Analysis of Reduced Order Model Based on Doubly-Fed Induction Generators during Different Fault Times

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Abstract

In this study, three phase fault analysis of wind turbines consist of Doubly-Fed İnduction Generators (DFIGs) has been examined. The dynamic analysis of DFIG has been conducted by Reduced Order Model (ROM). Three Phase fault has been made in 34.5 kV bus, happended in three bus power systems. The three phase fault time has been choosen as 0.02 second, 0.05 second and 0.1 seconds. 154 kV bus voltage, 34.5 kV bus voltage, DFIG output voltage, DFIG angular speed, DFIG electrical torque and DFIG d-q axes stator and rotor current variations of system in different fault times has been examined. According to the results, it has been seen that three phase fault is especially effective upon 34.5 kV bus voltage and DFIG output voltage in different fault time's analysis.

1. Introduction

Wind energy is one of the fastest growing industries at present and it will continue to grow worldwide, as many countries have plans for future development. The increased penetration of wind energy into power system over the last decade generates new challenges for the power system operators, which have to ensure a reliable and safe grid operation [1]. Doubly fed induction generator (DFIG) wind turbine has recently become the most widely used wind turbine for wind farms, since it presents noticeable advantages such as: the variable speed generation, the decoupled control of active and reactive powers, the reduction of mechanical stresses and acoustic noise, the improvement of power quality.

The behavior of a wind farm with DFIG wind turbines can be simulated by a complete model including the modeling of all the wind turbines and the internal electrical network. This model presents high-order if a wind farm with high number of wind turbines is simulated. In order to represent DFIG wind turbines without unnecessarily increasing the complete wind farm model, reduced models of wind turbines have been used [2]. Reduced Order Model are described and the control of the wind turbine discussed. The capability of the DFIG for voltage control, speed control, positive-negative sequence control, weighting factor its performance during fault is also addressed [3-6]. Integration of variable speed wind systems with reduce order model based on DFIG four-quadrant back to back converter connected to the rotor windings increases the transient stability margin of the electrical grids [7-8]. ROM based on DFIG with the capability to provide short-term frequency regulation is investigated [9]. The implementation of the algorithm for optimizing the controllers parameters is described in detail. In the analysis, the generic dynamic model of WT with DFIG and its associated controllers is presented, and the small signal stability model is derived [10-11]. The power quality impact by the ROM based on DFIG wind turbine system is measured and evaluated. Such as flicker emission, reactive power, and harmonic emission, is measured and analyzed [12]. Stability analysis of ROM wind generators in a system with different time 3 phase faults analysis are carried out in this study. First, the reduced order model of a DFIG is derived. Later, the responses of DFIG against different time 3 phase faults are investigated by observing the variation of several parameters such as bus voltages, angular speed, electrical torque and d-q axes stator and rotor current variations.

2. Doubly Fed Induction Generator (DFIG) Modeling

DFIG wind turbines use a wound rotor induction generator, where the rotor winding is fed through a back-to-back variable frequency PWM converter as shown in Fig. 1.
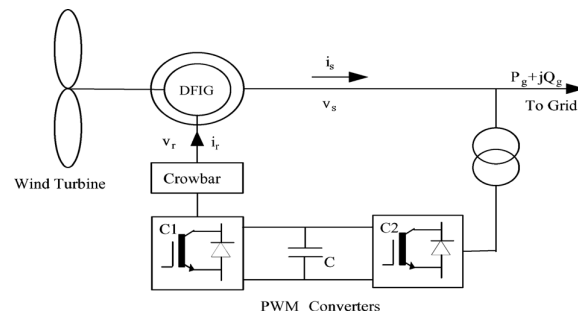

Fig. 1. DFIG circuit model

Voltage limits and an over-current "crowbar" circuit protect the machine and converters. The converter system enables the two-way transfer of power. Converter 2 (C2) is fed from the generator stator terminals via a reactive link and provides a dc supply to Converter 1 (C1) that produces a variable frequency three-phase supply to the generator rotor via slip rings [13]. In modeling DFIG, the full order model is represented by 5 equations, considering the generator's variables in the dq synchronous reference frame. The equations for the stator and rotor windings with the torque equations can be written as follows:

$$v_{ds} = R_s i_{ds} + w_s \lambda_{qs} + \frac{d}{dt}\lambda_{ds} \qquad (1)$$

$$v_{qs} = R_s i_{qs} - w_s \lambda_{ds} + \frac{d}{dt}\lambda_{qs} \qquad (2)$$

$$v_{dr} = R_r i_{ds} + sw_s \lambda_{qr} + \frac{d}{dt} \lambda_{dr} \qquad (3)$$

