

Investigation of Doubly-Fed Induction Generator with Grid Disconnection

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Abstract—This paper describes the transient behaviour of a doubly-fed induction generator (DFIG) driven by wind turbine after its disconnection from the grid. The induction machine runs at a specific speed with the stator disconnected from the grid ($I_s=0$), the rotor is suddenly excited with slip-frequency voltages derived from voltage regulators so as to produce commended open-circuit stator terminal voltage. Behavior under varying rotor speed typically observed. A MATLAB computer simulation study was undertaken and results are presented.

Index Terms- Doubly-Fed Induction Generator (DFIG), Dynamic Modeling, Grid Disconnection, Transient Analysis

I. NOMENCLATURE

V_{qs}, V_{ds} are the three-Phase supply voltages in d-q reference frame, respectively

i_{qs}, i_{ds} are the three-Phase stator currents in d-q reference frame, respectively

V_{qr}, V_{dr} are the three-Phase rotor voltages in d-q reference frame, respectively

i_{qr}, i_{dr} are the three-Phase rotor currents in d-q reference frame, respectively

$\lambda_{qr}, \lambda_{dr}$ are the three-Phase rotor flux linkages in d-q reference frame, respectively

r_s, r_r are the stator and rotor resistances of machine per phase, respectively

$\varphi_{ds}, \varphi_{qs}$ are the stator d and q winding flux linkage

$\varphi_{dr}, \varphi_{qr}$ are the rotor d and q winding flux linkage

L_{ls}, L_{lr} are the leakage inductances of stator and rotor windings, respectively

ω, ω_r are the supply and rotor angular frequency (electrical speed), respectively

T_e is the electromagnetic torque

P_s, Q_s are the stator-side active and reactive powers, respectively

II. INTRODUCTION

For stand alone or autonomous operation, mostly single induction generator or parallel operated induction generators are focused according to available analysed references. These induction generator driven by the individual prime movers employed excitation capacitor bank to build up desired voltage via self-excited phenomena. Hence the value of the excitation capacitor bank and the rotor speed determine the magnitude of the generated voltage and its frequency. Both voltage and frequency need to be controlled to feed the power to the

load. But for grid connected operation, there are two types of generators are used. (i.e., single output and double outputs). In order to feed the active power to the grid, the machine should run at a speed greater than the synchronous speed of the revolving magnetic field. (i.e. slip should be negative). The single output generator feeds active power to the grid via only stator side and double output generator feeds electrical power to the grid via both stator as well as rotor side. The latter is also called static Kramer, double-fed or double outputs induction generators. This is only the generator which generates the power more than rated power without overheating. Besides, this kind of power generation usually causes problems in the utility grid system. Because the control on active and reactive power of the machine is complex one. Wind turbines often do not take part in voltage and frequency control and if a disturbance occurs, the wind turbines are disconnected and reconnected when normal operation has been resumed. As the wind power penetration continually increases, power utilities concerns are shifting focus from the power quality issue to the stability problem caused by the wind power connection. In such cases, it becomes important to consider the wind power impact properly in the power system planning and operation. This paper will focus on the grid-connected induction generator feeding power with DOIG during steady state and transient conditions.

This paper describes the transient behavior of a doubly fed induction generator (DFIG) after its disconnection from the grid. The induction machine runs at a specific speed with the stator disconnected from the grid ($I_s=0$), the rotor is suddenly excited with slip-frequency voltages derived from voltage regulators so as to produce commended open-circuit stator terminal voltage.

Behavior under varying rotor speed typically observed in wind turbine is also reported. A MATLAB computer simulation study was undertaken and results are presented.

III. DFIG DYNAMIC MODELLING

A commonly used model for induction generator converting power from the wind to serve the electric grid is shown in Fig.1. The stator of the wound rotor induction machine is connected to the low voltage balanced three-phase grid and the rotor side is fed via the back-to-back IGBT voltage-source inverters with a common DC bus. The network side converter controls the power flow between the DC bus and the AC side and allows the system to be operated in sub synchronous and super synchronous speed. The proper rotor excitation is provided by the machine side power converter.

