WIND FARM GENERATOR CONTROL USING GRID TECHNIQUE-A REVIEW

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Abstract:

The stability of fine-tuned-speed induction engenderer (FSIG)-predicated wind turbines can be ameliorated by a StatCom, which is prominent and documented in the literature for balanced grid voltage dips. Under unbalanced grid voltage dips, the negative sequence voltage causes cumbersomely hefty engenderer torque oscillations that reduce the lifetime of the drive train. In this paper, investigations on an FSIG-predicated wind farm in amalgamation with a StatCom under unbalanced grid voltage fault are carried out by denotes of theory, simulations, and quantifications. A StatCom control structure with the capability to coordinate the control between the positive and the negative sequence of the grid voltage is proposed. The results demystify the effect of the positive- and the negative-sequence voltage emolument by a StatCom on the operation of the FSIG-predicated wind farm. With first priority, the StatCom ascertains the maximum fault-ride-through enhancement of the wind farm by compensating the positive-sequence voltage. The remaining StatCom current capability of the StatCom is controlled to compensate the negative-sequence voltage, in order to reduce the torque oscillations. The theoretical analyses are verified by simulations and quantification results on a 22-kW laboratory setup.

Keywords: Wind farm, Grid Technique, statCom Control structure, FSIG-based windfarm

1. INTRODUCTION

WIND energy is playing a key role on the way toward a sustainable energy future. Among the generator types used for wind turbines, the technical development has moved from fixed-speed to variable-speed concepts [1]. Although a major part of the newly installed wind turbines are of the variable-speed type using either a doubly fed induction generator (DFIG) or permanent-magnet synchronous generator, a non negligible percentage of 15% of the operating wind turbines in Europe in 2010 [2] is still of the fixed -speed induction generator (FSIG)-type directly connected to the grid. cannot provide reactive power control, it cannot fulfil the demanding grid code requirements[3] without additional devices. 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 and further fault propagation in the network. Different methods have been investigated to enhance the fault-ride-through capability and to fulfill grid code requirements. Besides using the pitch control of the turbine or installing additional equipment like a brake chopper or an energy storage system, the installation of a StatCom has been identified to provide the best dynamic stability enhancement capabilities [4]. A StatCom is a voltage source converter-based device providing dynamic reactive power support to the grid. Multilevel [5], [6] or hexagram converter topologies [7] are usually chosen to implement the high-power converters. Due to its flexible dynamic control capabilities, the StatCom can help to integrate wind power plants in a weak power system [8]. The capability of a static var compensator compared to a StatCom to increase the stability of FSIG-based wind turbines is given in [9] and [10]. The StatCom can also perform an indirect torque control for the same kind of generators [11], [12] 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 the unbalanced nature. The unbalanced-voltage problem can cause unbalanced heating in the machine windings and a pulsating torque, leading to mechanical vibration and additional acoustic noise. The StatCom control structure can be adapted to these unbalanced voltage conditions, and the positive and the negative sequence of the voltage can be controlled independently. Different current injection methods based on symmetrical components can also be applied to the StatCom, resulting in different output-power distributions. How these different current injection targets affect the operation of an FSIG-based wind farm is investigated. However, regarding the damping of the torque ripple of the generators, it is more effective to control the positive- and the negative-sequence voltage.

