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UNBALANCE COMPENSATION IN STAND-ALONE MICROGRIDS

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Abstract – **The study presented in this paper aims to develop a new method for active and reactive power balancing in a four-wire stand-alone microgrid (MG), which feds single phase loads. Two unbalance compensation controllers are used, for active and reactive powers. The compensation is based on a dump load (DL) and a static compensator (STATCOM), which ensure the balance of the active and reactive powers. The DL has the main role of frequency controller, but it is used for active power balancing between phases, too. The STATCOM accomplishes only the redistribution of the reactive power unbalance between phases, not the power factor correction. Thus, its rated power is low, according to the maximum reactive power unbalance that can be expected in the MG.**

This combination of the power converters ensures a good power quality, regarding the MG power balancing.

Simulations and experiments were carried out, both showing the effectiveness of the proposed solution.

Keywords: *microgrid, frequency control, unbalance compensation and power quality.*

1. INTRODUCTION

Microgrids (MGs) supplied by renewable energy sources (RES) are increasingly studied, due to their insignificant environmental impact, towards the classical power plants. A microgrid (MG) can be defined as a low-voltage network with its loads and several small modular generation systems connected to it, providing both power and sometimes heat (combined heat and power – CHP) to local loads.

Although there are no specific international standards about isolated electrical systems, the power quality of MGs should be similar to the interconnected systems. The consumers of both isolated and interconnected systems are the same, and therefore their equipments require the same power quality to operate.

As the loads are usually single-phase ones, power unbalance appear in the three-phase system. These currents produce unequal voltage drops in the system phases, and as result, unbalanced voltages appear. Thus, the zero and negative current sequences will appear in the MG lines, followed by their negative effects. For these reasons, an unbalance compensation technique must be implemented, in order to maintain an acceptable power quality level. In this direction, the literature proposes several methods. Ref. [1] proposes a power electronic converter to redistribute power between the grid phases. The converter consists in a three-phase PWM inverter, parallel connected to the grid. The converter operation principle is to take power from the lower charged phase and send it to the phases with higher load power demand. Another solution for power quality improvement in a four-wire MG, supplied by distributed generation sources is presented in [2]. Two four-phase-leg inverters (a shunt and a series) are used that are able to ensure a good power quality for the MG, both in steady state and transitory regimes. In systems that supply both unbalanced and nonlinear loads, a combined control of harmonics mitigation and unbalance compensation can be implemented [3]. Load power balancing and power factor correction can be achieved by using a static Var compensator (SVC) [4].

The compensation of all the undesired current components can be ensured by using an active filter (AF) that has the basic function to eliminate harmonics, unbalances and meet reactive power requirements of the load, so that the AC supply feeds only sinusoidal unity power factor currents [5].

All these methods are based on non-dissipative techniques, by using different types of static compensators (STATCOM).

This paper focuses on four-wire MGs, were the single-phase domestic loads are quite exclusive.

2. SYSTEM CONFIGURATION

Fig. 1 shows the proposed configuration for unbalance compensation, in a MG, supplied by a synchronous generator (SG) and an induction generator (IG). The SG is star connected with neutral available, while the IG is delta connected.

Under unbalanced load conditions the SG will be supplementary charged by the zero and negative current components, while the IG only with the negative ones. By using the compensation technique described in this paper, the unbalanced currents that flow through the generators' windings can be equalized, and so the corresponding negative effects.

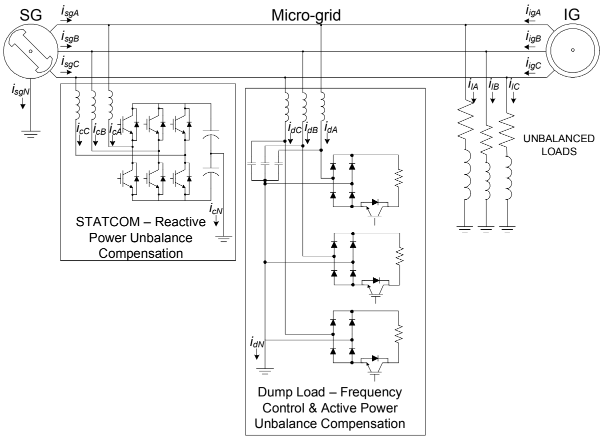

Figure 1: Proposed system configuration

An islanded MG must have its own resources to maintain the power quality, mainly the voltage and frequency rated values. Voltage control is achieved by controlling the excitation field of the SG.

