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Original Research Article

Voltage Stability Enhancement in Power System Using STATCOM Based ITC with Unbalanced Fault

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ABSTRACT

In this paper investigations on a fixed speed wind farm with squirrel cage induction generators (SCIG) directly connected to the grid in combination with a STATCOM based Indirect Torque Control (ITC) under unbalanced grid voltage fault are given by means of theory and simulations and also different kinds of control methods are discussed. Under unbalanced grid voltage dips causes additional generator torque oscillations. The simulation results clarify the effect of voltage compensation by a STATCOM on the operation of a SCIG wind farm which inference the improvement of voltage stability and reduction of torque oscillation.

Keywords: Voltage Stability, SCIG, Wind farm, low voltage Capability, STATCOM, Indirect Torque Control (ITC).

I. INTRODUCTION

Wind Energy is playing a key role on the way towards a sustainable energy future. Among the generator types used for wind turbines the technical development has moved from fixed speed to variable speed concepts. But still of fixed speed type using asynchronous generators directly connected to the grid. During voltage dips the induction generators may consume a large amount of reactive power as their speed deviates from the synchronous speed, which can lead to a voltage collapse in the network. Different methods have been investigated to enhance the fault ride through capability like installation of a STATCOM has been identified to provide the best dynamic stability enhancement. [3] A STATCOM is a voltage source converter based device providing dynamic reactive power support to the grid. Thus, the STATCOM can help to integrate wind power plants in a weak power system. [4] The STATCOM can also perform an indirect torque control for the same kind of generators [7] to decrease the mechanical stress during grid voltage dip. All these investigations have covered balanced grid faults, but the majority of grid faults are of unbalanced nature.

The unbalanced-voltage problem can cause unbalanced heating in the machine windings and a pulsating torque leading to mechanical vibration and acoustic noise. [8] The STATCOM control structure can be adapted to these unbalanced voltage conditions, [9] and positive and negative sequence of the voltage can be controlled independently.

The paper is structured as follows. An analysis of the induction generators behavior under balanced and unbalanced grid voltage in section II is followed by the presentation of the proposed STATCOM control structure with ITC in section III. Validate simulation results are presented in section IV. Comparison of different control methods for stability analysis is described in section V. In section VI, a conclusion closes the paper.

II. TORQUE-SLIP CHARACTERISTIC OF INDUCTION GENERATOR UNDER VOLTAGE DIP

To provide a graphical comparison the torque-slip characteristic of the machine for one specific acceleration process under a single phase to ground fault is taken from the simulation model and shown in Fig. 1.

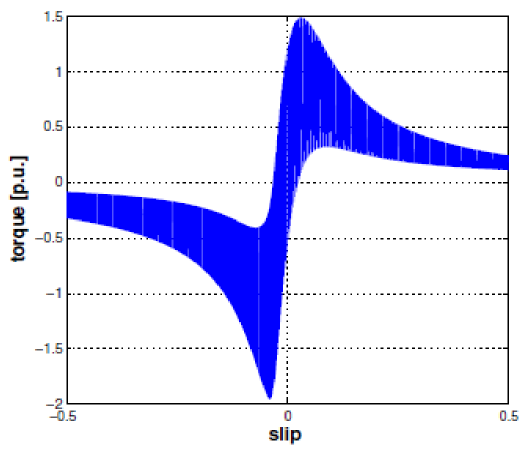

Fig1. Simulated torque-slip characteristic for a single-phase to ground fault (1ph→0)

III. INDIRECT TORQUE CONTROL CONCEPT

As torque is controlled through the voltage reference of the STATCOM, the method is labeled indirect torque control (ITC). [10-14] The phasor calculations has been shown how this can be used to estimate the rating of a compensation device needed to maintain stability of the system as a function of the speed of the machine when a fault is cleared. In the following sections, it will be shown how the same approach can be used dynamically during the recovery process after a grid fault, to indirectly control the torque of the induction machine by controlling the terminal voltage with the STATCOM. The focus will be on derivation, explanation, and proof of concept, with verification and illustration provided by detailed time-domain simulations.