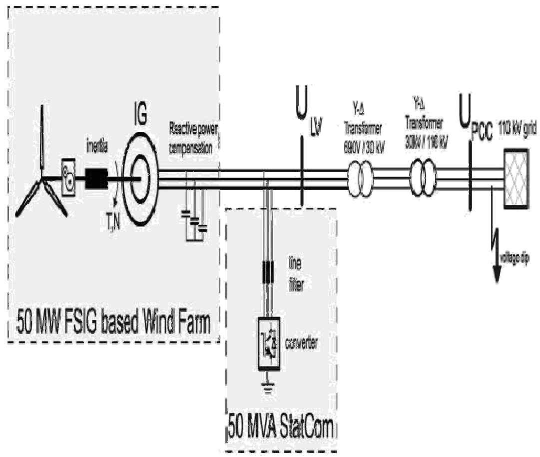

Fig. 1.1

This paper proposes the application of a StatCom that is connected to an FSIG-based wind farm and used to control the positive- and the negative-sequence voltage during grid faults. The novel contribution of this paper lies in the coordination of the positive- and the negative-sequence voltage control by the StatCom and the related effect on the wind turbine behaviour. While the positive-sequence voltage compensation leads to an increased voltage stability of the wind farm, the negative sequence voltage compensation leads to a reduction of torque ripple, increasing the lifetime of the generator drive train. First investigations have been published in [21], but here, deeper analysis and measurement results are presented. This paper is structured as follows. The investigated power system is described in Section II. An analysis of the induction generators behaviour under grid faults in Section III is followed by the presentation of the proposed StatCom control structure in Section IV. Simulation results are given in Section V. Under the unbalanced grid voltage condition, the StatCom is controlled here to either compensate the positive- or the negative sequence voltage. A coordinated control scheme is presentedin Section VI. Measurements taken at a 22-kW laboratory setup show the compensation of a stationary negative-sequence voltage by a StatCom and the effect on an induction generator in Section VII. A conclusion closes this paper.

2. MODELSYSTEM STRUCTURE

The investigated power system is shown in Fig. 1 and consists of a 50-MW wind farm with squirrel cage induction engenderers directly connected to the grid and a 50-MVA StatCom. An aggregate model of the wind farm is utilized as conventional here, which designates that the sum of the turbines is modelled as one engenderer utilizing the standard T-equipollent circuit. The StatCom is modelled as controlled voltage sources. Both contrivances are connected to the same low voltage bus and then connected to the medium voltage bus by a transformer. The medium voltage level is connected to the high voltage level by a second transformer. Both transformers are rated for the sum of the wind farm and StatCom power and have a series impedance of 5% and 10% per unit. The grid fault is postulated at the high voltage level of the grid, which is modelled by itsThe venin equipollent. All power system parameters are given in Tables I and II. The potency system is modelled with the potency electronics

3. INDUCTION GENERATOR UNDER VOLTAGE DIP

The torque of the induction engenderer T+ shows a quadratic dependence of the positive-sequence stator voltage magnitude V +s. It can be calculated utilizing (subscripts s and r) resistance and impedance parameters of the machine equipollent circuit, p is the number of pole pairs, ωsis the grid frequency, and s is the slip. When the theoretical steady-state torque–slip characteristic of the induction machine is plotted predicated on the steady-stateequivalent circuit of the machine for different stator voltages as shown in Fig. 2, the instability during balanced grid voltage dips becomes clear.