$$v_{qr} = R_r i_{qs} - sw_s \lambda_{dr} + \frac{d}{dt} \lambda_{qr} \qquad (4)$$

$$M = \lambda_{qr} i_{dr} - \lambda_{dr} i_{qr} \qquad (5)$$

Flux-inductance equations can be expressed in the dq synchronous frame as follows:

$$\lambda_{ds} = (L_s + L_m) i_{ds} + L_m i_{dr} \qquad (6)$$

$$\lambda_{qs} = (L_s + L_m) i_{qs} + L_m i_{qr} \qquad (7)$$

$$\lambda_{dr} = (L_r + L_m) i_{dr} + L_m i_{ds} \qquad (8)$$

$$\lambda_{qr} = (L_r + L_m) i_{qr} + L_m i_{qs} \qquad (9)$$

A reduced order model of a DFIG is employed to simplify the relationship between the steady state variable and the outputs of DFIG. The simplified model can enable us to easily predict the behavior of DFIG under transient conditions. In this model, a stator is represented by a transient voltage source behind a transient reactance where stator fluxes are neglected. The main idea is that the dc component is omitted from the stator transient current. Four electrical and one mechanical equations describing stator side and unchanged equations of rotor side in the reduced order model of the machine are given below [14]:

$$v_{ds} = R_s i_{ds} + X' i_{qs} + E_d \qquad (10)$$

$$v_{qs} = R_s i_{qs} - X' i_{ds} + E_q \qquad (11)$$

$$\frac{dE_{ds}}{dt} = -\frac{1}{T_0} [E_{ds} - (X - X') I_{qs}] \\ + sw_s E_{qs} - w_s v_{qr} \frac{L_m}{L_m + L_s} \qquad (12)$$

$$\frac{dE_{qs}}{dt} = -\frac{1}{T_0} [E_{qs} + (X - X') I_{ds}] \\ - sw_s E_{ds} + w_s v_{dr} \frac{L_m}{L_m + L_s} \qquad (13)$$

$$v_{dr} = R_r i_{ds} + sw_s \lambda_{qr} + \frac{d}{dt} \lambda_{dr} \qquad (14)$$

$$v_{qr} = R_r i_{qs} - sw_s \lambda_{dr} + \frac{d}{dt} \lambda_{qr} \qquad (15)$$

$$M = E_{ds} i_{ds} + E_{qs} i_{qs} \qquad (16)$$

Voltage current relationship of stator and flux-current relationship of rotor can be stated as follows:

$$E_{ds} = (L_s + L_m) i_{ds} + L_m i_{dr} \qquad (17)$$

$$E_{qs} = (L_s + L_m) i_{qs} + L_m i_{qr} \qquad (18)$$

$$\lambda_{dr} = (L_r + L_m) i_{dr} + L_m i_{ds} \qquad (19)$$

$$\lambda_{qr} = (L_r + L_m) i_{qr} + L_m i_{qs} \qquad (20)$$

In these equations; v_{ds}, v_{dr}, v_{qs}, v_{qr} : d and q axes voltages of stator and rotor, i_{ds}, i_{dr}, i_{qs}, i_{qr} :d and q axes currents of stator and rotor, λ_{ds} , λ_{dr} λ_{qs} , λ_{qr} : d and q axes magnetic fluxes of stator and rotor, E_{ds} and E_{qs} : d and q axes source voltages of stator, w_s : angular speed of stator, s: slip, R_s and R_r : resistance of stator and rotor, X : stator reactance, L_s and L_r : inductance of stator and rotor, L_m : magnetic inductance and M :torque Transient reactance of the model is expressed in equation (21), while transient open circuit time constant is given in equation (22)[15].

$$X' = X_s + \frac{X_r + X_m}{X_r X_m} \qquad (21)$$

$$T_0 = \frac{L_r + L_m}{R_r} = \frac{L_{rr}}{R_r} \qquad (22)$$

3. Simulation Study

A 2.3 MW wind power plant having DFIG is used to study the behavior of the system against different time 3 phase fault analysis. Modeling of the whole system is carried out as depicted in Fig. 2.
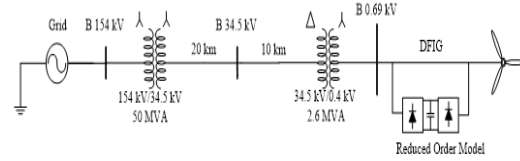