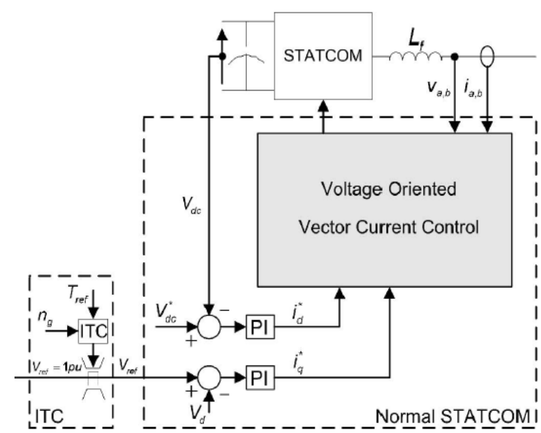

Fig 2. Proposed control structure of the STATCOM with ITC

The STATCOM control structure is based on a voltage oriented vector control [15] as usually applied to three phase grid connected converters. It is a cascade control structure with inner PI current controllers with grid voltage orientation. Note, that the control of the negative sequence currents can also be performed in a negative rotating reference frame with PI controllers, but by using resonant controllers in a positive rotating reference frame there is no need for a sequence separation of the currents. [15] The overall control structure is shown in Fig. 3. The outer control loops are designed to control the DC voltage and the positive and negative sequence of the voltage at the connection point of the STATCOM. Therefore a precise sequence separation of the measured voltage into positive and negative sequence components is necessary, which is performed based on dual second order generalized integrators. [15] Using the sequence separation the positive and negative sequence of the voltage appear as DC values and can be controlled by PI controllers. To ensure a safe operation of the STATCOM within its current capability the current references given by the four outer controllers must be limited to the maximum STATCOM current. The priority is on the positive sequence reactive.

Thus, the STATCOM ensures the maximum fault ride through enhancement of the wind farm by compensating the positive sequence voltage. If there is a remaining STATCOM current capability the STATCOM is controlled to compensate the negative sequence voltage additionally, in order to reduce the torque ripple during the grid fault. The positive and negative sequence current references are added. Note, that the negative sequence currents references must be transformed into the positive rotating reference frame by a coordinate transformation with twice the grid voltage angle.

For the investigations under unbalanced grid fault different control targets will be compared to clarify the effect of positive or negative sequence voltage compensation on the operation of the induction generators. The target of the first method is to compensate the positive sequence voltage, while the negative sequence voltage will remain unchanged. The target of the second method is to eliminate the negative sequence of the voltage, while the positive sequence voltage will remain unchanged

The results of this section enhance the understanding of the voltage control performed by the STATCOM and the resulting operation of the induction generators. By compensating the positive sequence voltage the torque capability of the induction generators is increased and acceleration during grid voltage dips can be decreased or avoided. By compensating the negative sequence voltage (the unbalanced component of the voltage) the torque oscillations of the induction generators can be decreased or avoided. The capability of the STATCOM to compensate a voltage component depends on the chosen current rating of the STATCOM and the impedance of the power system. For a high current rating of the STATCOM and a weak power system (with high system impedance) the voltage compensation capability of the STATCOM is also high.

