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A new topology for doubly fed induction generator to improve the overall performance of wind energy conversion system

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ABSTRACT
Doubly Fed Induction Generators (DFIGs) are currently extensively used in variable speed wind power plants due to their superior advantages that include reduced converter rating, low cost, reduced losses, easy implementation of power factor correction schemes, variable speed operation and four quadrants active and reactive power control capabilities. On the other hand, DFIG sensitivity to grid disturbances, especially for voltage sags represents the main disadvantage of the equipment. In this paper, a coil is proposed to be integrated within the DFIG converters to improve the overall performance of a DFIG-based wind energy conversion system (WECS). The charging and discharging of the coil are controlled by controlling the duty cycle of the switches of the dc-dc chopper. Simulation results reveal the effectiveness of the proposed topology in improving the overall performance of the WECS system under study.

Introduction

Wind power has been one of the most important renewable energy sources over the past decade. The global installed wind power capacity worldwide has significantly increased from 7.272 GW at the end of the year 2002 to 40.56 GW by the end of the year 2011 [1]. In 2008, wind power has produced over 1% of the global electricity generation and by the year 2020; it is estimated to produce about 10% of the global electricity. Currently, doubly fed induction generator (DFIG) is commonly used for wind turbines over 1 MW capacity [1]. DFIG-based wind energy conversion system (WECS) is gaining popularity because of its superior advantages over other wind turbine generator concepts [2, 3] that have seen DFIG application in large WECS reaching 55% of the worldwide total wind capacity during the year 2012 [4]. A typical configuration of DFIG wind turbine is shown in Fig. 1. Rotor side converter (RSC) and grid side converter (GSC) interface the DFIG with the grid. Both converters use forced commutated power electronic switches such as insulated gate bipolar transistors (IGBT) to convert AC to DC and vice versa. A capacitor connected to the DC link of the converter acts as a DC voltage source [5, 6]. The failure of a wind turbine to remain operational for a short time of voltage dip without tripping is referred to the low voltage ride-through (LVRT) capability of the turbine. Rotor crowbar circuit which is relatively a cheap solution with simple control, is usually used to protect the RSC, [4, 7, 8]. There are many papers in the literature that investigated various approaches to compensate WECS reactive power during voltage fluctuation events by mainly connecting a flexible AC transmission system (FACTS) device such as static synchronous compensator (STATCOM) to the point of common coupling (PCC) [9-15]. There is however a few publications considered the compensation of active power as well [16-19].

This paper presents a new topology for the DFIG converters by incorporating a coil within the converters to improve the overall performance of a DFIG-based WECS during faults at the grid side. Simulation is carried out using Simulink/Matlab software.

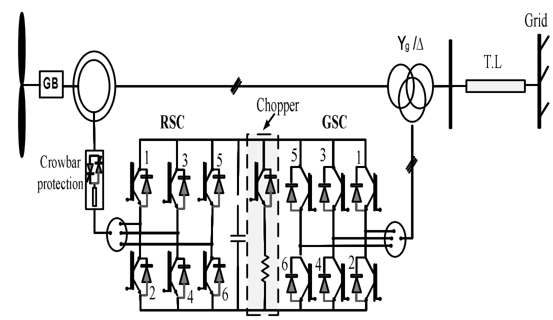

Fig 1. Typical configuration of DFIG

System under Study

Fig. 2 shows the system under study that consists of six 1.5-MW DFIGs connected to the ac grid at the PCC.

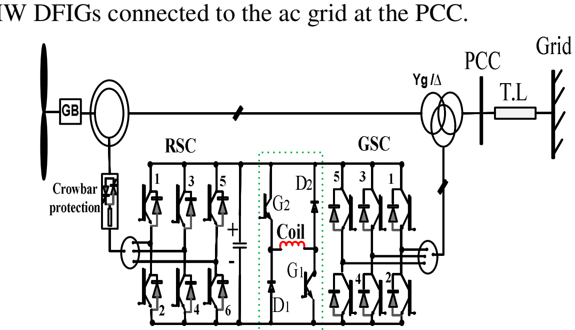

Fig 2. Configuration of a DFIG wind turbine equipped with a coil

The grid that is represented by an ideal three-phase voltage source of constant frequency is connected to the wind turbines via a 30-km transmission line and step-up transformer. During normal operating conditions, reactive power produced by the wind turbines is regulated at zero MVar to maintain unity power factor connection. For an average wind speed of 15 m/s, which is used in this study, the turbine output active power is 1.0 pu, and the rotor shaft speed is 1.2 pu [3]. A coil is connected to the DC link of the back-to-back power converters of the DFIG through a DC/DC chopper.

