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Fault ride-through capability of permanent magnet synchronous generator based wind energy conversion system

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In order to minimize the environmental pollution and to meet the demand of power generation, the electrical power is generated through the renewable energy resources. The wind energy is the massive energy resource compared to other mode of renewable energy resources. This paper deals on the fault ride-through capability of Permanent Magnet Synchronous Generator (PMSG) wind turbines. The main attention in the paper is, to control the PMSG wind turbine and its power converter and to the ability to protect itself without disconnection during grid fault is the main work focused in this project. Also this paper provides the necessary information on the interaction between variable-speed PMSG wind turbines and the power system subjected to faults, such as short circuit faults. The PMSG based WECS is subjected to the grid faults it will cause the oscillations in the DC link voltage at back to back converter. A crowbar and Super Conducting Fault Current limiters (SCFCL) is proposed to supress the DC link voltage oscillations and to enhance the Low Voltage Ride-through (LVRT) Capability of PMSG based wind turbine. To achieve the reactive power support at the grid side the STATCOM is implemented. The simulation results implemented in Matlab/Simulink show that the proposed control strategy not only improves the stability of PMSG by means of suppressing the DC-link voltage oscillation, but also provides a transient stability support to restraint the disturbance of the grid voltage.

Keywords: *PMSG (Permanent Magnet Synchronous Generator), DC link voltage, grid faults.*

1.0 INTRODUCTION

Wind energy is one of the fastest growing power generations at present and it continues to grow worldwide, as many countries have future plans for its development. The increased penetration of wind energy into power system over the last decade generates new challenges for the power system operators, who have to ensure a reliable and safe grid operation [1-2].The higher operating speed ranges allowing them to be tied up to the grid more easily. Variable speed operation of Wind Energy Conversion Systems (WECS) make them more ‘grid-friendly’. The power converter, whose rating is the same as that of the generator, connected between PMSG and grid allows full controllability of the system during normal operation and fault conditions. Further, PMSG operates at higher efficiency and better power factor than its counterparts especially when it functions as a direct driven generator [3-5].

Basically, for wind power these grids require an operational behaviour with several control tasks similar to those of conventional power plants. One of these control tasks is the fault ride-through

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capability of the wind turbines, which addresses primarily the design of the wind turbine controller and protection in such a way that the wind turbine is able to remain connected to the network during grid faults (e.g., short circuit fault).There is serious concern about the influence of the wind power on the power system stability, especially during grid faults. It is therefore necessary to carry out investigations of the dynamic interaction between power system and large wind farms, with suitable models and accurate transient simulations. A large research activity is carried out over the world with focus on the impact of system disturbances on wind turbines and consequently on the power system itself [6-7].

However, the key problem achieving low voltage ride-through of PMSG-based wind turbine is to maintain a stable DC-link voltage of the full scale frequency converter [8]. The main objective of this paper is to develop a crowbar system and Super Conducting Fault Current Limiter (SCFCL) to supress the oscillations of the DC link voltage when a multi-pole PMSG wind turbine under subjected to the grid fault conditions. The paper is organized as follows. Section 1 describes the traditional control strategies of generator-side converter and grid-side converter. Then the reason causing the DC-link voltage oscillation is studied in Section 3. On the basis of above analysis,Section 4 presents a protection system used to achieve the transient stability of the system. Simulation results on a 2MW PMSG-based wind generation system are provided in Section 5 and finally Section 6 draws the conclusions.

2.0 MODELLING AND CONTROL OF PMSG SYSTEM

A typical configuration of PMSG-based wind turbine is illustrated in Figure 1, Traditionally the Rotor Side Converter (RSC) is used to control the active and reactive power support to the WECS. The grid side converter is used to control the DC link voltage oscillations. Here to implement the PI controller for both RSC and GSC. When the grid voltage sags, the crowbar protection circuit is activated to provide a bypass for overflowing power, which makes it possible for PMSG to achieve the LVRT.

