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Fault Rid Through Protection of DFIG Based Wind Generation System

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Abstract: This study proposes a fault ride-through strategy for a Doubly Fed Induction Generator (DFIG) to enhance network stability during grid disturbances. To enable efficient computation a reduced order DFIG model is developed that restricts the calculation to the fundamental frequency component. However, the model enhancement introduced in the paper allows the consideration of the alternating components of the rotor current as well which is necessary for triggering the crowbar operation. As protection against short circuit transients, the crowbar protection is employed in the simulation. An equivalent model is constructed. Simplifications are made so as to have a system composed of grid, transformer, line and generator represented by elementary circuit elements (R, L, C and voltage sources). Equivalent circuit models are simplified so that the fault models may be used for synchronous machine parameters. It is assumed that the mechanical system cannot respond during the short time of a three phase short circuit. Simulation results in MATLAB\Simulink software are presented for model verification purposes.

Key word: Doubly Fed Induction Generator (DFIG), fault rid through, wind turbine

INTRODUCTION

The Doubly Fed Induction Generator (DFIG) is widely used in wind energy power generation. DFIG are variable speed generators, used more and more in wind turbine applications due to easy controllability, high energy efficiency and improved power quality, (Brekken and Mohan, 2003; Muller *et al*., 2000; Carlin *et al.*, 2001). As power converters in a DFIG system only deal with the rotor power, electronic costs are kept low, about 20-25% of the total generator power. This implies that the converter is dimensioned to the rotor parameters (Lightbody *et al*., 2006; Akhmatov, 2002; Holmes and Elsonbaty, 1984). This makes the system more economical than using a fully rated converter in a series configuration. Turbines are commonly installed in rural areas with unbalanced power transmission grids. For an induction machine an unbalanced grid imposes negative effects like overheating and mechanical stress due to torque pulsations. For an unbalance of 6% for example the induction generator is stopped from generating in the grid. By control of the rotor currents of a DFIG the effects of unbalanced stator voltage may be compensated. The drive system operates in four quadrants. This implies that a bidirectional flow of power is possible. The possibility of supplying and consuming reactive power enables the generator system to act as a power factor compensator. By the control of the back to back inverters the slip may be controlled. In the case of the squirrel cage induction machine, for example, as the rotor cannot be driven, the slip only depends on the stator and load inputs. As for synchronous machines a relatively large torque may cause the machine to oscillate. The DFIG does not encounter any synchronization problems. To observe the system and the flow of active and reactive energy a dynamic model is needed. The machine may be simulated as an induction machine having three phases supply in the stator and three phases supply in the rotor. The rotor circuit is connected through slip rings to the back to back inverter, arrangement controlled by PWM strategies. The voltage magnitude and the power direction between the rotor and the supply may be varied by controlling the switch impulses. Back to back converters consists of two voltage source converters (ac-dc-ac) having a dc link capacitor connecting them. The generator side converter takes the variable frequency voltage and converts into dc voltage. The grid side converter has the ac voltage from the dc link as input and voltage as grid parameters as output. The transformer couples the generator to the grid adjusts the parameters of the machine voltage to the grid voltage. The stator is connected directly to the grid. For a normal generation regime the energy obtained by processing the wind speed as an input is fed into the network by both, the stator and the rotor. In this paper the simulation of the DFIG included in a wind turbine system is presented. With this an idea of the validity of the simplified model is tested. Models elaborated in this paper are detailed. Normal duty and the fault ride through models are

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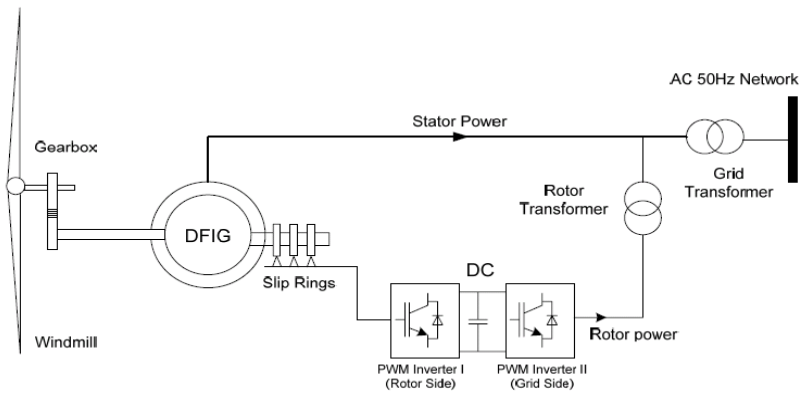

