Design, Simulation and Control of A Doubly Fed Induction Generator

Nalini Telu, K. Veeresham, Rohini Telu

ABSTRACT- The global electrical energy consumption is rising and there is a sudden increase in the demand of power generation. Large number of renewable energy units is now being integrated to power system for meeting and the rising demand of power generation. Slip ring induction machine in the variable speed wind turbine popularly known as double fed induction generator is mostly used in wind power generation. The main reasons for the popularity of the doubly fed wind induction generators connected to the power network is their ability to supply power at constant voltage and frequency while the rotor speed varies and motor converter handles fraction of stator power. The main goal of my project is to design doubly fed induction generator (DFIG) & to control the active and reactive powers by injecting the proper rotor voltage to the DFIG derived from PI controller so as to maintain the constant terminal voltage. The mathematical model of the machine written in an appropriate d-q reference frame is established to investigate simulations.

KEYWORDS - DFIG, Active And Reactive Power Stationary Reference frame, Dynamic Model.

I. INTRODUCTION:

Energy is main criteria for human development in any country. Any country that can produce energy in large scale can become a developed country in a short time. Mainly energy sources can be divided into two categories. Renewable energy sources and Non-renewable energy sources. Alternatively energy sources are the energy sources different from those in wide spread use at the moments (which are referred to as conventional). Alternative energy sources include solar, wind, wave, and tidal, hydroelectric and geothermal energy. Although they each have their own drawbacks, none of these energy sources produces significant air pollution, unlike conventional sources.Their energy is only oxygen in air to form carbon dioxide or carbon monoxide and water. Other elements within the fuels are also released into the air after combining with oxygen causing further pollution with SO_2 and nitrogen oxide gasses. In the case of coal, ash particles are also a problem. Non-renewable energy sources that exist in a limited amount on earth. Thus all available material could eventually be completely used up. Coal, Oil and gas are considered as non-renewable energy sources because the rate of their formation is so slow on human time scales that they are using them without being replaced. Generally wind energy is available in abundance. For conversion of this wind energy into electrical energy and induction generator is coupled with a wind mill offers an ideal solution. Wind energy is available in abundance in our environment. When compared with the conventional sources of energy, wind energy is clean, efficient, and sustainable form of energy. When the cost of supplying electricity to remote locations is expensive, wind energy provides a cost effective alternative. So to convert this wind energy into electrical energy, an induction generator will offer an ideal solution.

II. DOUBLY FED INDUCTION GENERATOR:

Wind turbines use a doubly-fed induction generator (DFIG) consisting of a wound rotor induction generator and an AC/DC/AC IGBT-based PWM converter. The stator winding is connected directly to the 50 Hz grid while the rotor is fed at variable frequency through the AC/DC/AC converter. The DFIG technology allows extracting maximum energy from the wind for low wind speeds by optimizing the turbine speed, while minimizing mechanical stresses on the turbine during gusts of wind. The optimum turbine speed producing maximum mechanical energy for a given wind speed is proportional to the wind speed. Another advantage of the DFIG technology is the ability for power electronic converters to generate or absorb reactive power, thus eliminating the need for installing capacitor banks as in the case of squirrel-cage induction generator.

2.1. Operating Principle of DFIG:

The stator is directly connected to the AC mains, whilst the wound rotor is fed from the Power Electronics Converter via slip rings to allow DIFG to operate at a variety of speeds in response to changing wind speed. Indeed, the basic concept is to interpose a frequency converter between the variable frequency induction generator and fixed frequency grid. The DC capacitor linking stator- and rotor-side converters allows the storage of power from induction generator for further generation. To achieve full control of grid current, the DC-link voltage must be boosted to a level higher than the amplitude of grid line-to-line voltageThe slip power can flow in both directions, i.e. to the rotor from the supply and from supply to the rotor and hence the speed of the machine can be controlled from either rotor- or stator-side converter in both super and sub-synchronous speed ranges. At the synchronous speed, slip power is taken from supply to excite the rotor windings and in this case machine behaves as a synchronous machine.The mechanical power and the stator electric power output are computed as follows

Pr=Tm*ωr (1)

Ps=Tem*ωs (2)

For a loss less generator the mechanical equation is

J (dωr/dt) =Tm-Tem (3)

In steady-state at fixed speed for a loss less generator

Tm=Tem and Pm=Ps+Pr (4)

And it follows that:

Pr=Pm-Ps=Tm ωr- Tem*ωs =-S Ps

Where

S= (ωs- ωr)/ ωs is defines as the slip of the generator.

