Adaptive Torque Control of Low Power Horizontal Axis Wind Turbine using Matlab-Simulink

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Abstract : *The proposed model was build with an aim to maintain constant output torque at a set-point irrespective of varying Wind speed. First a Wind turbine emulator for a Low Power Horizontal Axis Wind turbine using DC Motor was build in Matlab /Simulink then the strategy control was achieved by using Pitch angle control technique which comprises of an Integral controller and a switch .The output torque of the Wind turbine was fed to DC motor whose armature current was controlled by using a PI Controller.The Simulated result demonstrated a constant DC motor speed, armaturé Current ,armature Voltage at all permissible wind speed of the wind turbine. The developed system can be used to build a Wind Power Generation System.*

Keywords: *DC motor, PI Controller, pitch angle control ,wind turbine , wind turbine emulation*

I.   Introduction

Control Algorithm design for renewable energy production is a topic of great concern nowadays because of all efforts around the mitigation of greenhouse effects. Many countries have modified their energy production plans for the near future by advancing Green Energy technologies via Government funding and tax reductions [10] .In India after the Introduction of 2003 Electricity Act, the wind sector has registered a compound annual growth rate of about 29.5% [3].

Currently the India's Installed capacity up to 31st January 2014 due to renewable energy sources grid – Interactive power production was 30177.90 MW out of which Wind Power Grid Interactive generation comprises of 20298.83 MW thus contributing 67% of the net production [1].

There are many different types of wind turbines in use around the world, used in diverse applications from powering small water pumps on remote ranches to producing bulk electric power for modern cities. Capacity ratings vary from less than one kilowatt up to several megawatts. There are two principal turbine architectures: horizontal axis and vertical axis. Horizontal axis wind turbines (HAWT), which have an axis of rotation that is parallel with the wind direction, are the most common. The much less common vertical axis wind turbine (VAWT) spins like a top with an axis of rotation perpendicular to the wind. HAWTs have been shown to be more cost effective than VAWTs because the ability to place the HAWT rotor on a very tall tower allows the turbine to operate in a better wind resource due to vertical wind shear. In contrast, VAWTs are constrained to operate with one end of the rotor attached to the generator on the ground. Modern HAWTs typically have two or three blades and can be either upwind [14]

The wind speed is difficult to reproduce on a site .So the solution is a Wind turbine Simulator. Wind Turbine Simulator ,is an important equipment for the development of converting wind energy systems[5].

Wind turbine Simulators provides a controlled test environment without reliance on natural wind resources ,for the purpose of research and design into wind turbine drive trains ,especially energy conversion systems. Wind turbine simulators can significantly improve the effectiveness and efficiency of research and design in wind energy conversion systems. The simulator can be used for research applications to drive an electrical generator in a similar way as a wind turbine, by reproducing the torque developed by a wind turbine for a given wind velocity. [15].

Usually Induction Motor, separately excited DC motor can be used to reproduce the static and dynamic characteristics of real wind turbines [9].The proposed model Emulation of wind turbine is achieved by using DC motor.

[13] carried out Laboratory Experiment to Emulate a low power Wind Turbine with a DC motor using Matlab-Simulink Similarly [6] built an experimental setup for Modeling and Simulation of Wind turbine Emulator using Induction motor driven by Torque control Inverter .In their study they choose the value of beta pitch angle to be unvarying or constant zero degree further they presumed the wind speed to be constant.

Since the natural wind poses dynamic characteristic and its speed keeps on varying at every instance[11], therefore, to achieve a constant wind turbine output torque and an unvarying DC motor rotor

speed, voltage ,current .The varying speed characteristic of wind needs to be taken under consideration hence the above system needs to be redeveloped and modified.

II. Wind Turbine Modelling

According to aerodynamic characteristics of Wind turbine, the output mechanical power is given by:

$$P_m = \frac{1}{2} C_p(\lambda, \beta) \pi \rho R_t^2 V_s$$
(1)

Where, ρ is the Air density, R_t is the Wind turbine blade radius, V_s Wind velocity in m/s and C_p is the Power coefficient ,it's the function of the Tip speed ratio λ and blade pitch and pitch angle. The model of the Wind turbine presented in this paper corresponds to the horizontal lift based designs.