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Coil operational modes

There are three different modes of operation of the coil namely; charging, standby and discharging modes [3, 20]. The three modes of operation are shown in Figs. 3.IGBT (Insulated Gate bipolar Transistor) switches are used to simulate the DC-DC chopper in Fig. 3 and the switches are controlled by controlling the duty cycle as will be explained below.

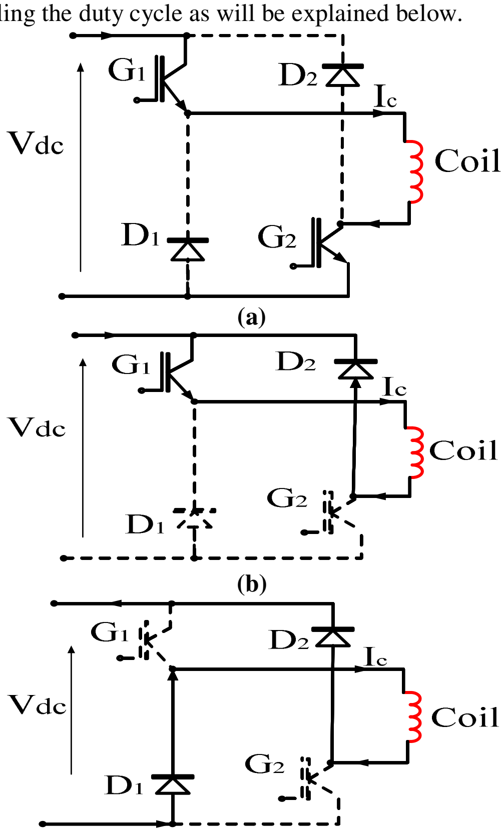

Fig. 3 Coil operation; (a) Charging mode, (b) Freewheeling mode, (c) Discharging mode

Charging Mode

In this mode, the coil is charged to its rated capacity. During charging mode, switch G_1 is always in the ON state while G_2 can be switched ON or OFF in every cycle. The coil is charged when G_2 is in the ON state. When the coil is charging, the relationship between the voltage across the coil and the voltage across the dc link capacitor is given by[20]

$$V_c = D * V_{dc} \quad (1)$$

Where V_c is the voltage across the coil, V_{dc} is the voltage across the dc link capacitor and D is the duty cycle of G_2.

In this mode, the duty cycle (D) of G_2 is kept constant at 1 thus that the coil can be chargedto the maximum possible charging rate.

Standby (Freewheeling) Mode

When the coil is in the freewheel mode, one of the two G switches should remain OFF. During this period, the current is circulated in a closed loop as shown in Fig. 3(b).

Discharge Mode

In this mode, the G_2 is always in the OFF state and the duty cycle of G_2 can be varied depending on the rate of discharge requirement. To have the maximum discharge rate, both G_1 and G_2 are kept in OFF state. The rate of discharge of the coil can be controlled by controlling the duty cycle of one of the G switches to be non-zero [20]. The voltage relationship between the coil and the dc link capacitor during the discharge cycle is given as [20]

$$V_c = (D - 1)V_{dc} \quad (2)$$

In order to have the maximum discharge rate of the coil into the dc link capacitor, the duty cycle of the G_2 is kept at 0 in the present simulation.

Simulation Results

In order to evaluate the proposed DFIG converter topology, the system under study shown in Fig. 2 is simulated using MATLAB SIMULINK. A Voltage sag is applied at the grid side at t = 5s and is assumed to last for 50 ms. Figs. 4 through 9 show the performance of the studied system without and with the proposed converter topology during such event. The voltage profile at the PCC is shown in Fig. 4, where without the coil, voltage will drop to 0.36 pu due to the fault. By integrating the coil within the DFIG converters, voltage drop at the PCC is raised to 0.52 pu due to the extra reactive power support by the coil. Compared with the fault ride through of Germany, the voltage at the PCC violates the LVRT of the Germany grid code when the coil is not integrated within the converters as shown in Fig. 5. This will call for the disconnection of the wind turbine from the grid. However, with connecting the coil, the amount of voltage drop decreases and reaches a safe level of the grids requirement (Fig. 5) and therefore the wind turbine connection to the grid is maintained.

