

POWER QUALITY ISSUES IN A STAND-ALONE MICROGRID BASED ON RENEWABLE ENERGY

IOAN ȘERBAN, CORNELIU MARINESCU

Key words: Microgrid (MG), Power quality, Dump load, Frequency control.

The paper presents several power quality issues in an islanded microgrid, regarding the frequency regulation. A load-frequency control technique has been implemented, which consists in a special device, named dump load (DL) that draws the extra power from the generators, transforming it into heat through a power electronics device. This paper compares more DL topologies from the power quality point of view, and suggests a new DL configuration developed by the authors. The simulations and experimental results show the effectiveness of the solution.

1. INTRODUCTION

Microgrids supplied by renewable energy sources (RES) are increasingly studied due to their insignificant environmental impact, concerning the classical power plants. The connection of small generation units (tens of kilowatts) in low voltage networks tends to be a more reliable solution. A microgrid 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.

An islanded microgrid must have its own resources to maintain the power quality, mainly the voltage and frequency rated values. The voltage variations depend of the system reactive power, while the frequency depends of the system active power balance. Voltage control can be achieved by controlling the excitation field of the synchronous generator (SG) [1–4] or by using power electronics converters [5–7].

The active power balance must be ensured at any moment, in order to maintain constant the system frequency. Because the loads are varying randomly, a load-frequency control (LFC) technique must be implemented. In high power systems, LFC is attained by controlling the generators prime movers mechanical power.

Transilvania University of Brasov, Department of Electrical Engineering, 29 Eroilor Bvd., Braşov, serban@leda.unitbv.ro, marinescu@leda.unitbv.ro

Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **53**, 3, p. 285–293, Bucarest, 2008

For low-power islanded microgrids supplied by RES, the most reliable and cost efficient LFC is by using an electronic load controller, without any control on the mechanical side of the generators. The method consists in using an additional device that draws the excessive power from the generators, transforming it in other type of energy [3–5, 8–11]. It can be stored and used in periods of lack of energy, or it can be transformed into heat in a CHP system, by using a dump load (DL). The DL based frequency controller provides frequency regulation only if the generated power is bigger than the consumed one. The power converter between the microgrid lines and the dissipative element (power resistor) makes the difference among various types of DLs.

This paper presents more DL topologies and shows their power quality aspects. The DLs topologies are chronological studied by the authors [9, 10], starting from the DL structure presented in [11]. Their features were improved until good power quality was obtained. The differences between these types of DLs consist in the high order current harmonics introduced in the microgrid by their operation.

2. DL TOPOLOGIES

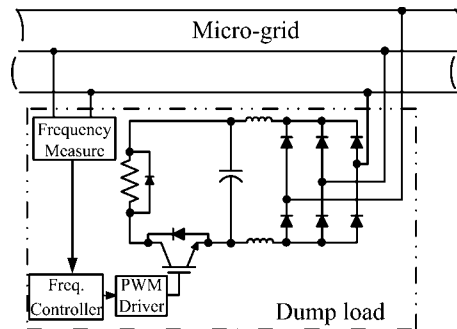
Fig. 1 presents the three main studied DL configurations. The differences consist in the power electronic converter between the microgrid and dumping resistances.

The energy is transformed from AC to DC, and a power transistor, driven in PWM mode, ensures the active power flow to the resistor. The control technique is the same for all three topologies. The microgrid frequency is determined through the line voltage measurement, and the actual frequency is compared with the rated value of 50 Hz. A PI controller computes the error and gives the duty cycles of the PWM driving waveform.

