**DESIGN AND SIMULATION OF 6kW WIND TURBINE**

**A PROJECT REPORT**

**Submitted by**

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**BONAFIDE CERTIFICATE**

Certified that this project report titled “**DESIGN AND SIMULATION OF 6kW WIND TURBINE**” is the bonafide work of “**AHELEE GUHA [Reg No: RA1711005030015], AVIRAL KRISHNA [Reg No: RA1711005010195]**”, who carried out the project work under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form any other project report or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

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**ABSTRACT**

This paper focuses on the efficiency, modelling, simulation and control of a 6KW wind power generator along with its performance analysis. In the world, where the renewable energy is slowly becoming a necessity and we are constantly trying to find a better alternative for our energy sources, wind turbine can be our ally and help us to generate energy. The generator connected is permanent magnet synchronous generator (PMSG). The simulation is done on the MATLAB/Simulink software and the blade is designed in the Qblade. The simulation and the performance are compared among different wind speed and load.

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**LIST OF SYMBOLS**

L Lift

Cl Lift coefficient

ρ Density

V Velocity

A Area

D Drag

CD Drag coefficient

b

tb

s

bref

β pitch angle

βref command of β

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**2.1) PMSG Specification**

**CHAPTER 1**

**INTRODUCTION**

The demand for wind energy generation has been increasing and is becoming a full industry with wind energy conversation system (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 grid or stored in battery for personal use. In India, 37.5GW of 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 6KW wind power generator is generally considered a small scale wind turbine.

1. **Wind Energy**

Wind power is the energy obtained from the wind. It is one of the oldest energy sources exploited by humans and today is the most established and efficient renewable energy source. It is a clean form of energy and people have been harnessing it since ancient times., for example a sailboat, grinding grains and Chinese water pumps. This report shall deal with how this wind energy can be harnessed to produce electricity.

1. **Wind Turbine**

A wind turbine is a special type of mechanical and electrical arrangement that operates in such a way as to produce an electrical output upon receiving a mechanical input. It operates on the principle of converting the wind's kinetic energy into electrical energy using generators.

1. **Types of Wind Turbines**

1.Vertical Axis wind turbine.

2. Horizontal Axis wind turbine.

1. **VAWT**

VAWT also known as the vertical axis wind turbine is a type of wind turbine where the main rotor shaft is above the main components that are at the bottom of the turbine. Since the main components like the generator and the gearbox are at the ground, its easier for maintenance and repairing. VAWTs do not need the wind sensing mechanism.

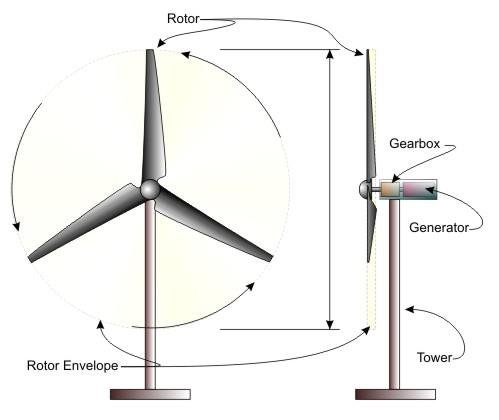
Diagram

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**Fig. (1.1): Vertical axis wind turbine with components**

1. **HAWT**

HAWTs are the most common wind machine designs in use today. HAWTs utilize aerodynamic blades (i.e. airfoils) fitted to a rotor, which can be positioned either upwind or downwind. HAWTs are typically either two- or three-bladed and operate at high blade tip speeds. HAWT wind turbines are what people generally think of when they think of a wind turbine, with their huge blades and long towers and they are especially known for their high efficiency and good power output.



**Fig. (1.2): Horizontal-axis wind turbine with components**

The figure shows the horizontal axis wind turbine which shall be further discussed in this report.

