iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** V **Month of publication:** May 2021

DOI: https://doi.org/10.22214/ijraset.2021.34499

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue V May 2021- Available at www.ijraset.com

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 arifoil 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.

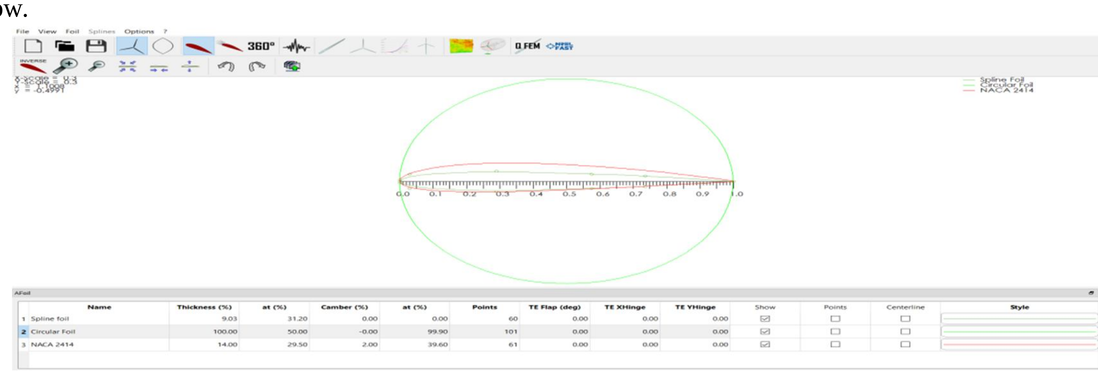

Fig -1: NACA 2414 Airfoil Design

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
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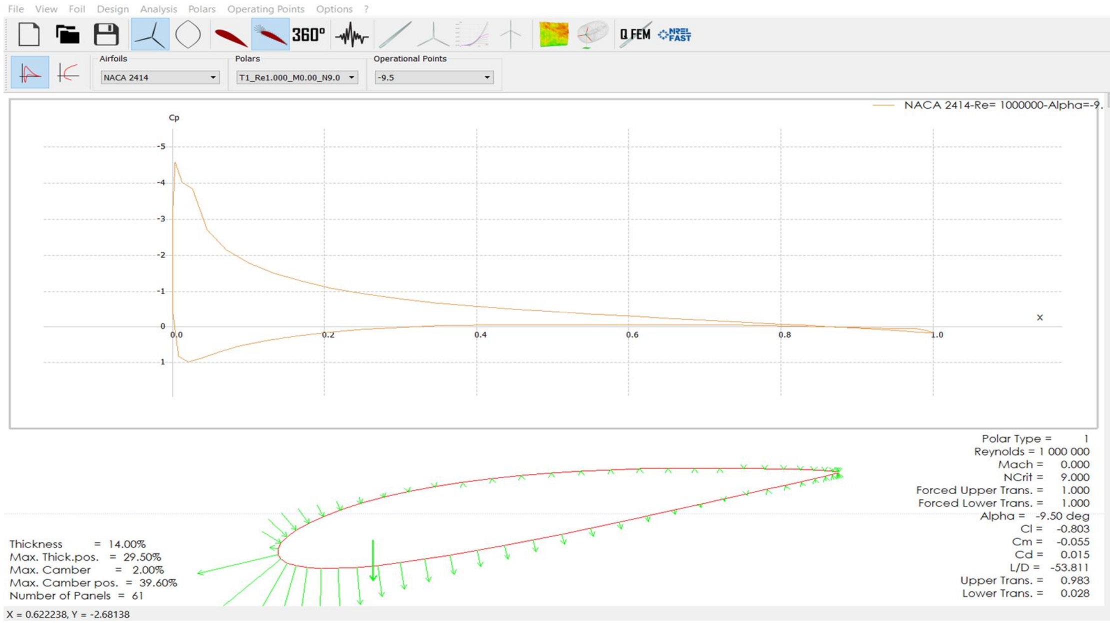