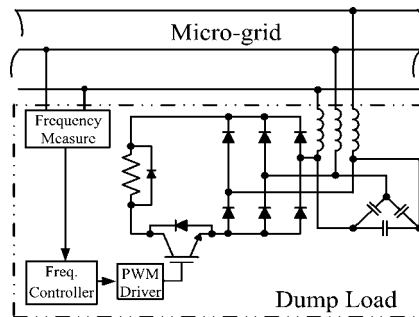
The first DL derives from a classical three-phase DC rectifier topology, as shown in Fig. 1a. A low-pass filter on the DC side of the rectifier bridge ensures the smoothness of the DC voltage. A DC chopper, based on a power transistor applies the PWM pulses voltage on the dumping resistance in order to modify the active power.

In the second configuration, the DL has a low-pass filter on the AC side, as shown in Fig. 1.b. The LC filter ensures the attenuation of the high order current harmonics produced by the DL's transistors switching.

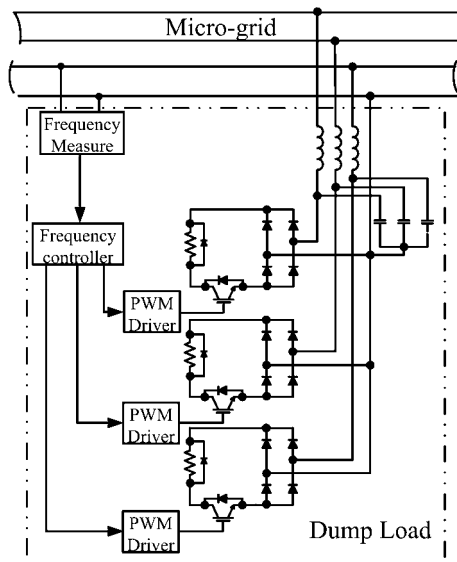
Analyzing the drawbacks of the previously presented DLs, the authors suggest a new configuration, which improves the situation in many aspects. This third DL configuration presented in Fig. 1.c has three separately arms for the three-phases; moreover, it can be used in a four-wire system.



a



b



c

Fig. 1 – DL topologies.

The power quality of the studied DLs is evaluated through the following performance parameters [13]:

– power factor:

$$PF = \frac{P}{S} = \frac{I_1}{I} \cdot \cos \varphi_1. \quad (1)$$

– displacement factor:

$$DF = \cos \varphi_1. \quad (2)$$

– total harmonic distortion:

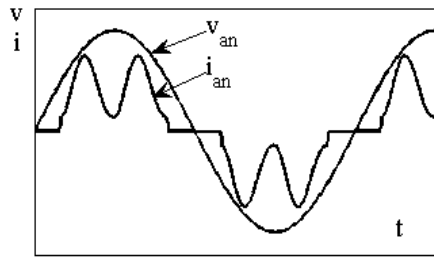
$$THD = \sqrt{\left(\frac{I}{I_1}\right)^2 - 1} = \sqrt{\left(\frac{DF}{PF}\right)^2 - 1}, \quad (3)$$

where: I_1 is the fundamental RMS input line current, I is the RMS input line current, φ_1 is the displacement angle.

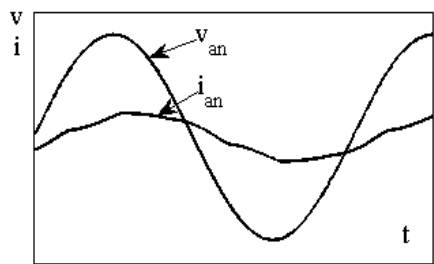
In the following, the line voltage will be considered sinusoidal, without high order harmonics. The power electronics component will be considered ideal, without voltage drops or power losses.

In order to evaluate the performance parameters, the input currents must be analyzed. Fig. 2 shows the line-to-neutral voltage and currents of each DL, for the same operating conditions. Fig. 3 shows the results of FFT analysis applied on the line current, and the performance parameters. It can be seen the difference between the three topologies in the current harmonic content. The 5th and 7th harmonics are predominant in the first two DLs, while the third one has the lowest current harmonics, and therefore it is the solution used in the further simulations and experiments.

