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Review

Isolated induction generator in a rural Brazilian area: Field performance tests

A.V. Braga [a,*], A.J.J. Rezek [a], V.F. Silva [a], A.N.C. Viana [a], E.C. Bortoni [a], W.D.C. Sanchez [b], P.F. Ribeiro [a]

[a] Federal University of Itajubá, av BPS, 1303, Itajubá, Minas Gerais, 37500-903, Brazil
[b] Federal Technological University of Paraná, av 7 de setembro, 3165, Curitiba, Paraná, 80230-901, Brazil

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ABSTRACT

Isolated generation in micro hydroeletric power plant (MHPP) through the induction generator (IG) has been the subject of extensive research due to the fact that this type of electrical machine is easy to operate, requires simplified maintenance, and has also a lower cost when compared to the synchronous machine, mainly in the range from 0.5 to 50 kW. In this work a single voltage control loop of an squirrel cage induction generator in an isolated operation system was implemented in a 30 kW MHPP. The proposed system uses a ballast load (BL) controlled via a digital circuit board. The generated voltage and frequency are maintained around their nominal rated values for typical applications in rural areas. For this purpose a control system has been implemented via phase anti–parallel thyristors. Tests were made with varying loads to obtain the voltage waveforms in the main load (ML) and BL. The control allowed by the electronic board was also tested for performance under sudden connection and disconnection of loads. The proposed system proved to be robust and effective in controlling the voltage and frequency of the isolated system.

1. Introduction

Isolated generation in MHPPs using induction generator (IG) [1] with load control has been the subject of previous research [2–4]. The induction motor as generator is used for this purpose due to the fact that this type of electrical machine, being easy to operate, having simplified maintenance, and a lower cost when compared to the synchronous machine in the range from 0.5 to 50 kW [5]. But the IG cannot by itself provide magnetizing or reactive power. To establish its magnetic field it absorbs reactive power from the synchronous generators, in the case of parallel operation, or capacitors in the case of isolated operation.

In an isolated generation, once the IG has established its rated voltage the loads can be connected. However, when loaded to convert mechanical power into electrical power, the IG requires a higher level of magnetization. A fixed capacitor bank (CB) cannot provide additional reactive power without a corresponding voltage drop. To improve this process the first CB is connected to promote the process of self excitation and thus permit the establishment of rated voltage at no load and nominal frequency. Then a second CB is connected. However, with the increase of the load, the voltage drops inevitably. It is necessary, therefore, to meet the additional requirements of IG and load. But when the electrical loads in isolated operation are changed, and for the power supplied by the IG to be equal to consumer demand, some form of speed control is required. The speed control is traditionally done by mechanical speed regulators similar to those used in large hydroelectric power plants, which are used to regulate the flow of water from the turbine as the load changes. But for the application of low cost of a IG, a mechanical speed governor is complex and expensive [6]. Therefore, an electronic load controller (ELC) must be implemented in a MHPP. Maintaining an approximately constant load to the turbine makes it possible to obtain a voltage generated with stable frequency and amplitude. The ELC automatically compensates for the variation in the load of the farm itself or main load (ML), through the variation of the power dissipated in a ballast load (BL), in order to maintain constant the total load supplied by the generator.

The control of BL can be accomplished through a frequency converter (Voltage Source Inverter, VSI) [2]. However, in this

* Corresponding author.
E-mail address: alexandrevbraga@gmail.com (A.V. Braga).

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work, due to the robustness of the thyristor compared to Insulated Gate Bipolar Transistor (IGBT) of the VSI, the control is performed in alternating current (AC), by an AC–AC converter, with the thyristors controlling the excess current diverted to the BL, in order to maintain constant the current in the IG terminals. The thyristor firing circuit is of type current source (Figure 22-1, page 569, of the reference [15] and is less susceptible to disruptive overvoltages when compared to voltage source (Figure 24-9, page 620, of the reference [15]. Furthermore, the i^2t (thermal capacity) of the thyristor is greater than the transistor one. Thus, the thyristor overcurrent protection can be made by the use of ultra rapids fusibles. In the case of the transistor, this is only made by the helping of electronic circuits, resulting in faster actuation, enabling the appropriate protection of this device against overcurrent.

2. The objective of the study

Considering a static reactive power compensator was used (Static Var Compensation, SVC) and a closed-loop with an optimization method of regulators [7] to control only the voltage of IG [8], the main objective of this research was to make possible the application of IG in rural areas, using a structure similar to the SVC structure, but controlling the voltage using just a closed–loop, thereby reducing the range of the frequency. The control performed with a closed–loop for a transistorized system proved to be more simple than the two closed–loops [9]. The contribution of this work, however, is to use a single, robust closed–loop system with thyristors. A control loop frequency is not necessary, provided that it is maintained in an acceptable range for use in rural areas. The proposed system was initially tested with analog control [10], however, the voltage source, the trigger circuit of the thyristors, and regulators were in separate modules, occupying much space in the control cabinet, which hampered the operation of the MHPP.

