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STATIC CONVERTERS FOR ACTIVE DISTRIBUTION GRID. FREQUENCY CONTROL FIELD TEST

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Deployment of distributed generation results in a large number of grid connected generators using static converters, with direct consequence a significant decrease in the total inertia of the power system. Frequency control will need smaller time constants and therefore real-time feedback moves into milliseconds domain. A possible methodology able to cope with fast frequency variations is to compensate the missing inertial mass by virtual synchronous generators (VSG). The paper describes the VSG validation in laboratory and field-testing. The generator functionality has been emulated using power electronic converters interfaced with an energy storage unit.

Keywords*:* frequency variation, virtual synchronous generator, static converter, real time control**,** rate of change of frequency

1. Introduction

Today electrical distribution networks are changing from traditional passive topologies to active ones by including power generating nodes at their bus bars. Driven by the EU policies for increasing the penetration of renewable energy sources (RES) with targets like that of 20% of total energy is to be produced in EU from RES by 2020 [1] – the deployment of distributed generation (DG) is increasing. Taking into account that (i) the frequency – as a system variable – is kept in the admissible interval around the rated value of 50 Hz by an algorithm [1]_applied to the rotational speed of synchronous power generators, subject to the mechanical inertia and that (ii) the deployment of DG (usually connected to the network using power electronics with zero inertia) is increasing, future systems can face frequency instability. Frequency control will need smaller time constants and therefore real-time reacting moves into milliseconds domain. Until all control strategies will be redesigned as to answer to the new time requirements, a possible methodology able to cope with fast frequency variations is to

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compensate the missing inertial mass by virtual synchronous generators, as demonstrated by the VSYNC project [3]. This has been achieved by implementing an appropriate control strategy to the power electronics interface of DG units equipped additionally with a short-term energy storage [4], making the resulting unit act like a virtual synchronous generator (VSG). The team from the University Politehnica of Bucharest (partner in the FP6 VSYNC project [3]) developed such a control algorithm capable of emulating virtual inertia by applying it to a power electronics conversion unit (90 kVA) interfaced with lead-acid battery. The power conversion unit is installed in a node (Cheia PT 20/0.4 kV) of the distribution network operated by Electrica SA. The paper presents the development of the experimental set-up used for validation of the control algorithm and the results of the testing campaign in a microgrid with finite inertia, created by isolating part of the network section.

2. Test Site Preparation

Cheia test site locates about 140 km North of Bucharest, accessible for transport of the demonstration equipment. The low voltage section under study is supplied by a 20 kV/0.4 kV, 100 kVA transformer to five feeders.

The load is mainly residential. The power conversion unit is connected to a reserved feeder at the low voltage side of the substation. A short-term storage system (lead-acid rechargeable batteries) is added to the existing power conversion unit (90 kVA).

Due to the local network configuration, the test system for islanding mode operation was designed with restrictions given by the available controllable loads (a total of 12kW, out of which 4kW controllable in steps of 1 kW).

Several sessions of tests in islanding mode required renting two diesel generators of different rated powers and with different degrees of controllability. The tests results reported in this paper, have been derived using a diesel generator of 8.5 kVA. As a consequence, the VSG operation was tested for low power ratings while additional oscillations have been introduced by the Diesel generator, which has operated at its upper limits. A significant constraint was also added by the additional load represented by the power conversion unit primary circuit itself (without running the VSG algorithm): approximately 5kW.

3. Equipment used in the field test

The setup in Cheia used for islanding mode demonstration is shown in the Fig. 1. The microgrid consists of a generation unit (GEN), the base load of 8kW and a variable load of total 4kW with 1kW steps.