2.2. Back-to-Back AC/DC/AC Converter Modeling:

Mathematical modeling of converter system is realized by using various types of models, which can be broadly divided into two groups: mathematical functional models and Mathematical physical models (either equation-oriented or graphic-oriented, where graphic-oriented approach is actually based on the same differential equations).

III. MATHEMATICAL EPRESENTATION OF DFIG:

An induction motor can be looked on as a transformer with a rotating secondary, where the coupling coefficients between the stator and rotor phases change continuously with the change of rotor position. The machine model can be described by differential equations with time varying mutual inductances, but such a model tends to be very complex, such as vector control, based on the dynamic d-q model of the machine. Therefore to understand vector control principle, a good understanding of d-q model is mandatory.

The transformation equation from a-b-c to this d-q-o reference frame is given by

$f_{qdo}=K_s{*}fabcs$ (5)

$$where,\quad (\mathbf{f}_{qd0s})^T = [f_{qs} \quad f_{ds} \quad f_{0s}],$$
$$(\mathbf{f}_{abcs})^T = [f_{as} \quad f_{bs} \quad f_{cs}],$$
$$\mathbf{K}_s = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos(\theta-\frac{2\pi}{3}) & \cos(\theta+\frac{2\pi}{3}) \\ \sin\theta & \sin(\theta-\frac{2\pi}{3}) & \sin(\theta+\frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix},$$

Where the variable f can be the phase voltages, current, or flux linkages of the machine. The transformation angle θ_r between the q- axis of the reference frame rotating at a speed of w and the a-axis of the stationary stator winding may be expressed as

$$\theta = \int_0^t \omega(t)dt + \theta(0). \quad (6)$$

3.1. qdo Torque Equations:

The sum of the instantaneous input power to all six windings of the stator and rotor is given by:

Pin=Vas Ias + Vbs Ibs+ Vcs Ics + Var Iar+ Vbr Ibr+ Vbr Ibr (7)

Using stator and rotor voltages to substitute for the voltages on the right hand side of (4.8), we obtain three kindsof terms: i^2r, idψ/dt and ωψi.(i^2r) terms are the copper losses. The electromagnetic torque developed by the machine is given by the sum of the (ω.ψi) terms divide by mechanical speed, that is:

Tem=(3/2) (p/2 ωr)[ω(ψds iqs-ψqs ids)+(ω- ωr)(ψdr iqr-ψqr idr)] (8)

Using the flux linkage relationships, Tem can also be expressed as follows:

Tem=(3/2) (p/2 ωr)[ω(ψds iqs-ψqs ids)+(ω- ωr)(ψdr iqr-ψqr idr)] (9)

Using the flux linkage linkage relationships, one can show that

Tem=(3/2) (p/2)[(ψqr idr-ψdr iqr)]

=(3/2) (p/2)[(ψds iqs-ψqs ids)]

=(3/2) (p/2)Lm[(idr iqs- iqr ids)] (10)

One can rearrange the torque equations by inserting the inserting the speed voltage terms given below:

Eqs= ωψds Eds= -ωψqs

Eqr= (ω- ωr)ψdr Edr= -(ω- ωr)ψqr.

3.1.1 Induction Machine Equations In Stationary Reference Frame:

Stator circuit equations**:**

$V_{qs}^s = d/dt\,(\psi_{qs}^s) + r_s\, i_{qs}^s$ (11)

$V_{ds}^s = d/dt\,(\psi_{ds}^s) + r_s\, i_{ds}^s$ (12)

Rotor circuit equations**:**

$V_{qr}^s = d/dt\,(\psi_{qr}^s) + r_r\, i_{qr}^s$ (13)

$V_{dr}^s = d/dt\,(\psi_{dr}^s) + r_r\, i_{dr}^s$ (14)

Flux linkage equations**:**

$\psi_{qs}^s = L_{ls}\, i_{qs}^s + L_m(i_{qs}^s + i_{qr}^s) = (L_{ls}+L_m) i_{qs}^s + L_m\, i_{qr}^s = L_s\, i_{qs}^s + L_m\, i_{qr}^s$ (15)