IV. SIMULATION RESULTS:

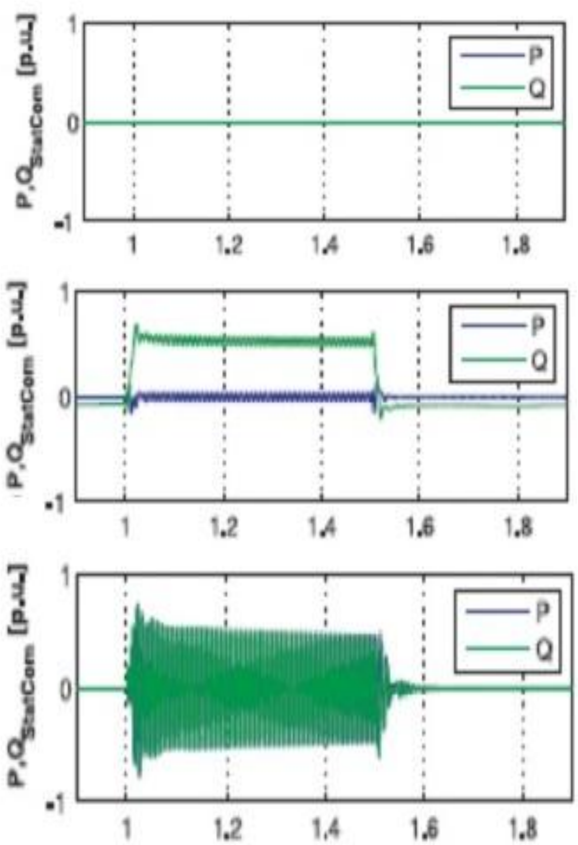

Fig.3. (a) STATCOM power (before fault), (b) Present fault, (c) After fault

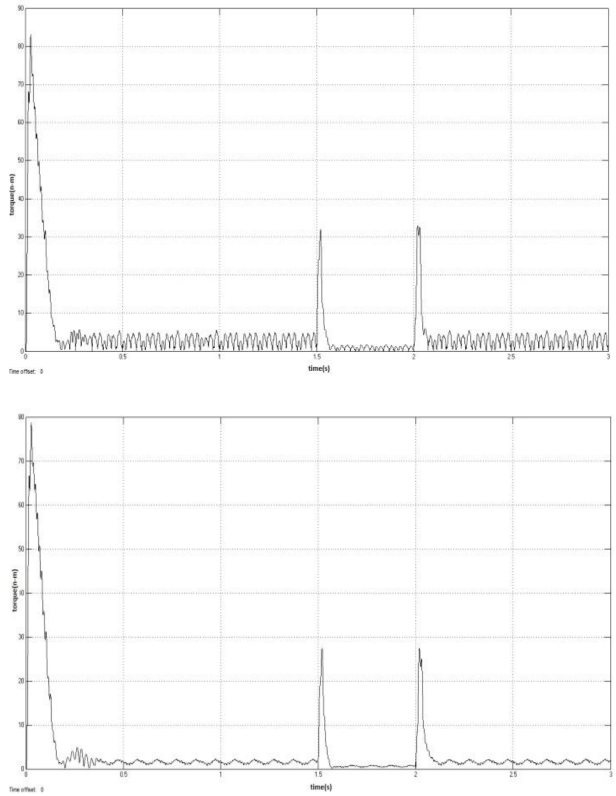

Fig.4 (a) Torque oscillation with grid fault (period 1.5 sec -2sec) – Without STATCOM, (b) With STATCOM

