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An Intelligent Control Scheme for DFIG Wind Farm to Control the Voltage Fluctuations

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ABSTRACT

In this project we investigates the control of doubly-fed induction generator (DFIG) based wind farms for compensating voltage fluctuations in weak networks. Under an unbalanced power grid voltage conditions, the DFIG's stator side active power, reactive power, and electromagnetic torque will generate twice-multiplied frequency pulse quantities. The proposed control methodology exploits the potential of the series-DFIG scheme to avoid that grid voltage unbalances compromise the machine operation, and to compensate voltage unbalances at the point of common coupling (PCC), preventing adverse effects on loads connected next to the PCC. The modeling of the system has been discussed and also the system parameters are plotted. MATLAB Simulink has been used as the tool to evaluate the system. The grid parameter variations are also discussed.
Keywords : PCC, RSC, GSC, DFIG, MATLAB

I. INTRODUCTION

In recent years, the average rate of world primary power consumption has increased to about 16TW (or) 16000GW. Moreover, the environmental impact on usage of the conventional sources has been disintegrative with the environmental issues such as pollution, global warming, excessive greenhouse effect etc. Because of these problems and our dwindling supply of petroleum, finding sustainable alternatives is becoming increasingly urgent. Perhaps, the greatest challenge is in devising a sustainable future, which relies on integration and control of renewable energy sources in grid distributed generation. Generation of power locally at distribution voltage level by using non-conventional (or) renewable energy sources like, solar photo voltaic cells, wind power, biogas, and fuel cell is known as distributed generation (DG). Hence for the present situation utilization of renewable energy has become a vital strategy. Hence wind energy conversion has been discussed in this paper.

In the past, as the penetration of wind power was very low, the wind turbine connection requirements were focused mainly on the turbine protection and, in case of disturbances, the wind turbines were simply disconnected from the grid. This scenario has changed and, currently, wind turbines should remain connected during system disturbances and, in some cases, wind turbines are required to actively support the grid. Among the possible disturbances, voltage unbalance is responsible for a poor wind generator performance and it is an important cause of partial or total disconnection of wind parks. As a consequence, some strategies for the operation of wind turbines under unbalanced voltage conditions have already been proposed and are still evolving towards an effective solution.

Among the current technologies used for wind energy conversion, the Doubly Fed Induction Generator (DFIG) has been one of the most employed in the last years due to its operational flexibility. When this generator is subjected to even a small unbalanced grid voltage, it presents highly unbalanced stator and rotor currents. These unbalanced currents are responsible for oscillations in the electromagnetic torque, compromising the machine integrity. When the grid operation is analyzed, the unbalanced machine operation can increase the grid voltage unbalance level, once the machine presents low negative sequence impedance.

Several control strategies have already been proposed for DFIG operating under unbalanced voltage conditions. The most of them have focused on compensating the negative effects of grid unbalanced voltages on the generator operation. Other strategies focus on improving the grid voltage unbalance levels by injecting a negative sequence current. The objectives of the negative sequence current injection usually are: to reduce the unbalanced current flowing in the grid; to reduce the voltage unbalance at the Point of Common Coupling (PCC); or to improve the whole grid voltage unbalance profile. The natural solution for voltage unbalance compensation is to use the converters already present in DFIG for this task. In a conventional DFIG, the machine rotor is coupled to the grid by a bidirectional converter, which is composed by the Rotor Side Converter (RSC), the DC link and the Grid Side Converter (GSC). The RSC is connected to the rotor windings and the GSC is connected in parallel with the machine stator winding and the PCC.

II. SYSTEM MODEL

The insertion of the SGSC as a third converter in the traditional DFIG topology has proved to improve the capacity of the DFIG to respond to voltage sags, swells and faults in the grid, since it enables controlling the stator terminal voltage by regulating the output voltage of GSC. When conventional parallel grid side converter is completely replaced by the GSC, as illustrated in Fig. 1, the GSC is responsible for controlling the stator terminal voltage, as well as the DC-link. In the series-DFIG scheme presented in Fig. 1, the GSC is coupled to the grid by a series transformer and the DFIG operational principles remain the same. As the current flowing through the GSC and through the stator machine are the same, or proportional to the series transformer relation, The rotor power flow is controlled by the voltage at the GSC, given by

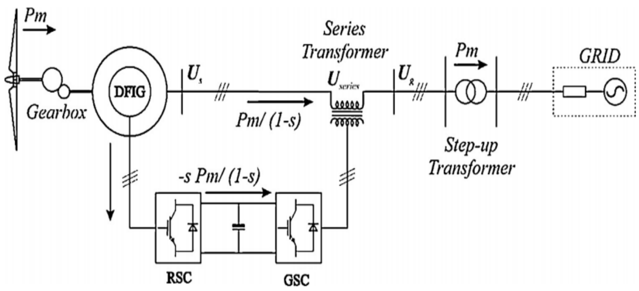

Fig. 1. Proposed DFIG scheme.

