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Design & Simulation of 6kW Wind Turbine

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Abstract: In these ever-changing times, the use of conventional energy resources is being questioned because of the effects they cause on the environment, and newer methods to produce or generate energy from natural resources are being taken into consideration. Such natural resources are termed renewable energy sources or RES. These RES mainly include wind, solar, hydro, and thermal resources. In this paper, a MATLAB/Simulink model for harnessing the energy from the wind with the help of a wind turbine is discussed. The design and simulation of this wind turbine will be discussed further in the paper and the rated power of this wind turbine is 6kW.

Keywords: Pitch Angle Control, Drive Train, Wind Turbine Matlab, Simulink, Simscape

I. INTRODUCTION

The demand for wind energy generation has been increasing and is becoming a full industry with wind energy conversation systems (WECS). The basic science of WECS is simple, the wind is used to rotate the blades in a wind turbine, and the kinetic energy generated is converted into electricity by joining it to a generator. The energy generated either is sent through the grid or stored in a battery for personal use. In India, 37.5GW of the capacity of wind turbines are installed. It currently accounts for about 10% of India's total electricity capacity. The top five wind energy generation farms are situated at Muppandal Wind Farm (1500MW), Jaisalmer Wind Park (1064MW), Brahmanvel Wind Farm (528MW), Dhalgon Wind Farm (278MW), and Vankusawade Wind Park (259MW). A wind turbine can be VAWT and HAWT and in this paper, the design and simulation for a HAWT are discussed. A 6KW wind power generator is generally considered a small-scale wind turbine and in this paper, the design and simulation for it are going to be shown and discussed along with the various steps that were taken into consideration in order to achieve the desired output power.

II. AIRFOIL

An airfoil is the foundation of wind turbine blade design, it is the cross-section of a blade in a wind turbine, or a blade used in helicopters or a wing of an airplane and accordingly, we can change the design of the airfoil which can give us better performance and efficiency. An airfoil plays a major role in the input efficiency of the wind turbine. An airfoil with a suitable design in accordance with the setup used can help achieve a better input efficiency because then the swept area by the air will increase and the lift and drag forces acting on it will help rotate it much better thereby increasing the input efficiency of the mechanical input that is given to the generator via the rotatory shaft. The software that is used to design blades or the airfoil of the blade is Q-blade. This software provides various simulation and designing tools that hold predefined values and data about the various types of airfoil structures that have been used commercially to this date. It also has an inbuilt Cl/Cd or a Cp calculator that can be used to find out the lift and drag ratio of that specific blade or airfoil. The desired blade can also be designed by giving input parameters and a graphical representation can be obtained as well and from there, various blades and their airfoil design can be compared and the one which gives the best results can be selected. The airfoil here taken into consideration is the NACA 2414 and its properties are discussed below.