$\psi_{qr}^s = L_{lr}\, i_{qr}^s + L_m(i_{qs}^s + i_{qr}^s) = (L_{lr}+L_m) i_{qr}^s + L_m\, i_{qs}^s = L_s\, i_{qr}^s + L_m\, i_{qs}^s$

$\psi_{ds}^s = L_{ls}\, i_{ds}^s + L_m(i_{ds}^s + i_{dr}^s) = (L_{ls}+L_m) i_{ds}^s + L_m\, i_{dr}^s = L_s\, i_{ds}^s + L_m\, i_{dr}^s$

$\psi_{dr}^s = L_{lr}\, i_{dr}^s + L_m(i_{ds}^s + i_{dr}^s) = (L_{lr}+L_m) i_{dr}^s + L_m\, i_{ds}^s = L_r\, i_{dr}^s + L_m\, i_{ds}^s$

3.1.2. d-q Torque Equations:

Tem= (3/2) (p/2) [(ψqr idr-ψdr iqr)]

= (3/2) (p/2) [(ψds iqs-ψqs ids)]

= (3/2) (p/2)Lm[(idr iqs- iqr ids)] (16)

IV.SIMULINK IMPLIMENTATION OF DFIG:

Simulink is a software package for modeling, simulating, and analyzing dynamical systems. It supports linear and nonlinear systems, modeled in continuous time, sampled time, or a hybrid of the two. Systems can also be multirate, i.e., have different parts that are sampled or updated at different rates. For modeling, Simulink provides a graphical user interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. With this interface, you can draw the models just as you would with pencil and paper (or as most textbooks depict them). This is a far cry from previous simulation packages that require you to formulate differential equations and difference equations in a language or program. Simulink includes a comprehensive block library of sinks, sources, linear and nonlinear components, and connectors. You can also customize and create your own blocks. For information on creating your own blocks, see the separate Writing S-Functions guide.

4.1. Simulink Implementation Of Mechanical System

The electromagnetic torque developed is

Te=2Hd/dt (ωm) + Bm ωm + Tl (32)

Where Te=Tg and Tshaft=Tl)

By neglecting the torque due to friction (Bm ωm)

Te-Tl=2Hd/dt(ωm) (33)

From above equation, the rotor speed (ωm) is

ωm = (Te-Tl)/ (2Hg) dt

= (0.5/Hg) (Te-Tl) dt (34)

similarly the turbine speed is

ωt = (Tl-Tw)/ (2Hw) dt

= (0.5/Hw) (Tl-Tw) dt (35)

from the above equations, we have

Tl= Km (θm- θt) = Km (ωm- ωt) dt

where θ= ω dt

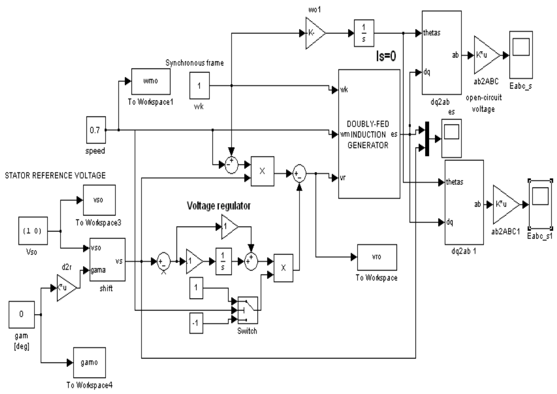

Fig.1: DFIG Open Model (Stator Open Circuited Is=0)

In the open model doubly fed induction generator is runned at a specified speed with the stator disconnected from the grid (Is=0). The rotor is suddenly excited with the slip frequency voltages derived from voltage regulator so as to produce commanded open circuit stator terminal voltage. The specified operating conditions and final values of the variables reached in the steady state are all saved in the workspace to serve as initial conditions in a subsequent simulation.