**CHAPTER 2**

**LITERATURE SURVEY**

1. **The WEI6K, a 6-kW 7-m Small Wind Turbine**

This project was selected by the U.S. Department of Energy under a DOE solicitation “Low Wind Speed Technology for Small Turbine Development.” The objective of this project has been to design a new small wind turbine with improved cost, reliability and performance in grid connected residential and small business applications, in order to achieve the overall DOE goal of cost effectiveness in wind resources.

The scope of work for this project has been to complete the preliminary design of an improved small wind turbine such as: preliminary loads and strength analyses, analysis and design of all major components, systems integration and structural dynamic analysis, estimation of life-cycle cost of energy, design documentation and review.

1. **Dynamic Modelling, Control and Simulation of a Wind and PV Hybrid System for Grid Connected Application Using MATLAB**

In this research paper, an operational wind and p.v. system is discussed and it’s modelling is shown. This research paper gives ample of knowledge about designing a basic operational wind turbine system and how to connect to a grid. This paper also shows how to model it’s own generator that is suited for the best efficiency and optimal output, a permanent magnetic synchronous generator. It has a number of formulae that are helpful in the design of wind energy harnessing and generation of electricity from it.

1. **Modelling and simulation of wind-generator with fixed speed wind**

**turbine under Matlab-Simulink**

This paper mainly focuses upon the type of generators that can be used in order to produce the electrical output from a given mechanical input. Basically, every proposed generator’s modelling and output variance from one another is shown from which the best one can be selected based upon the factors of overall compatibility with the turbine input and the efficiency, which is also depicted graphically. In this paper they have used a global system architecture for the design and simulation of the model so that every generator can be compared to one another based upon the same input parameter.

1. **Dynamic Modeling and Performance Analysis of Grid Connected PMSG based Variable Speed Wind Turbines With Simple Power Conditioning System**

This paper presents modeling, simulation and performance analysis of grid connected wind generation system using direct-driven Permanent Magnet Synchronous Generator (PMSG). The proposed system includes a wind turbine (WT), a permanent magnet synchronous generator, a three-phase diode rectifier bridge, a dc bus with a capacitor and a current regulated PWM voltage source inverter. In this paper complete modeling of wind power generation system with PMSG and power electronic converter interface along with the control scheme is developed using a Matlab/Simulink simulation package. The performance of the developed model is studied for different wind speeds and load conditions. Simulation results show that the controllers can regulate the DC link voltage, active and reactive power produced by the wind power generation system.

1. **Simulation and Control of Solar Wind Hybrid Renewable Power System**

This paper introduces a standalone hybrid power generation system consisting of solar and permanent magnet synchronous generator (PMSG) wind power sources and a AC load. A supervisory control unit, designed to execute maximum power point tracking (MPPT), is introduced to maximize the simultaneous energy harvesting from overall power generation under different climatic conditions. Two contingencies are considered and categorized according to the power generation from each energy source, and the load requirement.

1. **A review on the inclusion of wind generation in power system studies**

In this paper, a detailed review has been given on the power system including the wind generation. Some basic aspect of the wind power generation system has been discussed here including wind farm, wind power statistics, wind effect etc. Many designs of wind turbines and theoretical methods have been discussed and reviewed in this paper. This paper also covers review of different methods that is used in the power system planning.

**STRUCTURE OF WIND TURBINE**

1. **Tower**

The blades and nacelle are mounted on top of a tower. The tower is constructed to hold the rotor blades off the ground and at an ideal wind speed. Towers are usually between 50-100 m above the surface of the ground or water.

1. **Foundation**

In order to guarantee the stability of a wind turbine a pile or flat foundation is used, depending on the consistency of the underlying ground. The foundation anchors the wind turbine to the ground. The foundation fixes the wind generator into the ground. In order to guarantee the stability of the wind generator, pile foundations or shallow foundations are constructed depending on how stable the subsoil is.