Fig -2: Cp=Cl/Cd

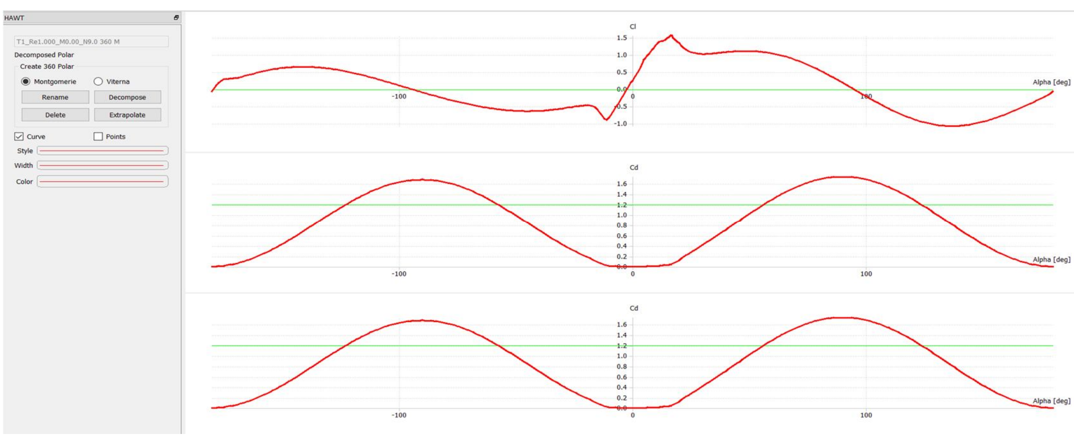

Fig 3 -: Graphs of Cl, Cd and CP

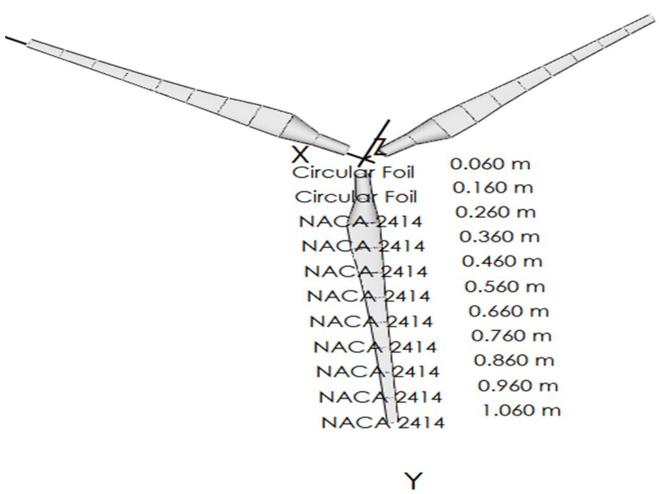

Fig -4: Obtained Airfoil by using the listed parameters

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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 PAC 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.