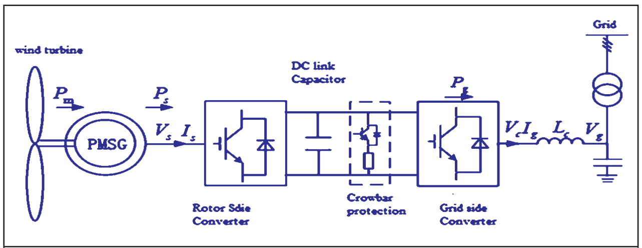

FIG. 1. BLOCK DIAGRAM OFWECS

2.1 Control Of Rotor Side Converter(RSC)

The RSC shown in Figure 2 is used to control both the active power and reactive powers of the stator terminal of the PMSG. The RSC is a power electronic full bridge 2-level, 6-pulse converter that converts the dc voltage of the DC link into ac voltage and connects to the rotor of the machine. In PMSG, as the rotor is fed by an inverter, the rotor currents are usually controlled using a rotating frame aligned with the stator flux. The RSC controller takes the terminal active powers Ps and the reactive power Qs as inputs and controls the output active and reactive powers. Park’s transformation is considered to convert the three phase quantities into the equivalent d and q components and vice versa. A proportional integral controller is used to produce appropriate reference signals for the three phase PWM signal generator block. The PWM generates pulses for switching the RSC.

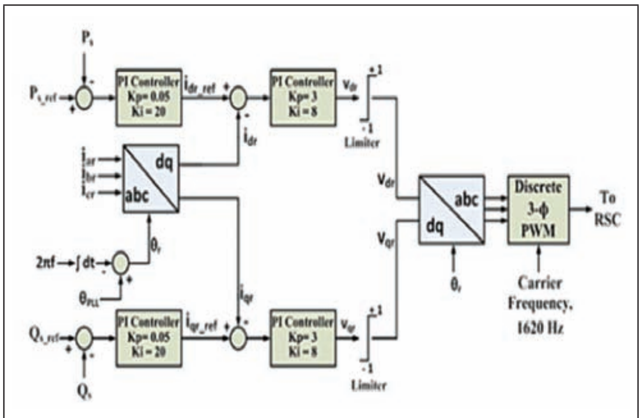

FIG. 2. CONTROL OFRSC

2.2 Control Of Grid Side Converter(GSC)

The GSC controller, shown in Figure 3 takes the DC link voltageV_DC and the rotor line reactive power as inputs to regulate the voltage of the DC link, and generates an independent reactive power that is injected into the grid. To control the reactive power of the PMSG, injection and consumption of reactive power needs to be controlled either by the rotor or the stator circuit. In fact, the GSC in the rotor circuit always controls the reactive power to zero, That is why, iqs_ref is considered to be zero. The GSC ensures the energy balance on both sides of the dc-link by maintaining the fixed dc-link voltage. In the PMSG model, a capacitor of 14, 000 μF is used to minimise the ripple of the DC voltage of 1200 Volts.