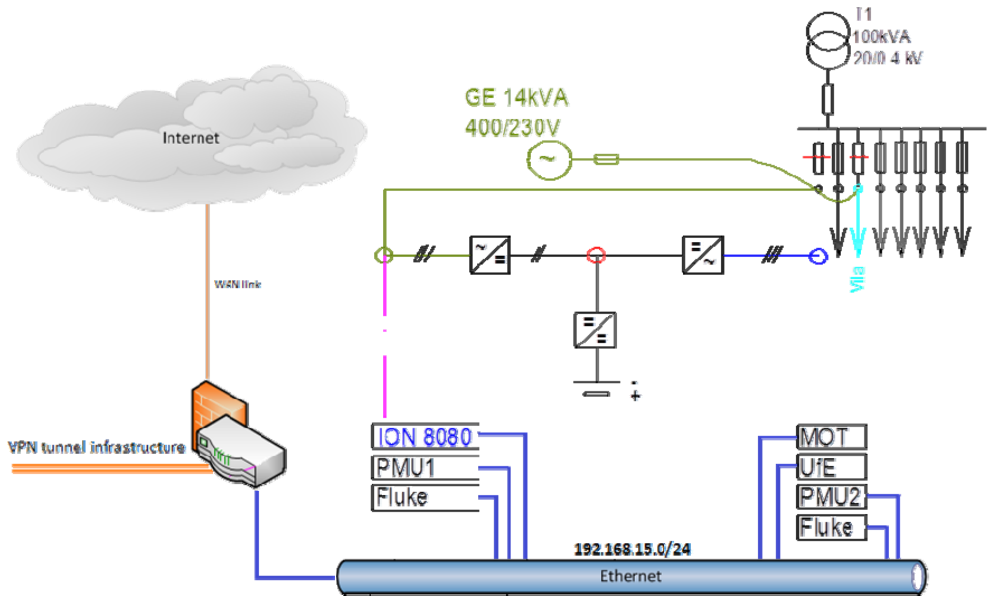


Fig. 1. Cheia field test – microgrid and measurement set-up

4. Power conversion unit 90 kVA

For the field test, a power conversion platform designed for prototyping control algorithms produced by Triphase® in Leuven, Belgium, was acquired. The Triphase platform consists of two AC/DC converters (rated at a total power of 90 kVA) connected in a *back-to-back* setup with externally available common DC link and two DC/DC converters interfacing the storage unit rated at 30kW. This setup allows a bidirectional energy exchange with the grid and with the storage unit. For raising the DC link voltage to the required level (750V), a 400/500 V, 40 kVA, transformer has been added as shown in Fig. 2.

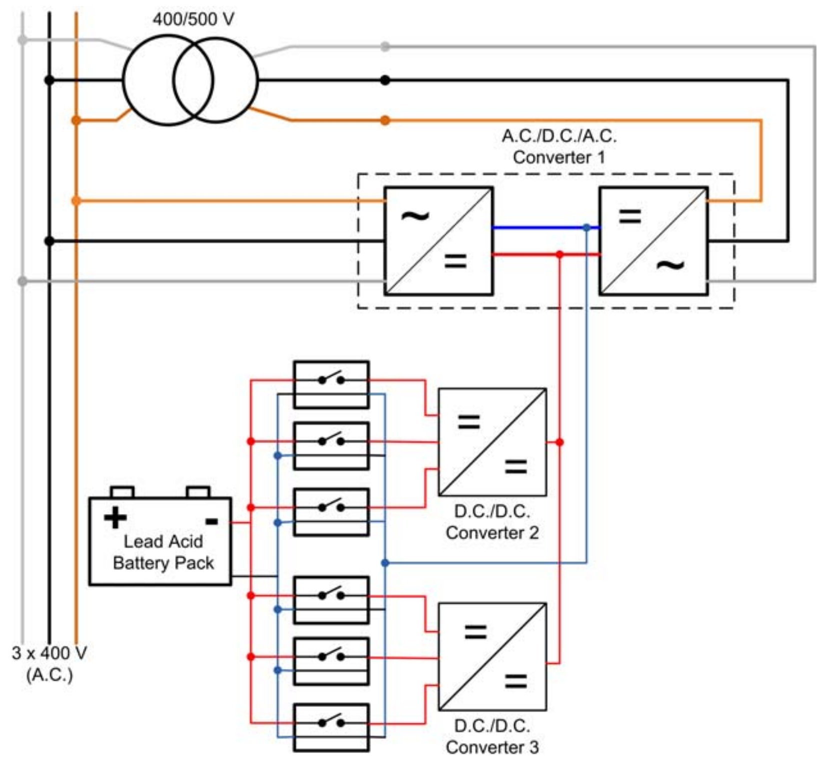


Fig.2. Simplified diagram of the VSG set-up based on the Triphase conversion unit (90 kW)