Fig.1: DFIG wind turbine system

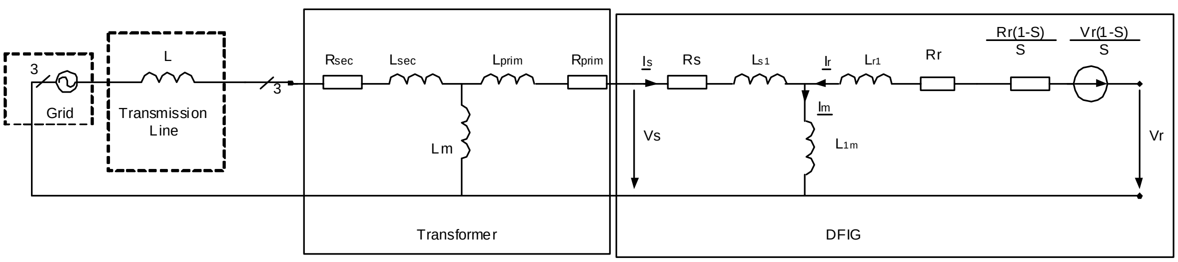

Fig. 2: Normal duty equivalent circuit

described. Consequences of the simplified assumptions implemented in the model are shown and the acceptability of results is discussed.

DFIG system description: In the following, the modeled drive system having a DFIG is described. Function of the DFIG is analyzed and the basic elements of the drive are presented. The aim is to represent the drive using an equivalent circuit in two cases: normal operation and crowbar active.

In Figure 1 the basic normal duty diagram for the wind turbine is presented. From the blade and shaft, the rotor of the generator receives the torque produce by the wind. The energy is fed to the grid through the back to back inverter system and the three phase transformer. The initial model of the transmission line consisted of a pi diagram containing the parasitic elements of the conduction cable. According to lines shorter than 100 km are considered short lines and may be modeled as an inductance. The grid was modeled as a three-phase voltage source. The grid side converter is connected to the transmission line through a three phased step down transformer. The grid is modeled like a 3 phase voltage source. In Fig. 2 the equivalent circuit of the system is presented. The grid was represented as an alternative voltage source. For the transmission line, a pi equivalent circuit was used and for both the transformer and the machine, a T equivalent circuit.

In order to simplify the equivalent circuit and consequently the mathematical model derived from it, a set of simplifying assumption were considered. Arguments are brought for each assumption to show their validity. As the line is considered to be short (<100 km), the model may be simplified to a single parasitic inductance. The magnetization branch of the transformer was neglected. This is done under the assumption that the current is too small in that branch and the reactance is small compared to the horizontal branch reactance.

Crowbar activated: Another protection for a short circuit is called the crowbar. This fault handler is a set of resistors used to short circuit the rotor windings in case of a severe fault. In literature it is also called ‘beak resistor’ because it has an electrical breaking effect on the accelerating rotor. The role of the circuit is to contribute to system stability during transients. The extra resistance introduced in the circuit dissipates the surplus energy generated during the fault in extremely high current conditions. The rotor of the generator is disconnected from the back to back inverter system and short-circuited with resistors (Fig. 3). Automatically disconnect after the fault had passed. K is a symbolical switch representing the connection apparatus and control.