The equations that represent the static behavior of the wind turbine are included below (2) defines the ratio of the angular speed of the blade tip and shaft rotating speed

$$\lambda = \frac{W_m \, r_r}{V_s}$$
(2)

where r_r is the rotor radius in meters, W_m is the angular speed in the low speed shaft in rad /s , V_s is the wind velocity in m/s.

The power extracted from the wind is limited by the aerodynamic design. The Power Curve of a turbine is defined by Eq (3) where C_p is the power coefficient and β the Pitch angle of the wind turbine. C_1, C_2, C_3, C_4, C_5 and C_6 are power coefficient and depend on each wind turbine design.

$$C_p(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3 \beta - C_4 \right) e^{-\frac{C_5}{\lambda i}} + C_6 \lambda$$
(3)

where

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3}$$
(4)

The parameters for a modern horizontal lift based turbine are $C_1 = 0.5176$, $C_2 = 116, C_3 = 0.4, C_4 = 5, C_5 = 21$ and $C_6 = 0.0068$ .These designs are given for a Three -bladed Wind turbine model used in this system.

The Torque coefficient is defined in (5) and is necessary to determine the mechanical torque T_m of the wind turbine given in (6)

$$C_m = \frac{C_p(\lambda, \beta)}{\lambda}$$
(5)

$$T_m = \frac{1}{2} C_m \pi \rho R_t^3$$
(6)

where the value ρ air density is chosen to be 1.293 Kg/ m^3, the value R_t wind turbine blade radius is taken to be 1.23 m .

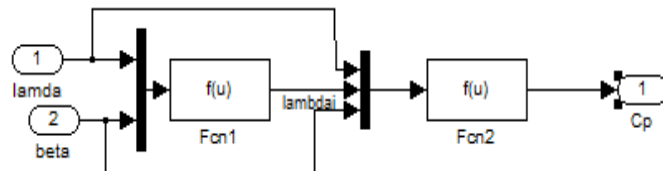**Fig:1 Internal Process of Subsystem**

$$F_{cn1} = \lambda_i = \frac{1}{\frac{1}{(u[1] + 0.08*U[2])} - \frac{0.035}{U[2]^3 + 1}}$$
(7)

$$F_{cn2} = C_p(\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3 \beta - C_4 \right) e^{-\frac{C_5}{\lambda i}} + C_6 \lambda$$
(8)

The wind turbine model is developed with aim to receive a fixed output torque despite having varying wind velocity. To achieve this Pitch angle control of wind turbine, the β is changed constantly for this a switch and an Integral Controller is used. .

A torque set-point is used to compare the output mechanical torque produced by the wind turbine, if there is any difference an error signal is generated and passed to the controller.

$$e\,(t) = T_{ed}(t) - \; T_m\,(t) \tag{9}$$

where T_{ed} is Torque set-point of the wind turbine and T_m is the output mechanical torque.

The pitch angle is varied . Thus, a constant torque is observed at the wind turbine side. This mechanical torque is fed as input torque of DC Motor.

Table: 1   Wind Turbine Specifications:

Cut –in Wind Speed	3.0 m/s
Cut – out Wind Speed	20 m /s
Rated Wind Speed	11.8 m/s
Number of Blades	3
Diameter	2.46 m
Swept area	4.75 m^2
Blade length	1.23 m
Air density	1.29 /s

