

Doubly Fed Induction Generator Control under Unbalanced Condition

Bhanu Ganesh Lukka, Bongu Mahesh, Vutukoori Bharath

Abstract

The global electrical energy consumption is rising and there is steady increase of the demand on power generation. So in addition to conventional power generation units a large number of renewable energy units are being integrated into the power system. A wind electrical generation system is the most cost competitive of all the environmentally clean and safe renewable energy sources in world. The recent evolution of power semiconductors and variable frequency drive technology has aided the acceptance of variable speed generation systems.

Both fixed-speed squirrel-cage induction generator and variable speed double fed induction generator are used in wind turbine generation technology. Therefore, a detailed model of induction generator coupled to wind turbine system is presented in the thesis. Modeling and simulation of induction machine using vector control computing technique is done in MATLAB/SIMULINK platform. The significant result of the analysis is also shown and being compared with the existing literature to validate approach.

Index Terms—AC generators, induction motors, power system dynamic stability, reactive power control, torque control, variable speed drives, wind energy.

I. Introduction

Wind energy generation equipment is most often installed in remote, rural areas. These remote areas usually have weak grids, often with voltage unbalances and under voltage conditions. When the stator phase voltages supplied by the grid are unbalanced, the torque produced by the induction generator is not constant. Instead, the torque has periodic pulsations at twice the grid frequency, which can result in acoustic noise at low levels and at high levels can damage the rotor shaft, gearbox, or blade assembly. Also an induction generator connected to an unbalanced grid will draw unbalanced current. These unbalanced current tend to magnify the grid voltage unbalance and cause over current problems as well [1-3].

Wind energy has been the subject of much recent research and development. In order to overcome the problems associated with fixed speed wind turbine system and to maximize the wind energy capture, many new wind farms will employ variable speed wind turbine. DFIG (Double Fed Induction Generator) is one of the components of Variable speed wind turbine system. DFIG offers several advantages when compared with fixed speed generators including speed control. These merits are primarily achieved via control of the rotor side converter. Many works have been proposed for studying the behavior of DFIG based wind turbine system connected to the grid. Most existing models widely use vector control Double Fed Induction Generator. The stator is directly connected to the grid and the rotor is fed to magnetize the machine [3].

Wind electrical power system are recently getting lot of attention, because they are cost competitive, environmental clean and safe renewable power sources, as compared fossil fuel and nuclear power generation.

The reason for the world wide interest in developing wind generation plants is the rapidly increasing demand for electrical energy and the consequent depletion reserves of fossil fuels, namely, oil and coal. Many places also do not have the potential for generating hydel power.

Then converted to synchronously rotating frame by the unit vector components $\cos\theta_e$ and $\sin\theta_e$ before applying them to the d^e-q^e machine model. The controller makes two stage of inverse transformation, so that the control currents i_{ds}^* and i_{qs}^* corresponds to the machine current i_{ds} and i_{qs} , respectively. The transformation and inverse transformation including the inverter ideally do not incorporate any dynamics therefore; the response to i_{ds} and i_{qs} is instantaneous.

To understand the torque and reactive power second harmonics, it is useful to use space vectors in the stationary, stator frame. In space vector theory, the positive sequence stator-voltage space vector rotates with constant amplitude in the positive direction, at the synchronous speed. The negative sequence stator-voltage space vector rotates at the synchronous speed with constant amplitude in the negative direction. The same will also apply to the flux: the flux arising from the positive sequence voltage will rotate synchronously in the positive direction, and the flux arising from the negative sequence voltage will rotate synchronously in the negative direction. These two flux vectors will add constructively and destructively

twice per revolution, which gives rise to the double synchronous frequency disturbance in the torque and reactive power [4].

In a synchronously rotating d-q reference frame, the d and q system variables will nominally be dc values in steady state. However, in the presence of a stator-voltage unbalance, the d and q variables will have a second harmonic component in addition to the dc component. This, in turn, causes second harmonic pulsations in the torque (active power) and reactive power.