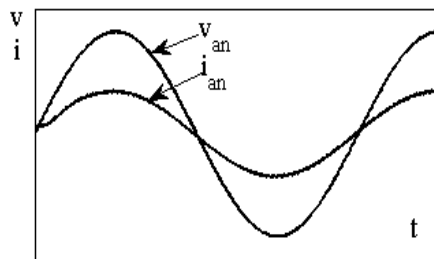
Another aspect that relies from the third DL configuration is the possibility of using the three arms to balance the active power between phases. Therefore, the DL can be used in islanded microgrid both for frequency control and unbalance compensation [8].



a

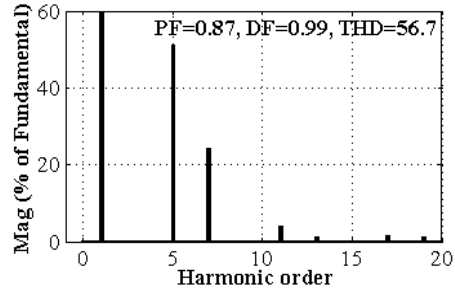


b

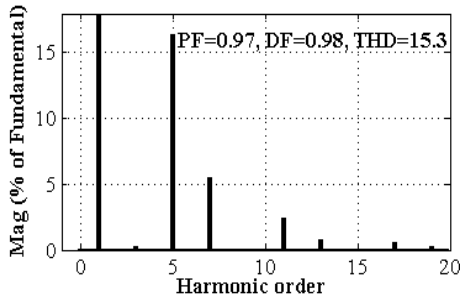


c

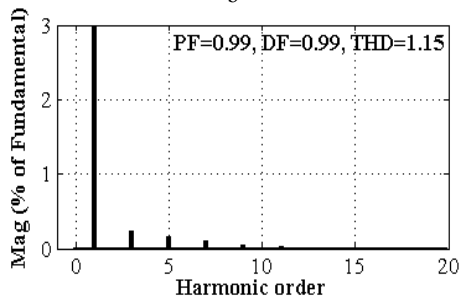
Fig. 2 – Voltage and current for the three DLs.



a



b



c

Fig. 3 – Current harmonic content for the three DLs topologies.

3. SIMULATION RESULTS

The simulation model consists in a three-phase four-wire microgrid with a 16 kVA SG, as shown in Fig. 4. Matlab/Simulink software environment has been used for modeling and simulations. During the steady state, the SG works at 90 % of its rated power. A balanced resistive-inductive load is used of 3 kW/2 kvar per each phase. The voltage is controlled through the excitation current of the SG’s field winding. The DL works at approximately 45 % of its rated power, according

to the load demand and SG available power, such that the frequency is kept constant.

Simulation results consist in steady state and dynamic measurements. Fig. 5 shows the SG current, during steady state operation. They are free of harmonics and balanced.

