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Modeling of Active Crowbar Protection Scheme for Various Types of Fault in Wind Energy Conversion System using DFIG

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Abstract: *Wind energy is one of the fastest growing non-conventional energy sources. Doubly Fed Induction Generator is often used nowadays in wind turbine. It is very sensitive to the grid disturbances, faults, and can harm the power electronic devices due to over voltages and over currents. Therefore, protection elements like Crowbar, Series Dynamic Breaking Resistor, DC Chopper are used to disconnect the machine during unhealthy conditions. In this paper, the crowbar protection method is used to ride through these disturbances. Low Voltage Ride Through (LVRT) is an important aspect for wind turbine systems to fulfil grid code requirements. In case of wind turbine technologies using doubly fed induction generators (DFIG), the reaction to grid voltage disturbances is sensitive. Since the stator of a DFIG is directly connected to a grid, this sort of machine is very sensitive to grid disturbances. Grid faults cause voltage sag and over-currents and over-voltages in rotor windings, which can damage the rotor-side converter (RSC). In order to protect the RSC, a classical solution as suggested in this paper is the installation of the Active Crowbar Protection Scheme Simulations have been carried out in MATLAB SIMULINK and the results demonstrate the effectiveness of the proposed strategy.*

Keywords: *Doubly Fed Induction Generator (DFIG), Active Crowbar Protection (ACP), Rotor Side Converter (RSC), Grid Side Converter (GSC), Low Voltage Ride-Through(LVRT), Fault Ride Through (FRT) Wind Energy Conversion System (WECS).*

1. INTRODUCTION

The increased amount of power from decentralized, renewable energy systems, as especially wind energy systems, requires strong grid code requirements to maintain a stable and safe operation of the energy network. The grid codes cover rules considering the fault ride through behavior as well as the steady state active power and reactive power production. The actual grid codes stipulate that wind farms should contribute to power system control like frequency and voltage control to behave much as conventional power stations. A detailed review of grid code technical requirements regarding the connection of wind farms to the electrical power system is given in [1]. For operation during grid voltage faults it must be ensured that becomes clear that wind turbines must stay connected to the grid and should support the grid by generating reactive power to support and restore quickly the grid voltage after the fault.

Among the various wind turbines, the doubly fed induction generator (DFIG) shown in Fig. 1 are widely preferred due to their variable speed operation, the separately controllable active and reactive power and their partially rated power converter. But, the reaction of DFIGs to grid voltage disturbances is sensitive [2], for symmetrical and unsymmetrical voltage dips, and requires additional protection for the rotor side power electronic converter.

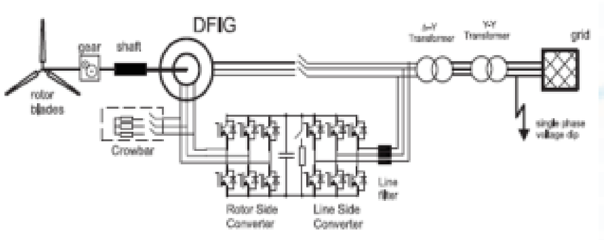


Fig1: *Schematic diagram of DFIG wind turbine system*

However, because the stator of a DFIG is directly connected to the electrical grid, it is extremely sensitive to grid voltage disturbances. Voltage dips at the stator due to grid faults induce Over-voltage in the rotor windings, resulting in over currents of the rotor circuit, which may cause severe damage to the vulnerable rotor-side power electronic converter and large fluctuation of the dc-link voltage. Such a large rotor inrush current, dc-link overvoltage, and torque oscillations caused by grid faults are quite harmful for the DFIG-based wind turbines [2] and can lead to the destruction of converter and mechanical parts. Traditionally, once over-currents occur in rotor windings, the so-called crowbar is used to protect the rotor converter by short circuiting the rotor windings.

Fig. 1 shows the block diagram of a DFIG equipped with a crowbar [6]. As can be seen, the active crowbar consists of resistors in series and capacitor, which are controlled by power electronic devices.

2. DOUBLY FED INDUCTION GENERATOR

Variable speed turbines are more popular than fixed wind speed turbine, due to its ability to capture more energy from wind, improved power quality and reduced mechanical stress on the wind turbine. DFIG can run at variable speed but produce a voltage at the frequency of the grid. In contrast to a conventional simple induction generator the electrical power generated by a DFIG is independent of the speed. Therefore, it is possible to realize a variable speed operation which requires adjusting the mechanical speed of the rotor to the wind speed so that the wind turbine operates at the aerodynamically optimal point over a certain wind speed range. DFIG has various advantages like its low converter rating consequently its relatively high efficiency, lighter in weight, its low cost and its capability of decoupling the control of both active and reactive power. Therefore, the DFIG has its distinguished place among many variable speed wind turbine generators.