Fig. 2. Simulation study modeling

The DFIG is represented with the reduced order model as explained in previous section. The plant is connected to a 34.5 kV system through a 2.6MW, 0.69kV Y/34.5kV Δ transformer. There is 30 km distance between the plant and 154kV substation. A 50 MW 34.5kV Y/154kV Y transformer provides the transmission grid connection. Wind speed is considered to be 8m/s constant. Saturation of transformers are neglected. In DFIG, stator resistance 0.00706 ohm, rotor resistance 0.005 ohm, stator enductance 0.171 henry, rotor enductance 0.156 henry and inertia constant 3.5 have been choosen.
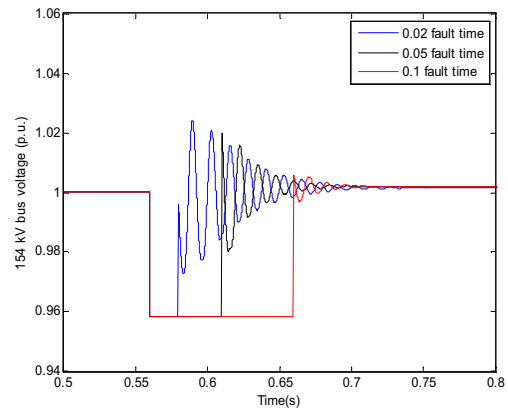
4. Simulation Study Results
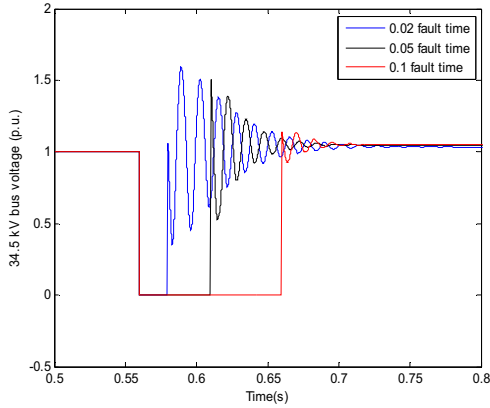

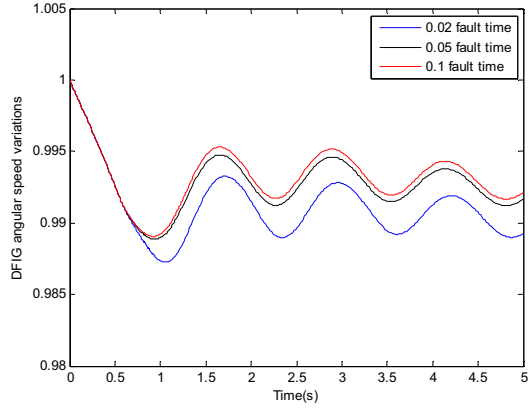**Fig. 3.** 154 kV bus voltage

Fig. 4. 34.5 kV bus voltage

Fig. 5. DFIG output voltage

Fig. 6. DFIG angular speed variations

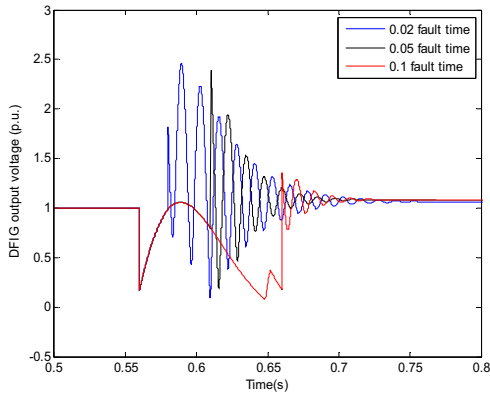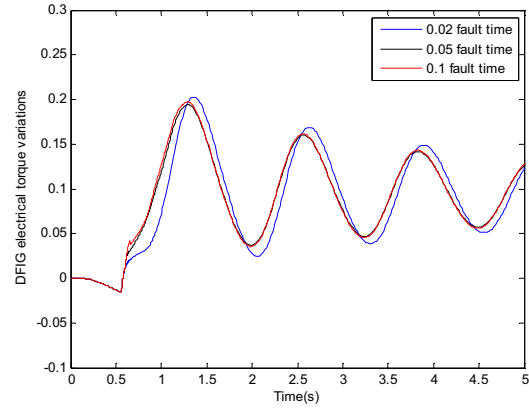**Fig. 7.** DFIG electrical torque variations

As a result of simulation study, three phase fault has been conducted between 0.56-0.58, 0.56-0.61 and 0.56-0.66 seconds in 154 kV bus voltage 34.5 kV bus voltage, and DFIG output voltage variations have been shown between Fig. 3 and Fig. 5.