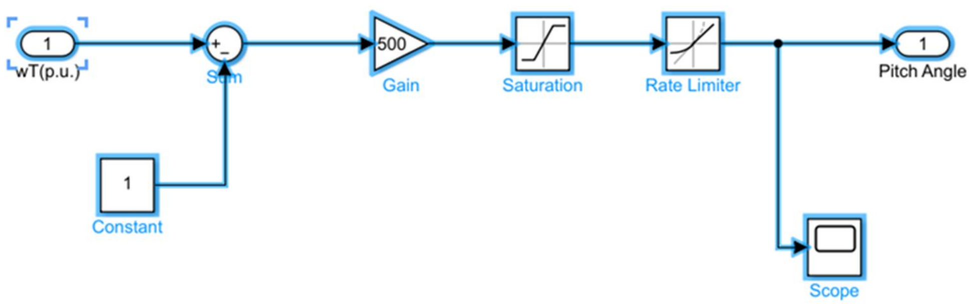

Fig -5: Pitch Angle Controller

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

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

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

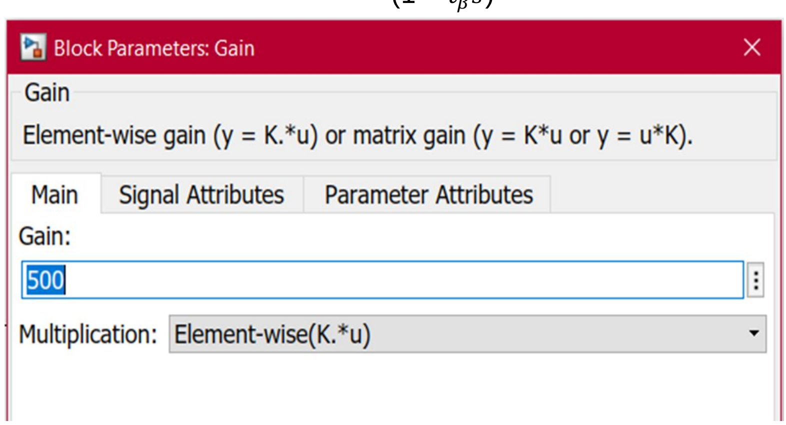

Fig -6: Gain PAC

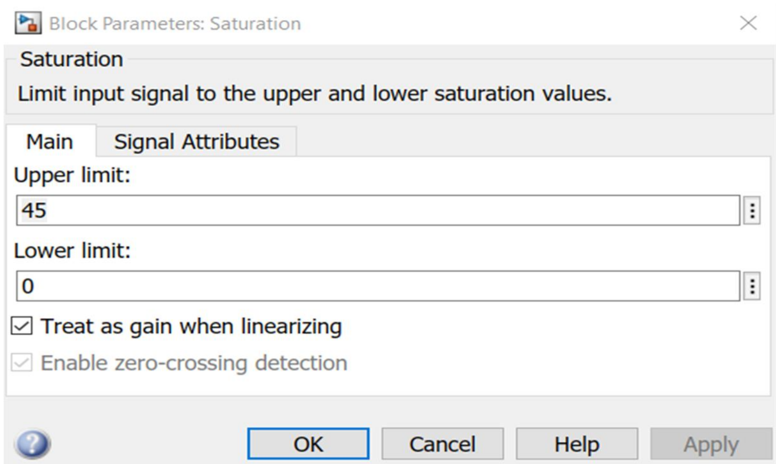

Fig -7: Saturation of PAC

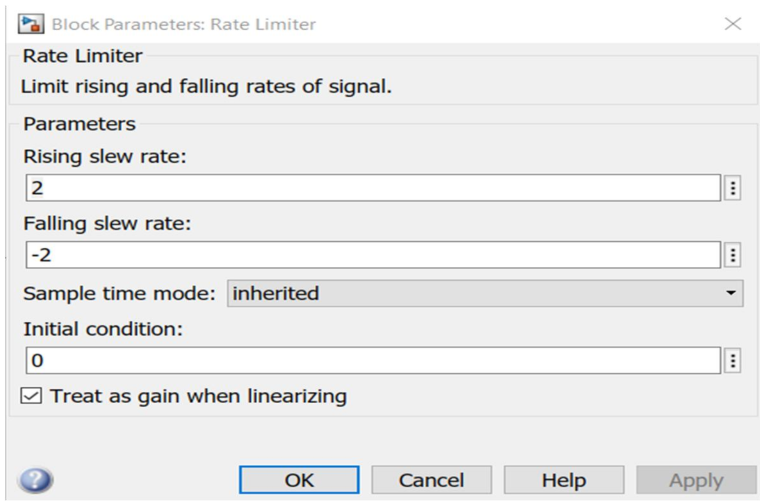

Fig -8: Rate Limiter PAC

