MICRO HYDRO POWER PLANT WITH INDUCTION GENERATOR SUPPLYING SINGLE PHASE LOADS

C.P. ION[1] **C. MARINESCU**[1]

Abstract: *This paper presents a new method to supply single-phase loads using a three-phase induction generator (IG). The voltage and frequency regulation, as well as the phase IG phase balancing is ensured by a combination between a voltage source inverter (VSI) and a dump load (DL). Operating at constant frequency, the VSI keeps the system frequency also constant and deals with unbalances compensation, while the DL performs the voltage regulation. Through simulations and experiments the reliability of such a configuration is tested.*

Key words: *renewable energy, induction generator, unbalances compensation, voltage source inverter, dump load.*

1. Introduction

The rapid depletion and enhanced costs of conventional fuels, combined with growing concerns about the environment, have led to an important technical progress in the field of renewable energy systems. For autonomous micro hydro power plants (MHPP), the induction generator (IG) is more suitable then the synchronous one in terms of robustness, low maintenance and capital cost. In rural and isolated places with installed powers bellow 10 kW single-phase consumers are predominant. As three-phase induction machines are available in a wide power range, their use for supplying single-phase consumers is of real interest [1], [2], [5-6], [8], [10]. In this regime, the autonomous IG control requires also phase balancing, besides voltage and frequency regulation.

In this paper, a voltage source inverter (VSI) and dump load (DL) combination is used to ensure the balanced operation and parameters regulation of an autonomous three-phase IG when supplying unbalanced loads.

2. System Configuration

The circuit diagram of the proposed topology, depicted in Figure 1, contains the three-phase IG, a capacitor bank, the single-phase loads and the control part (VSI+DL). The excitation capacitors supply almost the entire reactive power necessary for the IG self-excitation process; they also sustain the rated voltage in steady-state regime. The voltage source inverter (VSI) operates at constant synchronous frequency (f_n = 50 Hz), maintaining the IG frequency constant. The dump load (DL) connected to the VSI DC side will be controlled so that the voltage across the C_{DC} capacitor remains at a constant level, maintaining the system voltage in a standard variation

---

[1] POWERELMA Research Laboratory, *Transilvania* University of Braşov.

range, like in [3]. The amount of power delivered to the DL is controlled by modifying the PWM duty cycle that drives the T_D transistor.

As the loads are connected between two phases, the IG currents become unbalanced. A supplementary function, added to the VSI command algorithm, will balance them back. The unbalances compensator will redistribute the currents through the VSI in order to obtain balanced currents at the IG leads [4].

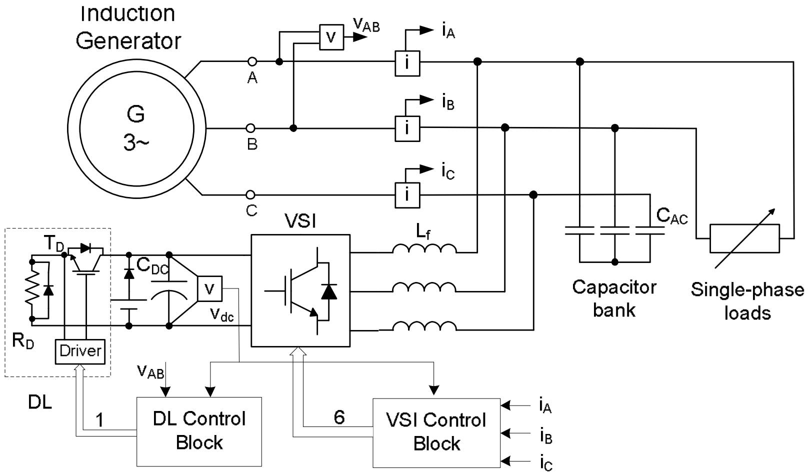

Fig. 1. *Circuit diagram of the studied topology*

3. The Control System

The VSI is a three-phase PWM inverter with six transistors. Its control requires the generation of six PWM pulses, which drive the transistor bridge. The VSI operates at constant synchronous frequency ($f_n = 50$ Hz), maintaining the IG frequency constant, excepting the start-up [3].

In order to achieve balanced currents at the IG leads the VSI performs as an unbalance compensator according to the load. As the loads are varying randomly, the VSI control must quickly adapt to maintain the IG balance currents.