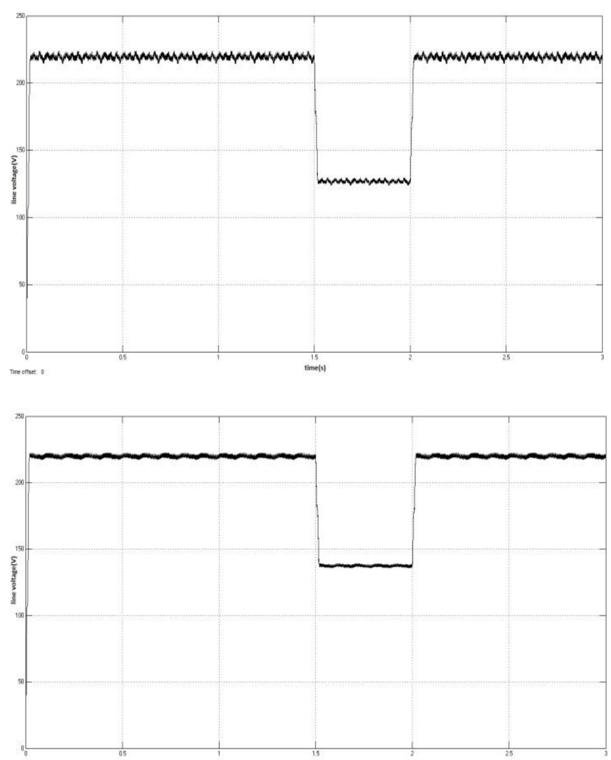

Fig.5 (a) Grid Voltage with grid fault (period 1.5 sec -2sec) – Without STATCOM, (b) With STATCOM

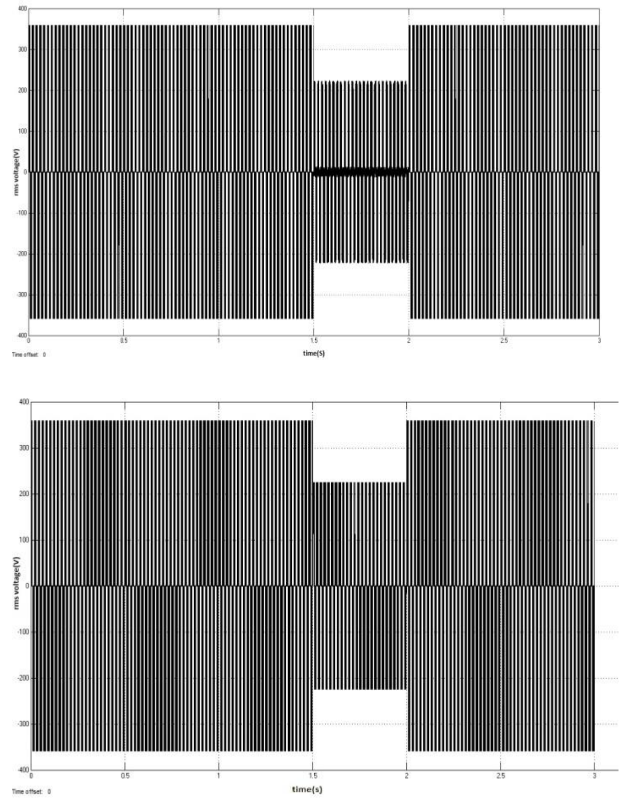

Fig.6 (a) Grid RMSVoltage with grid fault (period 1.5 sec -2sec) – Without STATCOM, (b) With STATCOM

The power compensation of STATCOM is shown in Fig.3. Fig.3 (a) shows the STATCOM power capability under the normal condition. Fig.3 (b) shows the STATCOM power capability under the grid fault condition. Fig.3 (c) shows after the grid fault condition which clearly shows the power oscillation gets more than after clearance of fault.

Torque oscillation of the power system under grid fault condition with the period of 1.5 to 2 sec without STATCOM is shown in Fig.4 (a) and Fig.4 (b) shows the better torque oscillation reduction at the grid fault period with STATCOM.

Grid voltage of the power system under grid fault condition with the period of 1.5 to 2 sec without STATCOM is shown in Fig.5 (a) and Fig.5 (b) shows the better grid voltage improvement at grid fault period with STATCOM. Grid RMS voltage of the power system under grid fault condition with the period of 1.5 to 2 sec without STATCOM is shown in Fig.6(a) and Fig.6(b) shows the better grid RMS voltage improvement at grid fault period with STATCOM.