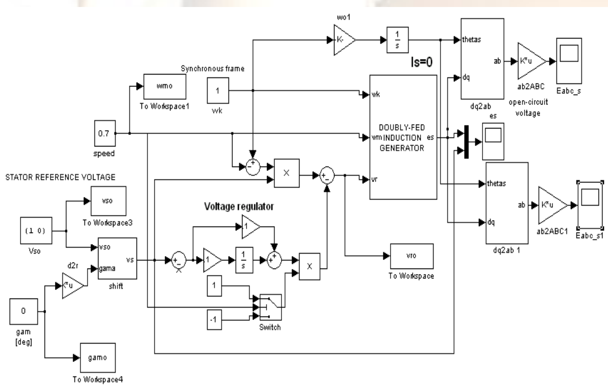

Fig.2: DFIG Open Model (Stator Open Circuited Is=0)

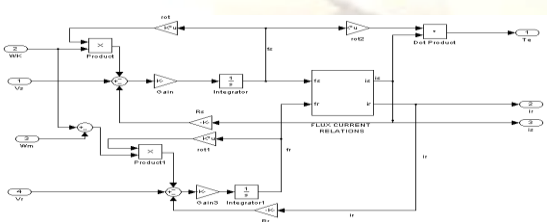

Fig.3: Dynamic Model of Induction Machine in Arbitrary Reference Frame

The rotor-side converter is used to control the wind turbine output power and the voltage measured at the grid terminals. The power is controlled in order to follow a pre-defined power-speed characteristic, named tracking characteristic. This characteristic is illustrated by the ABCD curve superimposed to the mechanical power characteristics of the turbine obtained at different wind speeds.

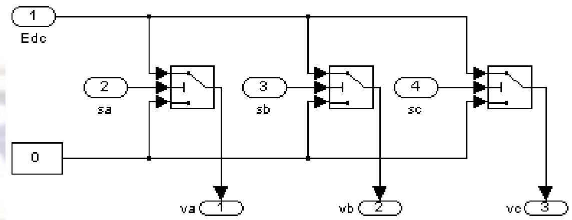

Fig.4: Simulink Diagram for Rotor Side Converter

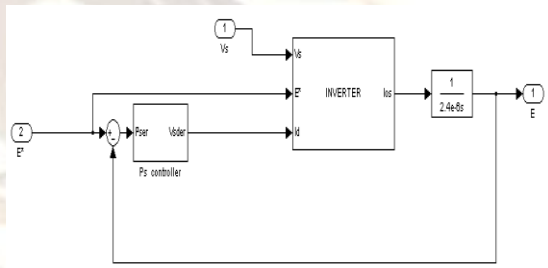

Fig.5: Simulink Diagram for Stator Side Converter

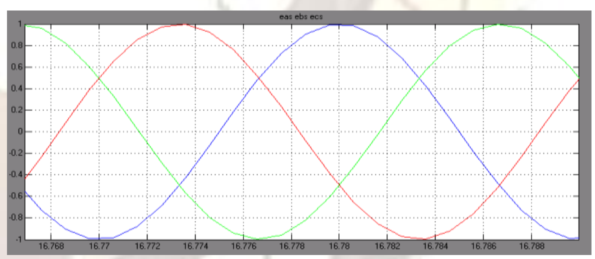

Fig.6: Stator Open Circuit Voltages

The above figure shows three phase open circuit voltages e_a, e_b, e_c which are displaced by 120 electrical degrees apart. Hence from this we can say that power is generated from doubly fed induction generator.