The platform is controlled using a so-called Target PC, which is able to send PWM signals to the converters' IGBTs using an FPGA interface. The Target PC is running a real time version of Debian Linux and is programed using a work station running Matlab™/Simulink™, transforming the computer in an Engineering PC. It offers the facility that, after uploading the Simulink™ model designed for the converters control, the internal measurements are also made available and, in addition, most of the model variables can be changed in real time during the algorithm operation. Communication among the components of the power conversion platform (sensors, switches, FPGA interface, cooling fans etc.) is performed by the EtherCAT field bus allowing the Target PC to achieve full real-time control capabilities. Ethernet connects the Engineering PC to the target PC via TCI/IP protocol. This allows the system to be controlled remotely via Internet - a useful feature especially when the physical system is placed in a remote location like the case of Cheia site.

In order to operate the platform, one has to follow several steps: (i) design the control algorithm in Simulink™ on the Engineering PC; (ii) upload it on the Target PC and (iii) run it.

The control algorithm designed and used in the field test was described in [5] and its logic is presented in Fig. 3.

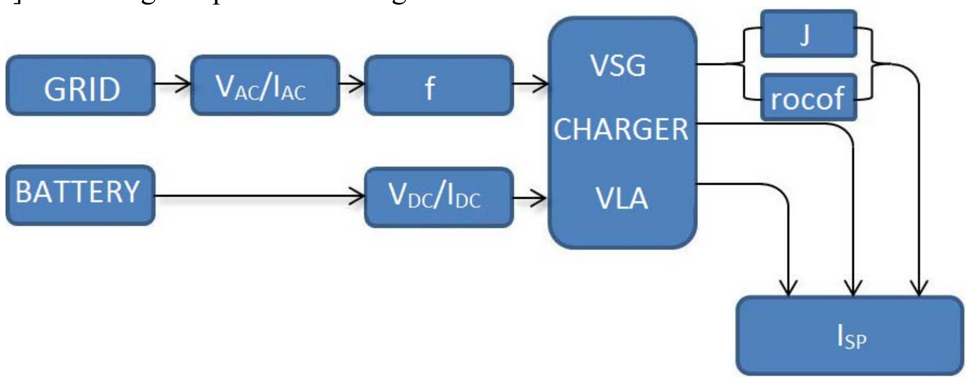


Fig.3. Control logic for the VSG algorithm [5]

The microgrid includes six appliances (variable load 0-2 kW, with 1kW fixed step) acting as controllable load, fixed resistors summing 4. For monitoring the VSG operation, several measurement devices have been used: one Fluke 434 power quality analyser, one Dranetz Mavosys 10 unit and two phasor measurement units (PMUs) Arbiter 1133A Power Sentinel with high accuracy (0.0001 %) for frequency measurements [6].

5. Testing Program

Algorithm testing has been organized following an experimental program with the following outline:

a. Tests with reactive power insertion for developing a voltage control

b. VSG operation in islanding mode

  b.1. Preliminary testing to evaluate microgrid parameters in case of overload

  b.2. Tests for evaluating microgrid parameters with Triphase equipment acting as a simple load in the microgrid (without VSG algorithm)

  b.3. Tests for evaluating microgrid parameters with Triphase equipment with VSG algorithm without the variable load

  b.4. Tests for evaluating microgrid parameters with Triphase equipment with VSG algorithm and with variable load acting as overload.

c. Testing the VSG algorithm on Cheia’s electrical grid section

5. 1.Voltage Source connected mode (a)

The Voltage Source connected mode was not possible to be tested with the set-up in Cheia. Instead the correctness of the control algorithm implemented as a secondary control (U-Q) in grid-connected mode (Fig. 4) has been checked.

