Application of bidirectional switches in the development of a voltage regulator for self-excited induction generators

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- Voltage regulator

1. Introduction

The three-phase squirrel cage induction machine has stirred interest within the scientific and industrial communities, for applications in actuators or generation systems. Due to its robust nature, constructively simple design, low maintenance, high power density, and reduced cost, this machine is widely used across a number of industrial applications [1–9]. Besides this, it is easily replaced as it presents wide commercial availability. Given these characteristics, the use of the induction motor as an energy generator has become a viable alternative for reducing costs in non-conventional electric energy generation systems [1,8].

The induction generator (IG) being a machine that does not possess a circuit that creates a self-excited field, as in synchronous generators, means it needs an external reactive energy source in order to function. This source can be obtained from the power network or a capacitor bank, sized in the correct manner and connected onto the terminals of the machine. In isolated systems the squirrel cage induction generator with excitation capacitors is called the self-excited induction generator (SEIG) [1,5,6,10].

Although there are a number of advantages to SEIGs, when these are actuated through energy sources such as biomass, biogas, biodiesel motors and small hydroelectric plants, the generated voltage frequency can be maintained practically constant for open circuit as well as with rated load conditions [11]. However, poor voltage regulation has been the main disadvantage concerning this generator. It is for this reason that specific voltage regulators for SEIGs were developed, which when faced with a load variation maintain the terminal voltage constant.

Therefore, it is in this context that the proposal of the presented voltage regulator is put forward in this paper, where use is made of bidirectional switches, which control the flow of reactive power on the inductive load. The goal here is thus to consume reactive power from the fixed capacitor bank, which self-excites the induction generator, thus controlling the voltage. The control of the terminal voltage is performed by a PID controller, which controls a PWM signal that is carried to the trigger circuit of the bidirectional switches of each phase, thus generating an effective voltage on the inductive load. This consumes the reactive power necessary for maintaining the terminal voltage of the generator within the permitted voltage regulation range in steady state (0.95 ≤ Vt ≤ 1.05 pu).

In order to validate the operation of the voltage regulator proposed herein, this paper presents the results obtained by means of computer simulation and experiments. The tests performed in this paper, had as their objective to present a critical operational condition, which is the triggering of the dynamic load. In this case, the SEIG of 3 hp supplies the direct start-up of a 1 hp induction motor. Even under this worse condition scenario, the regulator manages to recuperate the terminal voltage of the generator to a permitted voltage regulation value (1.02 pu).
the direct start-up of a 1 hp induction motor. Highlighted here is that the direct start-up of induction motors can demand a start-up power of up to 6–8 times the value of the nominal power of the motor [12]. In the case of isolated operation, this can impair the voltage profile even when using synchronous generators, which have the capacity to supply reactive power to the load. In regards to self-excited induction generators, which do not generate but need reactive power, the effects of direct start-up are far more pronounced. This may even result in voltage instability.

When using generators that are starting up induction motors with a close power range, as in this case, and start up methods are not used (star-delta starting method, auto transformer starting, soft starter, variable-speed drive (VSD)), one should opt for an oversized generator with a power range as given in [12]:

$$S_{kVA} = HP \times (LR_{kVA}/HP) \times S_{kVA_{factor}}$$ (1)

where HP is the nominal power of the motor in hp, LR_{kVA}/HP is the average kVA/HP for the NEMA Code letter of the motor, $S_{kVA_{factor}}$ is 1.0 for full voltage starting.

Eq. (1) is applied to synchronous generators, which have the capacity to supply reactive power. In the case of using induction generators, the situation becomes more critical, due to the need that this generator has for external reactive power from a capacitor bank for its self-excitation and for supplying possible inductive loads, as in the case of motors. In particular in this case, in accordance with Eq. (1), a generator with a power range above 3 hp should be used, in order to avoid instability or attenuated sag at the moment of start-up of the 1 hp induction motor. However, this measurement was not adopted for demonstrating the robustness of the proposed voltage regulator. In this situation, the voltage regulator has its performance taken to its operational limit. Therefore, this study opted to present a situation which is the most critical possible in terms of operation, when dealing with isolated induction generators.

2. Voltage regulation schemes for SEIGs

Voltage regulation of SEIGs can be achieved through control schemes of the reactive power used, such as shunt and series compensation [13]. As the focus of this paper proposes a shunt voltage regulation structure, in the following the voltage regulation schemes for SEIGs with shunt compensation found in the literature are highlighted.

2.1. Existing shunt voltage regulation schemes

Due to the various shunt voltage regulation schemes that exist in the Literature, these are classified according to inherent technology and the devices employed in their structure. These schemes can be classified through the following arrangements.

2.1.1. Classical shunt-compensation

This type of voltage regulation scheme is accomplished by means of synchronous condenser and saturable core reactor. This scheme has as its advantage simplicity and robustness, in addition to not generating harmonics or transients [13].

In [14,15] a saturable core reactor (SCR) is used that operates in parallel with fixed capacitor banks for controlling the terminal voltage of a SEIG. In the present case, the saturable core reactor functions as a self-excited magnetic amplifier, where it consumes the reactive energy from the fixed capacitor bank and controls the voltage on the SEIG. Schemes that use the SCR attain advantages such as better operational stability and reliability in relation to other classic shunt compensation schemes.

2.1.2. Switching device based shunt compensation

This type of voltage regulation is performed by means of solid-state switching devices. Among such, one can highlight the use of the following semiconductor devices: thyristor, gate turn off (GTO) and insulated gate bipolar transistors (IGBTs).

In [16] the authors propose a voltage regulation scheme based on a solid-state switched controlled inductor. The regulation scheme utilizes a capacitor bank that is permanently connected to an induction generator, in order that this obtains its terminal voltage at no load. After the self-excitation process, a programmable logic controller controls the terminal voltage for the generator by means of a controlled rectifier firing angle, which supplies the inductor. The programmable logic controller also takes on the role of adding other capacitor banks. This leads to the possibility of the generator operating with nominal load as well as allow for the direct start-up of the induction motor.

The paper in [17] presents as its proposal the use of the thyristor-switched capacitor (TSC) for regulating the terminal voltage of the
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