Fig -1: NACA 2414 Airfoil Design

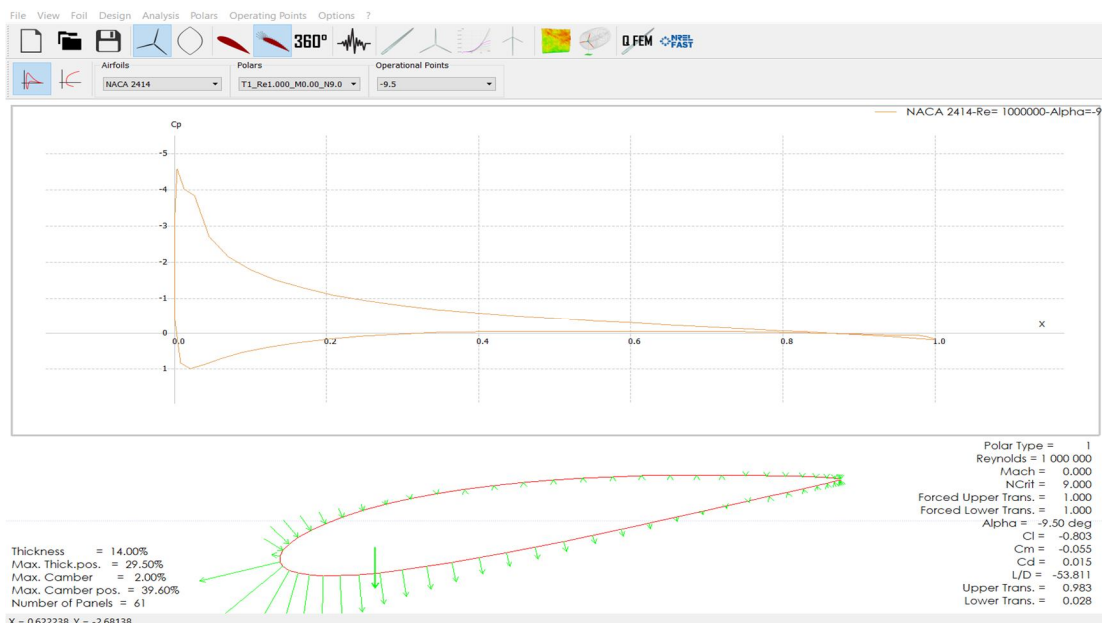


Fig -2: $C_p=Cl/Cd$

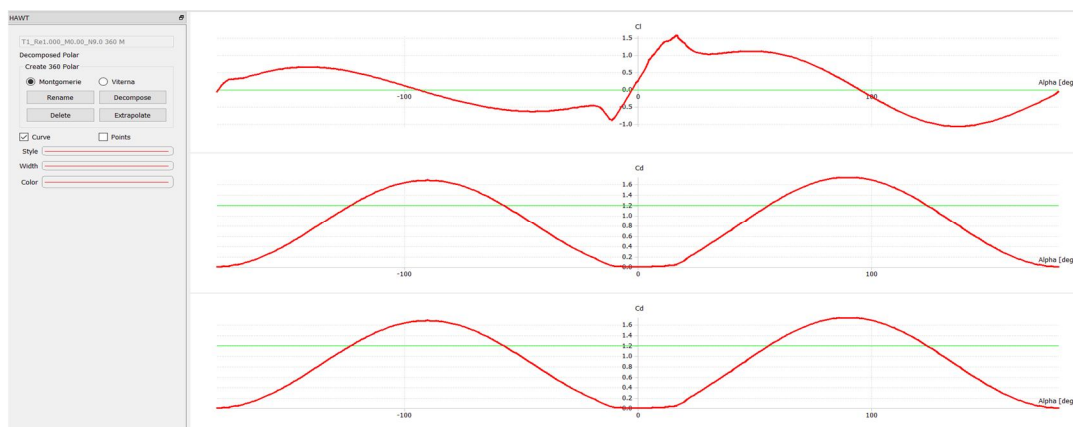


Fig 3 -: Graphs of Cl, Cd and CP

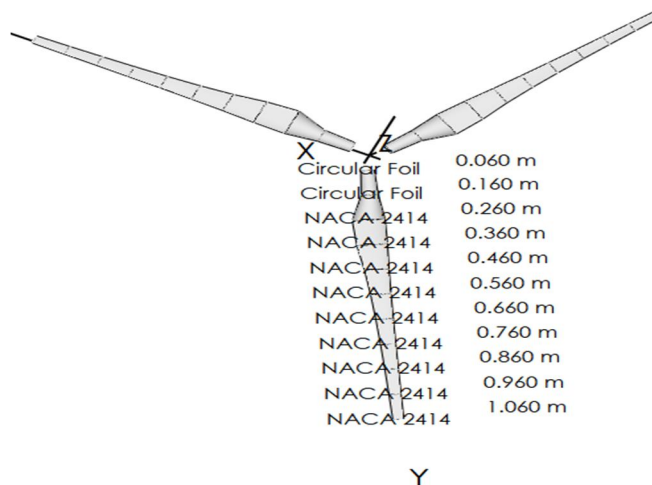


Fig -4: Obtained Airfoil by using the listed parameters

III.ELECTRICAL COMPONENTS

The proposed design is achieved using MATLAB and Simscape library in Simulink and running simulations have been carried out using Simulink. The various electrical components used in this design will be discussed further in the order in which they perform their functions in order to produce the desired range of electrical power. The components mainly have a wind turbine, two mass drive train, substations to get pitch angle, permanent magnet synchronous machine, three-phase V-I measurement, three-phase series RLC branch, voltage measurement, current measurement, RMS for voltage and current, first-order filter, two products, one divide, three gains of 1.732, -1, 1/152.8, three constants of 12 for wind speed, 8500, 152.8, eight scopes and two displays connected intricately as a network. In pitch angle substation includes one input for the energy wind turbine, one constant of one, one sum, one gain of 500, saturation, rate limiter, one scope, and one output of pitch angle. This circuitry consists of a reference input torque from the wind turbine or basically the variance in speed of the wind or rotation in blades which is positively summed to the gain of 500 which is element-wise gain ($y = K.*u$). This is then connected to a saturation block which just limits the input signal to the upper and lower saturation values. This whole setup is then connected to a rate limiter which is limiting rising and falling rates of signal from -2 falling slew rate to 2 rising slew rate and finally, the pitch angle control is obtained. A scope is connected to obtain the graphical representation for the same. This PAC is a method of Maximum power point tracking employed in a wind turbine as MPPT helps in always working towards getting the maximum power from the designed setup as MPPT algorithms are important in any renewable generation system. Wind energy system just like every other renewable energy generation system requires the to get as much energy as possible because according to Betz theory only 59.3% of total wind energy is converted into mechanical energy and hence wind turbine systems are operated at their maximum power point. Hence it is very crucial to have an MPPT procedure, PAC in this case to make the turbine operate at its maximum power point or optimal power point.