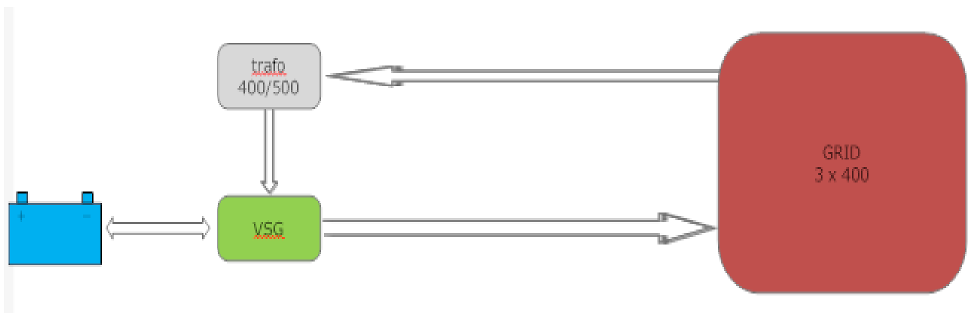


Fig. 4. Schematic of the set-up used for testing the secondary control algorithm, the Triphase equipment is connected directly to Cheia's network section

In Fig. 5 the results as registered by the PMU connected at the interface VSG-grid are presented. In the red rectangle it can be observed a rise in the voltage magnitude when 10kVAR are transfered from the equipment to the grid.

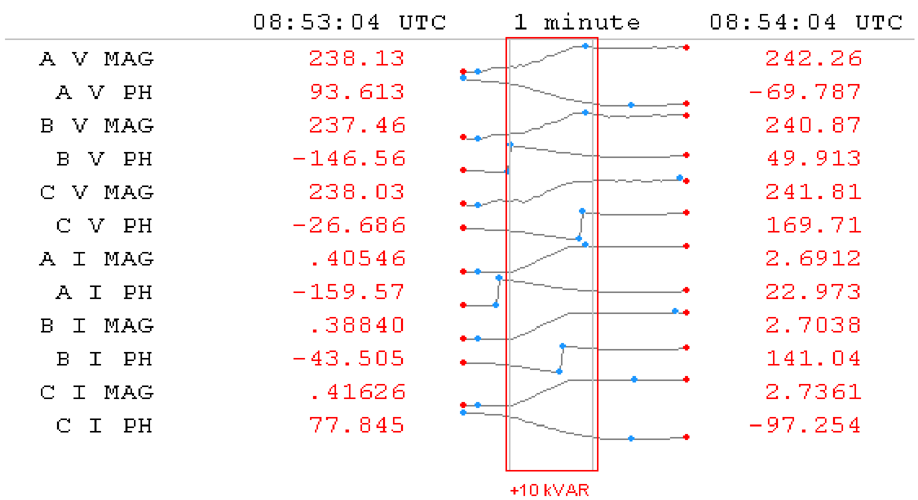


Fig. 5. Results for the secondary control algorithm
(1 minute montioring window)

This testing phase enabled us to derive the parameters of a proportional U-Q control resulting in a voltage variation in the PCC of (4...6) V for 10 kVAr exchange of reactive power.

5.2. Island operation mode (b)

Firstly, a set of preliminary tests have been pursued in order to evaluate microgrid parameters

5.2.1. Preliminary tests (b1)

Fig. 6 presents the simplified diagram for the preliminary setup for testing the algorithm in island mode VSG operation; the microgrid (generator plus base load) parameters are identified when variable load is added. Fig. 7 shows the results; in the circles we can observe the variation of frequency due to connection (+1kW) and disconnection (-1kW) of variable load