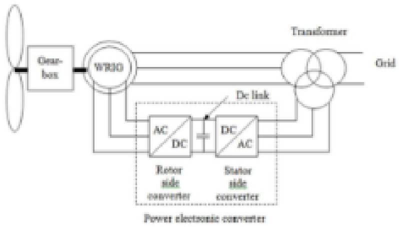


Fig2: *DFIG Scheme*

3. DFIG PROTECTION TECHNIQUES

There are so many protection techniques like DC Chopper, Dynamic braking register, crowbar for DFIG but the present work focused on Active Crowbar Protection technique which is explained in the detailed.

3.1 CROWBAR TECHNIQUE

The conventional crowbar (CB) protection circuit is a specially designed electrical circuit.. The Crowbar circuit provides a low resistance path or a short circuit across the output voltage. Generally, resistors, thyristor, TRIAC, IGBT's are used as the shorting device. The triggering of these devices depend on the current limiting circuitry of the power supply unit.

The Crowbar circuits can be classified as active crowbar circuits and passive crowbar circuits.An active crowbar provides the short circuit during the transient (high-voltage) conditions and it again allows the device to resume normal operations when the transient is over. Transistor, IGBTs, gate turn off thyristor or forced commutated thyristor are generally used in active crowbars for switching purposes. Active crowbar is used to protect the RSC of the DFIG from high voltage and the current transients produced by the voltage sags during grid faults. Hence, the DFIG can ride through the fault and can continue the power supply even during the grid voltage sags.

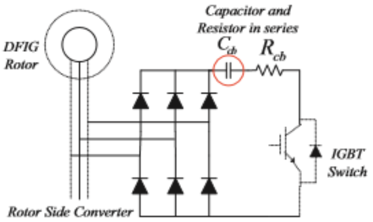


Fig 3: *Active Crowbar for DFIG rotor*

Conventional crowbar circuit, previously used in DFIG systems is consisting of resistors and power electronic switches. Due to the presence of resistors, it can restrict the high short-circuit current up to a certain extent but it cannot restrict DFIG from absorption of reactive power from the grid during the fault which further adds instability to the system performance along with power quality of the system. In order to overcome such issues and to improvise the FRT capability, a new design scheme of an active crowbar circuit is proposed which shows better performance in limiting the rotor current as well as improving the active and reactive power profile of the DFIG compared to traditional crowbar circuits. In this

ACB protection circuit, a capacitor in series with the resistor, an IGBT switch and a diode based rectifier circuit is connected together as shown in Fig 4. This scheme is Named as Novel Active Crowbar Protection (NACB_P) circuit. The capacitor is selected to compensate reactive power during fault and to accommodate the ripples generated in the dc link. It forces the current through the DC-link to be balanced and hence tries to keep the DC-link voltage maintained during fault.

3.2 MODELLING OF ACTIVE CROWBAR

When the crowbar is in ON condition the RSC pulses are totally disabled and the machine will behave like a Squirrel Cage Induction Machine (SCIM) directly coupled to the grid side. The magnetization of the machine which was provided by the Rotor Side

Converter during the normal operation is lost and the machine will draw large amount of reactive power from grid, which is called "grid codes". Though, triggering of crowbar circuit produces high stress to the mechanical component of the system. This scheme (crowbar protection) is reliable just because of its low cost and simple construction. Simulation diagram of DFIG with crowbar protection is shown in Fig 4 developed using MATLAB/Simulink.

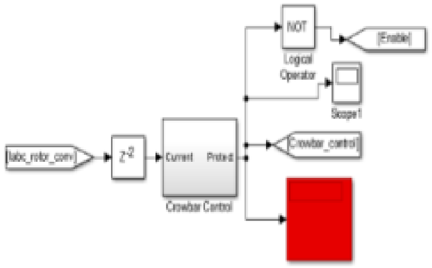


Fig 4: *Simulink diagram of Active Crowbar*

Crowbar protection can be designed by connecting 3 phase resistance. It is connected on the rotor with the help of a controllable breaker. since, it is not the real case i.e. (in reality, the crowbar may be made up of the combination of one or many resistances fed through a switched rectifier bridge), but it may be quite sufficient to assess the overall impact of crowbar protection on LVRT. The breaker is normally kept open, but it is closed during short-circuiting the rotor through the resistance. If either the rotor current or the DC-link capacitor voltage goes too high, the switching of RSC is stopped. The value of crowbar resistance is selected as 20 times higher than the rotor resistance. The choice of crowbar resistance is an important because; as it determines how much power, i.e. reactive power, the DFIG will draw while the crowbar is inserted to the circuit. When the crowbar is disconnected from the system, the rotor current and the DC- link voltage will return to their normal operating range and RSC is reinserted.

