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Research Paper

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Analysis, Modelling, and Control of Wind Energy Conversion System

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ABSTRACT *Till date there are number of control schemes applied for the wind energy conversion systems (WECS), in this we propose a new scheme. A mathematical modeling is done and explained with control strategies, also validate with using some sort of software. The new scheme will give better efficiency, pitch control and yaw coordination too. The proposed scheme also provides new ideologies to the researcher to understand optimization methods for the wind energy conversion system using DFIG. To study DFIG mathematical modeling and control strategies also Simulation of Pitch angle control, Wind Turbine Model and DFIG systems.*

KEYWORDS : Doubly-fed induction generator (DFIG), wind energy conversion systems (WECS), wind turbine modeling, Converter, Pitch Actuator System Modeling.

Introduction:

In recent years, the environmental pollution has become a major concern in People daily life and a possible energy crisis has led people to develop new technologies for generating clean and renewable energy. Wind power along with solar energy, hydropower and tidal energy are possible solutions for an environmentally-friendly energy production. The available renewable energy is solar, wind, bio-fuels, fuel cells. Among these renewable energy sources, wind power has the fastest growing speed (approximately 20% annually) in the power industry. Wind energy has lesser cost and more clean as compare to other renewable energy sources. Wind energy is one of the most important and promising of renewable energy all over the world, mainly because it reduces the environment pollution caused by traditional Power plants as well as the dependence on fossil fuel, which have limited reserves. Electric energy, generated by wind power plant is the fastest developing.

In the mid-1990s, variable-speed wind power turbines gave an impulse to the wind power industry. A better turbine control reduces power fluctuations. Moreover, new wind turbine technology integrates power electronics and control making it possible for wind power generation to participate in active and reactive power control. The typical generator configuration for new variable speed turbine is the doubly fed induction generator. This configuration consists of a wound rotor induction generator where the stator windings are directly connected to the grid and the rotor windings connected to a back-to-back. The doubly fed induction generator (DFIG) is used widely and accurately in with the wind turbine to produce electric energy. Since its flexibility the direction and speed of wind may vary from location to location and time to time.

SYSTEM DISCRIPTION AND MODELING

A. Doubly-fed induction generator (DFIG)

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.

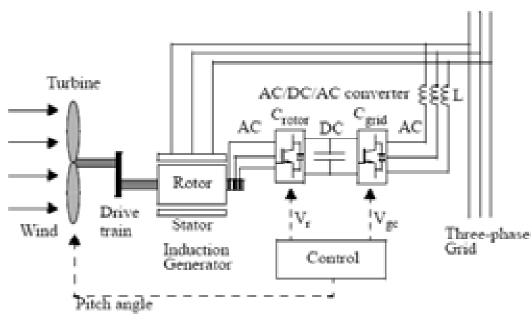

Fig.1 Basic diagram of doubly fed induction generator with converters

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. Where Vr is the rotor voltage and Vgc is grid side voltage. The AC/DC/AC converter is basically a PWM converter which uses sinusoidal PWM technique to reduce the harmonics present in the wind turbine driven DFIG system. Here C rotor is rotor side converter and C grid is grid side converter.

B. Power Flow in 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 as shown in fig 3.2. 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 voltage. The 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. As a result, the machine can be controlled as a generator or a motor in both super and sub-synchronous operating modes realizing four operating modes. Below the synchronous speed in the motoring mode and above the synchronous speed in the generating mode, rotor-side converter operates as a rectifier and stator-side converter as an inverter, where slip power is returned to the stator. Below the synchronous speed in the generating mode and above the synchronous speed in the motoring mode, rotor-side converter operates as an inverter and stator side converter as a rectifier, where slip power is supplied to the rotor.

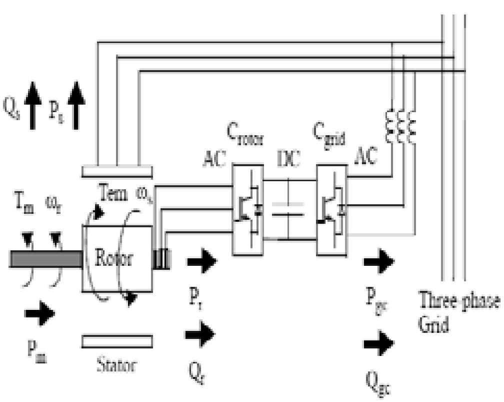

Fig.2 Power flow diagram of DFIG

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.