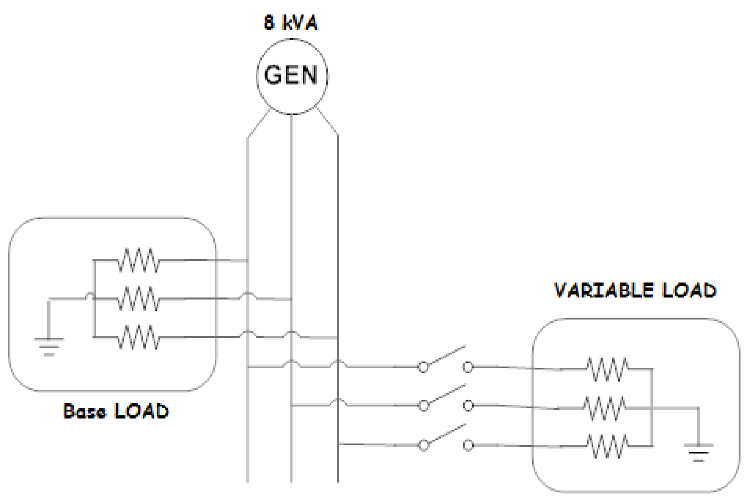


Fig. 6. Simplified diagram for the preliminary setup for testing the algorithm in island mode;

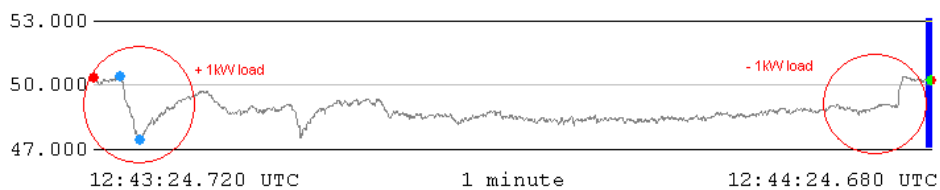


Fig. 7. Preliminary results – island mode, no VSG algorithm, stability versus load variations.

5.2.2. Tests for evaluating the microgrid parameters with Triphase equipment acting as a simple load in the microgrid (b2)

The simplified diagram for the set-up for evaluating the microgrid parameters with Triphase equipment acting as a simple load in the microgrid is shown in Fig. 8.

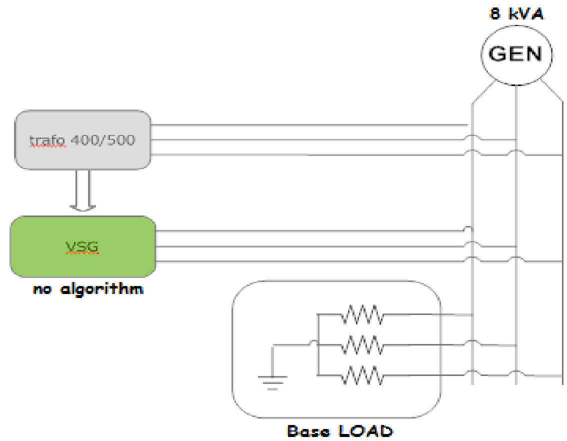


Fig. 9. Simplified diagram for evaluating microgrid parameters with Triphase equipment as electrical load

5.2.3. VSG algorithm in island mode (b3)

Set-up is shown in Fig. 9 and an example of frequency variation is shown in Fig. 10b. The VSG connection is similar to that studied in case b2, except that now, the VSG algorithm is powered up, and its influence on the microgrid frequency can be observed in Fig. 10.

