A New Voltage Regulator for Self-Excited Induction Generator - Design, Simulation, and Experimental Results

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Abstract - This paper describes the design process of a new Voltage Regulator (VR) for a Self Excited Induction Generator (SEIG). The control philosophy of the regulator was implemented using both digital and power electronics technology. The VR designed was built and tested with a 3.5 KW SIEG supplying both a resistive load and an induction motor, obtaining a good performance.

I. INTRODUCTION

In recent years, the Self-Excited Induction Generator (SEIG) has emerged as the best electromechanical energy converter to replace the conventional synchronous generator in isolated power generators driven by renewable energy resources : biogas, micro-hydroelectric, wind, etc. The main advantages of the SEIG are: low cost, ruggedness, absence of a separate DC source for excitation, brushless rotor construction (squirrel cage construction). and ease of maintenance. The fundamental problem with using the SEIG was its inability to control the terminal voltage and frequency under varying load conditions. The analysis of the SEIG under steady-state conditions and imposed speed is already known [1]-[6]; however there are few papers about steady -transient operation [7]-[9]. In the last few years the development of microelectronics, power electronics, control techniques and digital systems have made possible the construction of more efficient VR's [10]-[15].

In this paper the design process of a VR for a SEIG is described. First, control strategies are developed to permit SEIG to operate as a stand-alone generator supplying any type of load; then this control philosophy is implemented using a PID controller . The PID was digitaly formed by a PLC. The PLC's parameters were estimated by digital simulations. A prototype of the VR was built and tested with a 3.5 KW SEIG showing good performance in the operation of resistive and inductive loads.

II. VOLTAGE REGULATOR PHILOSOPHY

Fig.1 shows a diagram about the philosophy of control and operation of a newly developed VR. In this VR, the control signal arises from monitoring the voltage, this signal permits us to decide what current range should be supplied to the excitation circuit in order to mantain a constant voltage when a change in the power occurs in the load. The C1 capacitor bank is permanently connected at the stator terminals in order to excite the generator itself, it provides both power to the PLC and also, three-phase voltage in the actuator. After the self-exciting process is finished, the PLC makes the contact K1 close, to balance the reactive power when the SEIG is supplying power to a load in order to mantain the set point voltage. The reactive power supplied by the C2 capacitor bank is absorbed by the coil connected to the actuator. In this moment the PLC makes the Actuator absorb all the C2 energy, in order for the tensión not to increase.

In spite of the fact the K1 is conected, the PID detects the voltage is decreasing, this makes the contact K2 close and the excitation grows taking the SEIG to the set point value again. The C3 capacitor bank is mainly used when the starting inductive load, such as the induction motors, is connected.

III. VOLTAGE REGULATOR DESIGN

A. A Power Actuator Design

A three-phase full converter was selected as Actuator, Fig. 2. To obtain a controlled and linear output at the level of the DC supply to the load, the control signal from the PLC is varied. Because the modification of the control signal level displaces the firing pulse of the thyristor. The use of the switch capacity of the thyristor permits us to change the power factor of a system through the a control of the current capacitor bank. Several solutions have been presented by Brennen [11] and Gyugyi [12].

A reactive power generator which works as a current source can be made by a AC / DC converter with an inductive load, Figure 2. The basic operating principle of that kind of exciter consists of connecting both a fixed capacitor bank and bridge rectifier with an inductive load to the generator terminals. If the delay angle of the thyristor is varied by the output signal then the reactive lag which is absorbed by the inductive load on the side of the DC brigde is varied, too. Therefore, there is a continuous control of the magnetizing current given by the capacitor bank to the SEIG excitation circuit.

The bridge rectifier should have the following characteristics:

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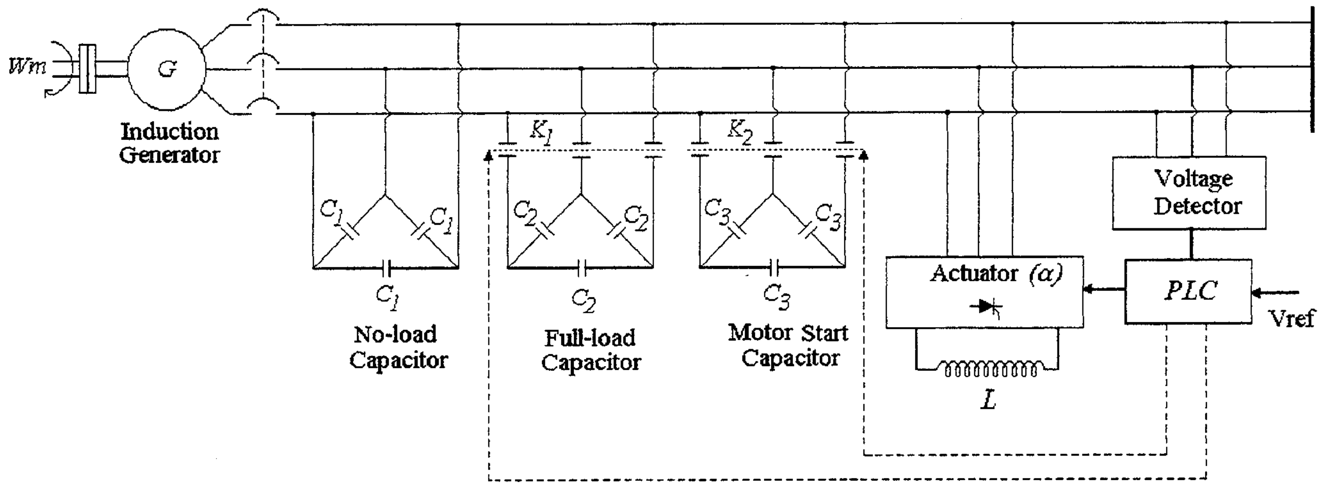