V.COMPARISON OF STABILITY ENHANCEMENT

TABLE I VALUES OF INDEXES FOR DIFFERENT STABILIZATION METHODS

Index	Pitch	BR	STATCOM	SMES	W/o Controller
Voltage (p.u.sec)	1.73	0.32	0.26	0.22	4.46
Speed (p.u.sec)	0.48	0.02	0.02	0.02	7.81
Power (p.u.sec)	2.86	0.10	0.18	0.16	4.63
Angle (degsec)	75.04	56.4	48.54	46.00	103.05

Although actually the wind speed is randomly varying, during the short time span of the analysis of the transient stability the variation of wind speed can be considered negligible. Table I shows the values of the performance indexes in case of successful reclosing of circuit breakers. It is seen that all methods are effective in transient stability enhancement, however, from the viewpoint of the index Power (p.u.sec), the BR is the best, while with respect to the index Speed (p.u.sec), the BR, STATCOM, and SMES exhibit the same performance. From the perspective of Voltage (p.u.sec) and angle (deg.sec), the performance of the SMES is the best, and the STATCOM is better than the BR. The pitch method exhibits the worst performance with respect to all indices.

Fig. 7 shows the responses of the IG terminal voltage. It is seen that the IG terminal voltage returns back to its steady state value due to the use of any of the devices of the SMES, STATCOM, BR, and pitch controller. In this case it is seen that any of the devices of the SMES, STATCOM, BR, and pitch controller can maintain the IG real power at the rated level. Fig. 8 shows the responses of the SG load angle. However, although each of the devices of the SMES, STATCOM, BR, and pitch controller can make the wind generator stable, it is evident from the simulation results that the performance of the SMES & STATCOM are the best. But compared with cost, SMES is higher and STATCOM is lower.

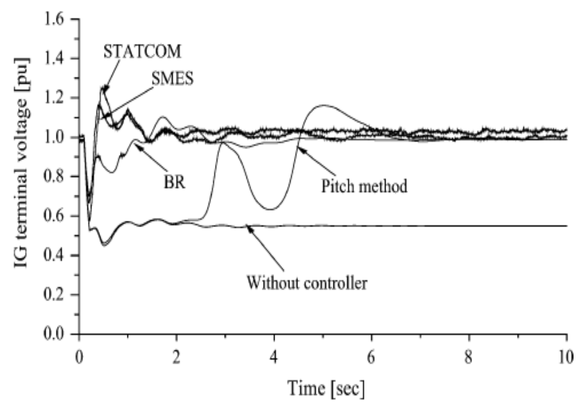

Fig. 7.Responses of IG terminal voltage.

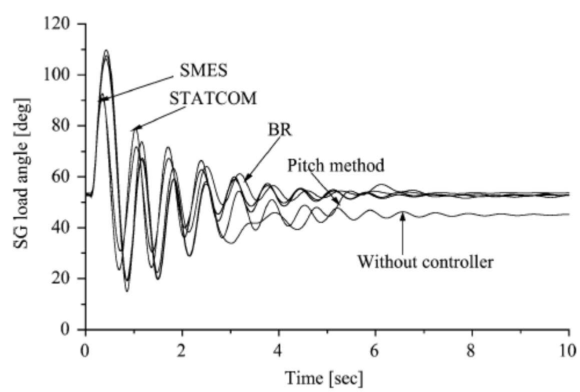

Fig. 8. Responses of IG load angle.

VI. CONCLUSION:

The proposed structure controls the positive and negative sequence of the voltage independently with priority on the positive sequence voltage. Thus, the STATCOM ensures the maximum fault ride through enhancement of the wind farm by compensating the positive sequence voltage. A voltage control structure for a StatCom at a Fixed Speed Wind Farm under unbalanced grid voltage condition has been analyzed. If there is a remaining StatCom current capability the StatCom is controlled to compensate the negative sequence voltage additionally, in order to reduce the torque ripple during the grid fault. Hence the positive component is used to improved the voltage stability and negative component is reduces the torque oscillation of the induction generator. Then the life span of the generator parts is increased. Different methods of control techniques are analyzed with validation simulations.

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VIII. BIOGRAPHIES

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