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Emulation of a Low Power Wind Turbine using DC Motor mechanically coupled to Synchronous Generator in Matlab- Simulink

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Abstract –

Wind poses dynamic characteristic and its speed changes constantly which affects the power generation through a Wind turbine continuously. To get a solution to this problem initially a Wind turbine Emulator for Wind Energy conversion system using a Separate Excited DC motor was built then it was mechanically coupled to the Synchronous Generator. The strategy control was implemented in simulation using Matlab/Simulink. The developed model provides a constant output torque despite the varying wind speed which ranges from the wind turbine "rated wind speed" up to the "cut-out wind speed" .It was achieved by maintaining the torque of the wind turbine to the set-point 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 which rotates with a speed set as reference. Each cycle of simulation consisted of five input of varying wind speed .A constant output torque was obtained as against the torque set-point. The simulated results demonstrated the effectiveness as no fluctuations in speed of generator was observed. Thus, the load voltage and frequency remained constant at all permissible speed of the wind.

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

I. INTRODUCTION

Development and Utilization of Wind Energy has become an important part of World Sustainable Energy Development Strategy. Wind power generation is the most important form of development and utilization of wind energy [2]. Wind Energy, an emission free renewable source of energy is becoming a very attractive alternative to volatile fossil fuels. Currently it generates less than 1% of the world's electricity today, however the stable technological growth of wind power suggests that it could become an indispensible energy source for many nations in the next decade [11] .The Installed capacity as on 31st January, 2014 from renewable energy sources Grid-Interactive power is 30,177.90 MW out of which Wind Power grid Interactive Generation comprises of 20298.83 MW thus comprising of 67% [1].

Wind Turbine Simulators (WTS) are important equipment for developing wind energy conversion systems and are used to simulate wind turbine behavior in a controlled 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. Also, it can be used as an educational tool to teach the behavior, operation and control of a wind turbine. Usually Induction Motor, separately excited DC motor can be used to reproduce the static and dynamic characteristics of real wind turbines [9].

[14] 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.

If one aim's to develop a wind power generation system with help of above developed models, then the new model based on emulating the low power wind turbine using DC motor mechanically coupling it with synchronous generator. Since the natural wind poses dynamic characteristic and its speed keeps on varying at every instance[12], therefore, to achieve an unvarying Voltage and constant frequency at the Synchronous generator output side ,the varying speed characteristic of wind needs to be taken under consideration hence the above system needs to be redeveloped and modified.

II. DC MOTOR MODEL

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.

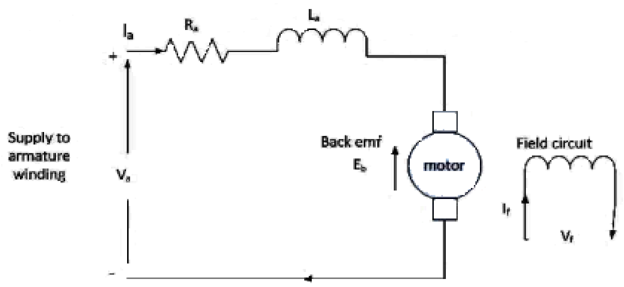

Figure : 1 Circuit Diagram of Separately excited DC Motor

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:

$$V_a = E_g + I_a R_a + L_a \frac{dI_a}{dt} \quad (1)$$

Now the torque equation is will be given by :

$$T_d = T_l + B_w + J\frac{dw}{dt} \quad (2)$$

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 :

$$T_d = T_l + J\frac{dw}{dt} \quad (3)$$

Equation for back emf of motor will be :

$$E_g = K\emptyset W \quad (4)$$

Also, $$T_d = K\emptyset I_a \quad (5)$$

$$w = \frac{(V_a - I_a R_a)}{K\emptyset} \quad (6)$$

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. The generated wind turbine torque is fed as the electromagnetic torque of DC motor. The output speed W_m of the DC motor is compared with the reference speed W_{ref} and the 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 .

II. WIND TURBINE MODEL

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

$$P_m = \frac{1}{2} C_p(\lambda, \beta)\pi\rho R_t^2 V_s$$
(7)

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

$$\lambda = \frac{W_m \ r_r}{V_s} \quad (8)$$

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.

$$C_p\ (\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right) e^{-\frac{C_5}{\lambda i}} + C_6\lambda \quad (9)$$

where

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3} \quad (10)$$

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)

$$C_m = \frac{C_p\ (\lambda, \beta)}{\lambda} \quad (11)$$

$$T_m = \frac{1}{2} C_m \pi \rho\ R_t^3 \quad (12)$$

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 .