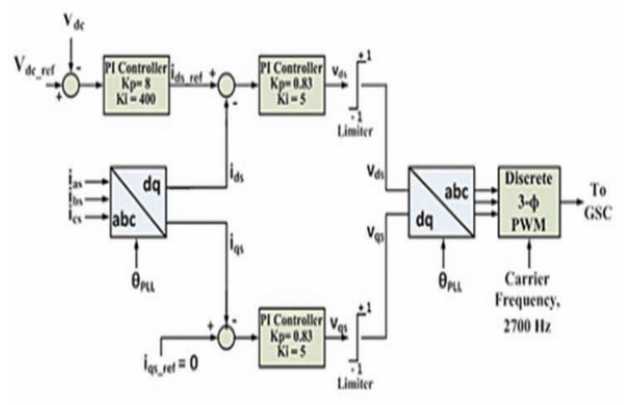

FIG. 3. CONTROL OF GSC

3.0 ANALYSIS ON THE DC-LINK VOLTAGE OSCILLATIONS DURING GRID FAULTS

When a grid fault occurs and the grid voltage dips, for this reason that the converter decouples the generator from the grid, and the generator and the turbine system are not directly subjected to grid faults, the generator-side converter continues to transmit the power flow from the wind turbine to the grid. However, the grid-side converter is directly affected by the grid fault, and it can transfer less power to the grid than in normal operation conditions. As a result, the surplus power through the generator-side converter starts to charge the DC link capacitor and cause overvoltage in the DC-link, which not only induces the DC-link voltage oscillations but also seriously influence steady operation of PMSG-based wind generation system. In order to suppress the DC-link voltage oscillations and achieve the LVRT of PMSG, an additional device, i.e. crowbar, is generally installed to burn the surplus power in the traditional control strategy. The crowbar protection system is connected across the DC link capacitor through the IGBT power electronic Switches. To limit the magnitude of fault Current the SCFCL is also implemented in the system.

4.0 CONTROL STRATEGY

The PMSG based WECS is under grid fault condition the DC link voltage it losses the stability. In order to implement the transient stability of the system and to reduce the magnitude of fault current the various control strategies is implemented [9].

4.1 Crowbar Protection System

A simple protection method of the PMSG under grid faults is to supress the oscillations in DC link capacitor through a device called crowbar. The crowbar protection is external impedance, coupled via the IGBT power Electronic Switches to across the DC link capacitor, as illustrated in Figure 1. The value of the crowbar resistance is dependent on the generator data, and therefore in case of another generator, a new value of the external resistance has to be chosen. The function of the crowbar is to limit the DC link capacitor voltage. When the WECS is subjected to the grid faults the DC link capacitor it will charge by overvoltage. So the DC link capacitor voltage it losses the stability. At the time the crowbar is triggered and to provide additional path for the excessive DC link voltage. The crowbar system is suppressing the oscillations through external impedance. After the DC link voltage it attain the stability margin the Crowbar system is again isolated from the WECS.

The crowbar protection is designed to the PMSG based WECS by using Matlab/simulink, while its control is modelled using the dynamic simulation language of the considered power system toolbox.

The crowbar protection can be removed after a predefined time or according to additional criteria, such as the magnitude of the grid voltage. When the crowbar is removed, the RSC is enabled again to control independently the active and reactive power.

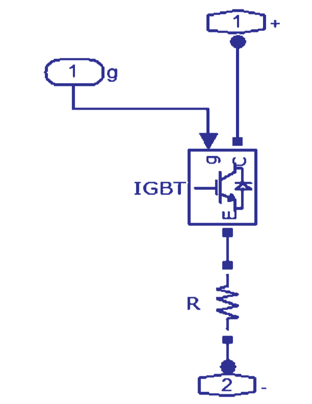

FIG. 4. SIMULINK DIAGRAM OF CROWBAR SYSTEM.

4.2 Super Conducting Fault Current Limiters

In this paper, an application of Super Conducting Fault Current Limiter (SCFCL) is proposed to limit the fault current that occurs in power system, SCFCL is a device that uses superconductors to instantaneously limit or reduce unanticipated electrical surges that may occur on utility distribution and transmission networks. Due to the difficulty in power network reinforcement and the interconnection of more distributed generations, fault current level has become a serious problem in transmission and distribution system operations. The utilization of Fault Current limiters (FCLs) in power system provides an effective way to suppress fault currents and result in considerable saving in the investment of high capacity circuit breakers is felt. In this work, a resistive type SCFCL model is implemented by Matlab/Simulink.

4.3 DC Resistive Type Super Conducting Fault Current Limiters

The DC resistive SCFCL is a combination of the rectifier and resistive type SCFCL shown in Figure 5, where a low inductance super conducting coil is designed to quench when the current flows over the rated value, thus minimising excessive fault current [10]. The quench resistor of the super conducting coil is represented by RSC, which varies with the current intensity. During normal operation of the system, the resistance of RSC is negligible. The rectifier with the combinations of the four diodes (D1–D4) in each phase, allows the superconductor to operate in nearly DC current conditions. This helps reduce the AC losses in the superconductor, and hence improves the efficiency of the system. In the DC resistive SCFCL, one half cycle of the electrical frequency line current (I Line) is carried through the path D1–RSC–LSC–D3, and for another half cycle, this path becomes D2–RSC–LSC–D4. Due to this, the current (ISCFCL) flowing through the super conducting coil is unidirectional. This helps minimise the loss across the coil, LSC. Although there are some power losses across the rectifier diodes, it is reported that using the DC resistive SCFCL provides better system efficiency, even when considering these losses.