III.   Dc Motor Modelling

When a separately excited dc motor is excited by a field current of I_f and an armature current of I_a flowing in the circuit, the motor develops a back EMF and a torque to balance the load torque at a particular speed. The field current I_f is independent of the armature current I_a. Each winding is supplied separately. Any change in the armature current has no effect on the field current. The I_f is generally much less than the I_a.
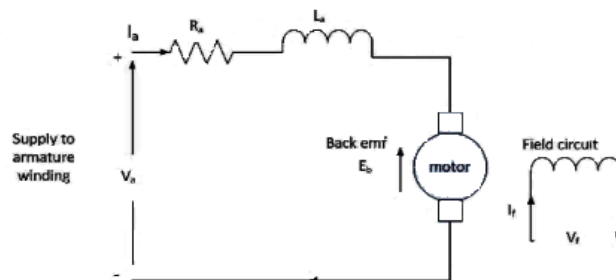
Fig:2 Circuit Diagram of Separately excited DC Motor

In above figure, suppose V_a is the armature voltage in volt, I_a is the armature current in ampere, E_g is the motor back emf in volt, L_a is the armature inductance and Henry R_a is the armature resistance in ohm.

The armature equation is shown below:

$$V_a = E_g \; + \; I_a \; R_a \; + \; L_a \frac{dI_a}{dt} \tag{10}$$

Now the torque equation is will be given by :

$$T_d = T_l + \; B_w + \; J\frac{dw}{dt} \tag{11}$$

Where T_l is load Torque in Nm , T_d is the torque developed in Nm, J is moment of inertia in Kg/m^2 ,B is friction coefficient of the motor and ω is angular velocity in rad/ sec.
Assuming absence (negligible) of friction in rotor of motor, it will yield B = 0 .Therefore, new torque equation will be given by :

$$T_d = T_l + J\frac{dw}{dt} \qquad (12)$$

Equation for back emf of motor will be :

$$E_g = K\emptyset\, W \qquad (13)$$

Also, $T_d = K\emptyset I_a \qquad (14)$

$$w = \frac{(V_a - I_a\, R_a)}{K\emptyset} \qquad (15)$$

from above equation it is clear that speed of DC motor depends on applied voltage ,armature current, armature resistance and field flux.

In the proposed model constant speed of DC motor is obtained by controlling the armature current of the DC motor. A Proportional –Integral (PI) Control is a special case of the classic controller family known as proportional –Integral –derivative (PID).

The major feature of the PI Controller is its ability to maintain zero steady state error to a step change in reference.For the designed PI Controller for 1 MW Horizontal axis wind turbine error signal was selected as :

$$e\,(t) = W_{ref}(t) - W_{ed}(t)$$

where W_{ref} is Speed value set as reference of the DC Motor and W_{ref} is the output rotor speed of the DC Motor.

The generated error signal is fed to speed controller i.e. the PI Controller the proportional term does the job of fast correction and the integral term takes finite time to act and make the steady state error zero .

IV.   Simulation Results

Each cycle of simulation consists of five input of Varying wind speed. Results of four such cycle has been presented . The Varying speed of wind ranges from the wind turbine "rated wind-speed " up to the "cut – out wind speed ".
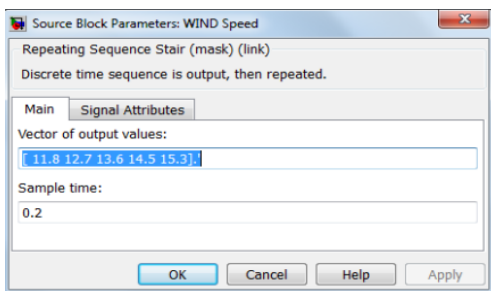

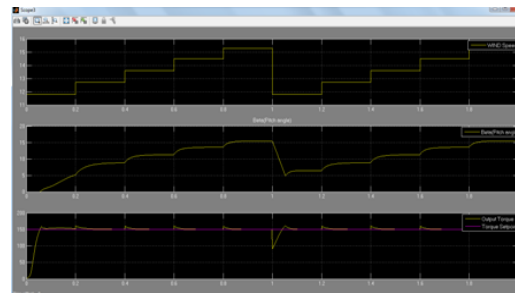**Fig: 3Varying Wind Speed -11.8 12.7 13.6 14.5 15.3**