1. **Nacelle**

The nacelle contains a set of gears and a generator. The turning blades are linked to the generator by the gears. The gears convert the relatively slow blade rotation to the generator rotation speed of approximately 1500 rpm.

1. **Rotor**

The rotor is the component which, with the help of the rotor blades, converts the energy in the wind into rotary mechanical movement. Currently, the three-blade, horizontal axis rotor dominates. The rotor blades are mainly made of glass-fibre or carbon-fibre reinforced plastics (GRP, CFRP). The blade profile is similar to that of an aeroplane wing. They use the same principle of lift: on the lower side of the wing the passing air generates higher pressure, while the upper side generates a pull. These forces cause the rotor to move forwards, i.e. to rotate.

1. **Rotor Blades**

Rotor blades are a crucial and elementary part of a wind turbine. Various demands are placed on them, and they must withstand very great loads. Most rotors have three blades, a horizontal axis, and a diameter of between 40 and 90 meters. The rotor blades mainly consist of synthetics reinforced with fiberglass and carbon fibres. The

layers are usually glued together with epoxy resin. Wood, wood epoxy, and wood-fibre-epoxy compounds are less widely used. One of the main benefits of wooden rotor blades is that they can be recycled. Aluminium and steel alloys are heavier and suffer from material fatigue. These materials are therefore generally only used for a very small wind turbine.

1. **Hub**

The hub is the centre of the rotor to which the rotor blades are attached. Cast iron or cast steel is used. The hub directs the energy from the rotor blades on to the generator. If the wind turbines have a gearbox, the hub is connected to the slowly rotating gearbox shaft, converting the energy from the wind into rotation energy. If the turbine has a direct drive, the hub passes the energy directly on to the ring generator. The rotor blade can be attached to the hub in various ways: either in a fixed position, with articulation, or as a pendulum. The latter is a special version of the two-blade rotor, which swings as a pendulum anchored to the hub. Most manufacturers currently use a fixed hub. It has proved to be sturdy, reduces the number of movable components that can fail, and is relatively easy to construct.

1. **Gearbox**

A gearbox is used for the conversion of low r.p.m of shaft rotated by the blades to a higher r.p.m of the shaft towards the generator input. The gearbox converts the rotor motion of 18-50 rpm into the approx. 1,500-2000 rpm which the generator requires.

1. **Generator**

The generator in a wind turbine converts mechanical energy into electrical energy. For high power wind turbines, doubly-fed asynchronous generators are most frequently used. Usually, Synchronous generators are used because they are more efficient and cost productive when used with a wind turbine.

1. **Control Systems**

A control system is used in a wind turbine along with the generator that controls the function and the operation of the key components of the wind turbine. One such example of a control system used in turbines is a pitch angle controller or a stall controller which shall be discussed further in the report when the respective components and techniques are explained.

1. **Heating and Cooling system**

The temperatures inside a nacelle can be quite high due to the waste heat from the gearbox and the generator. Special ventilators are therefore installed in the nacelle to keep it cool. In addition, there are usually special cooling units for the individual components of a wind turbine, such as the gearbox. Heating During the winter, temperatures often fall below freezing where wind turbines are set up. When the oil in the gearbox freezes, it is hard to get the system running again after it has been motionless for some time. Therefore, heaters are often used to warm up the oil in the gearbox. In addition, rotor blades are also heated to prevent them from icing over or being damaged by condensed water. Finally, anemometers and weather-vanes also have to be heated in cold regions to prevent them from malfunctioning and damaging the turbine.

**FORCES ACTING ON A WIND TURBINE**

There are two main forces that act on a wind turbine blade that makes it rotate. Since the blade design is somewhat similar to that of an airplane wings, the concepts of lift and drag are very important and decide the input efficiency of the wind turbine.

1. **Lift**

When a fluid like air when flowing around or over an object exerts a force on it, that component of the force that is perpendicular to the oncoming flow direction is called the lift. Lift conventionally acts in an upward direction in order to counter the force of gravity, but it can act in any direction at right angles to the flow.