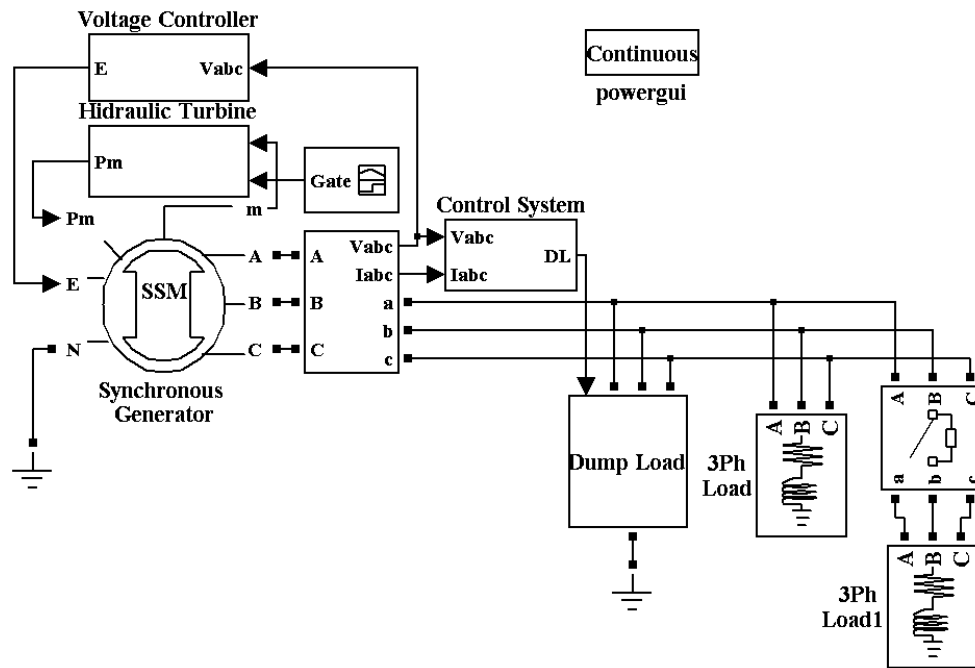


Fig. 4 – Simulink block diagram.

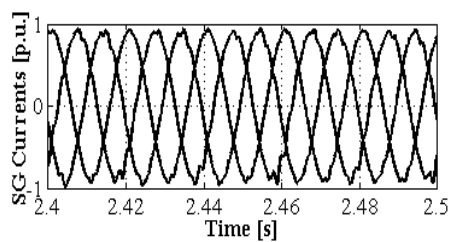


Fig. 5 – SG line currents.

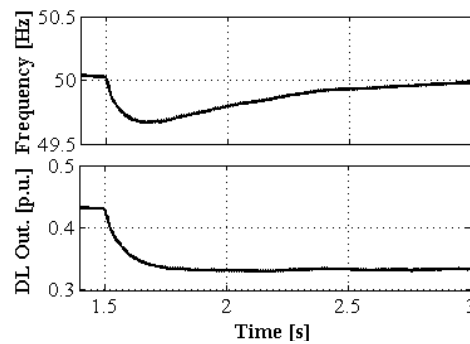


Fig. 6 – Frequency and DL output during load connection.

Another aspect regarding the power quality is the frequency deviation at a sudden load connection. Working as an islanded system, the DL is the main controller that provides necessary conditions for the frequency stability. Therefore, the next simulation deals with a 1 kW three-phase load connection at $t = 1.5$ s. Fig. 6 shows the system's frequency and DL output behavior at the load connection. The frequency deviation is about 0.35 Hz. In order to re-establish the frequency rated value the DL output decrease from approximately 0.44 p.u. to 0.34 p.u.. The transitory process takes around one second.

4. EXPERIMENTAL RESULTS

The experimental test bench was accomplished on a laboratory-scale prototype, which contains a MG based on a single 4 kVA SG, as shown in Fig. 7. The control system, and data acquisition were implemented using a DS1102 dSPACE™ card (TI DSP TMS320C31). Data acquisition is based on mlib/mtrace dSPACE interface libraries. The results were fetched in Matlab workspace from the real-time DSP and are plotted in Figs. 8 and 9.

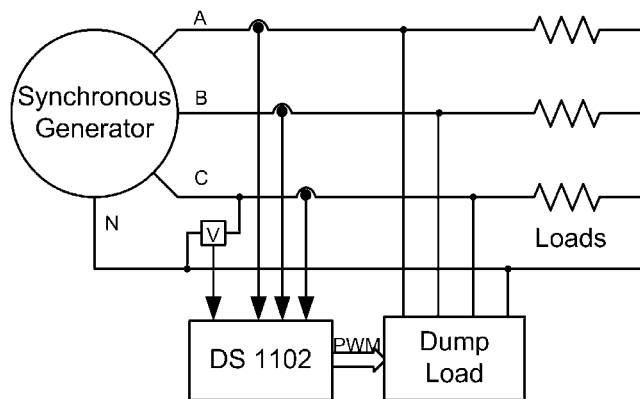


Fig. 7 – Experimental test bench.