Fig:4 Wind Turbine Model output - Wind Speed , Pitch Angle ,Output Torque Vs Torque Set-Point for wind speed 11.8 12.7 13.6 14.5 15.3
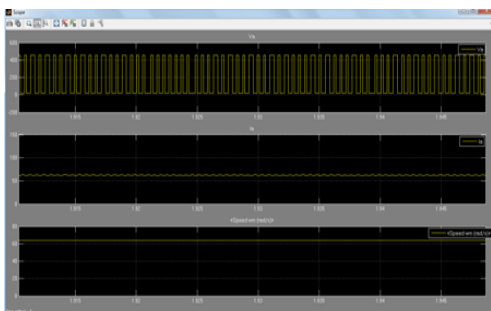

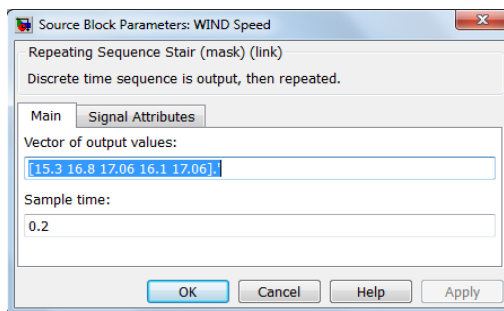**Fig: 5 DC Motor Model output - Armature Voltage ,**

Fig : 6 Varying Wind Speed -15.3 16.8 17.06 16.1 17.06 Armature Current ,Motor Speed wind speed 11.8 12.7 13.6 14.5 15.3
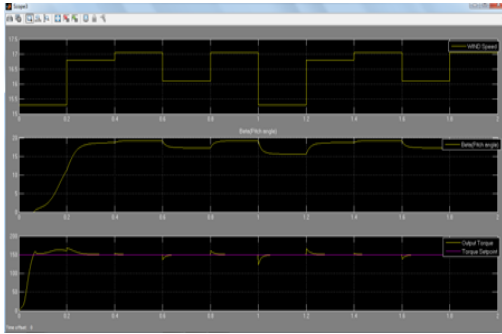
Fig: 7 Wind Turbine Model output - Wind Speed , ,Pitch Angle Output Torque Vs Torque set-point For wind speed 15.3 16.8 17.06 16.1 17.06
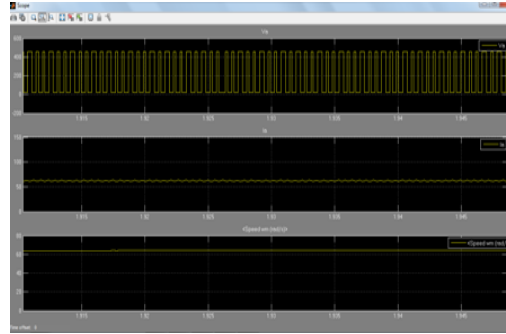

Fig :8 DC Motor Model output - Armature Voltage Armature Current ,Motor Speed for wind speed 15.3 16.8 17.06 16.1 17.06
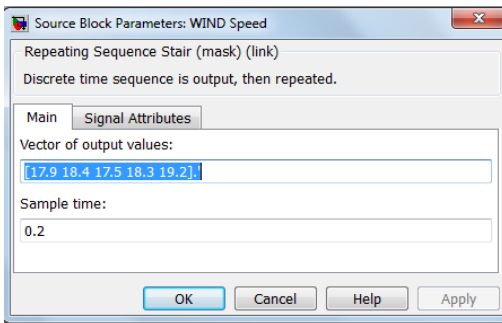

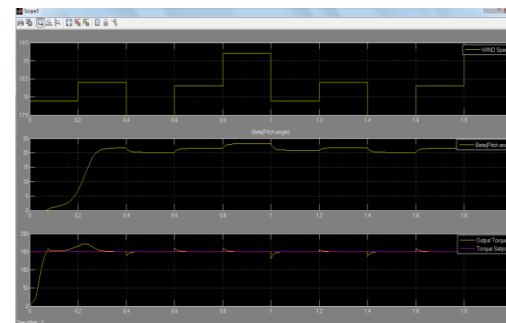**Fig :9 Varying Wind Speed – 17.9 18.4 17.5 18.3 19.2**