C. Wind Turbine Model

The output power of a wind turbine generator system is usually given by

$$Pm=0.5\rho*A*Cp*Vw^3.....(01)$$

Where:

- C_p is the coefficient of performance also called power Coefficient
- A is the swept area by the turbine' blades (m^2)
- ρ is the air density (kg/m^3)
- V_w is the wind speed (m/s)

The coefficient Cp is not a constant. It actually depends on two basic parameters namely: tip speed ratio, λ and blade pitch angle β (deg) . With this consideration, equation 1 can be rewritten as

$$Pm=0.5\,\pi*\rho R2Cp\,(\lambda,\beta)\,Vw^3....(02)$$

The tip speed ratio λ is defined as the ratio of the angular rotor speed of the wind turbine to the linear wind speed at the tip of the blades and can be expressed as follow

$$\lambda=\omega rR/Vw$$

Where ω_r is the mechanical angular velocity of the turbine rotor in rad/s and V_w is the wind speed in m/s. The rotational speed n (r/min) and angular velocity ω_r are related by equation

$$\omega r=2\pi n/60$$

According to the driving torque around the rotor shaft can be given by the equation

With C_T the torque coefficient given by

$$CT=CP/\lambda$$

```
n=800;   % n rotational speed m/s
r=1;
Vw= [10:0.001:100];
Beta= [0 4 8 12 16];% beta is the pitch angle
Ro=1;
%End Inputs
For k=1:5
Wr=2*pi*n/60;
Lambda= r*wr. /vw;  % lambda is the tip ratio
% Calculation of lambda_k
lambda_k=1./((1./(lambda+0.02*beta(k)))-
(0.03/((beta(k))^3+1)));
% Calculation of power coefficient
cpcp=0.73*(151./lambda_k-0.58*beta(k)-
0.02*(beta (k))^2.14-13.2).*exp(-18.4./lambda_k);
% Calculation of power
p=0.5*pi*ro*r^2.*cp.*vw.^3;
```

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% Result

Figure (1)

plot (vw,p), grid on, hold on,

Figure (2)

Plot (lambda, cp), grid on, hold on,

End

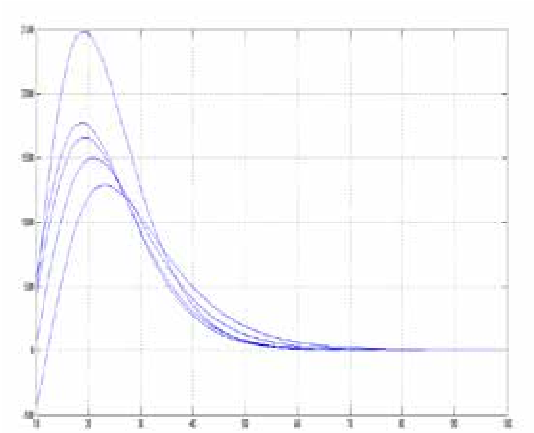

Fig.3. Plot the Turbine's output power versus wind speed for varying pitch angles.

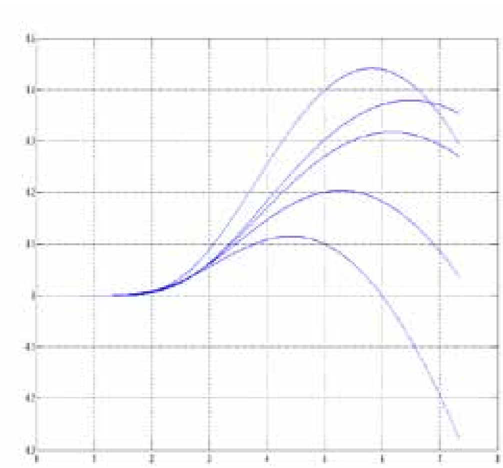

Fig.4. Plot the Power coefficient of the Turbine versus tip ratio for varying pitch angles.

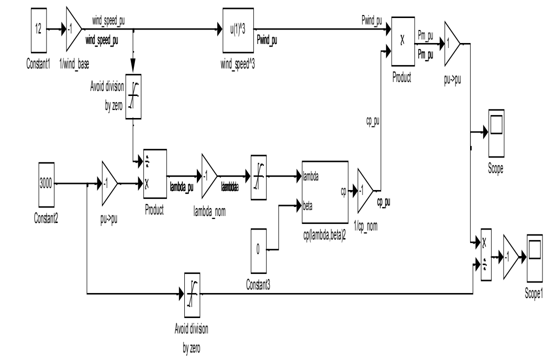

Fig.5. Wind Turbine Model

Doubly-fed induction generator (DFIG) Mode:

In Fig. 6 an equivalent circuit of the DFIG system can be seen. As mentioned earlier, the system consists of a DFIG and a back-to-back voltage source converter with a dc link. The back-to-back converter consists of a grid-side converter (GSC) and a machine-side converter (MSC).

