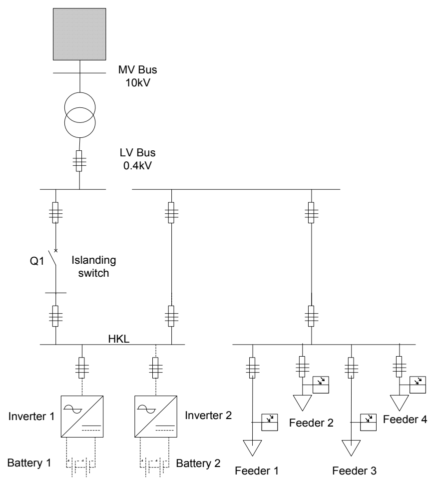

Fig. 1. Bronsbergen Single-Line Diagram

Historical data shows that the site was experiencing power quality problems such as unbalance in the voltage and currents, harmonic distortions, and voltage dips. The asymmetry of the voltage and current is even more evident during times of high irradiation as can be seen in the current and voltage profiles in Fig. 2 and Fig. 3, respectively. The unbalances can be attributed to the unequal distribution of single-phase loads and the PV systems.

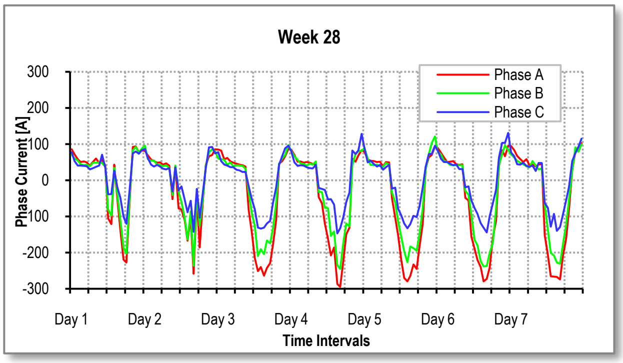

Fig. 2. Current profile

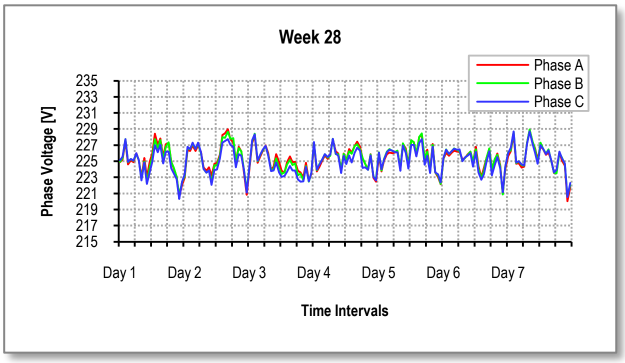

Fig. 3. Voltage Profile

3. MICROGRID COMPONENTS

To transform the network into a microgrid, a flexible AC distribution system (FACDS) which is comprised of two voltage-source inverters (VSI), coupling or islanding switch (Q1 in Fig. 1) and a microgrid central controller and storage devices were installed. The VSIs are equipped with frequency/active power ($\Delta f/\Delta P$) and voltage/reactive power ($\Delta V/\Delta Q$) droop characteristics which enable them to respond independently to load/ generation changes. Each unit of the inverter is comprised of three single-phase inverters that can regulate the voltages per phase. The energy storage is equipped with a monitoring system that checks the conditions of each of the battery sets. The microgrid central controller (MGCC) manages the operation of the microgrid and enables, among other functions, a seamless transition from one operation mode to another.

The microgrid is designed to operate in parallel with the grid or autonomously and is capable of providing at least 4 hours of power to the low voltage network in case the medium voltage grid is unavailable.

4. HARMONIC COMPENSATION

Measured data from the site shows harmonic distortions which are higher than the average in the Dutch low voltage networks [3]. The voltage distortions are caused by the background harmonics in the external grid and by the PV inverters. Furthermore, the PV inverters create a resonance frequency in the network at approximately 650 Hz. The resonance is even intensified by the negative-impedance behaviour of the PV inverters leading to harmonic levels higher than what is permitted in EN50160 [4].