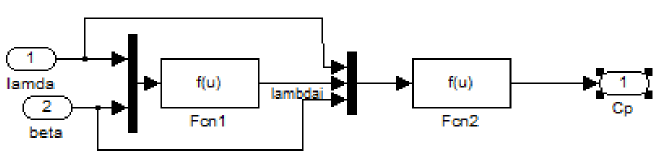

Figure 2: Internal Process of Subsystem

where

$$F_{cn1} = \lambda_i = \frac{1}{\frac{1}{(u[1] + 0.08 * U[2])} - \frac{0.035}{U[2]^3 + 1}} \quad (13)$$

$$F_{cn2} = C_p\ (\lambda, \beta) = C_1 \left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right) e^{-\frac{C_5}{\lambda i}} + C_6\ \lambda \quad (14)$$

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.

$$e\ (t) = T_{ed}(t) - T_m\ (t) \quad (15)$$

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 m/s

IV. GENERATOR MODEL

After emulation of wind turbine using DC Motor was achieved it was further coupled to Synchronous Generator to form a Wind Power generation system. The Generator Model was selected from the available models from Simulink Library.

V. SIMULATION RESULTS

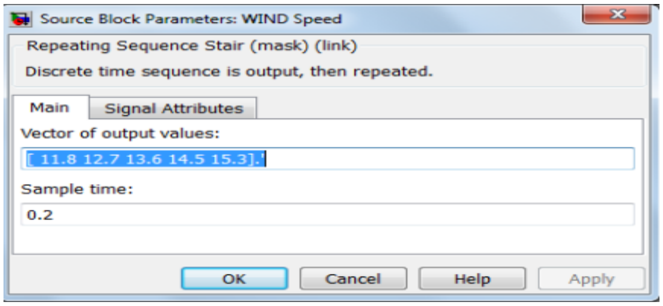

Fig : 3 Varying Wind Speed -11.8 12.7 13.6 14.5 15.3

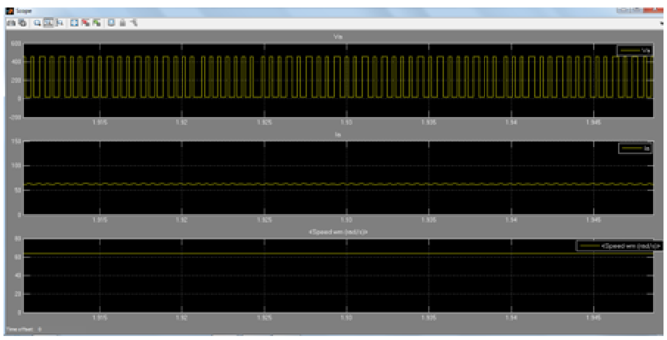

Fig : 4 DC Motor Model output - Armature Voltage , Armature Current ,Motor Speed for wind speed 11.8 12.7 13.6 14.5 15.3

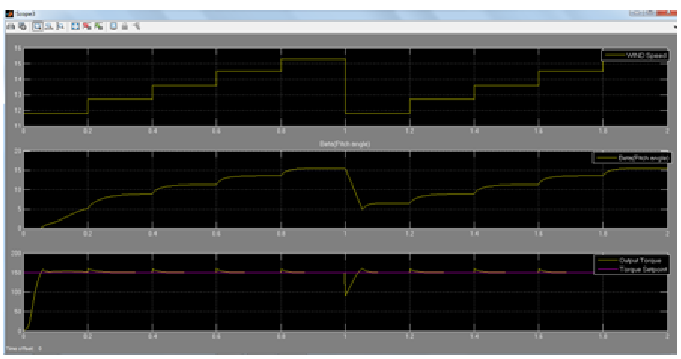

Fig : 5 Wind Turbine Model output - Wind Speed , Pitch Angle ,Output Torque Vs Torque Set-Point for wind speed 11.8 12.7 13.6 14.5 15.3

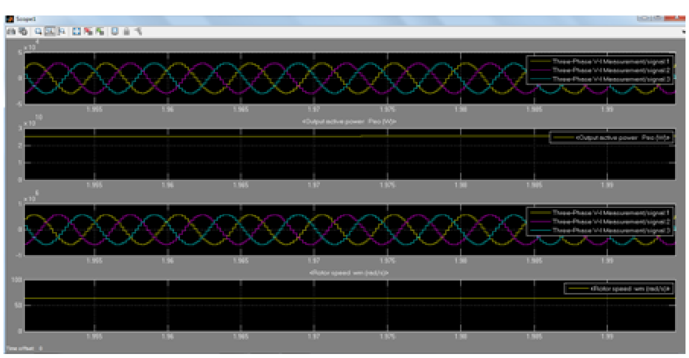

Fig : 6 Synchronous Generator output Voltage , Active power, Current,Rotor Speed for wind speed 11.8 12.7 13.6 14.5 15.3