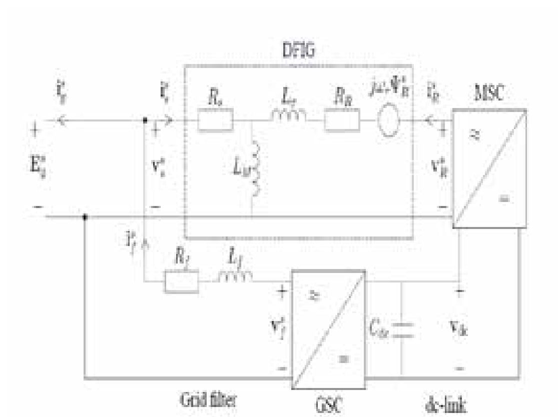

Fig.6. Equivalent Circuit of the DFIG System..

The equations describing the induction machine in a reference form are:

Stator Voltage Equations:

$$V_{qs} = r_s i_{qs} + \omega\varphi_{ds} + p\varphi_{qs}$$

$$V_{ds} = r_s i_{ds} - \frac{\omega}{\omega_b}F_{qs} + \frac{p}{\omega_b}F_{ds}$$

Rotor Voltage Equations:

$$V'_{qr} = r'_r i'_{qr} + (\omega - \omega_r)\varphi'_{dr} + p\varphi'_{qr}$$

$$V'_{dr} = r'_r i'_{dr} - (\omega - \omega_r)\varphi'_{qr} + p\varphi'_{dr}$$

Power Equations:

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

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

Torque Equation:

$$T_s = -3P/4(\varphi_{ds}i_{qs} - \varphi_{qs}i_{ds})$$

Stator Flux Equations:

$$\varphi_{qs} = L_{ls}i_{qs} + L_M(i_{qs} + i'_{qr})$$

$$\varphi_{ds} = L_{ls}i_{ds} + L_M(i_{ds} + i'_{dr})$$

Rotor Flux Equations:

$$\varphi'_{qr} = L'_{lr}i'_{qr} + L_M(i_{qs} + i'_{qr})$$

$$\varphi'_{dr} = L'_{lr}i'_{dr} + L_M(i_{qs} + i'_{qr})$$

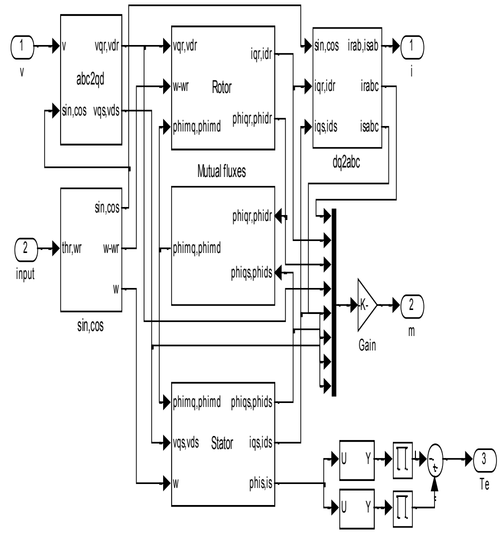

Fig.7. Electrical Model.

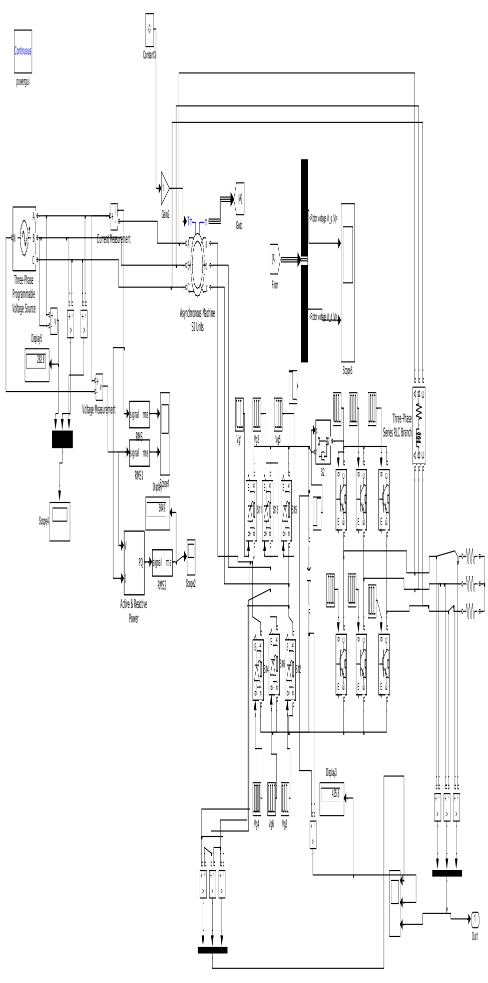

Fig.7. DFIG Model.