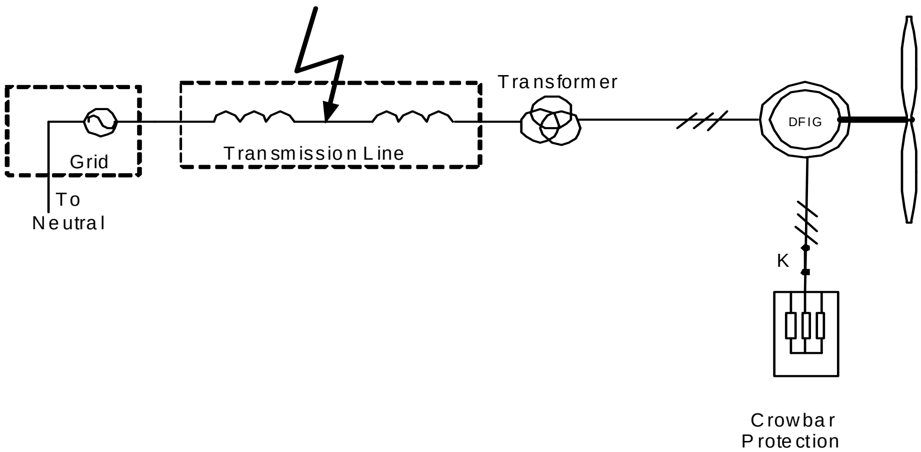

Fig. 3: Crowbar activated diagram

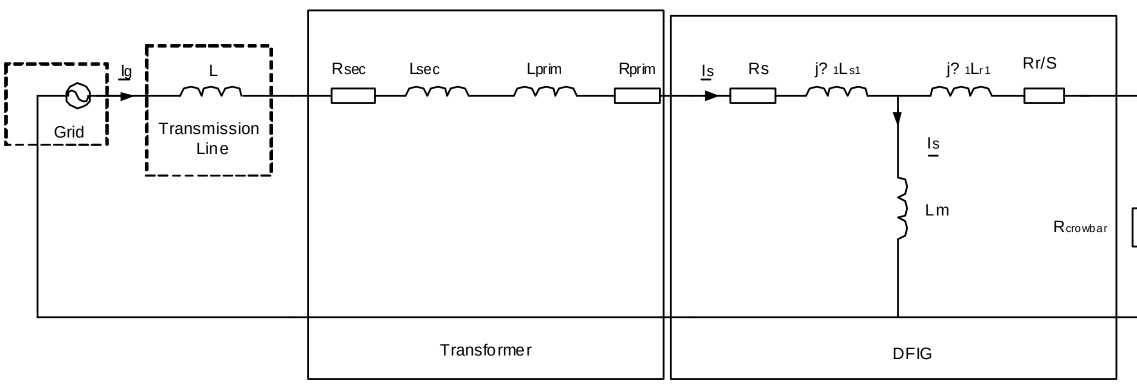

Fig. 4: Crowbar activated equivalent circuit

The equivalent circuit of the crowbar activated diagram is shown in Fig. 4. As can be seen, the magnetization inductance of the transformer was neglected in the short circuit simulation. Equations derived from Fig. 4 are presented in the following. In the first circuit loop, the equation is written as:

$$U_g = R_{ech} i_g + (dl_{ech}/dt)\, i_g + (dL_m/dt)\, i_m \quad (1)$$

The equivalent elements are written as sums of series components:

$$R_{ech} = R_{sec} + R_{prim} \quad (2)$$

$$L_{ech} = L_{sec} + L_{prim} + L_{line} \quad (3)$$

For the second circuit loop, as the rotor is disconnected from the voltage source, only the energy stored in the motor magnetizing branch intervenes. This is the main reason why the magnetizing element must not be neglected in this case.

$$0 = R_a i_r + \frac{d\psi_r}{dt} + \left(R_{crowbar} + \frac{R_r}{s}\right) i_r \quad (4)$$

If the slip is considered to be constant, the resistor value of the rotor would remain constant:

$$0 = R_a i_r + \frac{d\psi_r}{dt} + (R_{crowbar} + R_r^{'}) i_r \quad (5)$$

$$\psi_r = L_r i_r + L_m i_s \quad (6)$$

The circuits presented above were used as a base for fault simulation models. Each circuit was simulated and analyzed separately as shown if the next chapter. the separation has been made in order to facilitate the basic understanding of the model and to shorten computational time.

DFIG system simulation: Figure 5 shows the main simulation level of the crowbar fault response. The