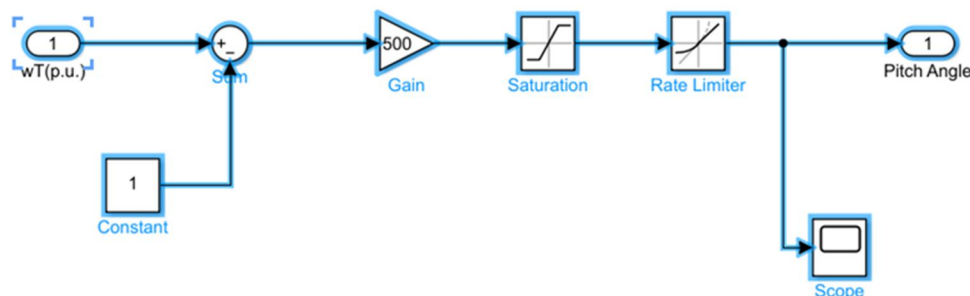


Fig -5: Pitch Angle Controller

$$\beta_{ref} = \beta_0 = 0 \quad \text{for } 0 < \Omega_t < \Omega_m$$

$$\beta_{ref} = \frac{\Delta\beta}{\Delta\Omega}(\Omega_t - \Omega_m) + \beta_0 \quad \text{for } \Omega_t > \Omega_m$$