The SG line currents during steady state are shown in Fig. 8. The presence of high order harmonics, which can be seen in the SG currents waveforms, is the consequence of the SG phase voltages waveforms. They contain the 3rd, 5th, 7th, 9th order harmonics, and the LC filter of the DL behaves as a filter, having a low impedance for these harmonics. The current harmonics content can be essentially reduced by using an active power filter (APF). The authors intend to solve this problem in the future studies.

In the second step, the system dynamic behavior is tested. The results are presented in Fig. 9. At $t = 0.5$ s, the load is connected to the SG lines. As the SG power remains constant, the connection of the additional load affects the power balance, and the frequency decreases. The DL will act in consequence and decrease its power until the frequency is brought to the rated value of 50 Hz.

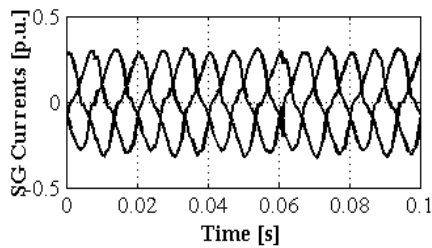


Fig. 8 – SG line currents.

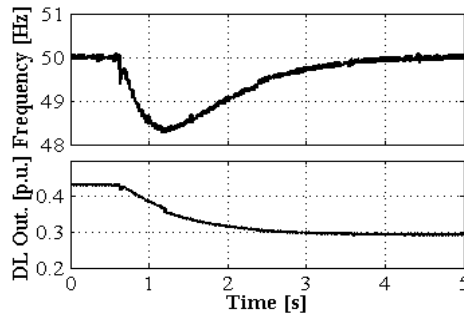


Fig. 9 – Frequency and DL output during load connection.

5. CONCLUSION

The paper has shown some power quality aspects in a stand-alone microgrid that uses a dump load (DL) to ensure the frequency stability. Three configurations of DLs are compared from the current harmonics content point of view.

The authors suggest a new DL configuration, which improves the power quality in many aspects. Between all the previous studied DLs and those found in literature, the proposed DL has less harmonic content than the others, and it has the possibility to enhance the behavior with an unbalance compensation feature.

The accomplished simulations and experiments show the practical approaches and the effectiveness of the proposed solution.

ACKNOWLEDGMENT

The Romanian Ministry of Education and Research supports this research theme under projects CNCSIS: TD no. 303/2007 and IDEI no.134/2007.