Results of DFIG Model:

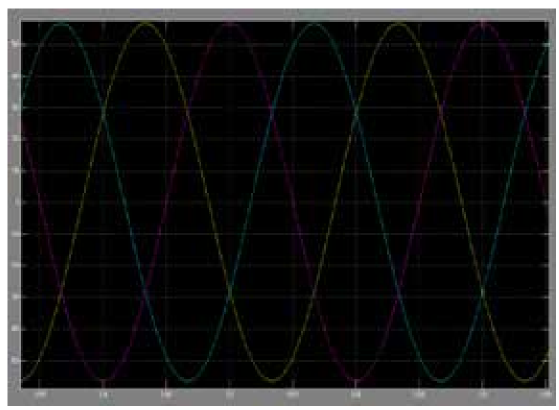

Fig.8. Supply Voltage

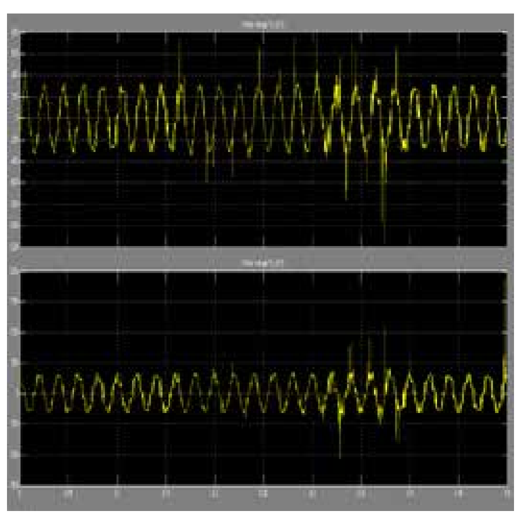

Fig.9. Rotor voltage Vr_q (V), Rotor voltage Vr_d (V)

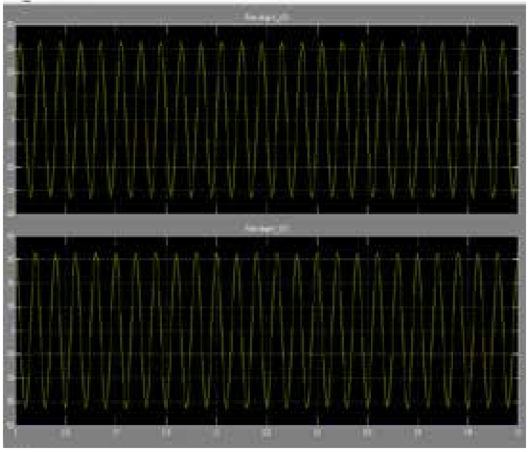

Fig.10. Stator voltage Vr_q (V), Stator voltage Vr_d (V)

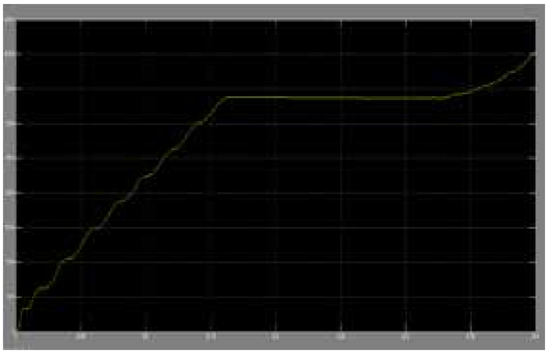

Fig.11. Rotor Speed

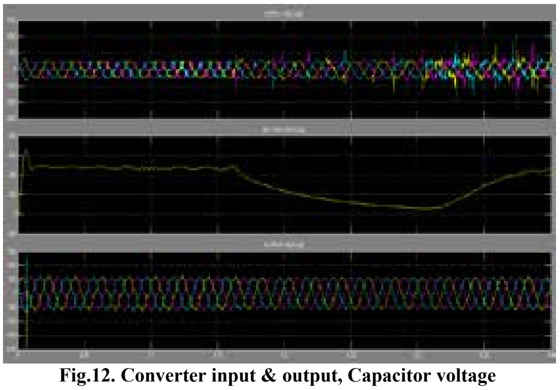

Fig.12. Converter input & output, Capacitor voltage

CONCLUSION:

The theory of wind turbine was analyzed in detail leading to the modeling in the synchronous frame of reference employing a doubly fed induction generator. DFIG modeling was done and equations were simulated in MATLAB simulink. Also we have discussed here the basic operation of DFIG and its controls using AC/DC/AC converter. A complete model of AC/DC/AC converter in MATLAB sumulink. We have discussed here the Wind Turbine Model is developed in MATLAB sumulink.

APPENDIX

The machine and controller parameters that have been used During the simulations are given below.

Sr.No	Parameter	Value
01	Voltage	415V
02	Frequency	50Hz
03	Stator Resistance and Inductance	0.087Ω,0.8e-3H
04	Rotor Resistance and Inductance	0.2287Ω,0.8e-3H
05	Mutual inductance	34.7e-3H
06	Rotor Speed	< 3000rpm
07	Wind Speed	12 m/s
08	Active Power	1943W(02MW)
09	pole pairs	02

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