Diagram

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**Fig. (2.1): Lift created due to high pressure low velocity or low pressure high velocity**

1. **Drag**

The force that opposes to the motion of the rotating object under the influence of the acting fluid such as air is called drag, it is also the horizontal component of that exerting force.

![Diagram

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AAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAMjAyMTowNToxNiAxMjoxMjo1MQAyMDIxOjA1OjE2IDEyOjEyOjUxAAAAAAYBAwADAAAAAQAGAAABGgAFAAAAAQAAEZQBGwAFAAAAAQAAEZwBKAADAAAAAQACAAACAQAEAAAAAQAAEaQCAgAEAAAAAQAAHO0AAAAAAAAAYAAAAAEAAABgAAAAAf/Y/9sAQwAIBgYHBgUIBwcHCQkICgwUDQwLCwwZEhMPFB0aHx4dGhwcICQuJyAiLCMcHCg3KSwwMTQ0NB8nOT04MjwuMzQy/9sAQwEJCQkMCwwYDQ0YMiEcITIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIyMjIy/8AAEQgAdAEAAwEhAAIRAQMRAf/EAB8AAAEFAQEBAQEBAAAAAAAAAAABAgMEBQYHCAkKC//EALUQAAIBAwMCBAMFBQQEAAABfQECAwAEEQUSITFBBhNRYQcicRQygZGhCCNCscEVUtHwJDNicoIJChYXGBkaJSYnKCkqNDU2Nzg5OkNERUZHSElKU1RVVldYWVpjZGVmZ2hpanN0dXZ3eHl6g4SFhoeIiYqSk5SVlpeYmZqio6Slpqeoqaqys7S1tre4ubrCw8TFxsfIycrS09TV1tfY2drh4uPk5ebn6Onq8fLz9PX29/j5+v/EAB8BAAMBAQEBAQEBAQEAAAAAAAABAgMEBQYHCAkKC//EALURAAIBAgQEAwQHBQQEAAECdwABAgMRBAUhMQYSQVEHYXETIjKBCBRCkaGxwQkjM1LwFWJy0QoWJDThJfEXGBkaJicoKSo1Njc4OTpDREVGR0hJSlNUVVZXWFlaY2RlZmdoaWpzdHV2d3h5eoKDhIWGh4iJipKTlJWWl5iZmqKjpKWmp6ipqrKztLW2t7i5usLDxMXGx8jJytLT1NXW19jZ2uLj5OXm5+jp6vLz9PX29/j5+v/aAAwDAQACEQMRAD8A9/ooAKKACigAooAKKACigAooAgvLy20+zlu7uZYbeJdzux4AotLu3v7SK7tJlmglXcjqcgilzK/L1NPYz9n7W3u3tfz3sT0UzMKKACigAooAKKACigAooAKKACigAooAKKACigAooAKKACigDyr4xQX62dpcPf5sWmEaWix4+baTuZs/MeOOBj88v+DsF+dOurlb/wD0ETGNrRo8/NtB3K2fl68jHOK820vre/8AXY+0c6P+rvwdbb9b/Ft+HbS56lRXpHxYUUAFFABRQAUUAFFABRQAUUAFFABRQAUUAFFABRQAUUAFFAHm3xm/5Fyw/wCvv/2Rqf8ABr/kV73/AK/T/wCgJXB/zGfI+tf/ACTv/b36no1Fd58kFFABRQAUUAFFABRQAUUAFFABXJXdprJuLox/a1u3vU8m4M7G3W33LkeWrjkIG6gfNyDyKAI7LxvIY4Fv9OaO4MEZlgjf98JWjjfb5R5C5lVAS33uMd61Y/FVhLLMAlwsVvbyz3ErRELF5ZCsuejHO8fLkfu256UAbKSo7FVJ3AAkEYxnpT6ACigAooAKQkDqaAGmaIdZEH/AhSefF/z1T/voUAcD8WLWXUdE0+C22vJ9qLY3AcCNif5Uvwit3tvDl7HJt3faySFYNjKJ6Vw8r+tXPqfax/sD2fXmv+J6DRXcfLBSc59qAFPTiigAooAKKACigAooAKKACse6XxFDcvJZyadc25bIhmV4nUem8Fgf++aqPLf3iZc3QrPrs0S7dX8PXsShgd8KrcxjByD8vzcEA/d4qjbweFdRXUIdP1EQz34CzqLht+AzPtEcmQoJd8gKAdxqnTdrx1RKqK9paMnu/C11Lf8A26HU5Fma5jmcKzRqRvg352nn93BtAPHzHPBq74Zh1yKwf+3roT3RYYxEqBcKM42scgnJGcH2HSszQq+R43y2NQ8PkZ4/0Gbp/wB/aq39h47uNNuYU1fQ0keJlXyrCZWyQcYbzvlPv2oAp6D4c8e2+lxw6t41ieYDkxWCOy+29sbvqVzWn/wi2qyj/SfGmtt7Qx20Q/SLP60AUb/QfDWnLv1nxLqQA6/atdmiB/BXUfpWP5fw7mP+iabf60w/54xXV2p/4ExK/rQBIuj6PKR9j+E4cY4e8htYv5szfpSt4YDr/wAkv8Lxr/01uYwf/HYD/OgDE1mybRBFPb+GND0x5GKM1lqETFwRypWSILj369Pel0W2mlinuLWx15gZBul0XUIFWI7F+UxgpGx75CnrjtXJe+I/4b/hz6DlSyfmXV/3u/ry/hc1B4jv9NbD+KLyzP8Azz8S6PtX/v7EEX8cmt+18W6rHAs97oqXtoR/x+aJci6Qj1KHa4/DdXWfPm7pPiHSdcVjp19FO6f6yLO2SP2ZDhl/EVp0AFFABRQAUUAFFABRQAUUAZXiLW4vD2iTajKqP5ZVVjeZYg7EgAbm4HXP4VA3izSl3nzJCiqCJBGdjkqjgBunIkU+nPXigClaeO9KuH/ekwpLKi2xY/NKrRRPux2/1qjAye/rhfEeqaT9nvI5tLTUZ7c+UqSwjY0u1W2byDg7WDZHbOMkEU03HVA0tmWY/C1vCiNYXd/pr7eUt7ksgP8AuvuX9BSiDxPZ7RHe6fqSDqLiJrd/++l3D/x0Vpzxl8a+ZnytfCzmpNb8f20pW9srG2jLECWOwkuFA7E+XKW/8dFD3uva/p9zZ2vjHQEnmieNYo7CSKUMQRxum3KffHFDpveOqGprZ6Ms6F4N8U2mmxwar491GeXA3eRBCNvsHdGY/U1en8HaRHC02s6tqt3EB8zXmpOifiEKr+lZFmZbaj4B0uQpoWlQahcrxjSrH7QxPvIAVH/AmFav9oeMNRGLHRbLSYSeJNSn82QD/rlF8v8A5EoAydU8i0mEPiLx3evct0sdMVYWb6RxhpT/AN9VkS2mjyEPD4LurjdyJ/EOo+Ure+2R3f8ANBQDdjl/GVvBDp1uYtH8OWGZcZ0uRnkPB4YmNBj+tHg+0hm0yaR9K0+7YTYEkmrSWU44HC7VwR16sOSa4eVrGWa6H1fPH/Vy9/tfqdRFfS2aHZe+KdLjA5+0JHq1r+JQu4H1K1HBbR3TSX9nYWGolT8+o+E7z7PcD3eAttP0LN9K7j5QUn+2bjaDb+Ibi3/hbOm6xbD2+6H/APHAfetXSvEWqW9x9kstQGqSLy2lawn2PUEH+y+Nsv5Y/wBugDpNP8ZaVeXi2F0ZtM1JulnqCeU7f7p+6/8AwAmuhoAKKACigAooAKKACigCKa2guJIZJokd4H8yIsMlG2lcj0O1mH0JrltRHg+406fTprm1s4hcGAkYiKyoqkhdwwcKijoRgY9qHtqNFyysPDK2cDJLZ3AhjW5E8kiltoUASEj+HCKOw+Uegq1Da6DqN/cXUVvay3TfJJJsGX+VDnPcY8vkegHanZ3ZJsUUhnMsnjhnO2fw8i9swzMf/QhVHUfDPiTWrd4dR1TRCrAgbNJLMPoXkOD74pptO6E0nozM8K/DfV9K0byNT8X6o1w45Szk8uOP2GRk/XiqmoeHNL8KMt3q13oepN1V9clfzmPopZnBP0WtOeMvjXzI5XH4TUh8dXsukJLpnhC/ALbVZ4XjgA/vDCFyvuEplrKniJGbWvGUWzBL6dprG0AA6hiT5rf+O/Sk6bteOqGqi2ehRbULPTle28O2EOm2xPzSRoBLL7luv58+9ZhJZizEsxOSxOSfxrvoUVBXe54+JxDqystjnfF3/Hjb/wDXT+lO8Jf8g6b/AK6/0Feb/wAzT5fofZS/5JFf4/8A246AfKwZflYdCOCKbLFBczie5gWS4H3blWMc6/SVCH/Mke1epVoxqLzPi6OInSemxdeOfVI44Jjba2qHMdvqZEF3Gf8ApjcoACfTIU+9Mkb7UyaTM63r5ymjeJ08q5yP+fe5HDn0I3f7wrzJwcHZntU6kakeaI8ytuGkSzFS5wuh+Kk3LIfSC5Gd3ty5+lTQahcaDcR28OoXXh+ZjtTTtdzPZSH+7Fcg/L7Dd/wGpLOnXxmNOIj8TadNpB4H2vPm2bZ7+cowv/AwtdNBPDcwJPBKksTjcjowZWHqCOtAEl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**Fig. (2.2): Drag explained**