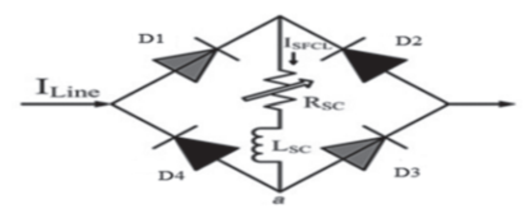

FIG. 5. DC RESISTIVE TYPE SCFCL.

5.0 RESULTS AND DISCUSSION

In this chapter the simulations results of the output performances are discussed. Fault Ride-through capability of PMSG based WECS is simulated. The output waveform by implementing the crowbar system and the SCFCL the DC link voltage is maintained to a constant value when it is subjected to the grid faults.

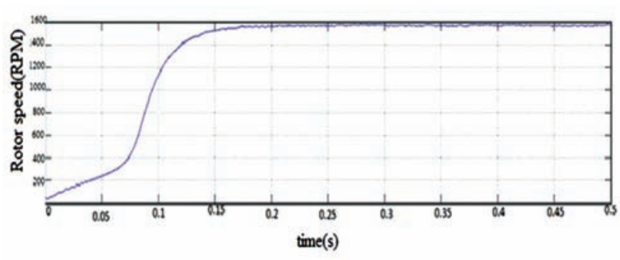

FIG. 6. ROTOR SPEED OF PMSG AT 15M/S.

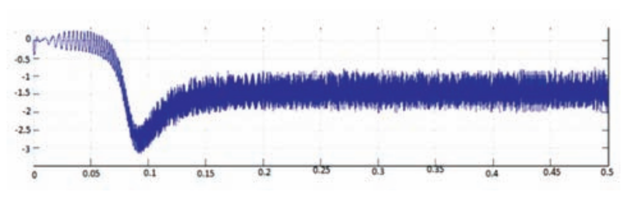

FIG. 7. ELECTROMAGNETIC TORQUE OF PMSG AT 15M/S.

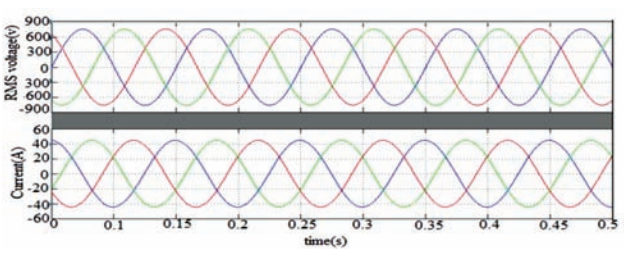

FIG. 8. GENERATOR SIDE VOLTAGE AND CURRENT AT 15M/S.

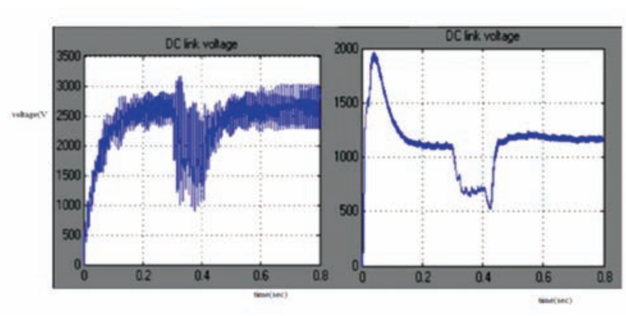

FIG. 9. DC LINK VOLTAGE.

Figure 9 shows the DC link voltage of the PMSG based WECS fault & Pre fault conditions. During the fault moment the DC link voltage it losses the stability margin. By triggering the crowbar system into the WECS it supress the oscillations in the DC link voltage.