$$\beta = \frac{1}{(1 - t_{\beta}s)}\beta_{ref}$$

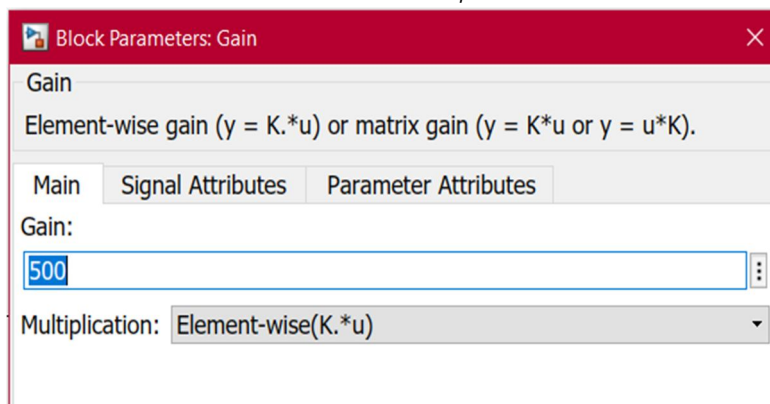


Fig -6: Gain PAC

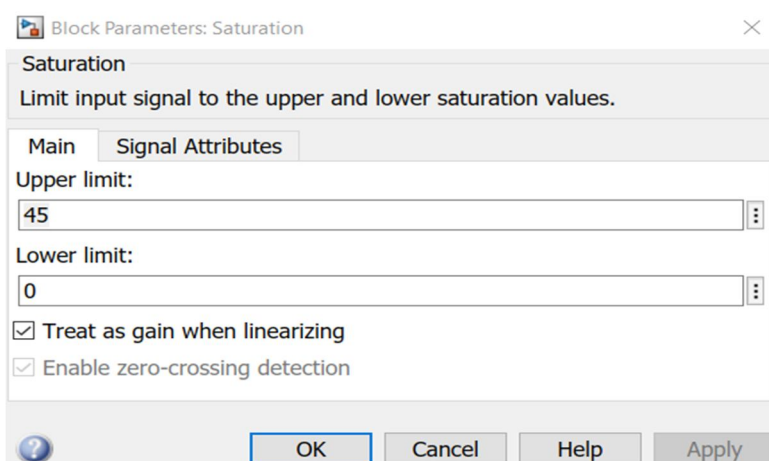


Fig -7: Saturation of PAC

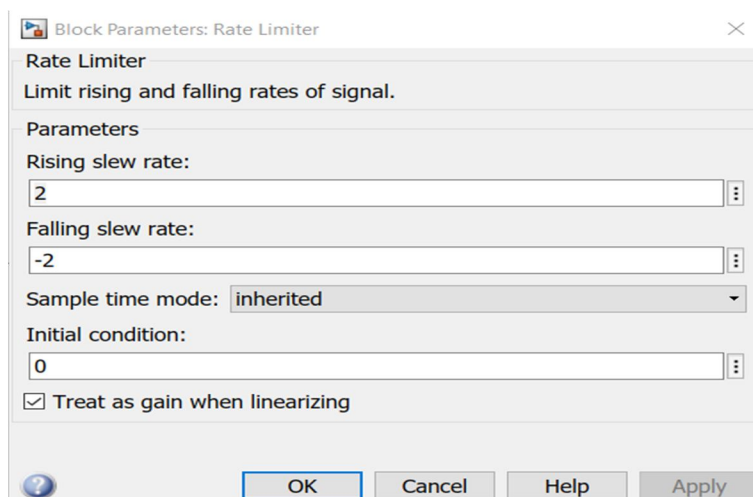


Fig -8: Rate Limiter PAC

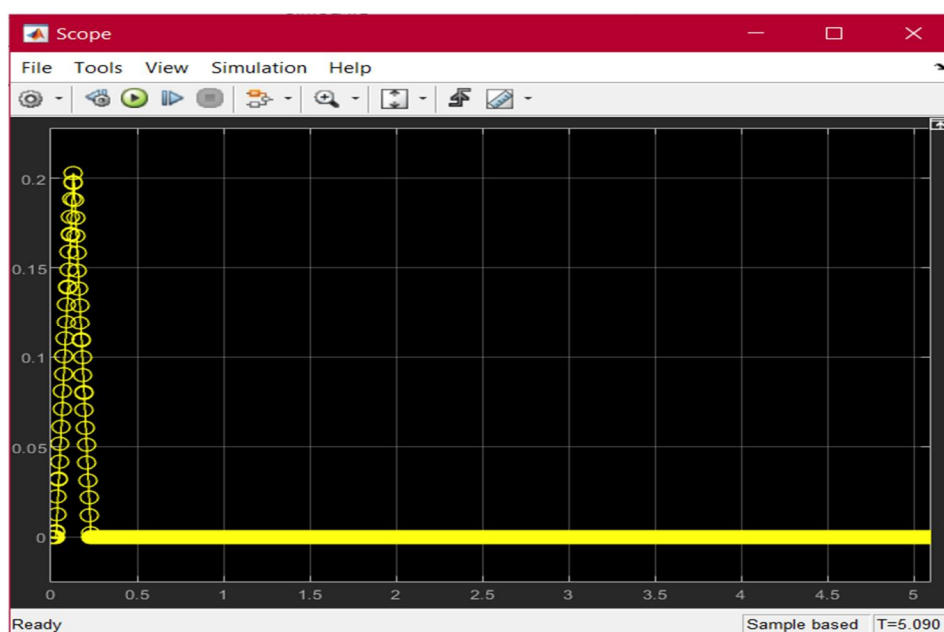


Fig -8: Graphical output of PAC

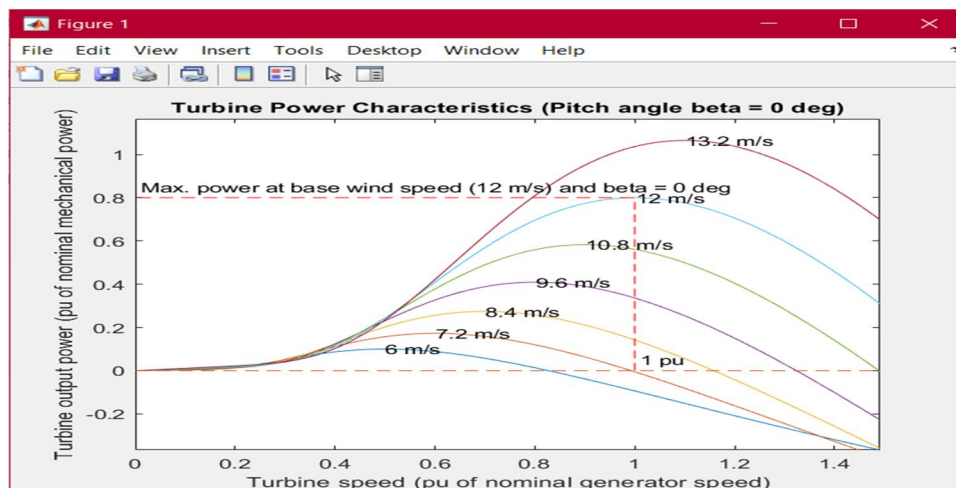


Fig -9: Turbine Power Characteristics

A. Wind Turbine Function Block

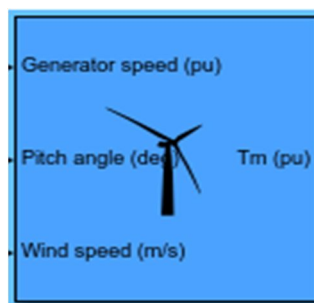


Fig -10: Function block of Wind Turbine

Block Parameters: Wind Turbine

Wind Turbine (mask) (link)

This block implements a variable pitch wind turbine model. The performance coefficient C_p of the turbine is the mechanical output power of the turbine divided by wind power and a function of wind speed, rotational speed, and pitch angle (β). C_p reaches its maximum value at zero β . Select the wind-turbine power characteristics display to plot the turbine characteristics at the specified pitch angle.

The first input is the generator speed in per unit of the generator base speed. For a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle (β) in degrees. The third input is the wind speed in m/s.

The output is the torque applied to the generator shaft in per unit of the generator ratings.

The turbine inertia must be added to the generator inertia.

Parameters

Nominal mechanical output power (W):

Base power of the electrical generator (VA):

Base wind speed (m/s):

Maximum power at base wind speed (pu of nominal mechanical power):

Base rotational speed (p.u. of base generator speed):

Pitch angle β to display wind-turbine power characteristics ($\beta \geq 0$) (deg):

☐ Display wind turbine power characteristics

Fig -11: Block parameters of that Wind Turbine

B. Two Mass Drive Train Function Block

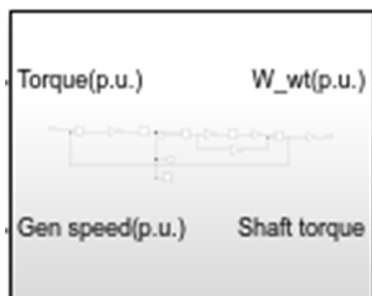


Fig -12: Function Block of 2 Mass Drive train

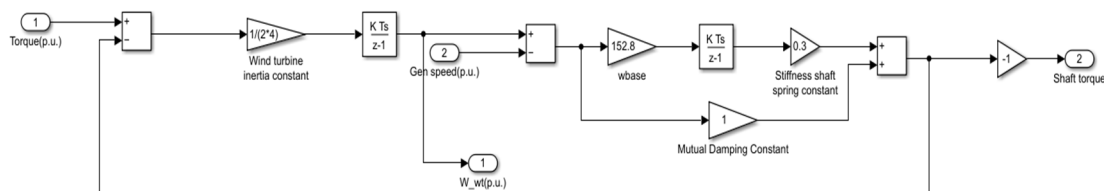


Fig -13: Design of the 2 Mass Drive train

In the above model, the torque input is given to the gain that is the wind turbine inertia constant which is then transferred to the wBase gain of the turbine which is then summed with mutual damping constant and the stiffness shaft spring constant, all of this along with the inverse gain is the shaft torque or that torque that is given to the generator as the mechanical input.