P = Useriesd × Isd − Useriesq × Isq

where Useriesd and Useriesq are the direct and quadrature components of the voltage induced by the transformer connecting the GSC, and Isd and Isq are the direct and quadrature components of the stator current.

Considering unbalanced operation conditions, the series-DFIG controls can be separated in positive and negative sequences. The controls applied to the positive sequence variables have the objective to maintain the main functions of the DFIG, controlling the active and reactive power output and the dc link voltage. For the negative sequence control, however, it is proposed a new control methodology. While the negative-sequence controls proposed for the series-DFIG focus only on regulating the output voltage of

GSC for maintaining balanced voltages at the machine stator, in this paper it is proposed to inject an unbalanced current into the grid to compensate the voltage unbalance at the PCC. Although this objective has been used for the conventional DFIG configuration, the series-DFIG presents a better performance for such task, once the consequences of the injection of unbalanced currents can be compensated by applying an adequate voltage at the machine stator, using the GSC. Besides, the series-DFIG scheme allows improving the voltage ride through capability.

To sum up, in the control proposed in this paper, the negative sequence control of the RSC has the objective of injecting a negative sequence current through the machine, and the GSC has the objective of imposing a voltage to the machine stator to minimize the torque oscillations produced by the negative sequence currents flowing through the machine. The models of the series converter and the machine are following described.

GSC model

The GSC is modelled as illustrated in the three-phase diagram of Fig. 2. A RC filter is connected in parallel to the Lc inductance to reduce the high-frequency distortions present in the output of the three-phase IGBT bridge converter. The equivalent circuit shown in Fig. 2(b) allows calculating the voltage in the series transformer (Useries) according to the voltage inserted by the IGBT bridge converter (Usc) and to the RLC values. It is worth noting in Fig. 2(a), the series transformer is delta connected and the RC filter is star connected.

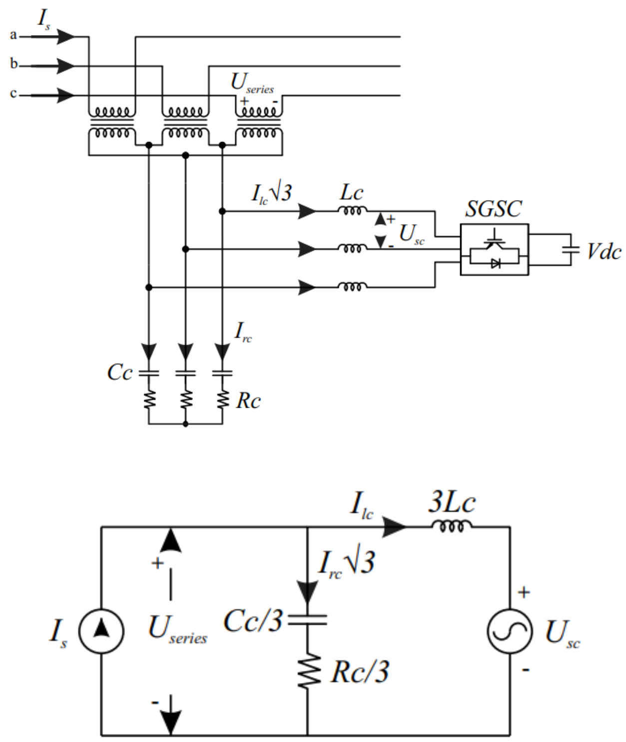

Fig. 2. (a) GSC three-phase scheme. (b) GSC equivalent circuit.

III. PROPOSED CONTROL METHODOLOGY

As already discussed, for controlling the RSC and the SGSC of the series-DFIG scheme, the variables are modelled in the positive and negative sequences and the control is performed independently for each sequence. The controls using the variables in the positive sequence have the objective to maintain the main functions of the DFIG, which are the active and reactive power output and the dc link voltage. The controls using the negative sequence of the variables are responsible for the negative sequence current injection and for minimizing the effect of the unbalanced currents in the machine torque. These controls are following described.

RSC

The RSC control using the positive sequence variables aims, as a conventional DFIG, controlling the active and reactive output power of the machine. The active power control follows the optimal relationship between the angular speed of the rotor and wind speed, and the reactive power control keeps unitary power factor. Fig. 3 illustrates the diagram block of positive sequence control. As can be noticed in Fig. 3, the d component of the rotor positive sequence current is responsible for controlling the active output power, while the q component is responsible for controlling the reactive output power. The reference used is based on the stator voltage orientation.