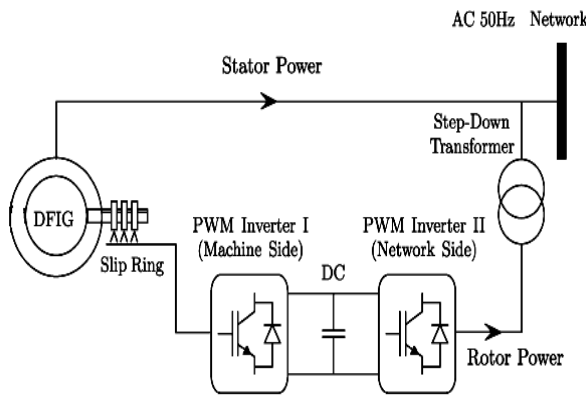


Fig.1. Model of DFIG

The general model for wound rotor induction machine is similar to any fixed-speed induction generator as follows.

A. Stator Voltage Equations

$$V_{ds} = r_s i_{ds} + \frac{d\phi_{ds}}{dt} - \omega \phi_{qs}$$

$$V_{qs} = r_s i_{qs} + \frac{d\phi_{qs}}{dt} + \omega \phi_{ds}$$

B. Rotor Voltage Equations

$$V_{dr} = r_r i_{dr} + \frac{d\phi_{dr}}{dt} - (\omega - \omega_r) \phi_{qr}$$

$$V_{qr} = r_r i_{qr} + \frac{d\phi_{qr}}{dt} + (\omega - \omega_r) \phi_{dr}$$

C. Power Equations

$$P_s = \frac{3}{2} (V_{ds} i_{ds} + V_{qs} i_{qs})$$

$$Q_s = \frac{3}{2} (V_{ds} i_{qs} - V_{qs} i_{ds})$$

D. Torque Equation

$$T_e = \frac{3}{2} p L_m (i_{qs} i_{dr} - i_{ds} i_{qr})$$

E. Stator Flux Linkage Equations

$$\phi_{ds} = L_s i_{ds} + L_m i_{dr}$$

$$\phi_{qs} = L_s i_{qs} + L_m i_{qr}$$

F. Rotor Flux Linkage Equations

$$\phi_{dr} = L_r i_{dr} + L_m i_{ds}$$

$$\phi_{qr} = L_r i_{qr} + L_m i_{qs}$$

Where

$$L_s = L_{ls} + L_m$$

$$L_r = L_{lr} + L_m$$

IV. TRANSIENT ANALYSIS DURING GRID DISCONNECTION

Fig (2) shows the three phase stator voltages under normal operating conditions. When the induction machine is running at a particular speed while the stator disconnected from the grid. So the rotor is suddenly got excited due to slip frequency rotor voltages from the voltage regulators in order to produce the commended stator terminal voltage. Since the variation of speed of the rotor, torque could also be varied on the machine. Fig (3) shows the transient response of the stator voltage of induction generator under torque disturbance. It is found that the voltage of the stator becomes slightly small value after disturbance. Fig (4) shows the transient response of the rotor voltage of induction generator under torque disturbance. Fig. (5) shows the transient response of the active power of the induction generator during disconnection. When induction generator is disconnected from the grid, the active powers supplied from induction generator decreases and quickly recover to original value after re-closed to the grid. The changes in a reactive power are also shown in Fig. (6). It is observed that the reactive power absorbed by the induction is also decreases rapidly, but the part of reactive power would be supplied by rotor side converter for compensation during reclosed to the grid. Negative values of active and reactive power indicate the machine working in generating mode.