$$2Ht \frac{dwt}{dt} = Tm - Ts \quad (i)$$

$$\frac{1}{webs} \frac{d\theta_{sta}}{dt} = wt - wr \quad (ii)$$

$$Ts = Kss\theta_{sta} + Dt \frac{d\theta_{sta}}{dt} \quad (iii)$$

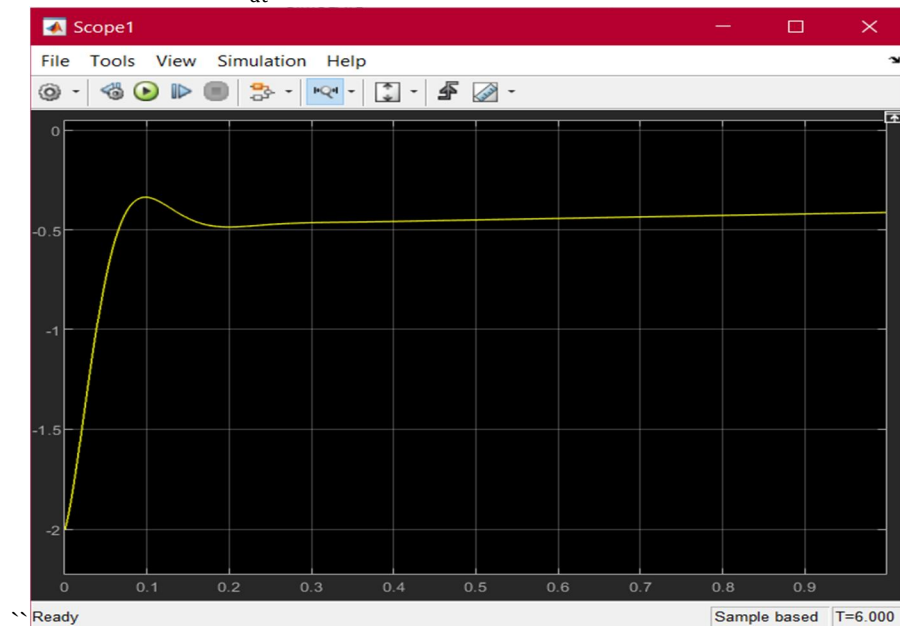


Fig -14: Torque Output characteristics

C. Modelling of a Permanent Magnet Synchronous Generator

The Permanent Magnet Synchronous Generator (PMSG) is used to produce electricity from the mechanical energy obtained from the wind. The two-phase synchronous reference frame is used to derive the dynamic model of the PMSG, which is the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. In order to maintain synchronization between the two-phase quantity (d-q reference frame) and the three-phase quantity (abc three-phase frame) by using a phase-locked loop (PLL). The mathematical model of the PMSG in the synchronous reference frame (in the state equation form) is given by:

$$\frac{di_d}{dt} = \frac{1}{L_{ds} + L_{ls}} (-R_s I_d + \omega_e (L_{qs} + L_{ls}) i_q + u_d) \quad (2)$$

$$\frac{di_q}{dt} = \frac{1}{L_{qs} + L_{ls}} (-R_s I_q - \omega_e [(L_{ds} + L_{ls}) i_d + \psi_f] + u_q) \quad (3)$$

Here subscripts d and q refer to the physical quantities of rotating reference frame; R_s is the stator resistance, L_d and L_q are the d and q axis inductances of the generator, L_{ld} and L_{lq} are the d and q axis leakage inductances of the generator, ψ_f is the permanent magnetic flux and ω_e is the electrical rotating speed of the generator. The electromagnetic torque equation of the PMSG is given by [4]

$$\tau_e = 1.5p \left((L_{ds} - L_{ls}) i_d i_q + i_q \psi_f \right) \quad (4)$$

Where p is the number of pole pairs of the generator. The PMSG gives better performance compared to the induction generator because it does not have a rotor current. The additional advantage of using a PMSG is that you can use it without gearbox results in the reduction of cost and reduction of weight of the nacelle.