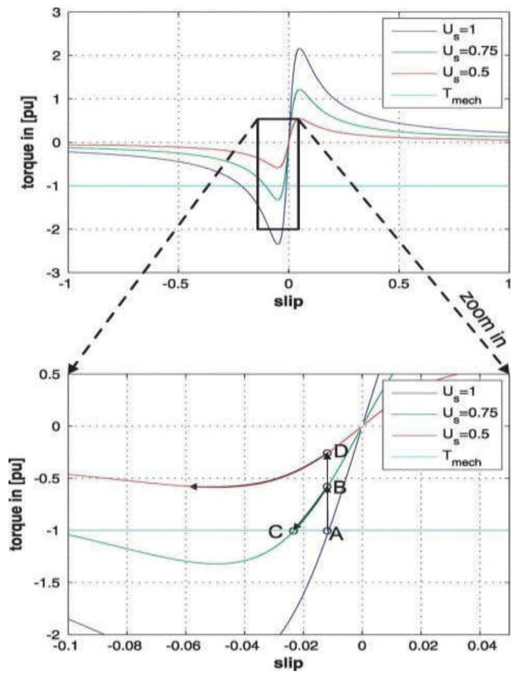

Fig 1.2

Transient torque peaks caused by the dynamic change of the grid voltage as identified in [11] are not addressed here. Customarily, the wind turbine operates at nominal stator voltage in operation point A where the electromechanical torque is equipollent to the mechanical torque. When the stator voltage is reduced due to a grid fault, the torque–slip characteristic changes. If the voltage dip is more diminutive, the induction engenderer may resume a stable operation point C via B. However, for a deep voltage dip, the induction engenderer will deviate from point D to an instable operation. The induction engenderers may have to be disconnected from the grid due to over celerity, or there may be a voltage collapse in the network due to the high consumption of reactive power at higher slip. When the grid voltage is unbalanced, i.e., it contains a negative sequence, the stator currents become unbalanced supplementally. A scintilla of negative sequence voltage V −s can lead to an abundance of negative sequence currents I−s.The negative-sequence currents do not contribute a lot to the average torque T+; thus, they can still be calculated. It becomes pellucid that the average torque is reduced due to the decremented positive-sequence voltage. Adscititiously, there are high torque oscillations of double grid frequency due to the negative-sequence voltage. Thus, a reduction of the positive sequencestator voltage will lead to a reduction of the average torque and an expedition of the turbine. A subsisting negative sequencestator voltage will cause torque oscillations, reducing the lifetime of the turbine drive train. When the positive- and the negative-sequence voltage can be controlled independently by a StatCom, the average torque and the torque ripple can adscititiously be controlled independently. The proposed StatCom control structure is presented in the next-section

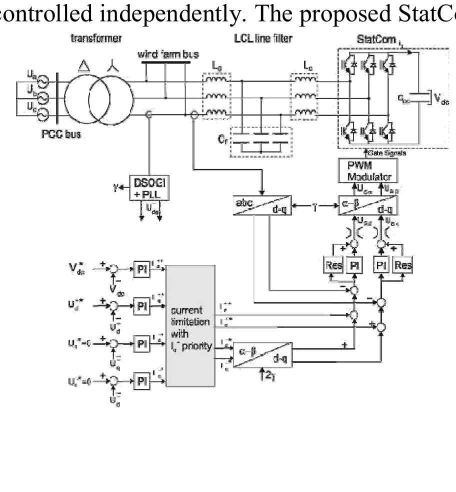

Fig 1.3

Thus, the StatCom ascertains the maximum fault-ride-through enhancement of the wind farm by compensating the positive sequence voltage. If there is a remaining StatComcurrent capability, the StatCom is controlled to compensate the negative-sequence voltage supplementally, in order to reduce the torque ripple during the grid fault. The positive- and negative-sequence current references are integrated. The negative-sequence current references must be transformed into the positive rotating reference frame by a coordinate transformation with twice the grid voltage angle. Note that the transient torques at the commencement and cessation of the grid fault remain uncompensated utilizing this control strategy. A control strategy to smooth the torque transients is not focus of this paper and is investigated in [11].

4.RESULTS FOR UNBALANCED GRID FAULTS

In this section, simulation results for the operation of the induction engenderers and the stabilization by the StatCom under an unbalanced grid voltage dip of 500-ms duration are presented and discussed. An unbalanced fault (single phase amplitude drops to 50%) is surmised at the high voltage bus of the puissance system (optically discern Fig. 1). The simulation results are shown in Fig. 4. The unbalanced grid fault leads to a negative-sequence voltage at the medium voltage bus The operation of the system without StatCom support is shown in the left part of Fig. 11.3. The reduction of the positive sequence voltage leads to a decrementation in torque and an expedition of the rotor. The consequential difference compared to a balanced grid fault are the cumbersomely hefty torque oscillations of the system caused by the negative-sequence voltage. For this simulation case, the grid voltage fault does not lead to a voltage instability because the engenderer can return to the rated operation point after the fault, but there is very high accentuate on the mechanical components of the system due to the torque oscillations. In the middle of Fig. 4, the simulation results are shown for the same grid fault, but now, the system is fortified by the StatCom. In this case, the StatCom is controlled to compensate the positive sequence of the voltage. Within the culled current rating of the StatCom (here, 1 p.u.), the positive-sequence

5.CONCLUSION

A voltage control structure for a StatCom at an FSIG-predicated wind farm under unbalanced grid voltage condition has been analyzed. The proposed structure controls the positive and the negative sequence of the voltage independently with priority on the positive-sequence voltage. The novel contribution of this paper lies in the coordination of the positive- and the negative sequence voltage control by the StatCom and the cognate effect on the wind turbine deportment. While the positive-sequencevoltage emolument leads to an incremented voltage stability of the wind farm, the negative-sequence voltage emolument leads to a reduction of torque ripple, incrementing the lifetime of the engenderer drive train. The coordination is realized by prioritizing the positive-sequence voltage control. If there is remaining StatCom current capability, the StatCom is controlled to compensate the negative-sequence voltage adscititiously, inorder to reduce the torque ripple during the grid fault.

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