The active power balance must be ensured at any moment, in order to maintain constant the system frequency. Therefore, the generators must immediately supply the electrical energy consumed by the loads. As the loads are varying randomly, it must be implemented a load-frequency control (LFC) strategy. This paper uses a dissipative-based LFC, by using a dump load (DL). The authors have studied before a robust DL configuration, consisting in three dumping resistances connected to the grid through power converters [6, 7]. Forwards, this paper investigate the possibility of compensating the active and reactive power unbalance, by using a DL in combination with a STATCOM.

The DL ensures the system frequency control and the active power balance, while the STATCOM ensures the reactive power balance between phases. By charging the STATCOM only with the reactive power unbalance, its rated power can be significantly reduced, in comparison with a classical one.

The STATCOM is a bidirectional PWM VSI connected in parallel with the MG. In order to obtain the neutral point of the VSI a simple approach is to use two capacitors to split the DC link and tie the neutral point to the middle point of the two capacitors.

The DL contains three single-phase rectifier bridges and three IGBT transistors, working in PWM mode.

3. CONTROL SCHEME

Fig. 2 shows the control diagram of the unbalance compensation system. The control is split in two parts: one is for the DL and another for the STATCOM.

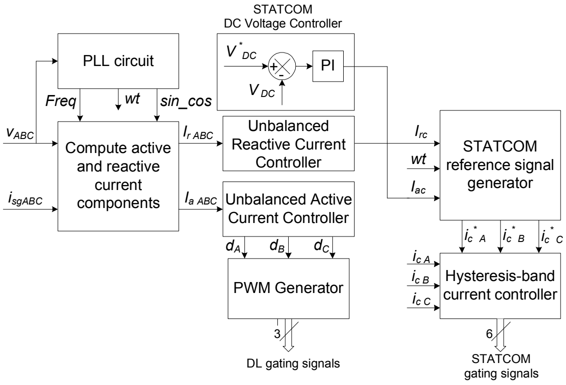

Figure 2: Block diagram of the proposed control scheme

The basic operation principle is to measure the SG phase-to-neutral current, and decompose it into the active and reactive current components. The active current is for the DL control loop, while the reactive one is for the STATCOM control. A phase locked loop (PLL) circuit is used to determine the system frequency and phase, and to synchronize the VSI output voltage with the MG.

3.1. DL control

The DL control is divided in two levels: one for frequency and the other for active power unbalance. Fig. 3 shows the MG power diagram on each phase: the power consumed by the loads (P_A, P_B, P_C) and the power absorbed by the DL (P_{DLA}, P_{DLB}, P_{DLC}). Their sum represents the available power at the generators leads.

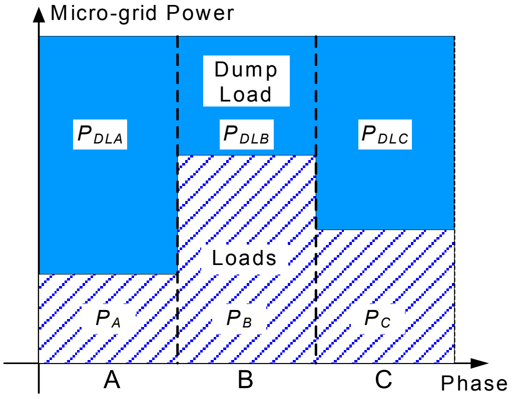

Figure 3: MG power diagram

The total generators power cannot be directly evaluated, but only the difference between the generators available power and the demanded power by the loads, equal to:

$$\Delta P = P_{MG} - (P_A + P_B + P_C) \qquad (1)$$

This difference will produce a frequency deviation $\Delta f = f(\Delta P)$, which can be directly measured.