**DESIGN**

In this project report a design of a small 6-KW wind turbine is carried out by using MATLAB/Simulink Ra2021and Q-blade build and the required steps are shown and explained.

1. **Airfoil**

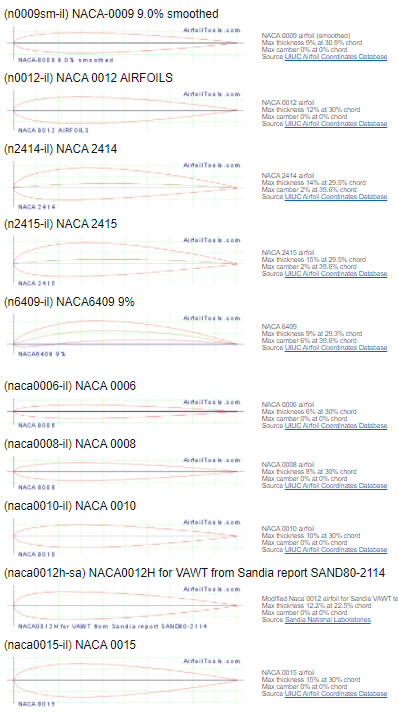
An airfoil is the foundation of wind turbine blade design, it is the cross section of a blade in a wind turbine, or a blade used in helicopters or a wing of an aeroplane and accordingly, we can change the design of the airfoil which can give us better performance and efficiency. An airfoil plays a major role in the input efficiency of the wind turbine. An arifoil with 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 or the mechanical input that is given to the generator via the rotatory shaft.