The unbalance compensation control scheme id depicted in Figure 2. The A phase current is considered as reference and the B and C current references are obtained by lagging the A current with 120 and 240 degrees. The unbalance compensation control scheme contains two stationary-frame regulators called Proportional-Resonant (PR) controllers, which are based on stationary-frame generalized integrators. These regulators report very good performances, actually achieving the same transient and steady-state performance as a classical synchronous-frame PI regulator [9], [11].

As the frequency is kept constant by the VSI, the system's power balance is reduced to the DC capacitor voltage control. The dump load connected to the VSI DC side will be controlled so that the voltage across the C_{DC} capacitor remains at a constant level, maintaining the system voltage in a standard variation range.

Thus, the difference between the power delivered by the IG and the loads demand will circulate through the VSI towards the C_{DC} capacitor, which acts as a short-time energy storage element. The DC voltage variation ratio depends on the capacitance value and on the amount of power transferred

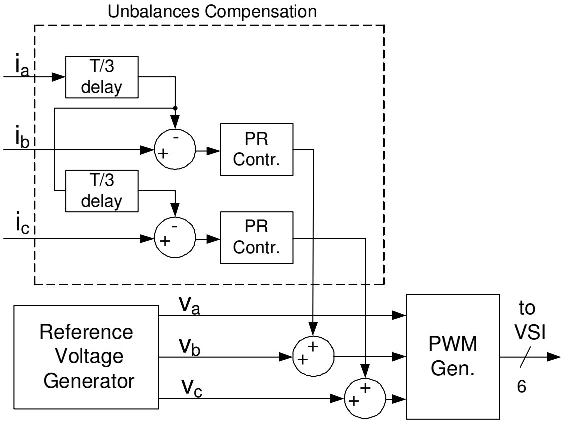

Fig. 2. *The unbalances compensation scheme*

transferred from the IG towards the capacitor. The capacitor value plays a very important role during transitory regimes, when it has to handle large amounts of energy (in or out). Large capacitors ensure low voltage drops across the IG lines when dynamic loads (as induction motors) are connected to the system [7]. Likewise, for unbalanced loads asymmetrical currents will flow through the inverter lines, producing voltage variations on the C_{DC} capacitor [3].

Two PI controllers are used to regulate the system voltage, as shown in Figure 3. The first PI controller is the leading voltage regulator. It compensates the voltage drops across the inverter arms and filter, IG leakage impedances, and other circuit elements, which usually led to a decrease of the IG voltage. The IG root-mean-square (RMS) voltage (V_{AB}) is the feedback signal, it is compared with the 230 V reference signal (V_{REF}), and the error feeds the PI controller, giving the reference signal (V_{DCref}) for the second controller. The second PI is used to maintain constant the C_{DC} voltage. The allowed voltage variation (ripple) across C_{DC} capacitor (ΔV_{DC}) will give the frequency and the width of the pulses that drive the T_d transistor from the dump load.

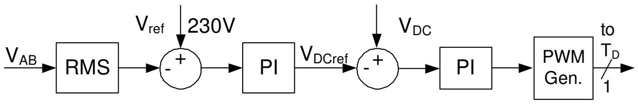

Fig. 3. *The DL control strategy*

4. Simulations and Experimental Results

The reliability of the proposed control topology is tested through a series of simulations and experiments. The simulations were made under the Matlab/Simulink environment. The configuration includes a 2.2 kW IG, a block that models the prime mover (hydraulic turbine), the VSI and DL, an adequate capacitor bank, loads and measurement blocks. The experimental setup consists in a 2.2 kW three phase induction generator, driven by a 3 kW induction motor which emulates a hydraulic turbine (with the use of a DS1102 system from dSPACE). The VSI is actually an industrial converter, connected to the IG leads through a filter with $R = 0.1\ \Omega$ and $L = 6.5$ mH. On the converter DC side there are two 4700 μF capacitors connected in series. The DL circuit consists in an IGBT transistor and a 155 Ω dumping resistance. Data acquisition and system command is ensured by a dSPACE 1103 control board.

4.1. Simulation Results

The IG is connected in Δ, thus its line voltage will be 230 V. Initially, the generator produces around 1300 W; this power flows through the VSI towards the DL. Then, a 600 W single-phase load is connected between two phases. When this thing occurs, at $t = 2.5$ s, the unbalances compensator is disabled. At $t = 3.5$ s the unbalances compensator is enabled. In approximately 1 second, the IG currents become balanced (around 6.5 A each). The RMS IG currents variation is depicted in Figure 4.