Received on 3 November, 2007

REFERENCES

1. T. Senjyu, T. Nakaji, K. Uezato, T. Funabashi, *A Hybrid Power System Using Alternative Energy Facilities in Isolated Island*, IEEE Trans. Energy Conversion, **20**, 2, pp. 406–414 (2005).
2. R. Jarman, P. Bryce, *Experimental investigation and modelling of the interaction between an AVR and ballast load frequency controller in a stand-alone micro-hydroelectric system*, Science Direct – Renewable Energy, **32**, 9, pp. 1525–2543 (2007).
3. R. Sebastian, J. Quesada, *Distributed Control System for Frequency Control in a Isolated Wind System*, Science-Direct – Renewable Energy, **31**, 3, pp. 285–305 (2006).
4. I. Șerban, C.P. Ion, C. Marinescu, *Frequency Control and Unbalances Compensation in Autonomous Micro-Grids Supplied by RES*, The IEEE International Electric Machines and Drives Conference, CD Proceedings, Turkey, May 2007.
5. B. Singh, A.Chandra, *Battery Based Voltage and Frequency Controller for Parallel Operated Isolated Asynchronous Generators*, Proceedings of IEEE International Symposium on Industrial Electronics – ISIE, Vigo, Spain, 2007, pp. 883–888.
6. F. Carastro, M. Sumner, P. Zanchetta, *Shunt Active Filter for Voltage and Power Improvements within a Micro-grid*, Proceedings of 12th International Power Electronics and Motion Control Conference – EPE-PEMC, , Portoroz, Slovenia, 2006, pp. 1665–1670.
7. Y. W. Li, D. M. Vilathgamuwa P. C. Loh, *Micro-Grid Power Quality Enhancement Using A Three-Phase Four-Wire Grid-Interfacing Compensator*, IEEE Trans. Industry Application, **41**, pp. 1707–1719 (2005).
8. I. Șerban, C. Marinescu, *Unbalance Compensation in Stand-Alone Microgrids*, Analele Universitatii din Craiova, Anul 31, Nr. **31**, Vol. II, pp. 223–228 (2007).
9. I. Șerban, C. Ion, C. Marinescu, M. N. Cirstea, *Electronic Load Controller for Stand-Alone Generating Units with Renewable Energy Sources*, The 32nd annual conference of the IEEE Industrial Electronics Society – IECON 06, Paris, France, 2006, pp. 4309–4312.
10. I. Șerban, C. Marinescu, *Hybrid Power System based on Micro-Hydro and Wind Turbine Generation*, 10th International Conference on Optimization of Electrical and Electronic Equipments”, OPTIM’06, Brașov, Romania, 2006, pp. 267–274.
11. B. Singh, S.C. Murthy, S. Gupta, *Analysis and Design of Electronic Load Controller for Self-Excited Induction Generators*, IEEE Trans. Energy Conversion, **21**, 1, pp. 285–293 (2006).
12. M. H. Rashid, *Power Electronics Circuits, Devices, and Applications, Third Edition*, Pearson Prentice Hall, 2004.
13. N. Mohan, T.M. Undeland, W.P. Robbins, *Power Electronics Converters, Applications, and Design*, Third Edition, John Wiley&Sons, Inc, 2003.
14. F. C. De La Rosa, *Harmonics and Power Systems*, Taylor&Francis, CRC Press Book, 2006.

Renewable sources of energy are becoming the most important sources for supplying electrical energy straight to the customer without traditional distribution system, especially for communities living far in areas where grid extension is difficult so generation of green sources such as photovoltaic (PV) and wind power for providing reliable energy with improved system efficiency and significant cost reduction is best way. Wherever any fault occurred on utility grid, microgrid switched to stand-alone mode [5] 2.1. Microgrid power systems configurations. Microgrid is configured based on the following technical topologies to couple the available renewable sources and to meet the required load. Here, voltage and the load demand are the determinant factors. Energies. Special Issues. Power Quality in Microgrids Based on Distributed Generators. Submit to Energies Review for Energies Edit a Special Issue. Journal Menu. cole de technologie sup@rieure, Montreal, QC, H3C 1K3, Canada Interests: power quality; renewable energy control and integration; microgrids Special Issues and Collections in MDPI journals. Special Issue in Energies: Power Management of Microgrids. Prof. Dr. Hua Geng Website Guest Editor. Power quality is the emerging issue in microgrids, and the problem is more complicated than that in conventional distribution systems because of the intermittent nature of renewable energy sources, as well as the increased infiltration of nonlinear loads and power electronic interfaced DG systems. 7 Power quality issyes in a microgrid based on renewable energy 291. Another aspect regarding the power quality is the frequency deviation at a sudden load connection. Working as an islanded system, the DL is the main controller that provides necessary conditions for the frequency stability. Therefore, the next simulation deals with a 1 kW three-phase load connection at $t = 1.5$ s. 5. CONCLUSION. The paper has shown some power quality aspects in a stand-alone microgrid. that uses a dump load (DL) to ensure the frequency stability. Three configurations. of DLs are compared from the current harmonics content point of view. The authors suggest a new DL configuration, which improves the power. quality in many aspects.