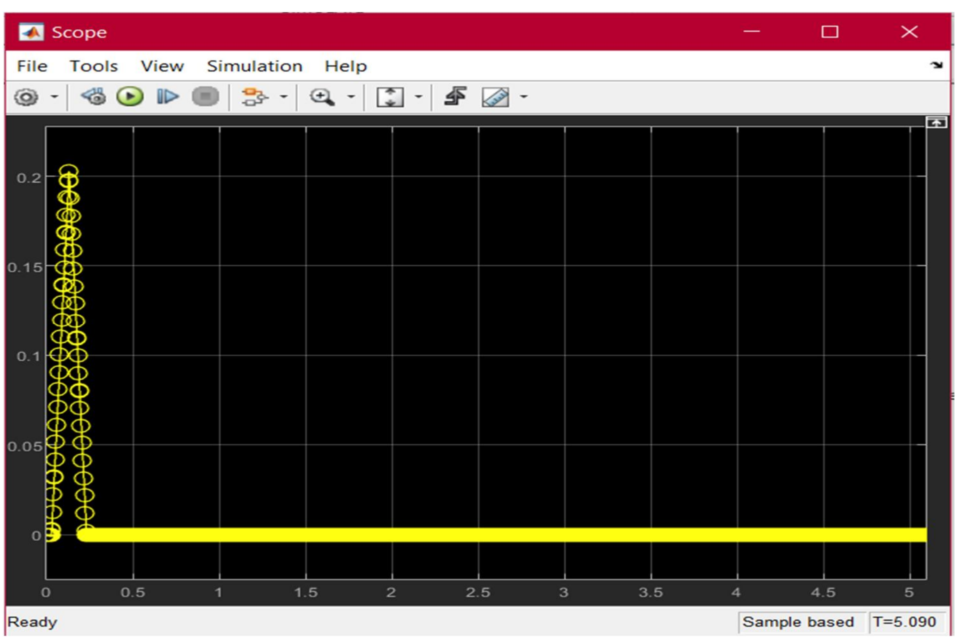

Fig -8: Graphical output of PAC

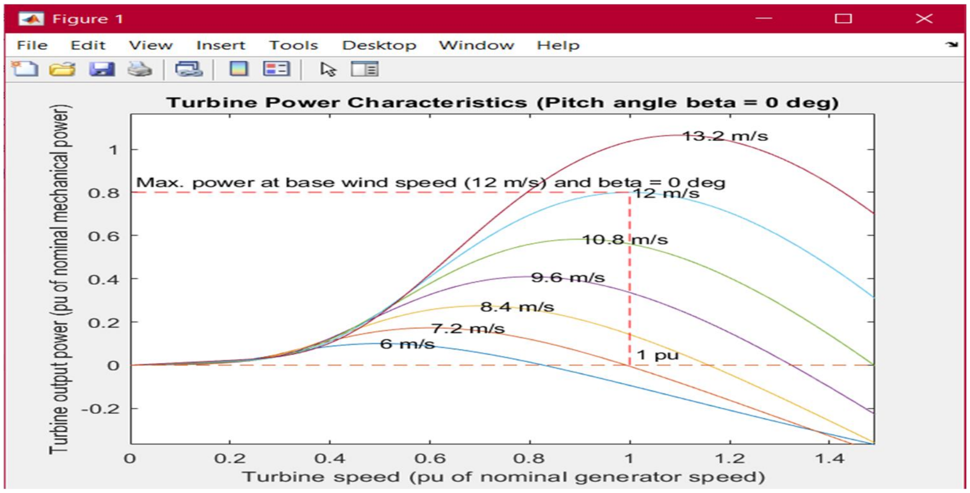

Fig -9: Turbine Power Characteristics

A. Wind Turbine Function Block

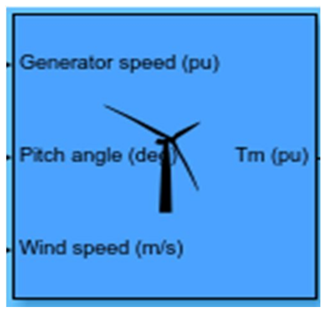

Fig -10: Function block of Wind Turbine

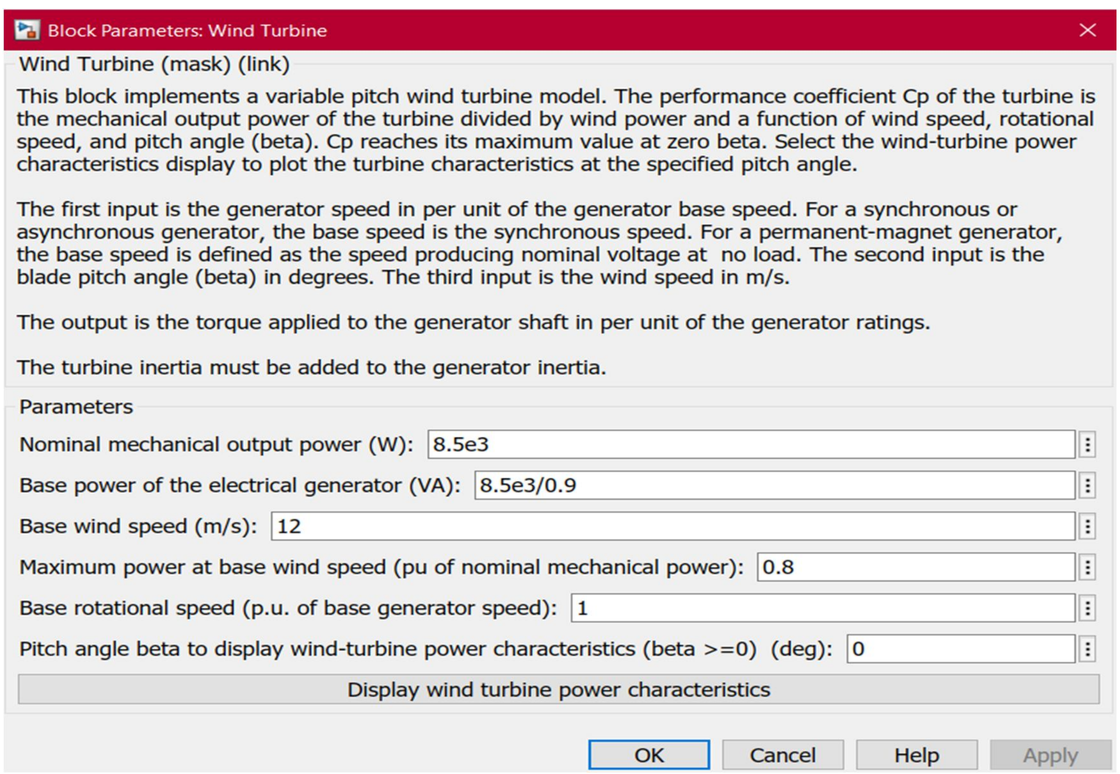

Fig -11: Block parameters of that Wind Turbine

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B. Two Mass Drive Train Function Block