Figure 1. Diagram of Voltage Regulator for Self-Excited Induction Generator

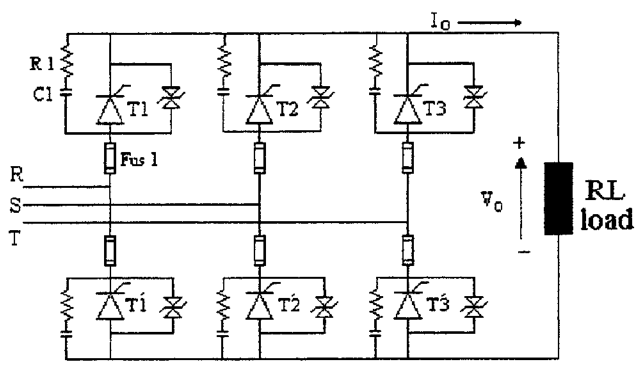

Figure 2. Power Actuator

- In an abrupt disconnecting of the load , it should absorb the necessary reactive power of capacitor bank in order to not increase the generator voltage.
- It should release the reactive power quickly when the load is required, so that the voltage will not be reduced.

To put the preceding requirements into effect, it is necessary to consider the maximun current condition in the bridge, which happens when the generator supplies a nominal load, the three capacitors are connected and suddenly a load disconnection occurs. Fig.3.

I_{C1} : Current to mantain the voltage generator at 220 V rms, in no-load conditions.

I_{C2}, I_{C3} : Current to mantain the voltage reference when the generator supplies the load.

The current Ic1 for calculating the brigde is not considered because this capacitor is calculated specifically to supply the electronics system. Considering the preceding points, it is possible to arrive at the following relations:

$$I_P = 1.25 * \left(I_{C2} + I_{C3}\right) \qquad (1)$$

$$I_p = 1.25 * \left(\frac{\sqrt{3}\,V_{LL}}{X_{C2}} + \frac{\sqrt{3}\,V_{LL}}{X_{C3}}\right) \qquad (2)$$

where I_P is the maximum current which supports the brigde and therefore it is related to the current which passes through the coil.

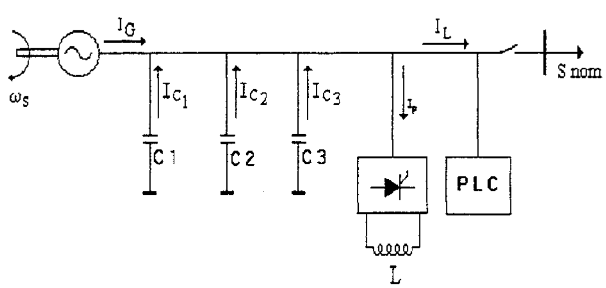

Figure 3. Maximun current in L.

B. Controler Design

The PID controller was designed with the following functions:

- The regulation function.
- Command and protection functions.
- Signal and alarm functions.

The regulation functions permit us to maintain a voltage reference in terminals which is determined by a set-point, in any load condition. The regulation is made by a single loop system which is commanded by a PID digital controller (the program in a PLC). The PID parameters were designed by a system simulation using the Mathlab program.

The command functions are useful as a PID support at regulator, in those functions the conditions are programmed to open and/or close the breakrer connected to both capacitors C2 , C3 and the load. The protection functions avoid that the SEIG works in excessive voltage conditions caused by breaker problems or by the feedback signal loss.

IV EXPERIMENTAL RESULTS

The VR prototype was tested with a SEIG rated:
3.5 KW, 220 V, 15 A, 60 Hz, 1200 RPM.
This SEIG was driven by a DC motor. Some results from tests are:

- The SEIG and VR were tested in abrupt load changes. Having the SEIG in no-load conditions, a resistive load of 3 KW was connected abruptly. Therefore the voltage dropped by 9.5% and then it stabilized at 220 V. in 5 s. After the load was disconnected abruptly , the voltage increased by 15 % and the period of stabilization was 3.5 s.

- Having the SEIG in a no-load condition a three-phase 2HP induction motor was connected abruptly. Therefore the voltage dropped by 13.4% and then it stabilized in 2.7 s. After the motor was disconnected abruptly, the voltage increased by 5% and the period of stabilization was 1.6 s.

V. CONCLUSION

- The developed Voltage Regulator presented good experimental results, even in more demanding tests like the abrupt connection of a three-phase induction motor .

- The simulation technique by computer allows us, to adjust parameters and to design elements the SEIG, and also to predict the effect of any change in the topology of control strategy.

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