A. Harmonic compensation test objectives

The harmonics test will verify if the battery inverters can compensate for the harmonics within the microgrid with priority given to the 11^{th} – 15^{th} harmonics. The FACDS should be able to absorb/ compensate for harmonics such that the distortion should not be more than 0.2% of the rated 50 Hz voltage for even harmonics and for the 9th, 15th, 21st, 27th and 39th and 1% of the rated 50 Hz voltage for each odd harmonic (except 9th, 15th, 21st, 27th and 39th)

The tests were done on a day with high irradiation to ensure that the harmonic contribution of the PV inverters would be as high as possible. Harmonic monitoring was done for three grid configurations:

1. No (voltage-source) inverters – the low voltage network is connected to the public grid and the voltage-source inverters are disconnected.
2. Parallel with the grid - the low voltage network is connected to the public grid and the voltage-source inverters are connected.
3. Autonomous mode - the low voltage network is not connected to the public grid and the voltage-source inverters are connected.

The measurements for each state were taken within 45 minutes from each other to keep the generation and consumption as similar as possible for all the configurations. The harmonics were calculated from a sample of the voltage waveforms recorded during the test. Calculations were made by applying a discrete Fourier Transform on the measured voltage waveforms which were recorded with a sampling frequency of 10 kHz. The results of the calculations were then validated by comparing them to the readings of the Power Measurement PQ meters which are installed on the distribution transformer.

B. Harmonic compensation test results

The harmonic distortions for the case without voltage-source inverters and with inverters in parallel with the external grid are shown in Fig. 4 and for the case with only the inverters (autonomous) are shown in Fig. 5.

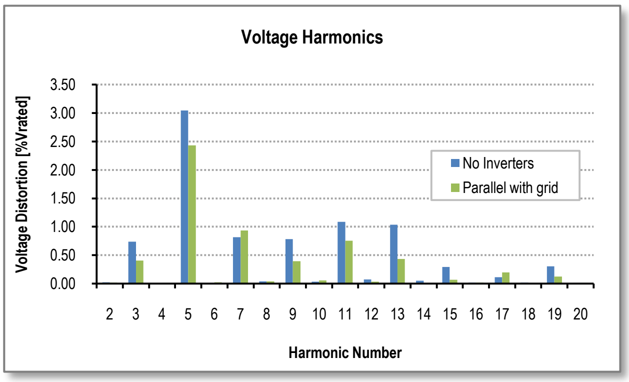

Fig. 4. Harmonic compensation parallel with grid configuration.

With the inverters running in parallel, the harmonic distortions are reduced for most frequencies. With the exception of the 5th and 9th harmonics, the FACDS was able to compensate harmonics such that the distortions are below the planning level.

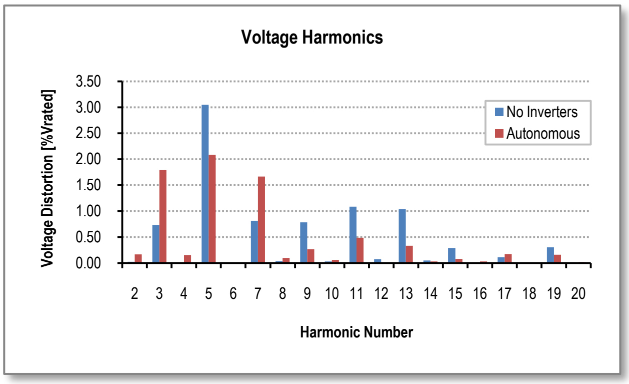

Fig. 5. Harmonic compensation autonomous configuration.

An increase in the 3rd, 5th and 7th harmonics can be seen in the autonomous configuration. This may be caused by the combination of electronic loads in the low voltage network and the output impedance of the voltage-source inverters. With the exception of the 3rd, 5th and 7th harmonics, the FACDS was able to compensate harmonics such that the distortions are below the planning level.

C. *Improvements*

While a reduction of harmonics was achieved in the desired frequencies, the following harmonic problems were observed during the tests:

- An increase in the 9th harmonic during grid-connected operation.
- An increase in the 3rd and 5th harmonic during autonomous operation brought about by the electronic loads in the microgrid combined with the output impedance of the inverters.

Due to these, the inverter control system was modified. The control systems of the voltage-source inverters were upgraded with closed-loop controls for the 3rd, 5th, 7th and 9th frequencies. The harmonic compensation which was intended for passive compensation of the 11th-15th was adapted for active harmonic compensation aimed at reducing harmonic contributions at the 3rd, 5th, 7th and 9th harmonic voltages.

To verify the upgraded harmonic compensation module, the harmonics were monitored again. Results of the no inverter and parallel with grid configurations are in Fig. 6. Due to time constraints, it was not possible to test the network in autonomous mode again.