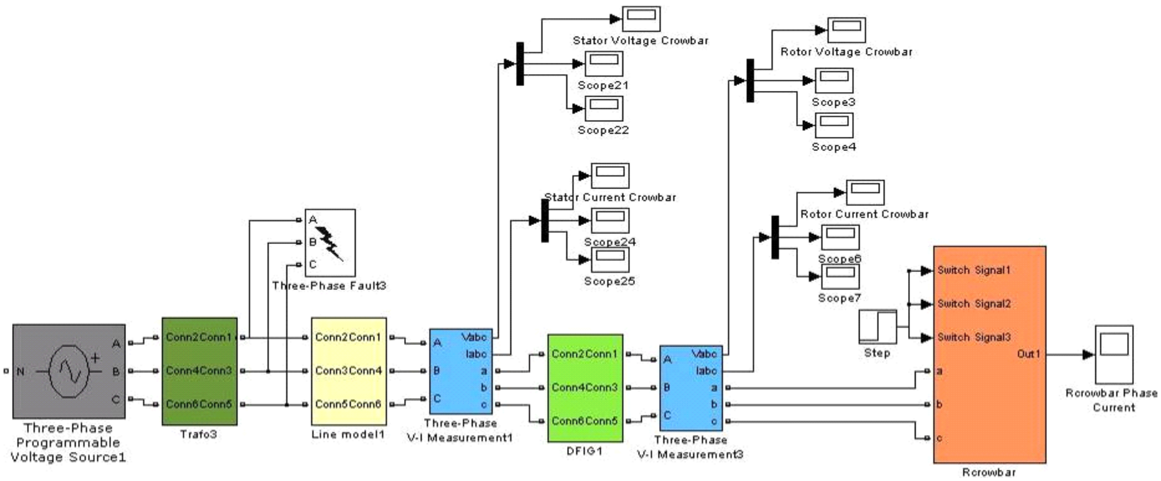

Fig. 5: Crowbar protection-main simulation level

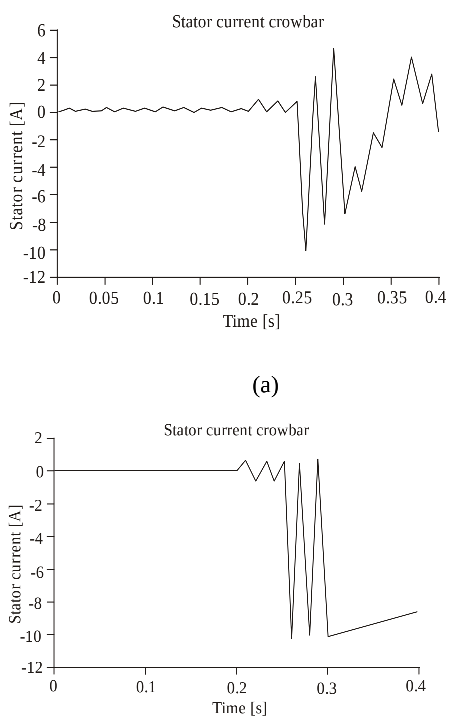

Fig. 6: Crowbar resistor simulation results - stator current vs. simulation time, (a) Library model, (b) Detailed model

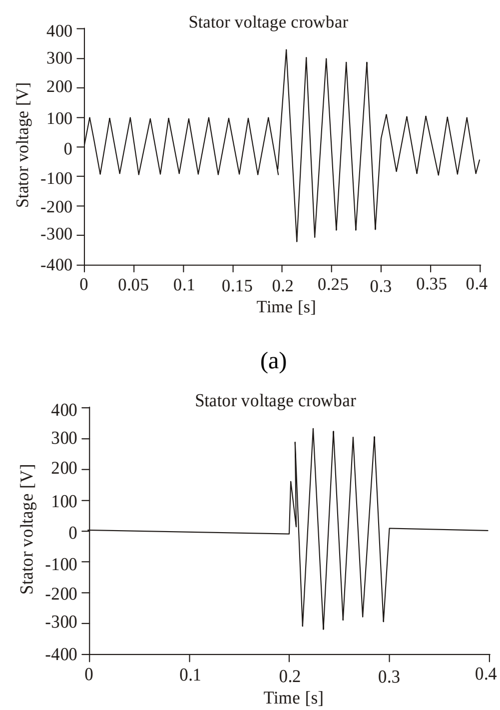

Fig. 7: Crowbar resistor simulation results - stator voltage vs. simulation time, (a) Library model, (b) Detailed model

protection is inserted at 0.25s via ideal switches driven by a step signal. The fault is introduced from 0.2 to 0.3 sec. Parameters used:

$R_s = 0.0021$; $L_s = 0.11$; $L_r = 0.07$; $R_r = 0.0021$; $L_m = 2.5$; $R_{line} = 0.05$; $L_{line} = 0.007$; $R_{crowbar} = 0.1$;
$L_{prim} = 0.007$; $R_{prim} = 0.05$; $L_{sec} = 0.007$; $R_{sec} = 0.05$

The results of this simulation are presented in Fig. 6 and 7. The Stator Current is presented in Fig. 6 and the Stator voltage is presented in Fig. 7.

CONCLUSION

As it may be observed from the simulation results, an over simplified model should not be used to analyze transients. The errors introduced in the results make the simplified model unacceptable. Besides the structure of the circuit its self, parameters and initial conditions must be accurately introduced in the simulation. The parameters used were not of a real system and the initial conditions were generated by the 0.2 s simulation prior to the fault. By comparing a complex (Sympower Systems) model to the simplified model, the last one has been proven to be unreliable due to the reduced number of elements.

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