The active power balance conditions on the three phases are:

$$P_{DLA} + P_A = P_{DLB} + P_B = P_{DLC} + P_C \qquad (2)$$

$$\Delta P = P_{DLA} + P_{DLB} + P_{DLC} \qquad (3)$$

From Eq. (2) and (3) the DL output powers are:

$$P_{DLA} = \frac{\Delta P + P_B + P_C - 2P_A}{3} \qquad (4)$$

$$P_{DLB} = \frac{\Delta P + P_A + P_C - 2P_B}{3} \qquad (5)$$

$$P_{DLC} = \Delta P - P_{DLA} - P_{DLB} \qquad (6)$$

The quantities P_A, P_B and P_C can be measured, while ΔP is indirect estimated by the frequency controller through the frequency deviations Δf.

Based on Eq. (4), (5) and (6) the DL controller block diagram is shown in Fig. 4. It contains two control loops, one for frequency and one for active power unbalance. The first is a high-speed loop, while the second is a slow speed loop. Both are based on PI controllers. The frequency controller is fed by the difference between the rated and actual frequency. Its output gives the amount of active power that has to be ensured by the DL, in order to stabilize the system frequency. The active power phase balancing is ensured by the slower control loop which consists in a redistribution algorithm of the DL power on the three phases. The outputs of the unbalance controller are added to the output of the frequency controller. The output of the DL controller, gives the duty cycles (d_{ABC}) of the three transistors from its component.

It is important to note that the unbalance controller does not influence the frequency controller, because it only redistributes power between phases and the DL total power is not affected. Thus, the two control loops are working separately with different speeds, ensuring a stable frequency and active power balance between phases.

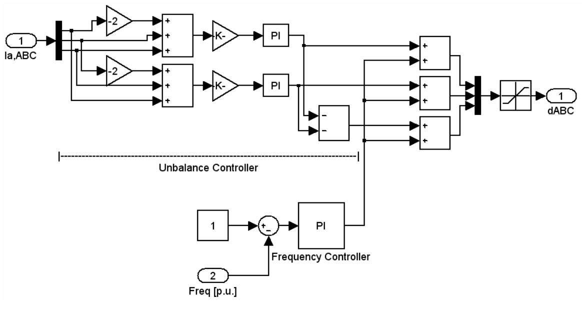

Figure 4: DL control diagram

3.2. STATCOM control

The difference between the three reactive currents will give the current flow through the STATCOM, in order to minimize the reactive current unbalance. The controller operation principle is shown in Fig. 5. The average value of the load reactive currents is determined, which will be used as a reference for the STATCOM control. The STATCOM reference reactive current (I_{rc}) is obtained from the difference between the average value and the actual reactive current on each phase that fed the PI controllers. Thus, all three reactive currents will have the same value, and the system will be balanced.

The STATCOM total current reference signals are obtained from the reactive current reference (I_{rc}) and active current reference (I_{ac}). The active current reference results from the DC voltage controller, which maintains the VSI DC capacitors voltage constant. The reference currents (i_{ca}*, i_{cb}* and i_{cc}*) are compared with the real currents in a hysteresis-band current controller. The results are six PWM pulses that feed the VSI power transistors.

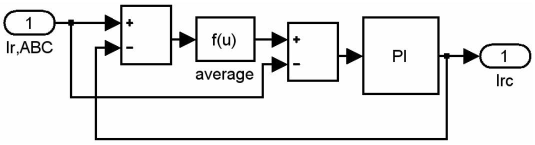

Figure 5: STATCOM control diagram

4. SIMULATION RESULTS

The modeling and simulation of the proposed system (Fig. 1) were accomplished by using the Matlab/Simulink software environment. Fig. 6 shows the model of the studied system. It is used a simplified model of a 16 kVA SG, and a 7.5 kW IG.

During the steady state, the SG and IG work at 90 % respectively 80 % from their rated power. The MG supplies one three-phase and two single-phase loads. Phase charging is as follows: phase A – 7 kW/4kvar, phase B – 5.5 kW/1kvar and phase C – 3 kW/2kvar. For both generators, SG and IG, the voltage is controlled through the excitation current of the SG's field winding.

The simulation results are split in two parts, the first presents the main steady state measures and the second one shows the dynamic behavior of the system during an unbalanced load connection.