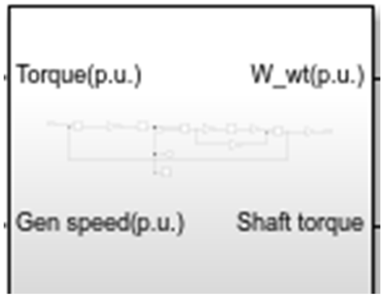

Fig -12: Function Block of 2 Mass Drive train

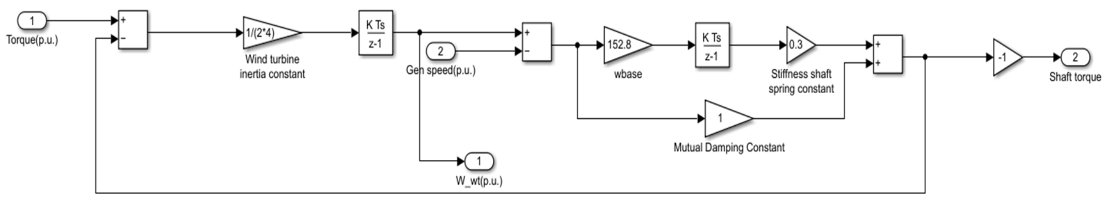

Fig -13: Design of the 2 Mass Drive train

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.

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

$$\frac{1}{webs}\frac{d\theta sta}{dt} = wt - wr \qquad \text{(ii)}$$

$$Ts = Kss\theta sta + Dt\frac{d\theta sta}{dt} \qquad \text{(iii)}$$

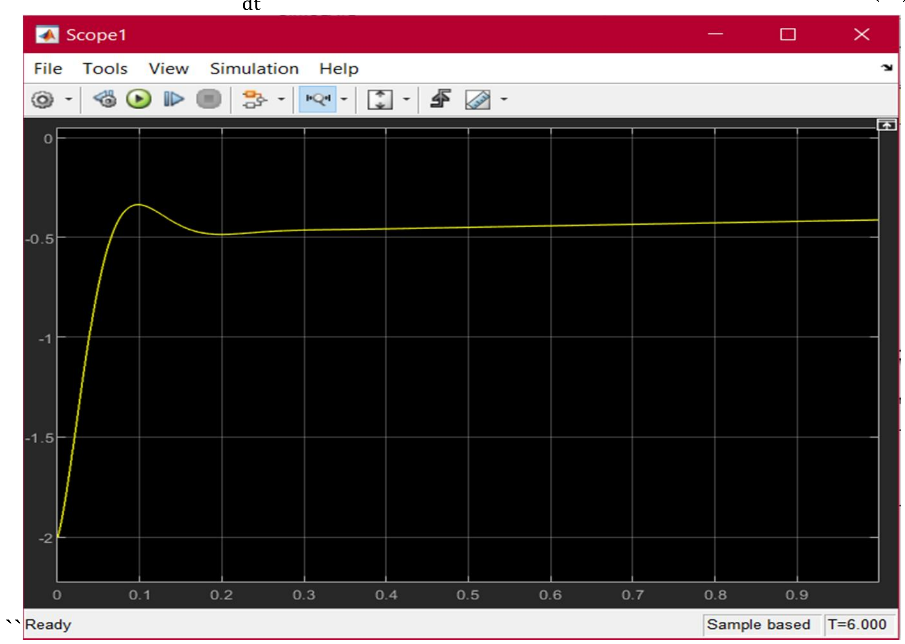

Fig -14: Torque Output characteristics

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:

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

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

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]

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

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.