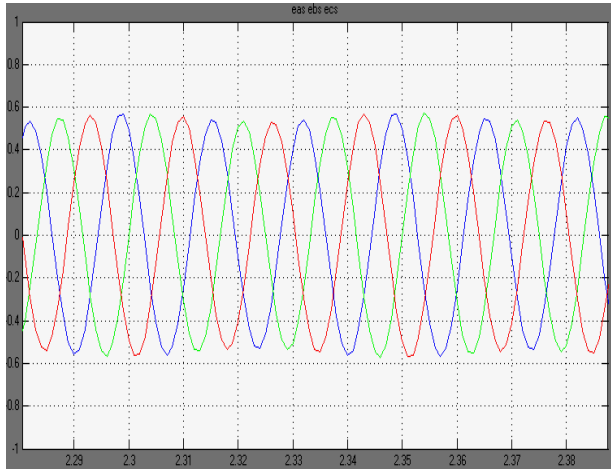


Fig. 2. Response of Three phase Stator voltages of DFIG

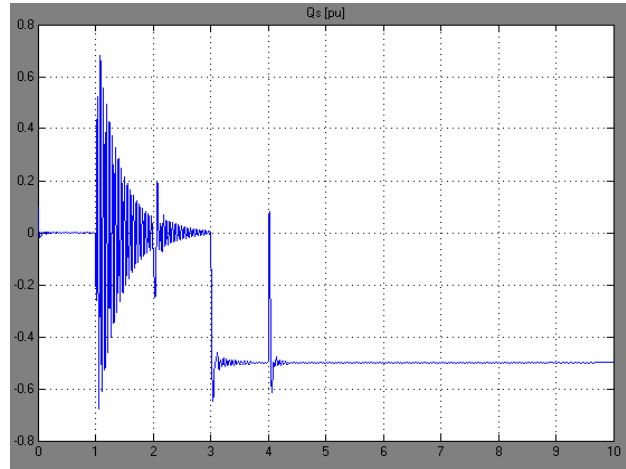


Fig. 5. Transient Response of Active power During Grid Disconnection

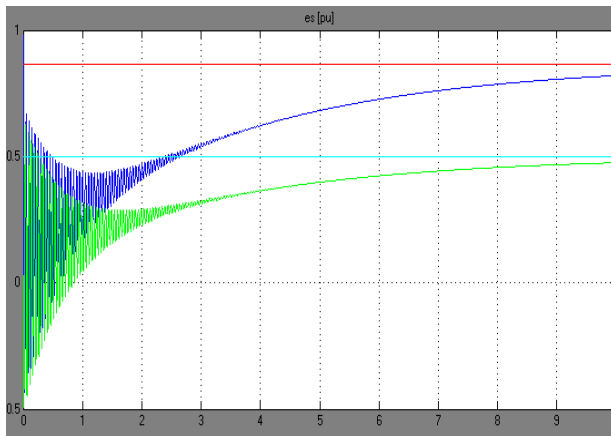


Fig. 3. Transient Response of Stator voltage During Grid Disconnection

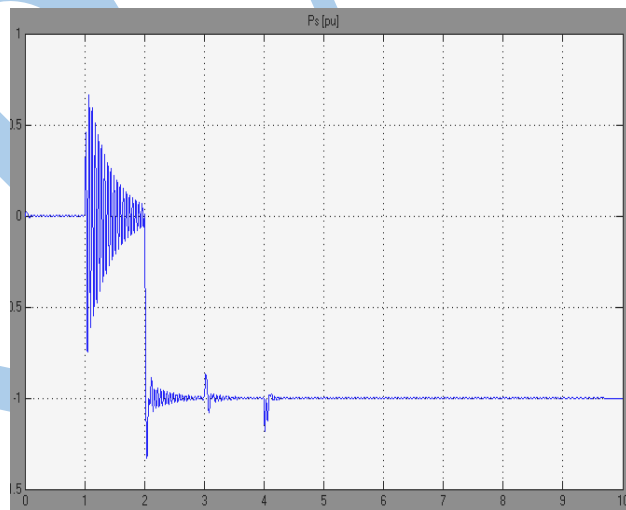


Fig. 6. Transient Response of Reactive power During Grid Disconnection

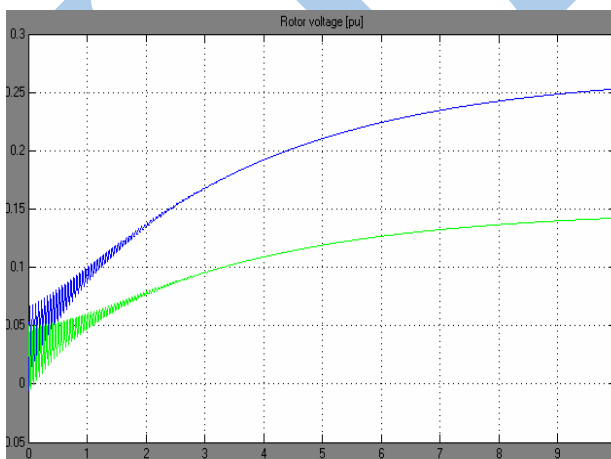


Fig. 4. Transient Response of Rotor voltage During Grid Disconnection

IV. CONCLUSION

In this paper, dynamic characteristics of double-fed induction generator have been studied during abnormal conditions of the grid. For this, dynamic d-q model was used to derive the dynamic equations of such machine in a synchronous reference frame. The choice of synchronous rotating reference frame makes it particularly favorable for the simulation of double-output configuration in transient conditions. When the stator is disconnected from the grid, the rotor is suddenly got excited due to slip frequency rotor voltages from the voltage regulators in order to produce the commended stator terminal voltage. So active and reactive power of the machine have been decreasing rapidly. For reactive power compensation during these conditions, rotor side converter has to supply necessary reactive power.

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