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Power rating reduction of distribution static synchronous compensator for voltage and frequency regulation of stand-alone self-excited induction generator

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ABSTRACT

This paper deals with the development of a new hybrid topology for voltage and frequency regulation in stand-alone micro hydro generation systems based on self-excited induction generator (SEIG). As the main contribution, the new topology proposes the rating reduction of DSTATCOM to a small part of the generated power with high voltage regulation quality. The proposed hybrid topology consist of a three-phase four legs distribution static synchronous compensator (DSTATCOM) and switched capacitor banks (SCB) connected in parallel to the point of common coupling (PCC) of a three-phase four-wire system. Voltage and frequency regulation are achieved by the association of DSTATCOM, SCB and electronic load control (ELC), this last connected by means of an uncontrolled rectifier, directly to the PCC. The association of such distinguished elements with different characteristics and the employment of suitable control techniques guarantee the voltage and frequency regulation in accordance to the international standards. Simulation and experimental results are presented to demonstrate the performance of the proposed hybrid topology on the rating reduction of DSTATCOM with efficient voltage and frequency regulation of a proposed SEIG based generation system.

1. Introduction

Distributed generation is a reality of the modern world and must get more signification in the next years with the development of new technologies and topologies of generation. The connection of such distributed systems, specially microgeneration system, to the conventional distribution grid is a reality worldwide, becoming an alternative to overcame the rising demand for electrical energy.

Although all the technological development, the society still faces challenges to make the electrical energy worldwide accessible by the conventional distribution system. Regions too far from the generation, with hard access or low people density do not offer technical or economic viability for the investment in large transmission lines.

In view of this, stand-alone generation systems based on renewable energy sources, such as hydro, wind, biomass and solar, has been considered as the solution for electric energy access in such regions. In this case, the challenge is on its conversion and regulation in accordance to the consuming requirements, which, in the most part, is still based on electric machines and regulation systems.

Squirrel cage induction machines applied as generator present some advantages as compared with the conventional synchronous generator, specially for stand-alone micro hydro generation systems in remote areas. Brushless construction, ruggedness and inherent shortcircuit protection are the most distinct advantages [1–3]. The induction generator (IG) depends on the well-known phenomenon of self-excitation to grow up and keep its terminal voltage in a specific value. For stand-alone hydro power systems, such self-excitation is usually done by the shunt-connection of a capacitor bank to the terminals of IG or point of common-coupling (PCC), which is usually specified to guarantee rated terminal voltages under a specific power condition and known frequency [4].

Under variable load condition, which is characteristic of stand-alone hydro generation systems, voltage and frequency profiles are not guaranted by the generator, thus requiring addictional systems applied for such variables regulation [2,5]. Another relevant load characteristic to be considered in stand-alone hydro generation systems is the balancing between phases. Residential loads are at most of single-phase characteristic, causing then inherent load

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unbalancing in the system. Current unbalances are not welcome for the SEIG healthy and must be avoid or compensated [6,7].

Several topologies for the voltage regulation of SEIG based system were proposed over the decades, being basically classified in two main groups. The first group, widelly applied in the beginning, is based on static var compensators (SVC) [3,8], which represents a cost effective alternative once it proposes the controled switching of reactive elements such as capacitor banks. This solution, however, offers poor voltage regulation in terms of amplitude, unbalances and harmonic compensations [8].

Invention of fast acting switches, like insulated-gate bipolar transistors (IGBTs), and digital signal processor (DSP), as well as the advances in digital control, promoved the use of converters, such as voltage source converter (VSC)-based distributed static synchronous compensators (DSTATCOMs) [1,2,7–12]. That provides a more efficient voltage regulation, once it exhibits a higher dynamic response and does not inject lower order harmonics into the system [2,9,10], although it represents an increase in the complexity and cost of the regulation system.

The proposed hybrid topology of voltage regulation was first introduced in [13], for a three-phase three-wire system, and further developed for a three-phase four-wire system [14]. It proposes the connection of switched capacitor banks (SCB) plus DSTATCOM in parallel with SEIG. The hybrid topology requires a lower power if compared the DSTATCOM operating alone, once it turns to compensates only the reactive power not compensated by the SCB. Moreover, it offers a more appropriated adjustment of voltage, compared with the solution that only uses capacitors.