Fig. 7 presents the SG and IG steady state currents with the unbalance compensation controller enabled, while Fig. 8 shows the same currents with the controller disabled. The load currents are presented in Fig. 9. When the controller is enabled, the load-unbalanced currents are not reflected in the generators currents, due to the action of the unbalance compensation. Fig. 10 shows the DL and STATCOM currents. They are unbalanced according to the load, so that the total current will be balanced.

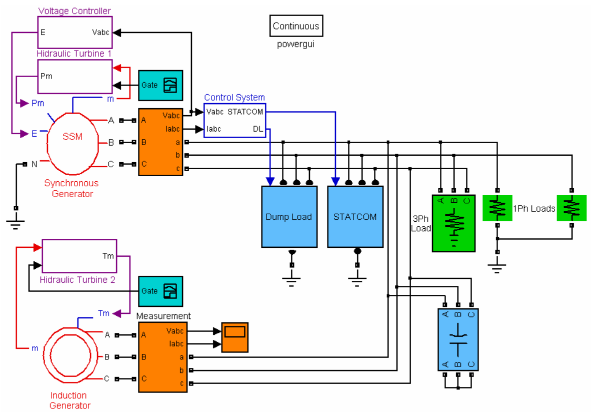

Figure 6: Simulink block diagram

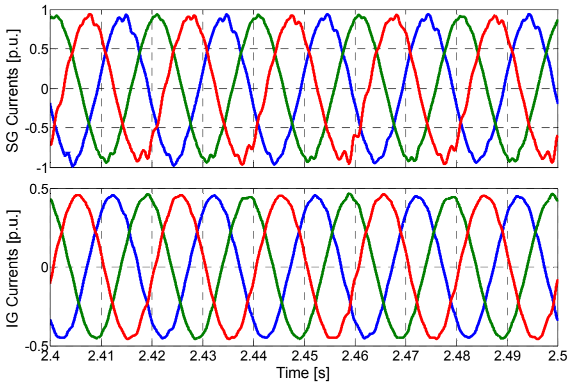

Figure 7: SG and IG currents with power unbalance compensation

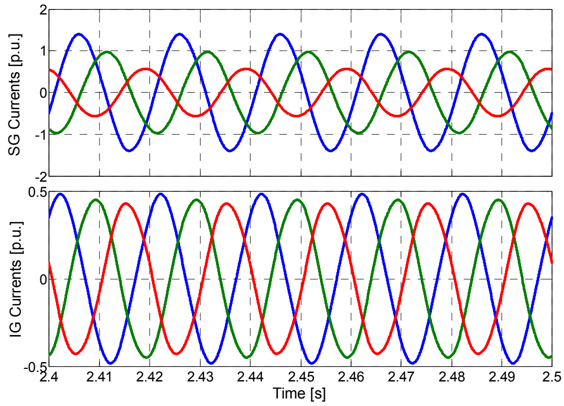

Figure 8: SG and IG currents without power unbalance compensation

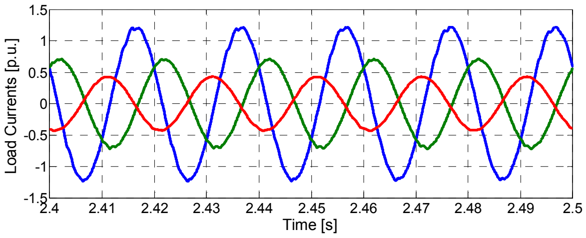

Figure 9: Load currents

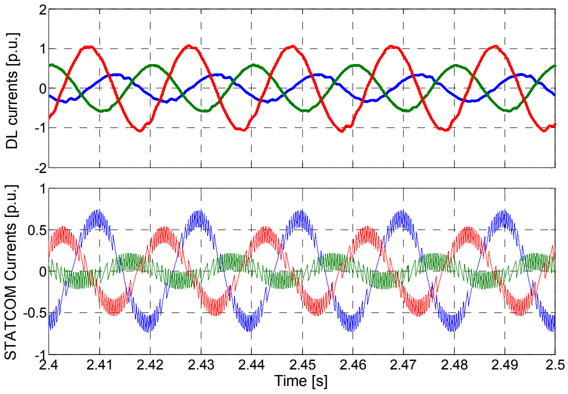

Figure 10: STATCOM and DL currents

In the second step, the system is constrained to a 2kW/1.5kvar single-phase load connection, on phase C at t=1.5 s. Fig. 11 shows the frequency and the frequency controller output. The connection of 2kW adds an extra power to the system load, while the generators power remains constant. Thus, the power balance is maintained by decreasing the DL power. The action of the unbalance controller during the single-phase load connection can be seen in Fig. 12, where are presented the active and reactive currents. At the connection moment, they are unbalanced and in relative short time, they become equal. The DL and STATCOM outputs are presented in Fig. 13. Their controllers act in consequence to balance the active and reactive powers.

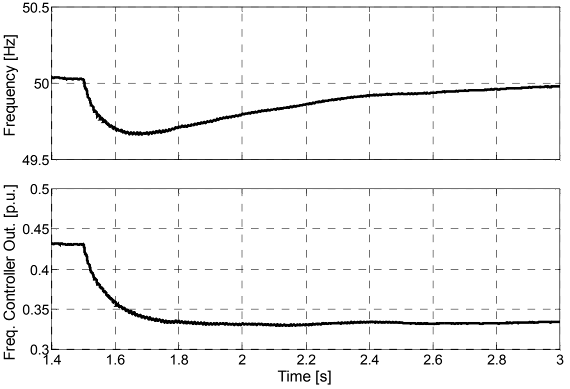