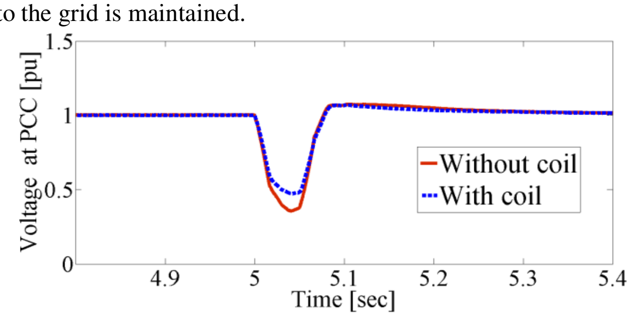

Fig.4 Voltage profile

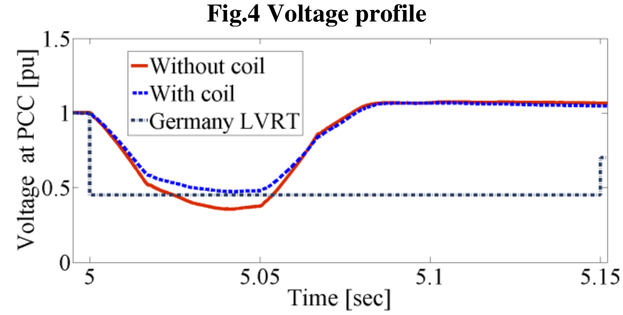

Fig. 5 PCC voltage compliance with Germany grid codes

Due to the fault and without the connection of the coil, the active power at the PCC will drop to 0.32 pu as shown in Fig. 6. When the coil is integrated within the DFIG converters, it can modulate the active power at the PCC to be 0.69 pu during the fault as shown in Fig. 6. Fig. 7 shows the reactive power at the PCC without and with the integration of the coil. With the coil, the reactive power at the PCC is almost leveled during the fault application

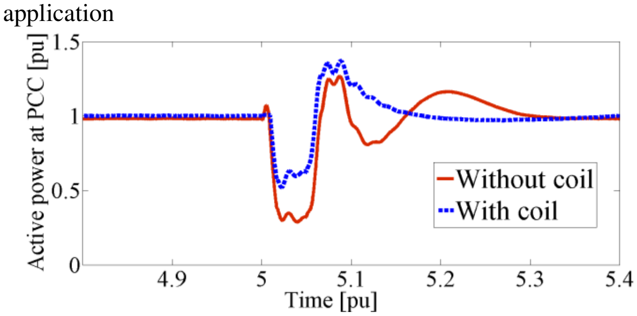

Fig. 6 Active power

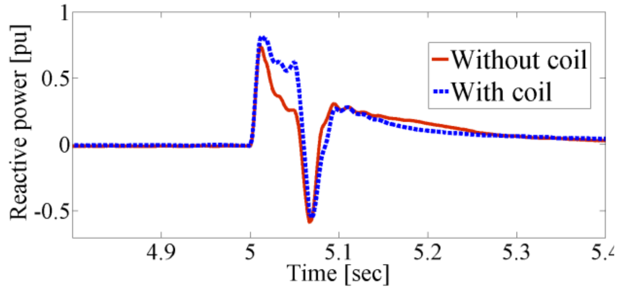

Fig. 7 Reactive power

The drop in DFIG generated active power causes the generator speed to be accelerated to compensate for the power imbalance as shown in Fig. 8 that reveals the generator speed will accelerate and reach a crest value of 1.31 pu. With the connection of the coil, the maximum overshooting in the speed will not only be reduced but the settling time is substantially reduced as well (Fig. 8). Same trend can be observed in the shaft mechanical torque shown in Fig. 9.