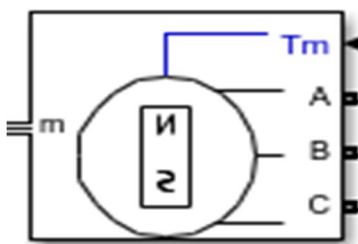
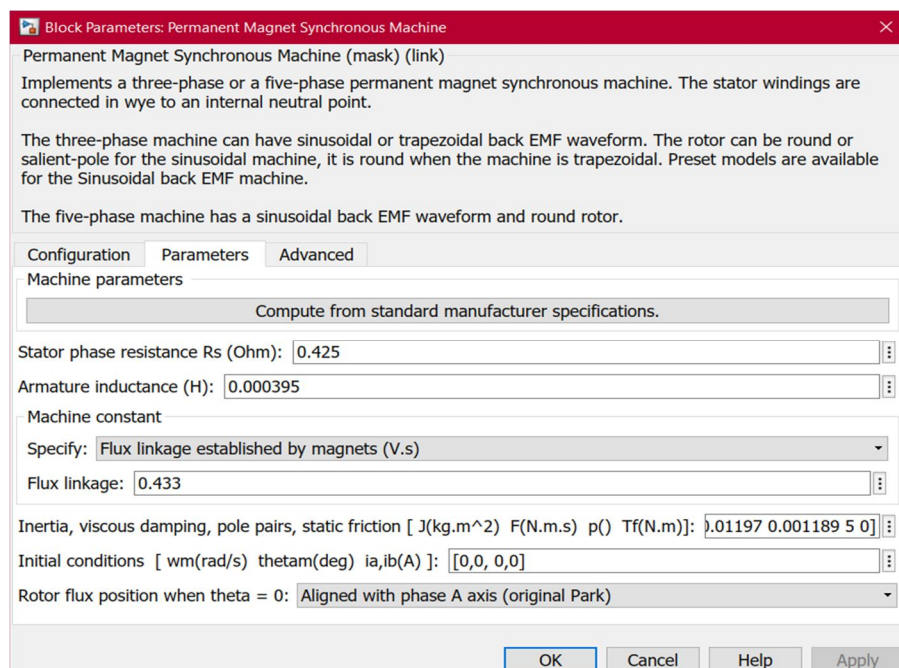


Fig -15: Block Function of PMSG



Block Parameters: Permanent Magnet Synchronous Machine

Permanent Magnet Synchronous Machine (mask) (link)

Implements a three-phase or a five-phase permanent magnet synchronous machine. The stator windings are connected in wye to an internal neutral point.

The three-phase machine can have sinusoidal or trapezoidal back EMF waveform. The rotor can be round or salient-pole for the sinusoidal machine, it is round when the machine is trapezoidal. Preset models are available for the Sinusoidal back EMF machine.

The five-phase machine has a sinusoidal back EMF waveform and round rotor.

Configuration Parameters Advanced

Machine parameters

Compute from standard manufacturer specifications.

Stator phase resistance R_s (Ohm): 0.425

Armature inductance (H): 0.000395

Machine constant

Specify: Flux linkage established by magnets (V.s)

Flux linkage: 0.433

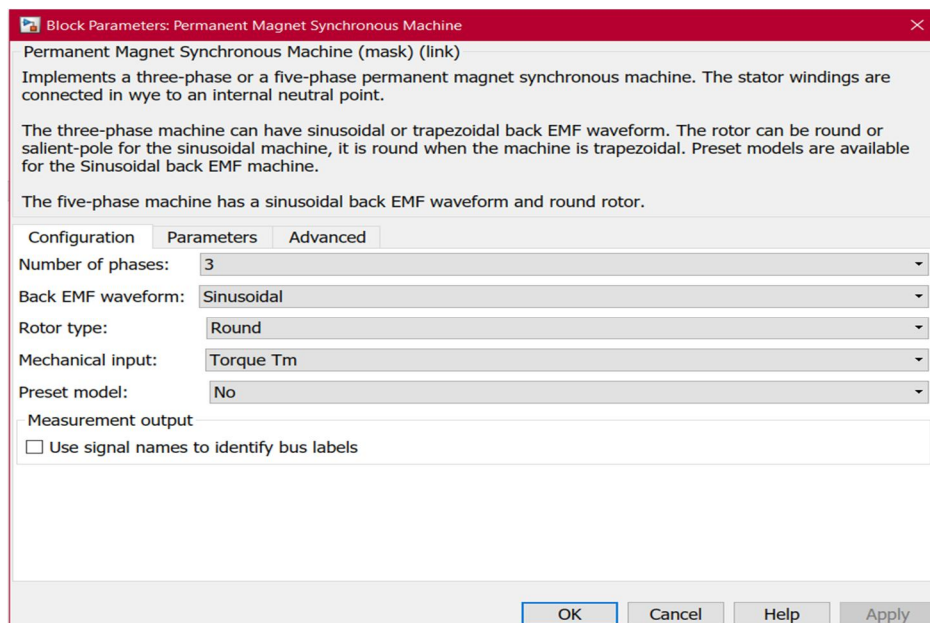
Inertia, viscous damping, pole pairs, static friction [J(kg.m²) F(N.m.s) p() Tf(N.m)]: 0.01197 0.001189 5 0

Initial conditions [ω_m (rad/s) θ_{em} (deg) i_a, i_b (A)]: [0, 0, 0, 0]

Rotor flux position when theta = 0: Aligned with phase A axis (original Park)

OK Cancel Help Apply

Fig -16: Parameters of PMSG



Block Parameters: Permanent Magnet Synchronous Machine

Permanent Magnet Synchronous Machine (mask) (link)

Implements a three-phase or a five-phase permanent magnet synchronous machine. The stator windings are connected in wye to an internal neutral point.