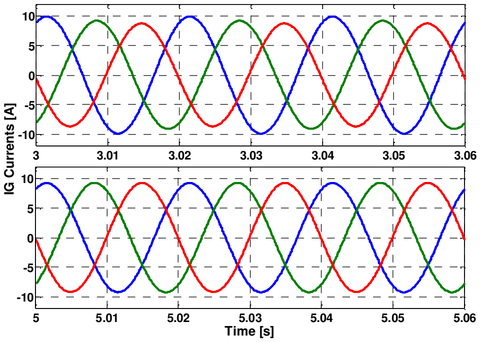

Fig. 4. *The IG currents without (upper) and with (lower) unbalances compensator*

The unbalances compensation consists in redistributing the currents through the VSI. Before the single phase load connection, the power produced by the generator flows through the VSI towards the DL circuit. After the load is connected, the VSI currents also become unbalanced, as can be seen in Figure 5. The unbalances compensator will redistribute the currents through the VSI in order to obtain balanced currents at the IG leads, as results from Figure 6.

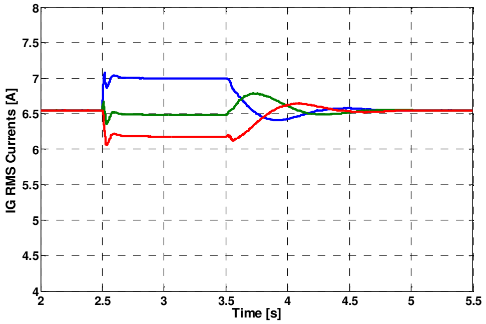

Fig. 5. *The IG RMS currents*

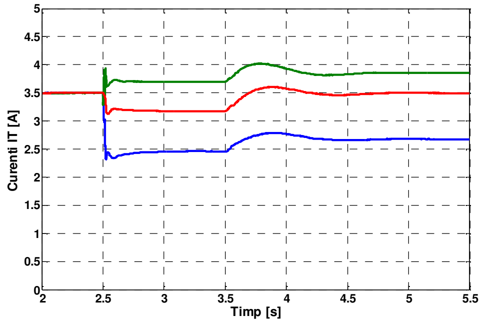

Fig. 6. *The VSI RMS currents*

4.2. Experimental Results

The same operating conditions as in the previous paragraph are applied to the experimental setup. After the load connection, the IG currents become unbalanced, as can be seen in Figure 7. The A phase current will settle at 6.5 A, the B phase current at 5.8 A and the C phase one at 6 A. The unbalances compensator activation leads to phase balancing, bringing all three currents to 6.25 A. The unbalanced VSI currents modify also, in order to ensure balanced currents at the IG leads, as results from Figure. 8. In Figures 9-10 are depicted the IG currents waveforms before and after the unbalances compensator activation.