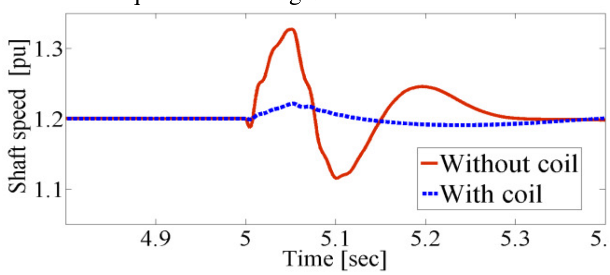

Fig. 8 DFIG shaft speed

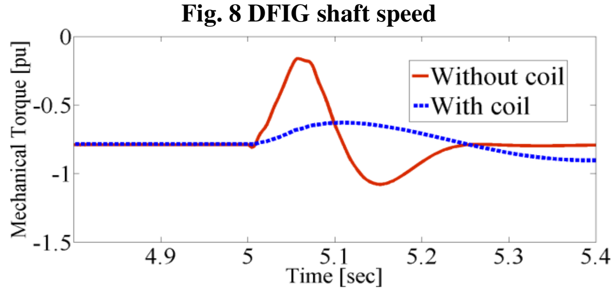

Fig. 9 Mechanical torque

The coil behavior during the fault can be investigated through Figs. 10 to 12 which respectively show the voltage across the coil, coil current, and coil stored energy during three modes. Before the fault application and during normal operating conditions, the voltage across the coil is equal to zero, and the coil current is held constant at its rated value; consequently, there will be no energy transferred between the coil and the grid (freewheeling mode). When the voltage sag occurs at t=5 sec the coil current decreases, and consequently, the voltage across the coil is turning negative. The energy stored in the coil is being delivered to the grid (Discharging mode). When the fault is cleared at 5.05 sec the coil current increases and the voltage across the coil is turning positive which means the energy transfers from the grid to the coil (charging mode).

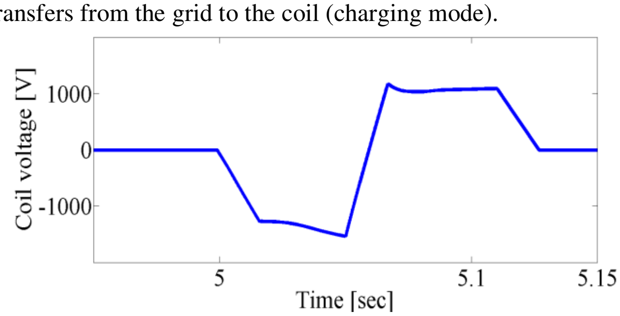

Fig. 10 Voltage across coil

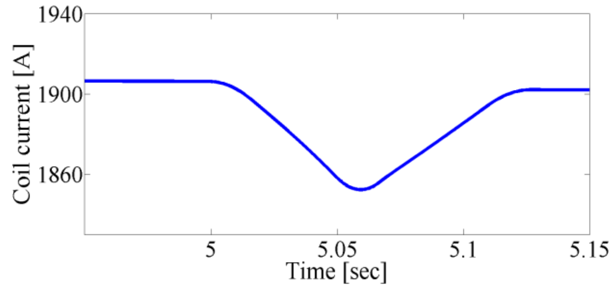

Fig. 11 Coil current

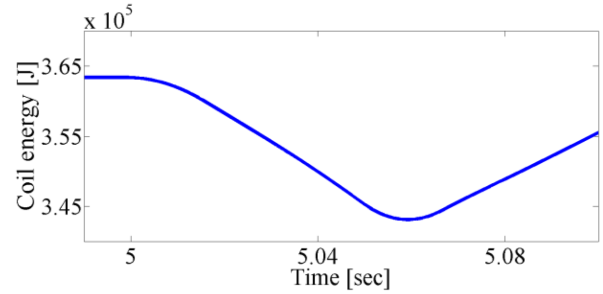

Fig. 12 Stored energy of coil

Conclusion

This paper presents a new topology for the DFIG converters by integrating a coil within the dc-link. A controller is employed to control the exchange of energy stored in the coil with the grid through controlling the duty cycle of the DC-DC chopper interfacing the coil with the converters dc-link. Results show that the proposed topology can improve the overall performance of the DFIG-based WECS during fault events without the need to connect an additional FACTS device as proposed in the literature.

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