The three-phase machine can have sinusoidal or trapezoidal back EMF waveform. The rotor can be round or salient-pole for the sinusoidal machine, it is round when the machine is trapezoidal. Preset models are available for the Sinusoidal back EMF machine.

The five-phase machine has a sinusoidal back EMF waveform and round rotor.

Configuration | **Parameters** | **Advanced**

Number of phases: 3

Back EMF waveform: Sinusoidal

Rotor type: Round

Mechanical input: Torque T_m

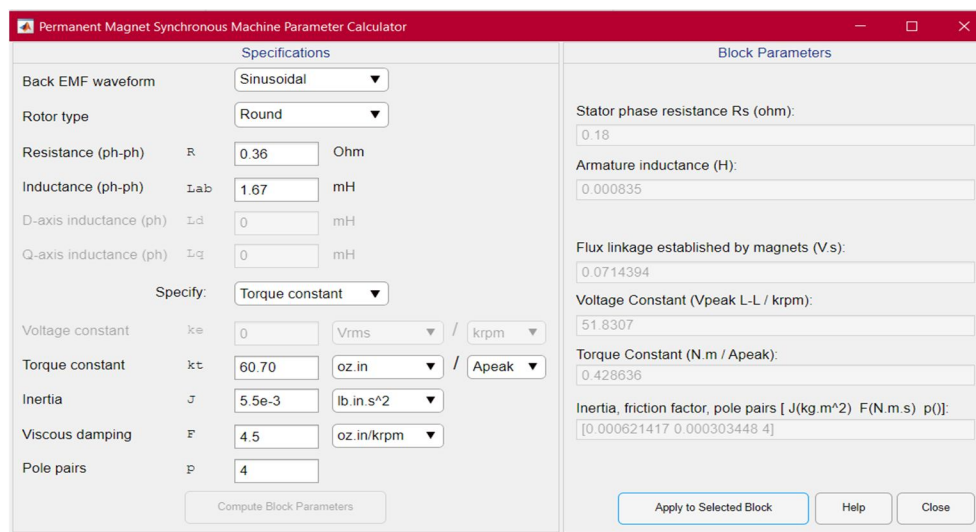
Preset model: No

Measurement output

☐ Use signal names to identify bus labels

OK Cancel Help Apply

Fig -17: Parameters of PMSG



Permanent Magnet Synchronous Machine Parameter Calculator

Specifications

Back EMF waveform: Sinusoidal

Rotor type: Round

Resistance (ph-ph) R : 0.36 Ohm

Inductance (ph-ph) L_{ab} : 1.67 mH

D-axis inductance (ph) L_d : 0 mH

Q-axis inductance (ph) L_q : 0 mH

Specify: Torque constant

Voltage constant k_e : 0 Vrms / krpm

Torque constant k_t : 60.70 oz.in / Apeak

Inertia J : 5.5e-3 lb.in.s²

Viscous damping F : 4.5 oz.in/krpm

Pole pairs p : 4

Compute Block Parameters

Block Parameters

Stator phase resistance R_s (ohm): 0.18

Armature inductance (H): 0.000835

Flux linkage established by magnets (V.s): 0.0714394

Voltage Constant (Vpeak L-L / krpm): 51.8307

Torque Constant (N.m / Apeak): 0.428636

Inertia, friction factor, pole pairs [J(kg.m²) F(N.m.s) p()]: [0.000621417 0.000303448 4]