Figure 11: Frequency and frequency controller output during unbalanced load connection

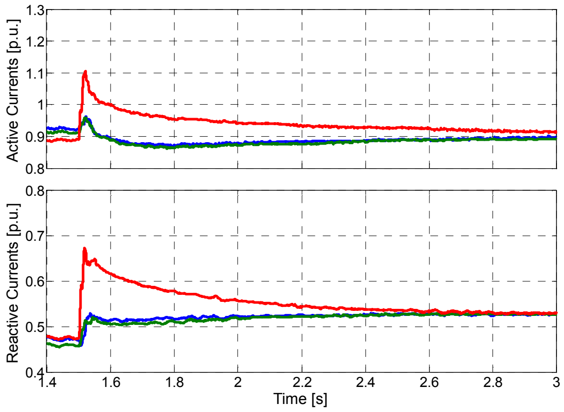

Figure 12: SG RMS active and reactive currents during unbalanced load connection

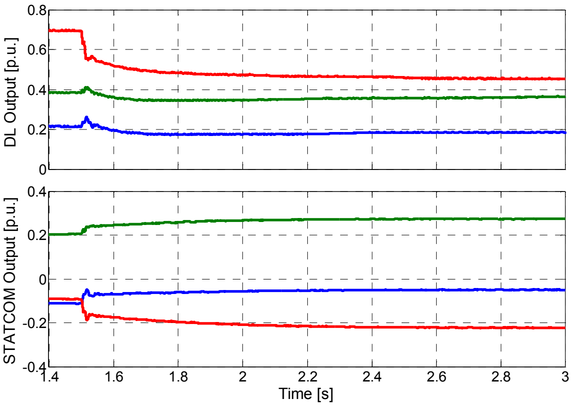

Figure 13: DL and STATCOM output during unbalanced load connection

5. EXPERIMENTAL RESULTS

The experimental test bench was accomplished on a laboratory-scale prototype, which contains a MG based on a 4 kVA SG. The loads are three unbalanced resistors with different values in order to create the unbalanced conditions. The control system, and data acquisition were implemented using a DS1102 dSPACE™ card (TI DSP TMS320C31).

The experiments are fulfilled only with the DL, because of the limitation of the available hardware control implementation. The STATCOM control implies the measurement of three currents and three voltages, while the DS1102 has only four analog inputs. Thus, the implementation of the STATCOM control is unfeasible.

The experiments are split in two parts: steady state and transitory regimes. In steady state, the SG currents are shown, for two cases: without and with unbalance compensation, as presented in Fig. 14. The presence of high order harmonics can be observed in the SG currents waveforms. The voltage delivered by the SG contains the 3rd, 5th, 7th, 9th order harmonics, due to the non-sinusoidal distribution of the magnetic field in the machine air-gap area. The simulation model of the machine, did not take into account this phenomena, in the previous section. The DL unbalance compensation feature can be clearly seen. The SG will sense a balanced load, no matter the real load unbalance.