The amplitude of the generated voltages is associated with the balance of the reactive power of the system, being strictly dependent of the power and power factor of the load applied. On the other hand, the frequency of generated voltages is associated with the balance of the active power of the system, which depends of the relation between the mechanical power delivered on the IG's shaft and the electrical power consumed by the electrical system [1,15].

In terms of frequency regulation, two main different scenariuns referent to the primar machine must be considered: constant-speed constant-frequency (CSCF); and variable-speed constant-frequency (VSCF) [16–18]. The first case considers the continuous adjustment of the primer machine speed, and consequently the load generated, by means of speed governors, in accordance to the load applied. This scenarium is found in fuel injection generation systems and large hydro power generation stations. The second case, by the other hand, considers the generation of constant power independently of the power demand by loads. The prime machine imposes a constant speed and the frequency regulation, in this case, must be done by the control of the consumed load, by means of auxiliary loads that are controlled to consume all the power generated, well know in the literature by electronic load control (ELC) [1,2,8,9]. This last technique is preferable in SEIG-based micro hydro power generation (<100 kW) because usually there is no reservoir, being the water flow constant. The speed governor is robust and very solid solution, but its large mechanical time constant limits a quick reaction to the frequency transients, specially in micro hydro generation systems [2,19].

In this context, this paper deals with a new hybrid topology, composed by SCB plus DSTATCOM shunt-connected to PCC, for voltage regulation of a SEIG-based micro hydro power generation systems. The frequency regulation is performed by means of an ELC, composed by a chopper with an auxiliary load connected to the DC-bus of a non-controlled three-phase rectifier, this last directly connected to the PCC. The DSTATCOM control is performed using discrete time proportional-integral controlers (PI) tuned to operate in association with the algorithm of SCB. The control of chopper switching is performed using a proportional-integral (PI) controller which considers the frequency of the system as reference.

In view of the control system proposed, the synchronization method applied plays an important role on voltage and frequency regulation performance. While the control system proposed for voltage regulation is developed in $dq0$ reference frame, the frequency regulation depends on the measurement of real time voltage frequency or its identification by appropriate algorithm. In this purpose a synchronization method based on Kalman filter and frequency identifier technique is then considered [20].

The proposed hybrid topology presents as main contribution the power reduction of DSTATCOM to a small part of the generated power, representing an alternative for regulation systems of high power generation systems. This is achieved by the association of elements with distinguished and complementary characteristcs, such a way the voltage and frequency parameters are kept within the international standard limits. The application of the hybrid topology, however, depends on a proper and integrated design of the elements, whose details are presented on this paper as well.

2. System configuration

The hydro power generation system is shown in Fig. 1. This system can be divided into three sub-systems which are power generation set, consumer loads and power regulation system.

The power generation set consists of an SEIG, mechanically coupled with and driven by an uncontrolled hydro turbine, and an excitation capacitor bank. The excitation capacitor bank is connected in parallel to the terminals of IG, and from the neutral point of star configuration is generated the fourth terminal of four-wire AC bus at the PCC. As prime mover, it is considered a constant power turbine with no real time control of mechanical power supplied to IG's shaft.

As consumer loads, it is considered any kind of linear balanced and unbalanced loads, which include conventional loads like single and three-phase, floating or grounded, three or four wires, with unit power factor (PF) or not. Once the ELC is essentially an uncontrolled rectifier, the system is able to compensate non-linear load on the same way.

The power regulation system is composed of the components dedicated to voltage and frequency regulation, including the IGBT four-legs voltage source converter (VSC)-based DSTATCOM, the switchable capacitor banks, the ELC, the inductive filter and the digital signal processor (DSP) with the digital control system.

3. Design of the system

In this section the design of the proposed system is presented. From the parameters of hydro power generation system and induction generator, it is possible to specify the others components of the system, including the DSTATCOM, excitation capacitors bank, SCB, DC-link capacitor, ELC auxiliary load and inductive filter.

Fig. 1 presents the active and reactive power flow for the proposed topology. Once the SEIG operates at a fixed operation point, determined by constant speed and rated power generation, all the reactive power required for its excitation is supplied by the excitation capacitor bank (C_{CA}). This way, the hybrid topology, composed by SCB and DSTATCOM, compensates only the reactive power required by the load, which can be capacitive or inductive.

The comprehension of the reactive power flow of the proposed system, despite of simple, is the key for the design of the hybrid topology.