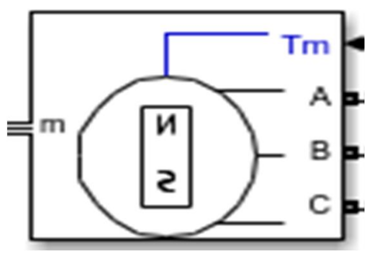

Fig -15: Block Function of PMSG

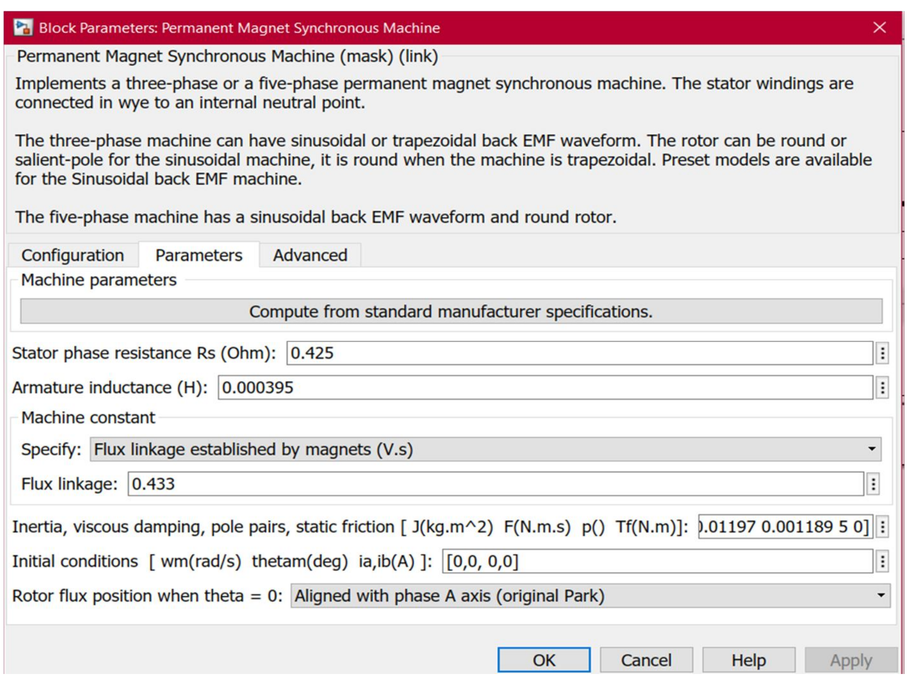

Fig -16: Parameters of PMSG

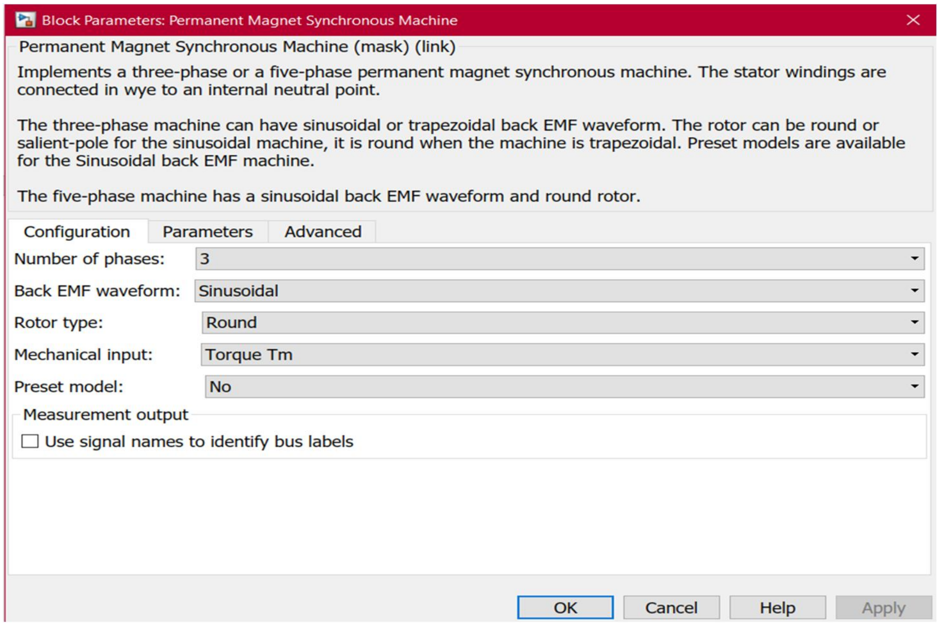

Fig -17: Parameters of PMSG

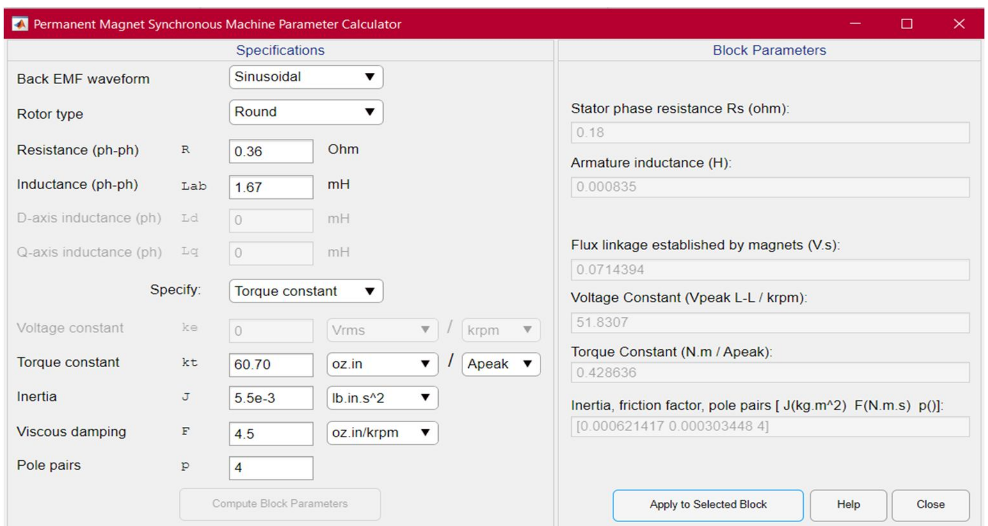

Fig -18: TABLE of Parameters of PMSG

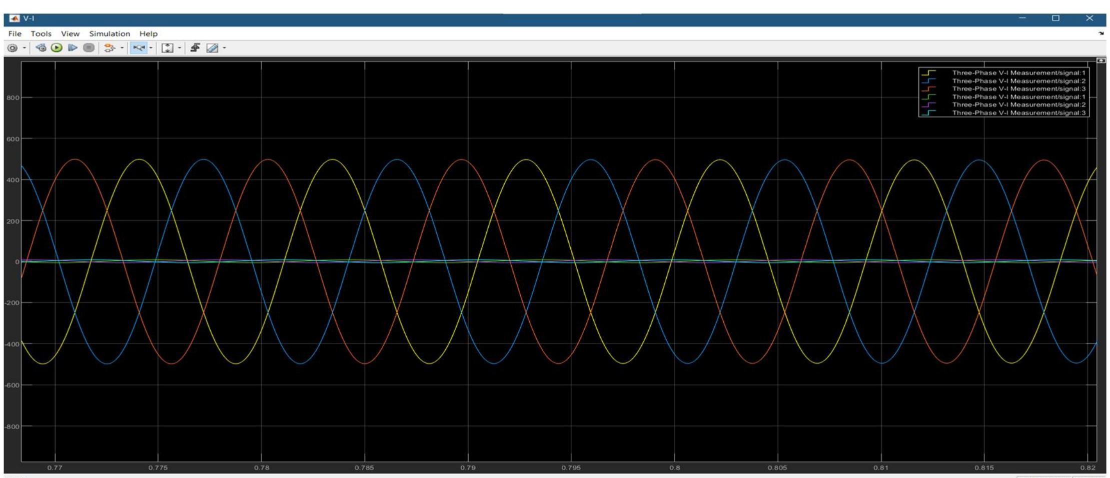

Fig -19: Voltage(V) Output

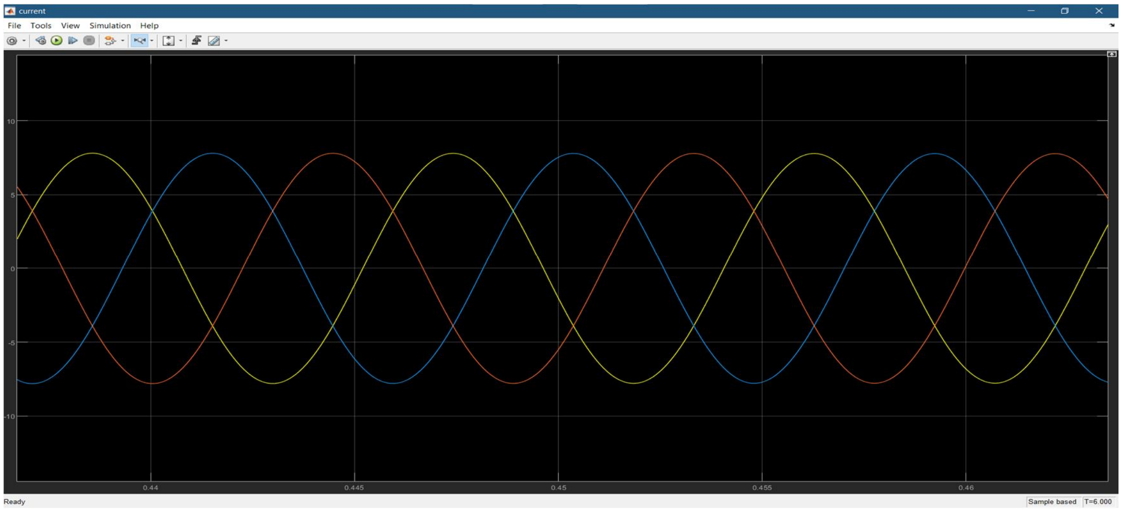

Fig -20: Current(I) Output

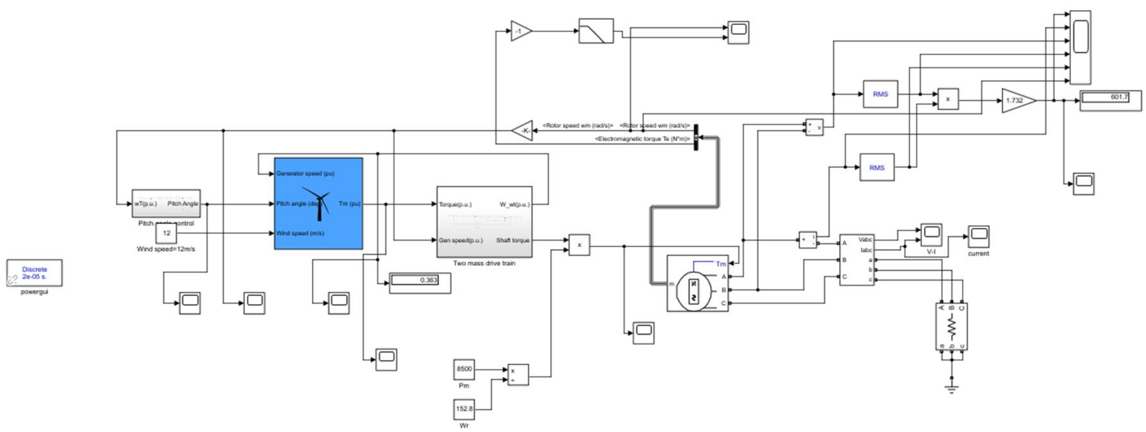

Fig -21: SIMULINK Final Design of the proposed model for 6kW Wind Turbine

D. Results

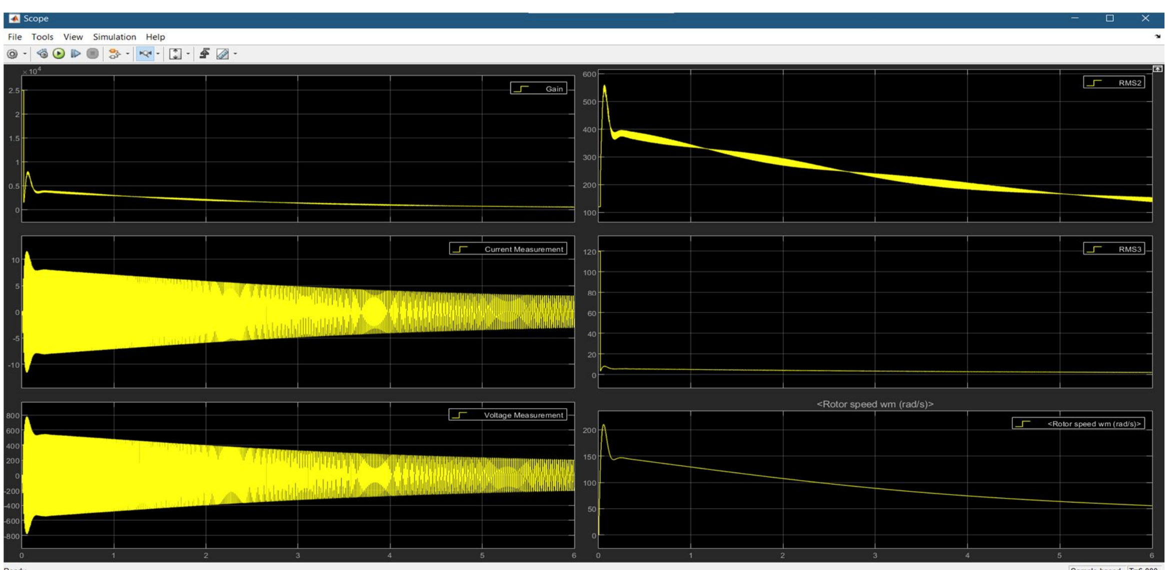

Fig -22: Generalised Graph of all the Outputs of the designed 6kW Wind Turbine

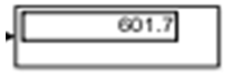

Fig -23: 6kW output generated and observed from the display box of the SIMULINK

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

I would like to extend my deepest gratitude and humbleness to my mentor and project guide Ms. Dhanusiya Bala who took great steps to help us with this project. She has provided valuable guidance, personal attention, encouragement, on-time help as well as providing me with a conducive atmosphere for doing the project. All through the work, in spite of her busy schedule, she has extended supreme and cordial support to me for completing this research work.

I would also like to express my gratitude and regards to Dr. HIMANSHU SHARMA H.O.D. EEE department S.R.M. Institute of Science and Technology, Ghaziabad for his support and guidance through his unparalleled knowledge of the field.

I would also like to thank and acknowledge all the faculties of the Electrical and Electronics department and the lab assistants for their support and guidance.

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