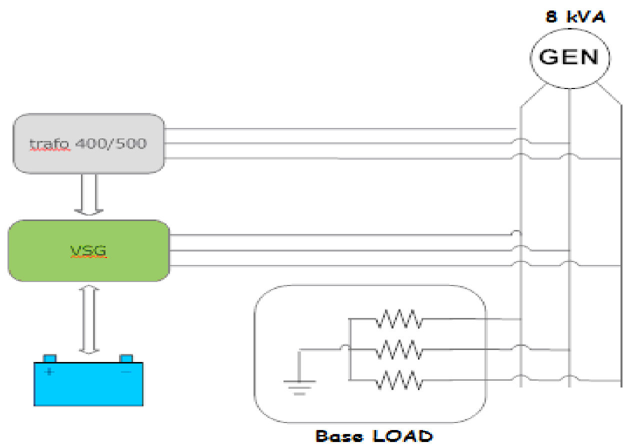


Fig. 10. Simplified diagram for the set-up for VSG testing in islanding mode

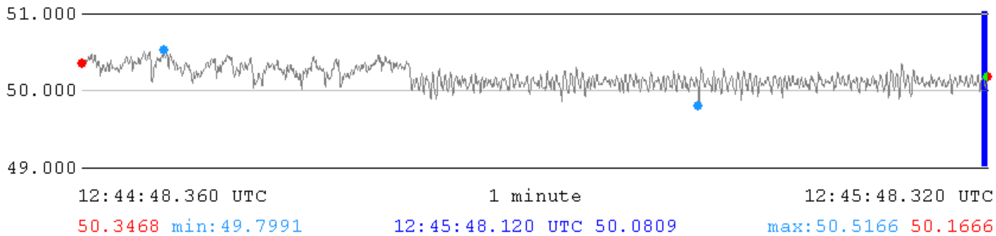
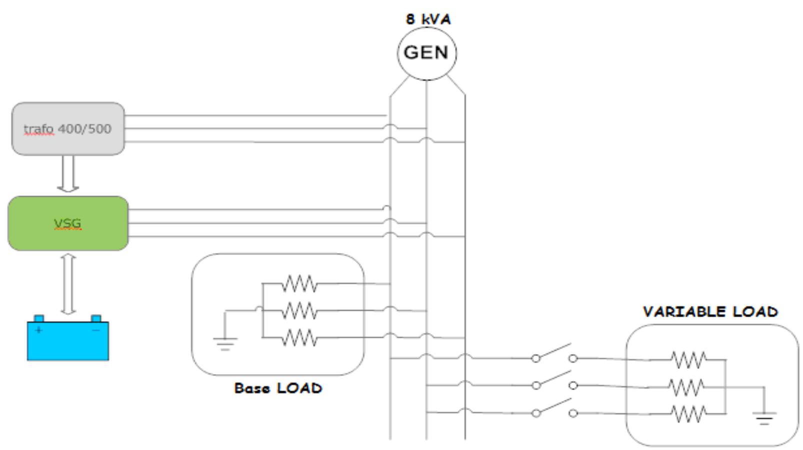


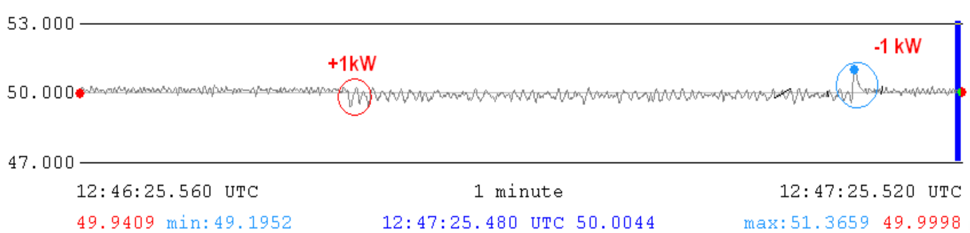
Fig. 11. Preliminary results – island operating mode, with VSG algorithm, frequency reference: 50 Hz

5.2.4. VSG algorithm preliminary tests for variable load (b4)

Fig. 11 (a) presents the simplified diagram of the microgrid with the VSG equipment connected and algorithm working for variable load and results (b), the circles showing the connection and disconnection of the variable load (1kW).



a)



b)

Fig. (a) Simplified diagram for the microgrid with the VSG equipment and algorithm working and varable load; (b) preliminary results– frequency restauration in island mode operation,

6. Conclusions

The paper summarizes the most important results in testing a virtual synchronous generator in a field test and validates its control algorithm.

In order to be able to validate the control algorithm, a microgrid had to be developed. Important technical issues had to be solved in order to design the testing environment. The most crucial issue was to isolate a section of the network in order to obtain a suitable microgrid operational with the existing VSG set-up.

Even though calculations were made prior to the testing of the microgrid, fine-tuning had to be made in the algorithm in order to eliminate frequency oscillations during the tests. Results of tests b3 show that the VSG has a stabilizing effect on the microgrid normal operation, improving the overall stability.

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