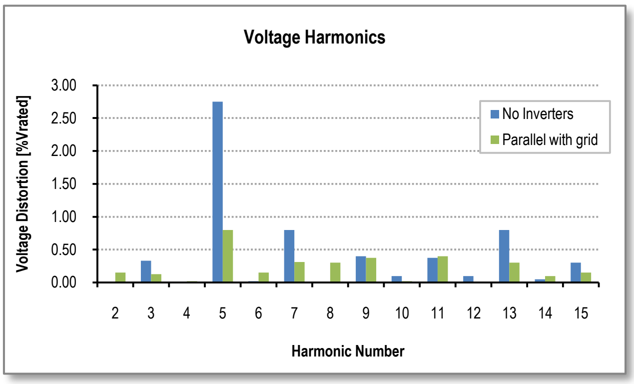

Fig. 6. Harmonic compensation parallel with grid configuration (with module improvements).

It can be seen in Fig. 6 that the FACDS was able to significantly reduce the harmonics in the desired frequencies. Most apparent is the almost three-fold reduction of the 5th harmonic which brings the harmonic distortion below the planning level.

5. .OTHER TESTS

Aside from the harmonic tests, different scenarios were simulated and tested in the field to determine the behaviour of the microgrid components during normal and emergency situations.

Short-circuit protection in a microgrid should be in such a way that faults are detected and isolated within a given time frame. In addition, fault isolation in autonomous operation should ensure that the fault current provided by the voltage source is sufficient to operate protection devices [5]. A total of twelve short-circuit tests were conducted to determine if an inverter/ both inverters will be able to clear faults during autonomous operation and restore microgrid voltage within 200ms after fault isolation. So as not to disturb the inhabitants of the park during the testing, the inverters were disconnected from the network during the tests. To simulate a short-circuit in one of the feeders, a 25-meter cable with variable resistors and a connection to neutral was used. In addition, simulations were also done to determine if the MGCC will be able to isolate the microgrid by opening Q1 (islanding switch) when there is a fault in the external network.

Fig. **7** shows the voltage and current during a fault in one of the distribution feeders. The single line-to-ground fault on Phase A occurred at 130ms and was isolated at 340ms. The voltage in phase A was restored at 20ms after isolation and this is within the allowed restoration time.

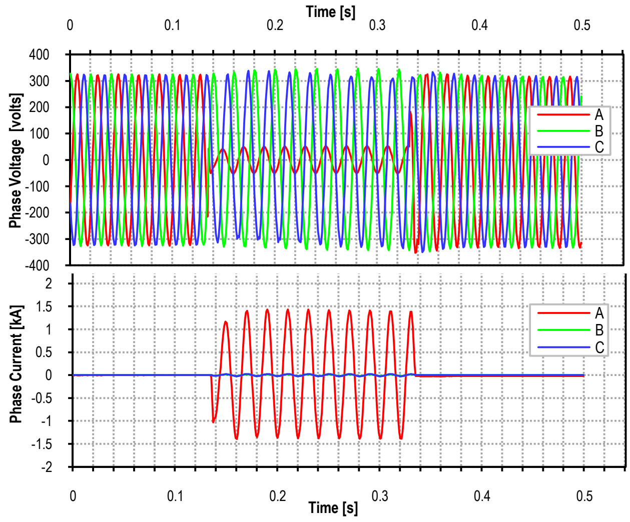

Fig. 7. Voltage and Current Profile SLG Fault

The other tests such as black start in autonomous operation, island detection, synchronization with external grid, active and reactive power exchange between inverters and fixed power exchange with the external grid were also conducted successfully.

A detailed report of all the tests conducted in the microgrid and the results can be found in [6].

6. CONCLUSION

This paper presents the implementation of a microgrid using FACDS and storage as well as the capability of the microgrid to improve the power quality of the site. Field tests and simulation results show that this microgrid can:

- Reduce harmonic distortions caused by background harmonics and PV inverters and keep distortions below statutory limits.
- Regulate voltage and frequency in autonomous mode and absorb or supply power when operating in parallel with the grid.
- Isolate internal faults while operating autonomously and isolate the microgrid when there are external faults.
- Manage the state of charge of the batteries in order to optimize their service life without compromising the reliable operation of the microgrid.

Since voltage and frequency control are localized other benefits such as voltage dip mitigation, efficient use of storage, harmonic compensation of other orders can also be realized. The use of FACDS and storage for microgrids is not dependent on the type of load nor on the energy source available thus, this concept can be used for microgrids with different load profiles and diverse type of distributed generators.

Acknowledgement

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