Apply to Selected Block Help Close

Fig -18: TABLE of Parameters of PMSG



Fig -19: Voltage(V) Output

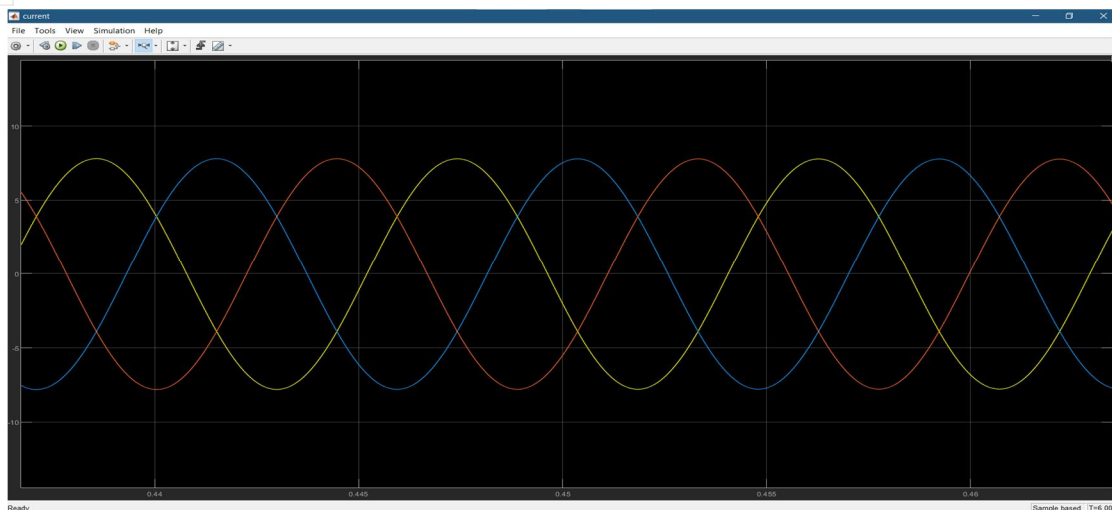


Fig -20: Current(I) Output

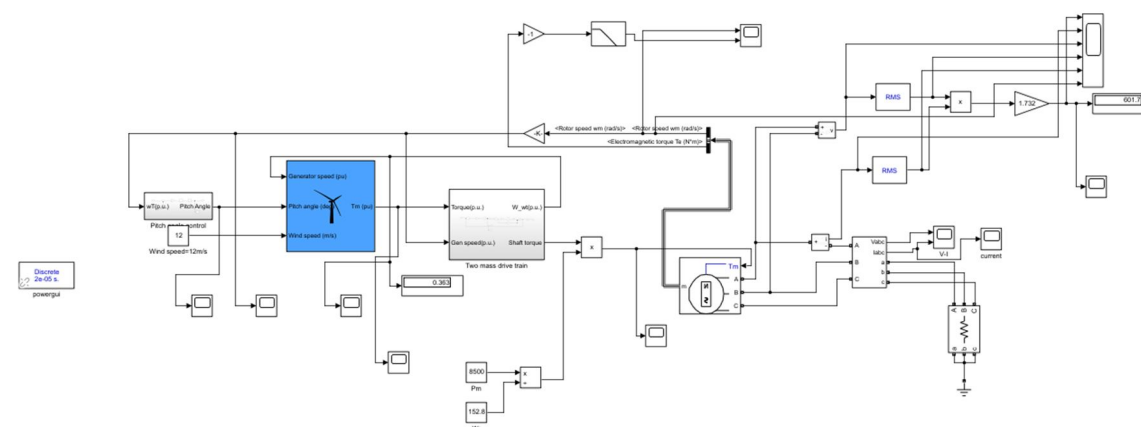


Fig -21: SIMULINK Final Design of the proposed model for 6kW Wind Turbine

D. Results

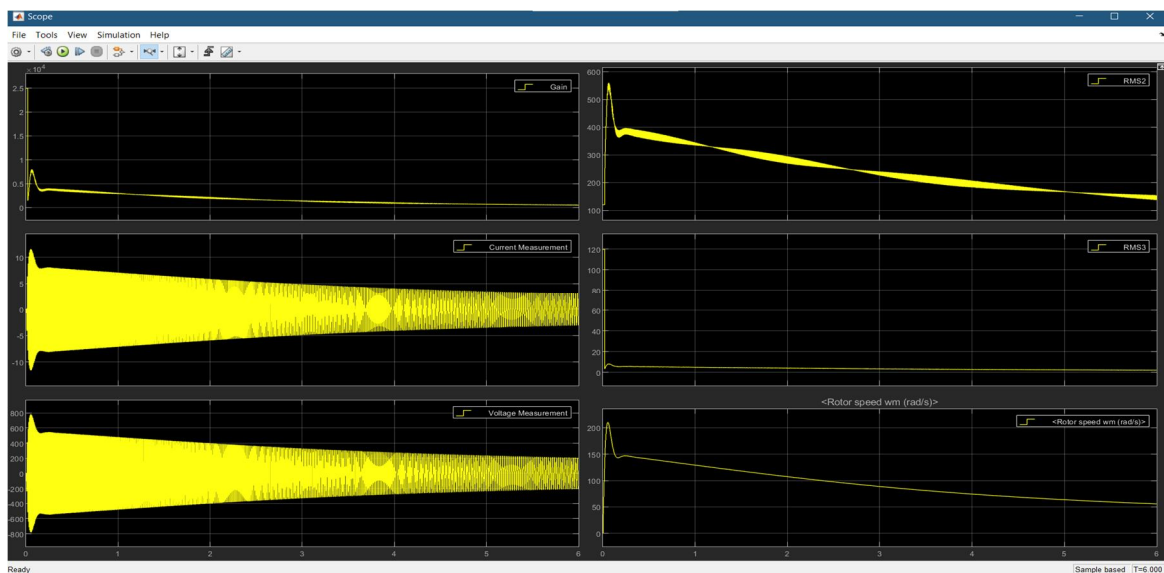


Fig -22: Generalised Graph of all the Outputs of the designed 6kW Wind Turbine

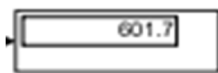


Fig -23: 6kW output generated and observed from the display box of the SIMULINK

IV. CONCLUSIONS

Wind energy is a better alternative to fossil fuels for the generation of electrical energy. It causes lesser pollution as compared to conventional resources and has a moderate maintenance cost as well. The simulation and design and the final results of the proposed 6kW were carried out successfully and the behavioural patterns were plotted graphically via the MATLAB/Simulink scope. Although, according to Betz theory only 59.3% of the total available 100% wind is converted into mechanical energy and hence windmills are operated at their maximum power point, and once such way to obtain that MPPT is by PAC which was also discussed and applied. This proposed design is believed to be more efficient than the trivial designs of a small 6kW wind turbine.

V. ACKNOWLEDGMENT

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