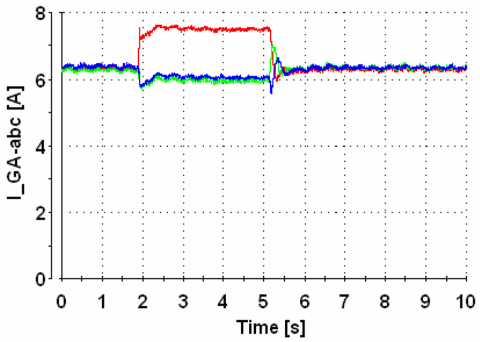

Fig. 7. *The IG RMS currents*

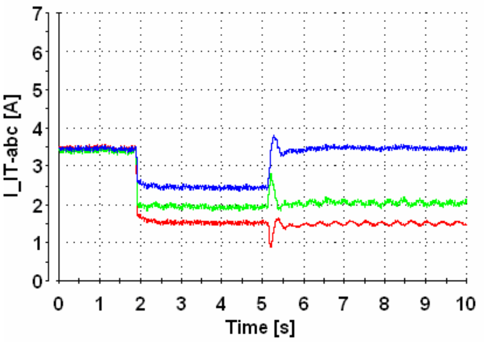

Fig. 8. *The VSI RMS currents*

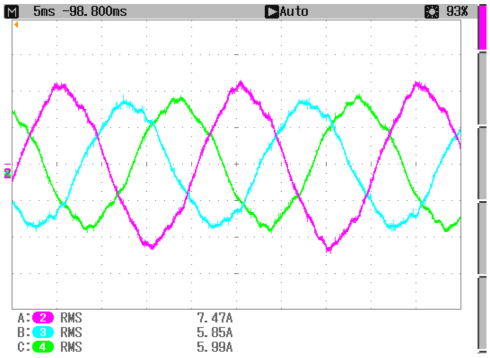

Fig. 9. *The IG currents without unbalances compensator*

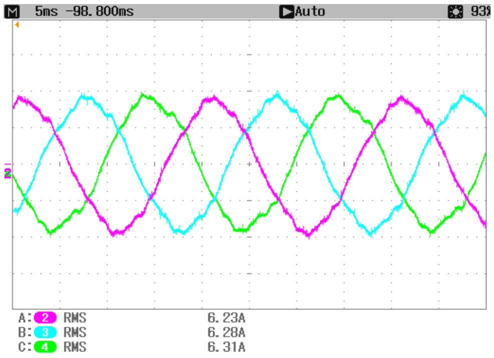

Fig. 10. *The IG currents with unbalances compensator*

5. Conclusions

This paper investigates the operation of an autonomous three-phase induction generator when supplying single-phase loads. The proposed control strategy employs a combination between a VSI and DL. Both simulations and experimental results have shown that the proposed control structure is effective, ensuring a balanced operation for the IG.

Acknowledgements

This paper was supported in part by the Romanian Ministry of Education, Research and Innovation, through contract CNCSIS ID_134.

References

1. Chan, T.F., Lai, L.L.: *Single-Phase Operation of a Three-Phase Induction Generator with the Smith Connection.* In: IEEE Transactions on Energy Conversion **17** (2002) Issue 1, p. 47-54.
2. Chan, T.F., Lai, L.L.: *Single-Phase Operation of a Three-Phase Induction Generator Using A Novel Line Current Injection Method.* In: IEEE Transactions on Energy Conversion **20** (2005) Issue 2, p. 308-315.
3. Ion, C.P., Şerban, I., et al.: *Operation of an Induction Generator Controlled by a VSI Circuit.* In: Proceedings of 2007 IEEE International Symposium on Industrial Electronics, Vigo, Spain,

June 4-7, 2007, p. 2661-2666.

4. Ion, C.P., Şerban, I., et al.: *Single-Phase Operation of an Autonomous Three-Phase Induction Generator Using a VSI-DL Control System.* In: Proceedings of 11th International Conference on Optimization of Electrical and Electronic Equipment OPTIM'08, Braşov, May 22-24, 2008, p. 333-338.
5. Machado, R.Q., Buso, S., et al.: *Three-Phase to Single-Phase Direct Connection Rural Cogeneration Systems*. In: Nineteenth Annual IEEE Applied Power Electronics Conference and Exposition, APEC'04, Volume 3, 2004, p. 1547-1553.
6. Mahato, S.N., Sharma, M.P., et al.: *Transient Performance Of A Single-Phase Self-Regulated Self-Excited Induction Generator Using A Three-Phase Machine*. In: Electric Power Systems Research **77** (2007) Issue 7, p. 839-850.
7. Marra, E.G., Pomilio, J.A.: *Induction-Generator-Based System Providing Regulated Voltage with Constant Frequency*. In: IEEE Trans. Ind. Electronics **47** (2000), No. 4, p. 908-914.
8. Singh, B., Murthy, S.S., et al..: *Analysis and Design of Electronic Load Controller for Self-Excited Induction Generators*. In: IEEE Transactions on Energy Conversion **21** (2006) Issue 1, p. 285-293.
9. Teodorescu, R., Blaabjerg, F., et al.: *Proportional-Resonant Controllers and Filters for Grid-Connected Voltage-Source Converters*. In: Proceeding of the IEEE Electric Power Applications **153** (2006) Issue 5, p. 750-762.
10. Wang, L., Deng, R.Y.: *A Novel Analysis of an Autonomous Three-Phase Delta-Connected Induction Generator with One Capacitor*. In: IEEE Power Engineering Society General Meeting, 18-22 June 2006. Available at: http://ieeexplore.ieee.org/xpl/freeabs_all.jsp?arnumber=1709192. Accessed: 02-03-2009.
11. Zmood, D.N., Holmes, D.G.: *Stationary Frame Current Regulation of PWM Inverters with Zero Steady-State Error.* In: IEEE Trans. on Power Electr. **18** (2003) No. 3, p. 814-822.