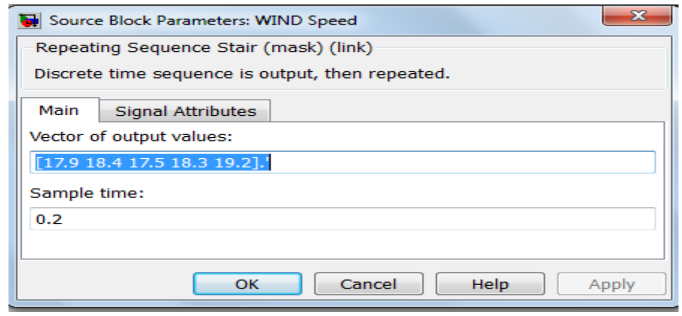

Fig 9: Varying Wind Speed – 17.9 18.4 17.5 18.3 19.2

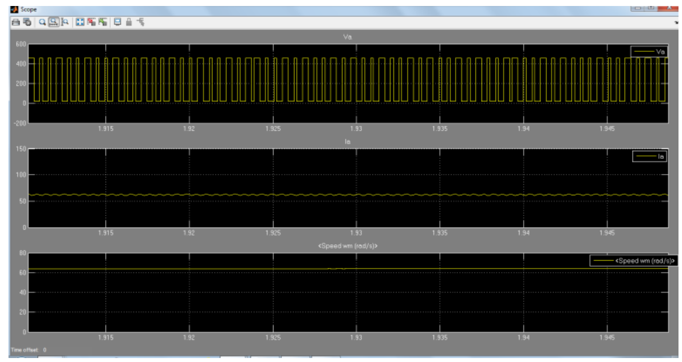

Fig 10 : DC Motor Model output – Armature Voltage , Armature Current , Motor Speed for wind speed 17.9 18.4 17.5 18.3 19.2

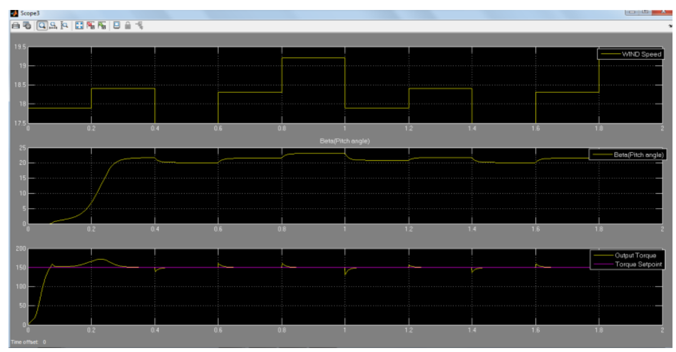

Fig :11 Wind Turbine Model output - Wind Speed , Pitch Angle ,Output Torque Vs Torque Set-Point for wind speed 17.9 18.4 17.5 18.3 19.2

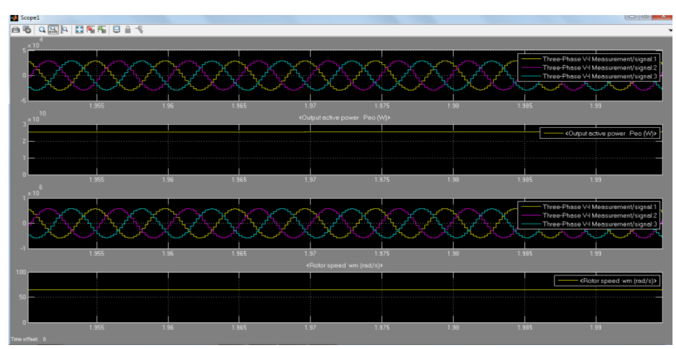

Fig:12 Synchronous Generator output Voltage , Active power, ,Current ,Rotor Speed for wind speed 17.9 18.4 17.5 18.3 19.2

VI. CONCLUSION

The simulation Tests carried on emulation of a low power wind turbine using DC motor mechanically coupled to synchronous generator showed positive results in power production , rotor speed, voltage and current output .The simulated results demonstrated the effectiveness of the technique as no fluctuations in speed of generator was observed. Thus, the load voltage and frequency remained constant at all permissible speed of the wind.

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