4. SIMULATION RESULTS

The simulation is carried out with a 1.7 MVA DFIG supplying active power to the grid. At time (t= 5.91) seconds, fault is applied at the point of common coupling (PCC). Except the DC-link voltage (in volts) and active power (in MW), all other responses are taken in p.u. scale with respect to time.

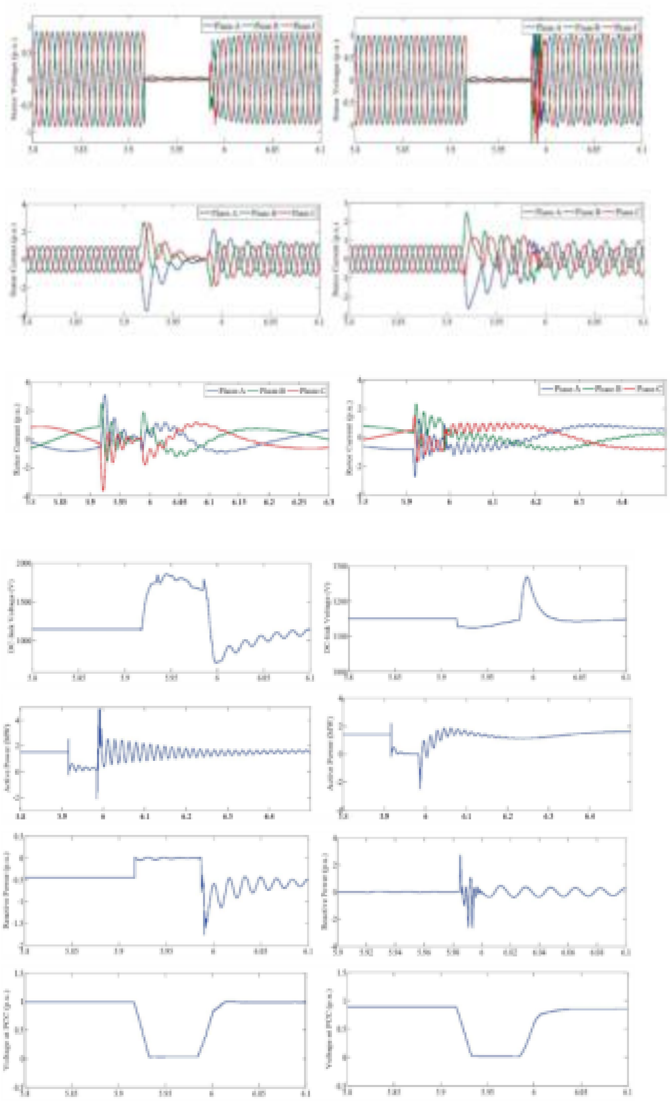
Two different cases covering both symmetrical and unsymmetrical faults are taken here in this analysis. The details of which are presented below in Table. I.

Table 1: *Margin specifications*

Case	***Nature of Fault***	***Types of Fault***	***Status of Protection device ACB_P***	
1	Symmetrical	3-φ to Ground	(a) Not Triggered	(b) Triggered
2	Unsymmetrical	1-φ ground		

Each case is analysed through a MATLAB/Simulink model of DFIG based WECS with NACBJ design circuit. two sub-cases are represented in each case where the first sub case (a) shows the responses when fault is there but the protection device is not triggered whereas (b) reveals that the protection is already triggered.

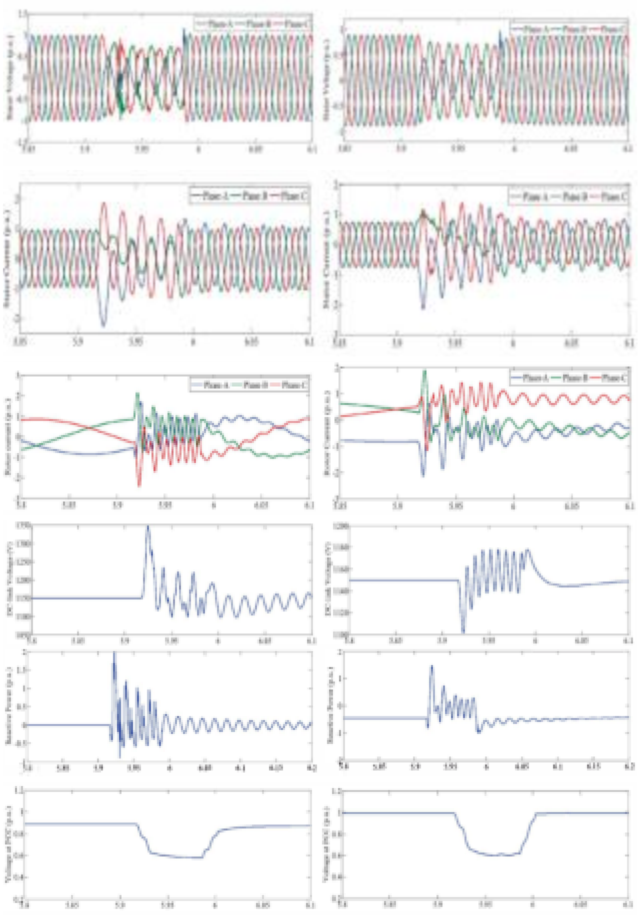
Case-1 (3-φ to Ground Fault)