Fig :10 Wind Turbine Model output - Wind Speed Pitch Angle ,Output Torque Vs Torque Set-Point for wind speed 17.9 18.4 17.5 18.3 19.2
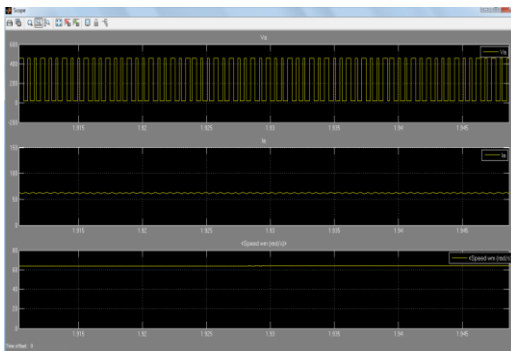

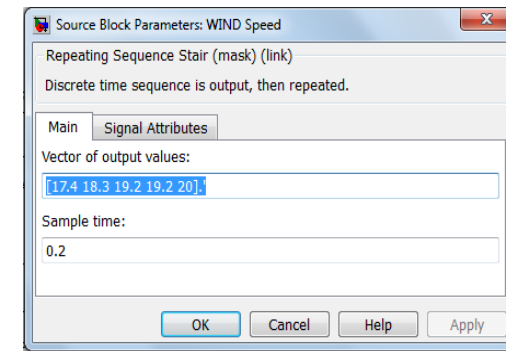**Fig :11 DC Motor Model output – Armature Voltage Armature Current , Motor Speed for wind speed 17.9 18.4 17.5 18.3 19.20**

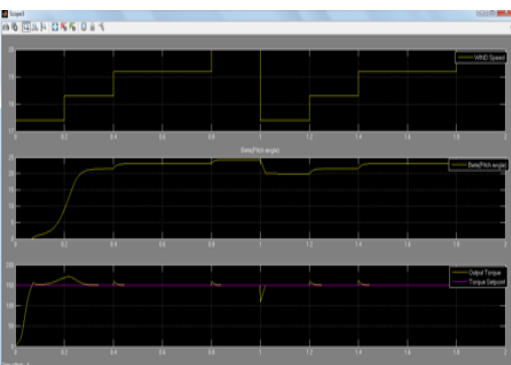**Fig :12 Varying Wind Speed -17.4 18.3 19.2 19.2 20**

Fig :13 Wind Turbine Model output - Wind Speed , ,Pitch Angle ,Output Torque Vs Torque Set-Point 17.4 18.3 19.2 19.2 20
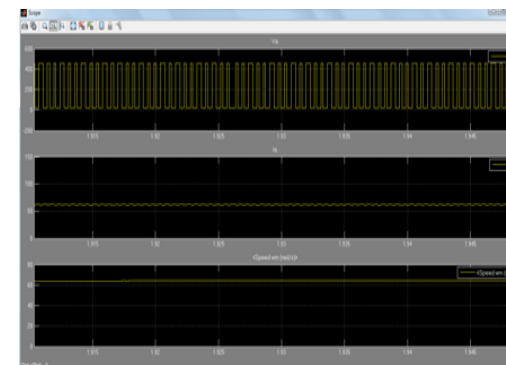

Fig :14 DC Motor Model output - Armature Voltage Armature Current ,Motor Speed for wind speed 17.4 18.3 19.2 19.2 20

V.   Conclusion

The simulation Tests carried on varying wind speeds demonstrated the effectiveness of the Technique used as a constant wind turbine Output Torque was obtained as aganist a torque set-point and the values of DC motor Speed, Armature Current ,Armature Voltage remained constant and showed no fluctuations at all permissible speed of the Wind. The above developed system can be used to build a Wind Power Generation System.

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