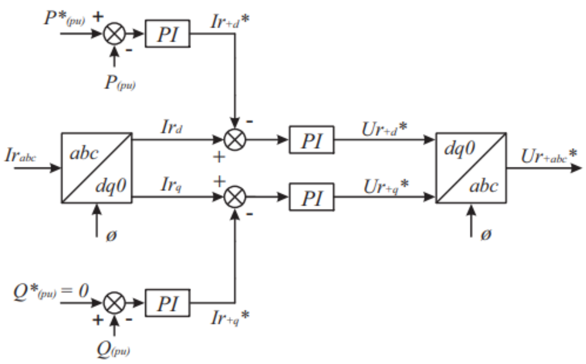

Fig. 3. Block diagram of control of the RSC.

As seen in Fig. 3, the measured active power of the DFIG (P(pu)) is compared with the active power of reference (P*(pu)), obtained of the aerodynamic model of the rotor, the result passes through a proportional integral controller (PI controller) establishing the reference for the direct axis rotor current (Ird*). To establish the reference for the quadrature axis rotor current (Irq*), the same process is applied, but using the difference between the measured and reference values of the reactive power of the DFIG (Q(pu), Q*(pu)) as input of the PI controller. The measured rotor current in the dq0 axis (Ird, Irq) is obtained by an abc–dq0 transformation block, and after compared to its reference value and passing through a PI controller, the reference for the positive sequence of the rotor voltage (Urd*,Urq*)is established.Adq0–abc transformation block establishes the rotor voltage in the abc frame. The RSC negative sequence control is responsible for the negative sequence current injected by the machine stator to compensate the unbalanced grid voltage. To reach this objective, the converter induces an unbalanced voltage at rotor windings, which will be responsible for a negative sequence current in the rotor windings and, therefore, in the stator windings as well. Fig. 4 illustrates the block diagram of the RSC negative sequence control.

GSC

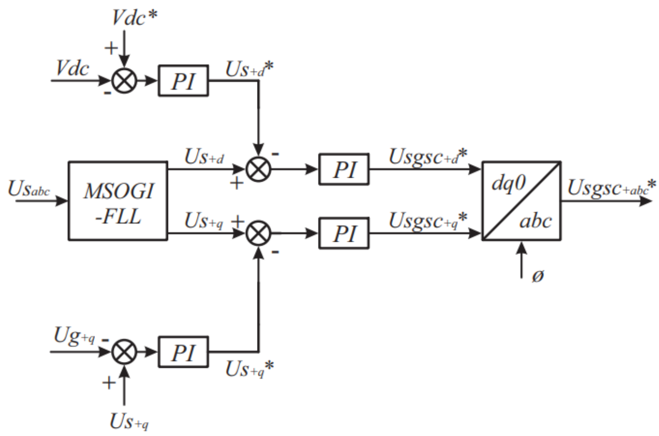

Fig. 4. Block diagram of control of the GSC.

The control of the GSC using the positive sequence components is responsible for regulating the DC-Link voltage. However, strategies to increase the fault-ride-through capability can also be implemented. Fig. 4 illustrates the block diagram of the DC Link voltage control using the GSC. The control is performed by the d component of the GSC positive sequence voltage. The q components of stator and grid voltages are kept aligned and null. As previously defined, the negative sequence proposed control results in negative sequence currents flowing into the rotor and stator windings. These negative sequence currents produce torque oscillations, which can be eliminated by a specific negative sequence voltage at the GSC.

IV. Conclusion

In this paper, it has been proposed a control methodology for the series-DFIG scheme for compensating the effects of voltage unbalance at the machine and the voltage unbalance at the PCC. As the results confirmed, the proposed methodology has succeed in improving the grid voltage unbalance without compromising the machine operation. Such task was possible due to the connection in series of the grid side converter, which allows imposing a specific voltage at the machine stator to compensate the effects of the negative sequence current injected by the machine on torque oscillations. As a result, the use of the DFIG scheme based in a series converter using the proposed control methodology can improve the penetration of the DFIG wind turbines in weak grids subjected to voltage unbalance, avoiding the propagation of the unbalance to the loads connected next to the PCC. Additionally, it is worth to highlight that other works have already demonstrated that the series-DFIG operation under grid faults have also presented good performance. As a consequence, this configuration presents a high potential to comply with more restrictive grid codes, requiring more support from the wind farm to the grid operation.

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