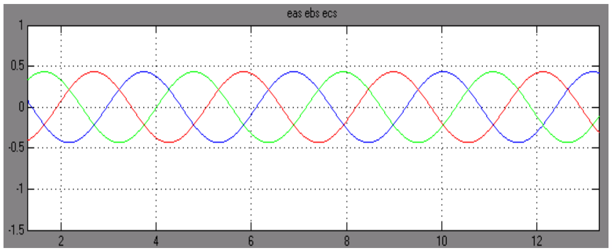

Fig.7: Three Phase Rotor Output Voltage

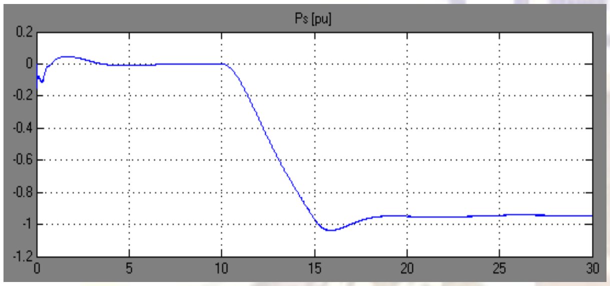

Fig.8: Stator Active Power

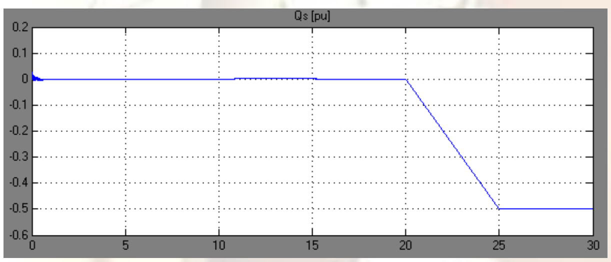

Fig.9: Stator Reactive Power

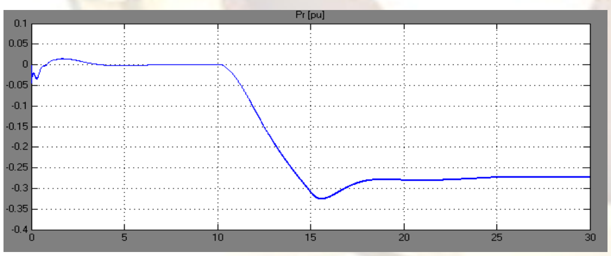

Fig.10: Rotor Active Power

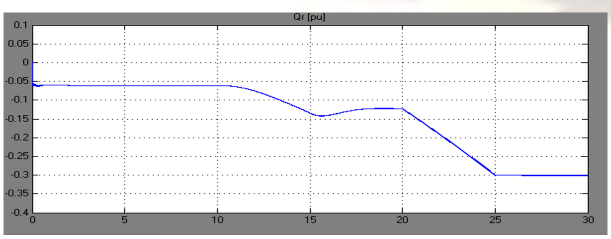

Fig.11: Rotor Reactive Power

The above figures represent simulation results for one reactive power and one active power set values. These figures shows that even though there is a change in Reactive power set value the Active power is not changed i.e., independent control of Active and Reactive power takes place. So we can conclude that Vector Implementation is applied.

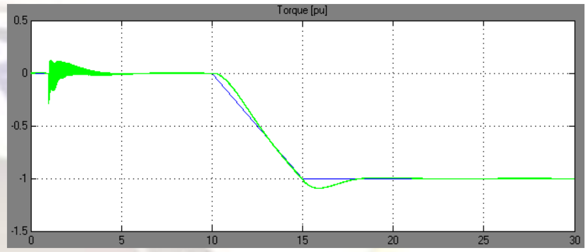

Fig.12: Torque of the Generator

Above figure shows the torque of the generator. From the figure we can say that when we applying negative torque to turbine suddenly, the torque of the rotor decreases rapidly and again come to steady state.

VII. CONCLUSIONS:

In this paper Doubly fed induction generator is modeled in vectorized form in the synchronous frame associated with the stator voltage space vector, and also active power and reactive power is controlled by using PI controllers by injecting the rotor voltage (slip frequency).Even though there is a change in reactive power set value the active power is not changed i.e., independent control of active and reactive power takes place. so we can conclude that the vector implementation is applied.

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IX. AUTHORS:

Nalini Telu is currently doing his Post Graduate course in Power And Industrial Drives in Electrical and Electronics Engineering, department of Dadi Institute Of Engineering And Technology, Anakapalle,Visakhapatnam, Andhrapradesh ,India, Bachelor degree in Electrical and Electronics Engineering from Vitam College Of Engineering, Parvatipuram, Andhra Pradesh, India, in 2005.

K. Veeresham received his master degree in Power Electronics from JNTU Hyderabad, in 2003, Bachelor degree from GITAM College of Engineering, Visakhapatnam, AndhraPradesh, India, in 1997. He is currently doing his PHD in Andhra University, Visakhapatnam,AndhraPradesh, India. And working as an Associate Professor of Electrical and Electronics Engineering department at Dadi Institute Of Engineering and Technology, Anakapalle, Visakhaptnam, Andhra Pradesh, India.

Rohini Telu is currently doing her Post Graduate course in Control Systems in Electrical and Electronics Engineering, department of Anil Neerukonda Institute of Technology and Sciences, Sangivalasa, Bhemunipatnam Mandal, Visakhapatnam dsit., Andhra Pradesh, India, Bachelor degree in Electrical and Electronics Engineering from Pydah College of Engineering and Technology, Boyipalem, Visakhapatnam,Andhra Pradesh, India, in 2010.