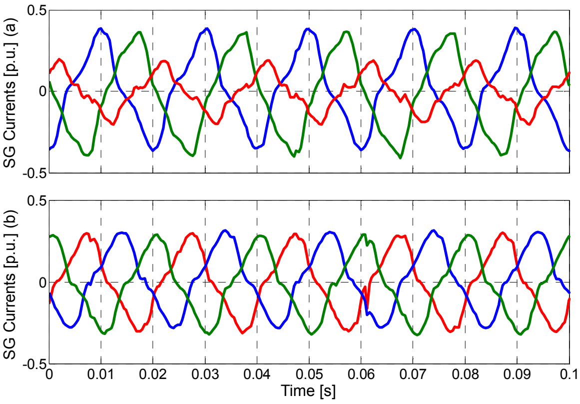

Figure 14: S.G. phase-to-neutral currents without unbalance compensation (a) and with unbalance compensation (b)

In the second step, the system dynamic behavior is tested. The results are presented in Fig. 15, 16. At t = 0.5 s, the unbalanced load is connected to the SG lines. Fig. 15 shows the frequency and the frequency controller output, during this event. As the SG power remains constant, the connection of the additional load affects the power balance, and the frequency decreases. The DL frequency controller will act in consequence and decrease its power until the frequency is brought at the rated value of 50Hz. Fig. 16 presents the SG RMS currents and the DL output, on the three phases, during the unbalanced load connection. Initially, the currents are unbalanced, and after a few seconds, they became equal due to the DL control action.

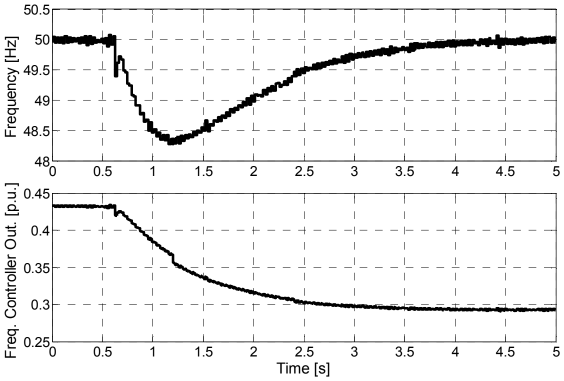

Figure 15: Frequency and frequency controller output during unbalanced load connection

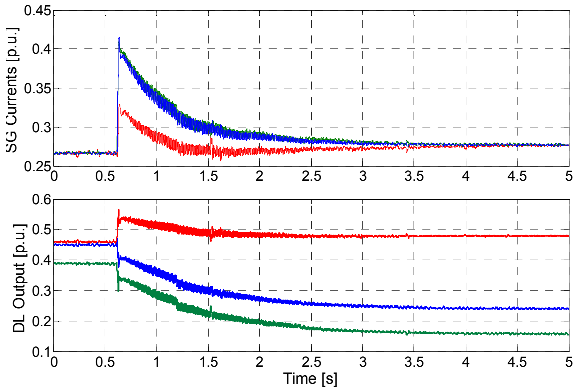

Figure 16: S.G. phase-to-neutral RMS currents and DL output during unbalanced load connection.

6. CONCLUSIONS

This research presents the control requirement, regarding the power unbalance compensation for a stand-alone MG. The compensation is based on a dump load (DL) and a static compensator (STATCOM), which ensure the balance of the active and reactive powers.

The DL, which has the main role of frequency controller, is able to accomplish its task as it can be seen in Fig. 11 (simulation) and Fig. 15 (experimental). In addition, the DL ensures the active power balancing between phases, too as shown in Fig. 12, 13 and Fig. 16.

The STATCOM accomplishes only the redistribution of the reactive power unbalance between phases, not the power factor correction, as shown in simulation results sections, Fig. 12 and Fig. 13. Thus, the STATCOM rated power is low, according to the maximum reactive power unbalance that can be expected in the MG.

The simulations and experiments carried out are showing the effectiveness of the proposed solution.

Acknowledgments

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