The operation and maintenance of MHPP shown in Fig. 1 was thus simplified. This MHPP is located at the Boa Esperança Farm [11], with an area of 211 ha [12], in the Serra da Mantiqueira (Mantiqueira Mountain Range), in the municipality of Delfim Moreira in the south of Minas Gerais State, Brazil.

3. The proposed system

In this work the turbine coupled to the IG is of the type pump operating as turbine(PAT) [13] [14], as shown in Fig. 2. This work does not use the mechanical speed regulator that acts to control the water flow. However, the ELC is used, which allows the turbine to operate without flow control (i.e. The water intake valve, located in the penstock, operates fully open).

Fig. 3 shows the electrical schematics of the proposed system presented in Table 1, The CBs and BL, both in parallel to induction generator output phases, the thyristor bridge to control BL, and the autotransformer.

Fig. 4 shows two cabinets in which the CBs, the thyristor bridge and the autotransformer are mounted on the right cabinet and the components of the control system are mounted on the left cabinet.

The components of the control system are also shown in Fig. 3. They are basically the reference voltage circuit, voltage transducer, the accomodation voltage circuit and the electronic control board used to trigger the thyristors. Due to the need for compression and simplification of operation, it was opted for the digital control, with embedded digital regulators contained on a single board. This board is manufactured by Semikron as MP410T. It provides that the arrangement of equipment within the framework be more compact. It is shown in Fig. 6 and, together with other devices, in Fig. 7. The numbered pins of this board are shown in Fig. 3 and are described in Table 2. The gain of the PI regulator of this board has been experimentally set at 0.05 and its time constant was, also experimentally, set to 40 ms.

A delta connection was used for the IG because the induction motor used was a generator that hads 380 V, rated voltage in star–connection, which means that it has 220 V phase-to-neutral. Since the farm loads need 127 V phase–to–neutral and 220 V phase-to-phase, the delta connection 220 V was necessary. The phase–to–phase has been used also as an auxiliar autotransformer 220/240 V, to allow the necessary neutral terminal. Furthermore, the cost of the three phase autotransformer is lower comparatively with the cost of the three–phase transformer.

The primary of the autotransformer 45 kVA, with ratio 220/240 V, provides a neutral to feed loads of the farm, once these can be supplied in 127 V or 220 V.

The CBs is formed by the set of three 220 V delta connected three–phase banks of 10kVAr and two banks of 5kVAr, totaling 40kVAr. As CBs are fed into 200 V, since they are connected to the IG terminals, this value must be multiplied by $(200/220)^2$, resulting their total reactive power 33kVAr.

The BL consists of immersion three–phase resistors of a maximum of 48 kW (if fed into 220 V), used for water heating in a thermal pool, see Fig. 5. The controlled BL keeps the generated voltage in the IG terminals in a narrow range of variation – around its nominal value of 200 V. The frequency will also be close to its

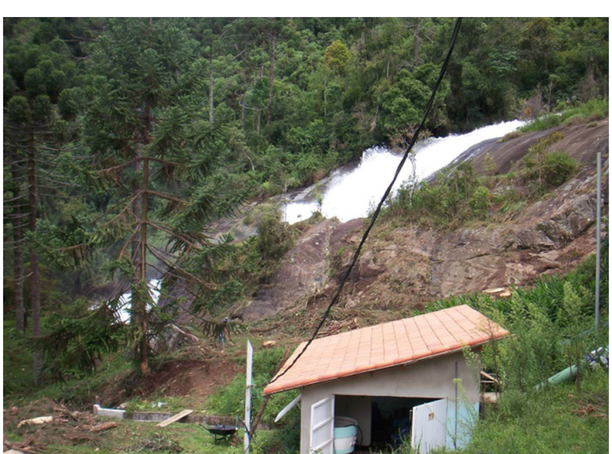

Fig. 1. Waterfall and power house.

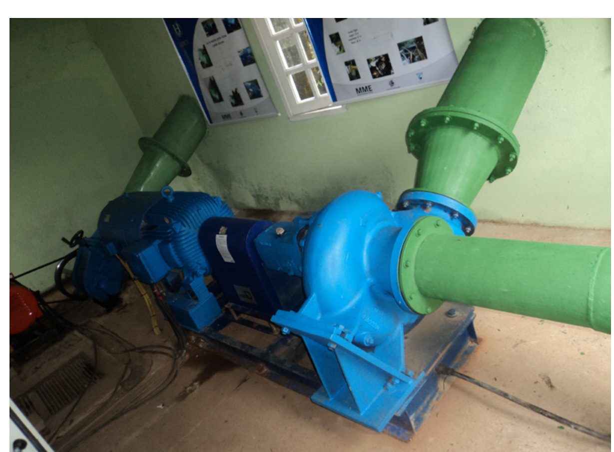

Fig. 2. Pump as Turbine/Induction Generator group.

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