For the proposed control, stator-voltage-oriented d-q vector control is used. This orientation can be called “grid flux oriented” control [5]. In this scheme, the d-axis is aligned with the stator-voltage space vector (instantaneously). Therefore, $v_{sq} = 0$ (steady state and transient) and $\omega_d = \omega_{syn}$ (steady state only). Since the d-axis is collinear with the stator voltage and the q-axis is quadrature, the d-axis is used to control torque and the q-axis is used to control reactive power. The control structure is shown in Figs.2and3 [2-6].The control topology is fairly standard except for the addition of the $C_{d,comp}$ and $C_{q,comp}$ controllers, which supplement the d- and q-axis rotor voltage. These supplementary feedback controllers give the loops a very high gain at the known disturbance frequency (100 Hz), allowing the controllers to compensate for the torque and reactive power pulsations that arise when the stator voltage is unbalanced. Reducing the reactive power pulsation dramatically improves the unbalance of the stator current.

II. Controller design

The outer speed and reactive power loops were designed in the standard cascade manner, having loop gain crossover frequencies well below that of the inner current loops. To design the speed controller, the $\omega_{mech}/ird(s)$ transfer function must be determined. For this, it becomes useful to use the concept of magnetizing current to simplify the derivation of the plant transfer function

$$isq + nirq = imq \tag{1}$$

$$isd + nird = imd \tag{2}$$

$$T = p/2 Lmn(isqird - isdirq) = p/2Lmn(imqird - imdirq). \tag{3}$$

The significant advantage of this form of the torque equation is that the magnetizing currents imd and imq are predominantly determined by the stator side voltage, and therefore, can be approximated to be constant. The magnetizing current space vector will lag the stator-voltage space vector by nearly 90°. Since the d-axis is chosen to be aligned with the stator-voltage space vector, the majority of the magnetizing current space vector will be reflected along the negative q-axis. Therefore, imq is large negative and imd is very small. Therefore, the torque can be approximated as having a proportional dependence on ird as

$$T \approx p/2Lmnimqird \tag{4}$$

$$Tird(s) = p/2Lmnimq. \tag{5}$$

Therefore

$$W_{mech}/ird(s) = p/2Lmnimq/sJ + B. \tag{6}$$

A lead-lag controller is used, and the loop gain bandwidth is designed for 1 Hz. A fast speed loop will respond more quickly to changes in the load, such as gusts of wind. This will cause the generator torque to respond quickly, thereby causing the power into the grid to change rapidly, mirroring the wind gusts. However, a slow speed loop will allow the generator to accelerate or decelerate as the wind changes, thus using the rotational energy of the machine as a buffer to smooth the power into the grid [6].

III. SIMULATION RESULTS

The proposed control was tested on a 15kW DFIG controlled with the rapid prototyping DSP package d Space, as shown in Fig. 7,8. The stator-voltage unbalance was created by placing a high-power variable resistance in series with the stator A-phase.

3.1. Transient Activation of Compensation Controllers

Figs.1-3 show the system operating with a 5% stator-voltage unbalance. Before $t = 0$, $C_{d,comp}$ and $C_{q,comp}$ are off. At $t = 0$, Fig. 3 shows the stator and rotor active power. Because the torque pulsations are eliminated, the active power is smoothed. The tradeoff is the extra power requirement of the rotor converter.

This is also shown in Fig. 2 as an increase in the rotor voltage. The results show that the compensating controllers greatly reduce the second harmonic torque pulsations, reactive power pulsations, and stator-current unbalance.

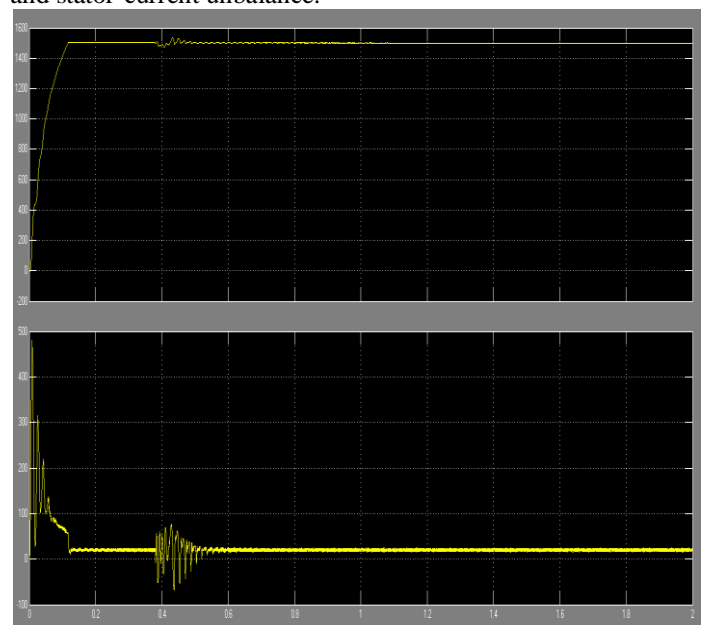


Fig.1. Outputs of Torque and Speed

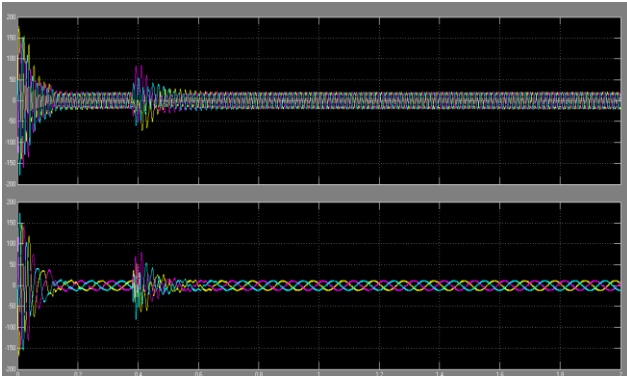


Fig.2. Outputs of Stator ,Rotor Currents.

range of stator-voltage unbalances can be determined.

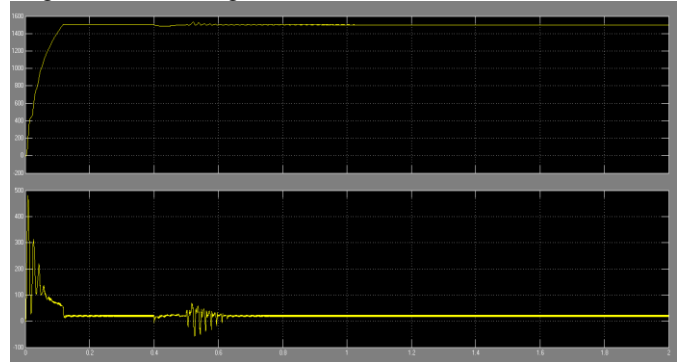


Fig.4. Output of Torque ,Speed .

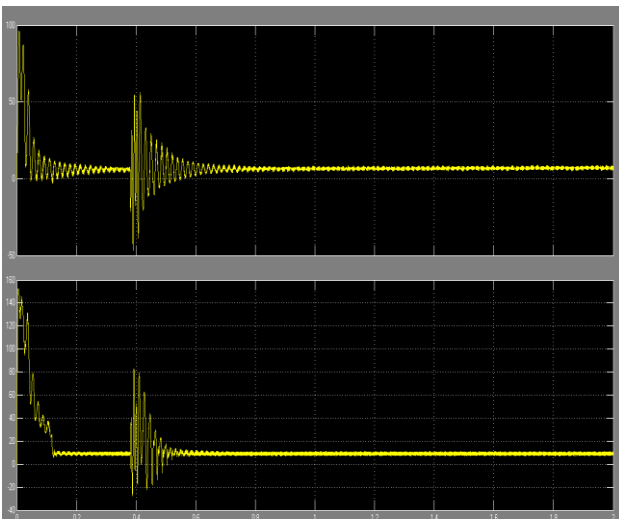


Fig.3.Active ,Reactive power.

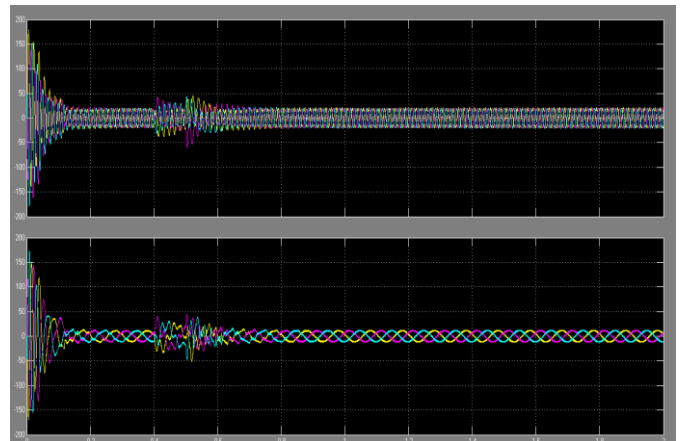


Fig.5.Stator, Rotor Currents.