(a) (b)

Fig 5: *Dynamic responses of DFIG under 3-φ symmetrical fault when NACBJ device is (a) not triggered, (b) triggered*

Case-II (l-φ to Ground Fault)



(a) (b)

Fig 6: *Dynamic responses of DFIG under 1-φ un symmetrical fault when NACB] device is (a) not triggered, (b) triggered*

The simulation results for the FRT performance of DFIG system with a three-phase symmetrical fault are shown in Fig. 5. The DFIG was intended to run at Ip.u. and its nominal load. The symmetrical fault occurs at t=5.91s, lasting for 0.7s. It is seen from Fig. 5 (a) that at the very moment when fault occurs and the protection circuit NACB _P is not triggered, the stator voltage nearly reduces to zero and the surge current in the stator winding gradually reduces below the rated value of 1 p.u that is to zero. All the three phases of the rotor current surges to 2p.u. which is hazardous for the partially rated RSC to withstand.

In Fig.5 (b), it is shown that the Novel Crowbar is triggered at t=5.91s as soon as the symmetrical fault occurred. Hence the voltage and current profile of the stator and that of rotor current improves significantly, ensuring enhanced FRT capability of the DFIG. Most importantly, the C-phase current of the stator which was zero in Fig.5(a), now stabilises to its rated value as seen in Fig. 5(b) soon after NACB_P is triggered. Similarly the other two phases, A and B of the stator current regains its balanced state very quickly.

The rotor current profile of the DFIG improves significantly reducing the surge value nearer to its nominal value after the application of proposed protection because the capacitor implemented in the protection design accommodates the ripples generated in the current due to the fault. It is observed from Fig. 5(a) that during fault, the DC-link voltage increases from steady state value 1150V to around 1600V which must be avoided to protect the DC-link capacitor as well as the GSc. But, as shown in Fig. 5(b), the DC-link voltage varies within the safe range from 11OOV to 1300V after the protection is triggered. The active power of the system suddenly becomes zero from rated value of 1.5 MW and the reactive value fluctuates around zero making the whole system unstable, the terminal voltage at PCC reduces to zero as seen from Fig. 5(a). But, as the protection circuit is triggered in Fig. 5(b), the capacitor used in the protection compensates reactive power making it nearly zero. Active power and terminal voltage characteristics of DFIG are also observed to be improved due to the control action of the novel protection circuit.

In Fig. 6 (a) and (b), the simulation responses of DFIG during an unsymmetrical I-φ to ground fault is observed without and with the proposed protection scheme respectively. In Fig.6(a), all the dynamic responses of the DFIG along with the instantaneous stator voltage and current profiles are presented which are affected due the fault in a similar manner as explained in case of symmetrical fault. But the difference lies in the number of phases of current and voltage affected. After the NACB _P is triggered, nearly steady-state values for stator current, rotor current and DClink voltages are observed in Fig. 7(b). The reason how it works is explained in previous section, that the capacitor Cb in proposed scheme is calibrated in such a way that it nullifies a major part of the transients generated in the rotor current and hence in the DC-link voltage.

5. CONCLUSIONS

In this paper, a protection design is described which has the objective to maintain the connection of the DFIG to the grid in case of grid faults so that it can continue the power supply after the clearance of the faults. The key objective of the protection design is to restrict the high current within safe limits and to facilitate a bypass for it in the rotor side of the generator through the set of resistor and capacitor connected in series. Compared to conventional crowbar, NACB_P is more effective in improving the Fault Ride through capability of DFIG. The proposed design is described and applied through a time dependent analytical expression of the transient stator and rotor currents of the DFIG. Simulation results reveal the effectiveness of the proposed novel crowbar applicable both in case of symmetrical and unsymmetrical grid faults.

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