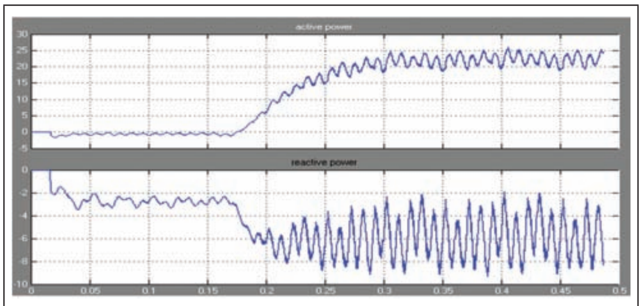

FIG. 10. REAL & REACTIVE POWER FROM THE GRID

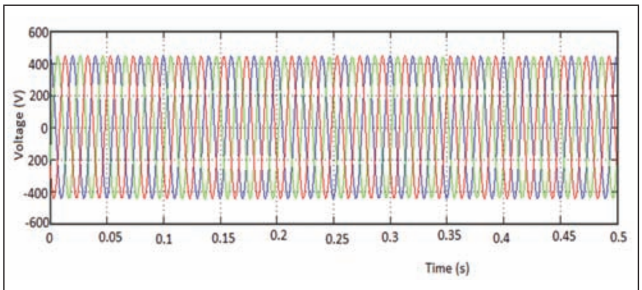

FIG. 11. GRID VOLTAGE

TABLE 1

MAGNITUDE OF FAULT CURRENT WITH & WITHOUT SCFCL.

	With SFCL (A)	With SFCL (A)
LG Fault	1500	600
LLG Fault	1500	580
LLLG Fault	1555	600
LL Fault	1250	500
LLL Fault	1550	600

Table 1 shows that magnitude of fault current for various types of faults with & without using SCFCL.

6.0 CONCLUSION

The output waveforms explains to apply the short circuit fault on the grid, the DC link voltage attain the peak value and the grid current reaches the low value. In that moment the protection system (i.e crowbar & SCFCL) was activated to overcome the issues. Finally Low voltage ride through capability of WECS is achieved by implementing the crowbar protection system and SCFCL.

Table 1 shows the magnitude of fault current for various types of faults with & without using SCFCL. This table clearly shows that the magnitude of fault current is reduced by using the SCFCL in WECS.

Figure 7 shows the electromagnetic torque generated by the PMSG generator. The negative torque value clearly shows that the PMSG will act as a generator**.** Figure 6 shows the PMSG rotor speed at 15m/s. The wind turbine is coupled to the PMSG generator. So the it starts to rotating at 1500 RPM. Figure 8 shows the PMSG generator side voltage and current waveform at 15 m/s. the rated line to line voltage is 690 V and the current is 50 A. Figure 9 shows the DC link voltage of the PMSG based WECS fault & Pre fault conditions. During the fault moment the DC link voltage it losses the stability margin.

By triggering the crowbar system into the WECS it supress the oscillations in the DC link voltage. If the DC link voltage crosses the threshold value means IGBT switches turn on the crowbar system. The crowbar system will absorb the enormous voltage and again it will attain the normal voltage. If the DC link voltage reaches the normal value, again the crowbar protection system is isolated from the system.

Figure 10 shows the real and reactive power generated by the test system. The dynamic model of variable-speed PMSG wind turbines with the fault ride-through control and protection is implemented in the Matlab/Simulink™.

By the overall analysis it can be concluded that PMSG is able to operate at a stable condition there by maintaining the constant dc voltage even after subjecting to different fault condition that can be inferred as per Table 1, the magnitude of fault current starts to decrease when SFCL based crowbar protection is implemented, where as without the implementation of SFCL, The magnitude of fault current is high and the range of decreament also occurs at a lower rate.

FUTURE WORK

- Implementation of high efficient controllers like robust controller may aid in better performance.
- Replacement of converter topologies with matrix converter will reduce the complexity of converter design.
- The performance characteristics of Induction generator has to be studied and it has to be compared with the proposed model of permanent magnet synchronous generator based wind energy conversion system.

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