3.2. Steady-State Analysis

In addition to transient analysis, a series of steady-state analyses with a swept stator-voltage unbalance are shown later. In Figs. 4,5 and 6, the second harmonic magnitude of torque and stator reactive power per unit is plotted versus stator-voltage unbalance. In Fig. 6, the stator-current unbalance is plotted versus stator-voltage unbalance. Both hardware and simulation results are shown. By comparing the slope of the trend lines, the effectiveness of the compensation controllers over a

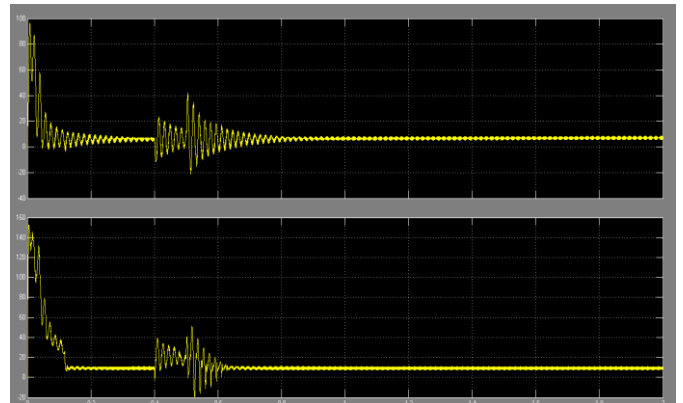


Fig.6. Active ,Reactive Power

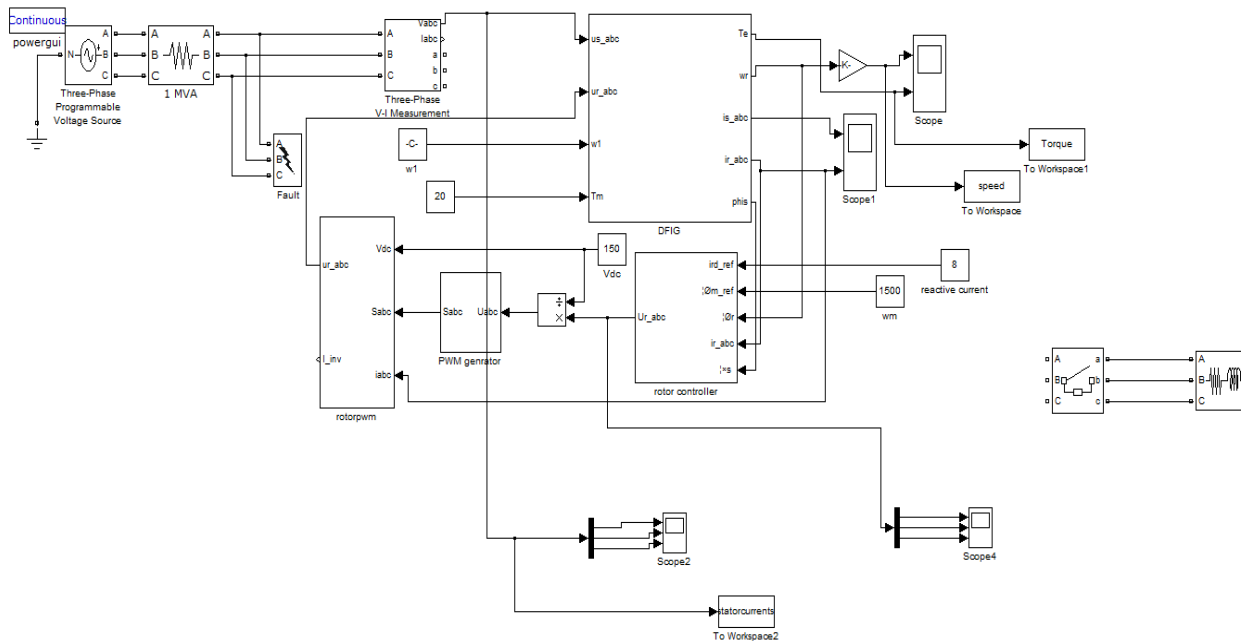


Fig.7. Simulink model for proposed circuit

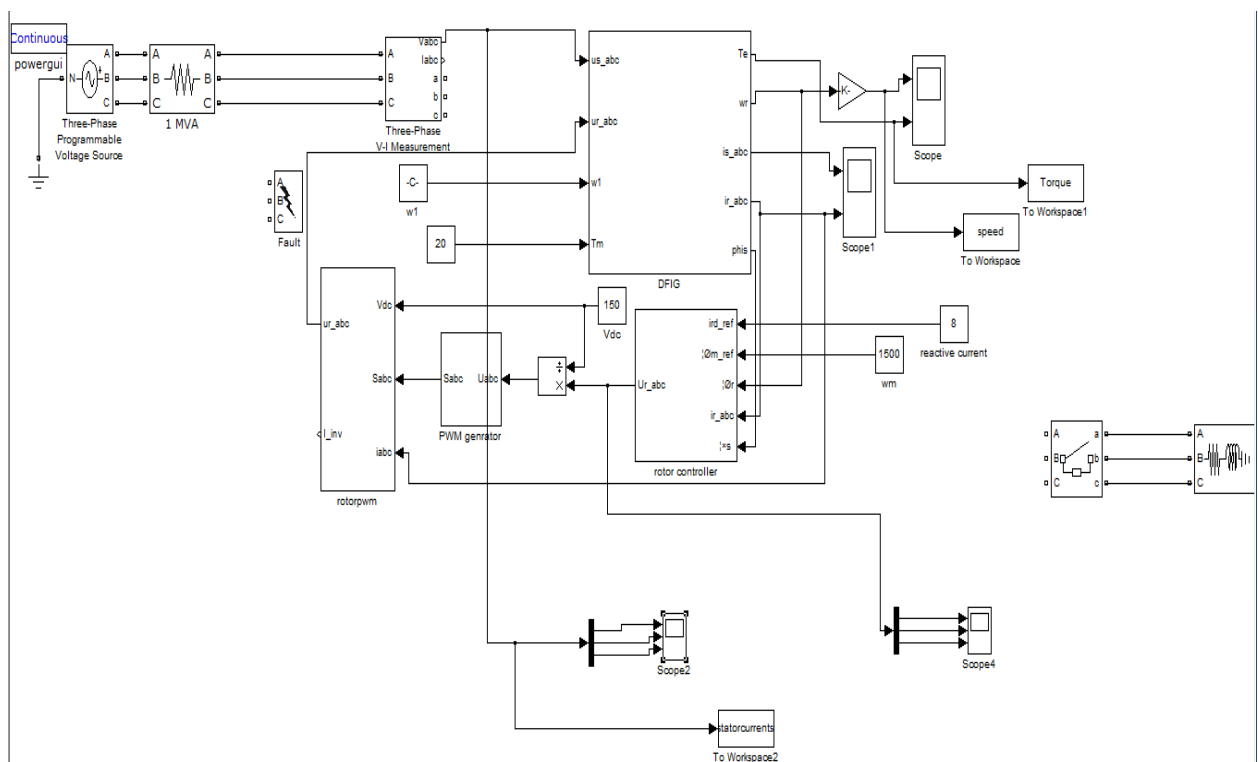


Fig.8. Proposed circuit for Steady state analysis.

IV. Conclusion

This thesis presents a study of the dynamic performance of variable speed DFIG coupled with either wind turbine or a dc motor and the power system is subjected to disturbances; such as voltage sag, unbalanced operation or short circuit faults. The dynamic behavior of DFIG under power system disturbance was simulated both using MATLAB coding and MATLAB/SIMULINK platform using matrix /vector space control concept. Accurate

transient simulations are required to investigate the influence of the wind power on the power system stability. Power converter are usually controlled utilizing vector control techniques which allow the decoupled control of both active and reactive power flow to the grid. In the present investigation, the dynamic DFIG performance is presented for both normal.

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