When the three phase fault time is 0.02 seconds, grid bus voltage has risen to 1.02 p.u. values, 34.5 kV bus voltage has risen to 1.58 p.u. value and DFIG output voltage has risen to 1.25 p.u. value. DFIG angular speed and DFIG electrical torque variations have been shown in Fig. 6 and Fig. 7.

In DFIG angular speed variaton, it becomes stable compared to other fault times, when the fault time decreases. İt has been seen that dampings have arisen with the decrease of fault time in DFIG electrical variations. DFIG d-q stator and rotor axes current variations have been shown in Fig. 8 and Fig. 11.
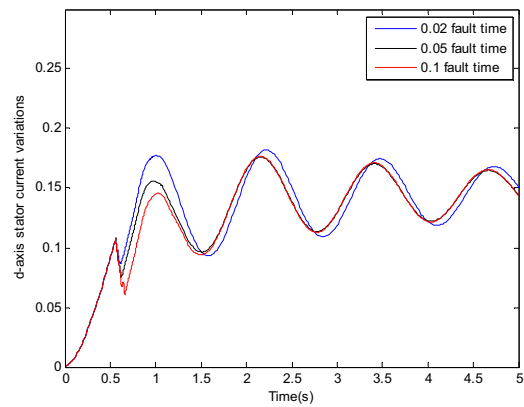

Fig. 8. DFIG d axis stator current variations

Fig. 9. DFIG q axis stator current variations

Fig. 10. DFIG d axis rotor current variations

Fig. 11. DFIG q axis rotor current variations

Three phase fault has caused to the increase in damping with the decrease of fault time In DFIG d-q axes stator and rotor current variations. While DFIG d axis stator and rotor current

becomes stable in 0.15 p.u. value, DFIG q axis stator and rotor current becomes stable 0.05 p.u. vaule.

5. Conclusions

Stability analysis of ROM wind generators in a system with different time 3 phase faults analysis are carried out in this study. As a result of this study which has been made with ROM used in DFIG dynamic modeling, it has been seen that three phase fault is quite effective upon 34.5 kV bus voltage and DFIG output voltage, compared to different fault times especially in grid part of modeled system. It has been observed that DFIG output voltage damping increase when the fault is shorter. Also, it has been seen that dampings are less when three phase fault time is longer.

7. References

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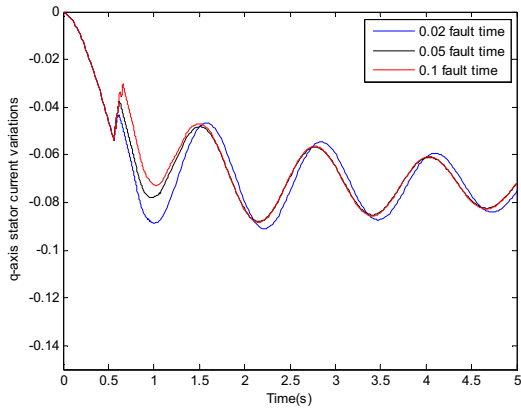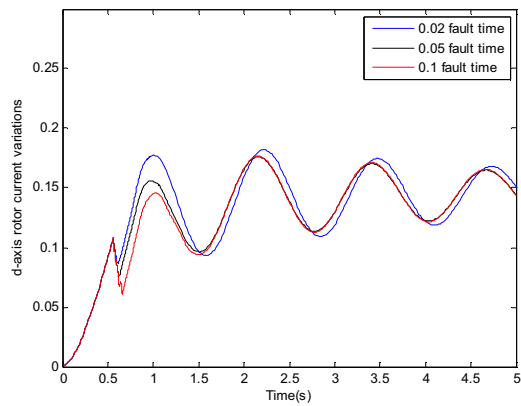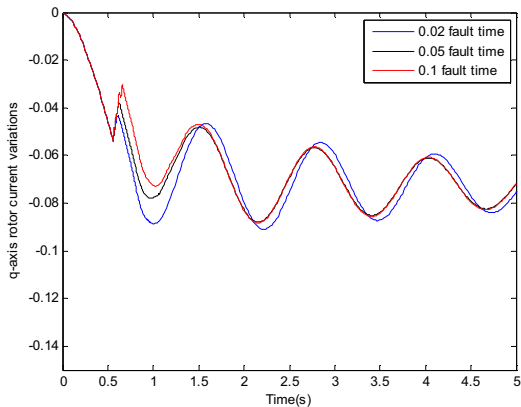
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