Diagram

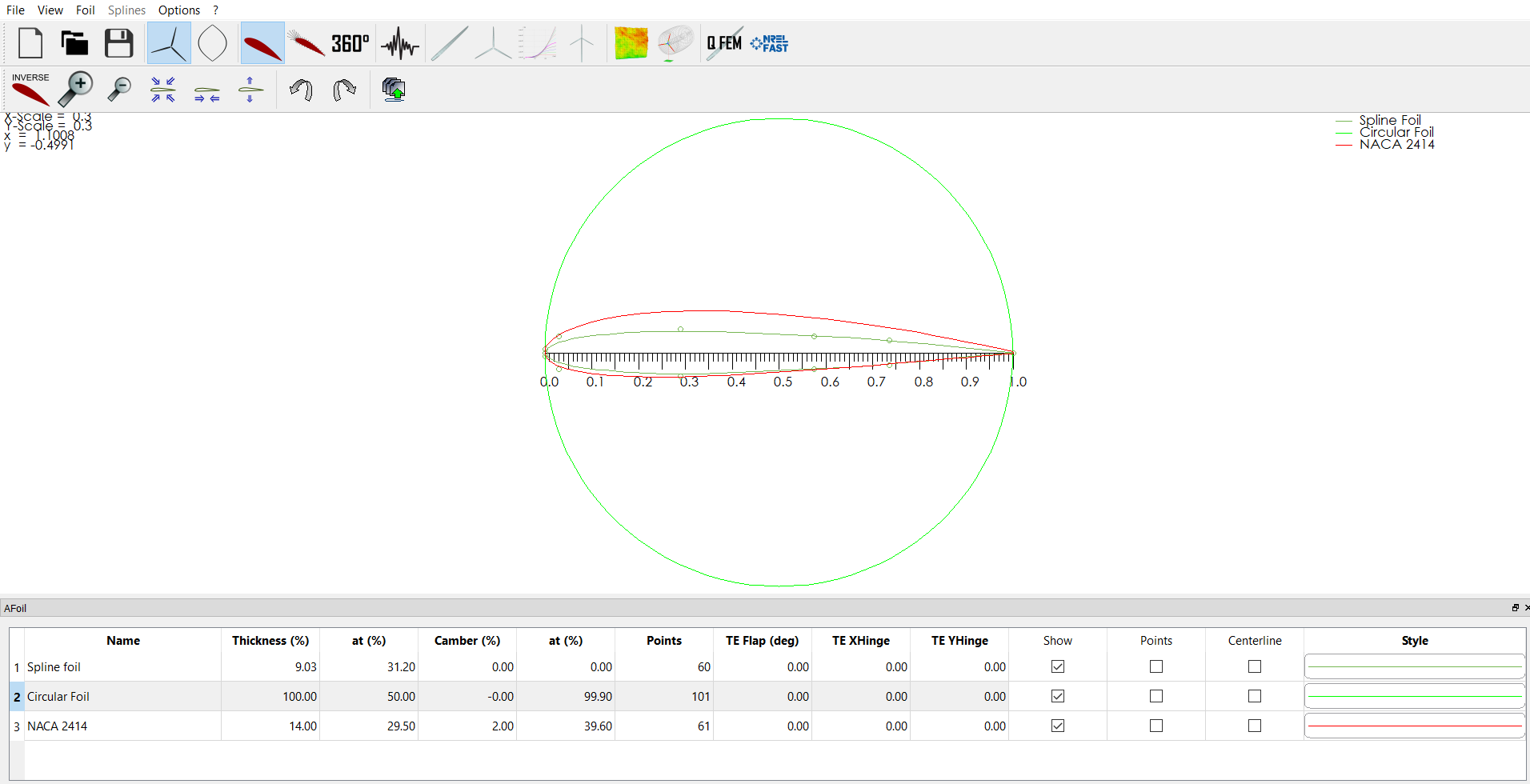
Description automatically generated

**Fig. (2.3): Cross section of an airfoil**

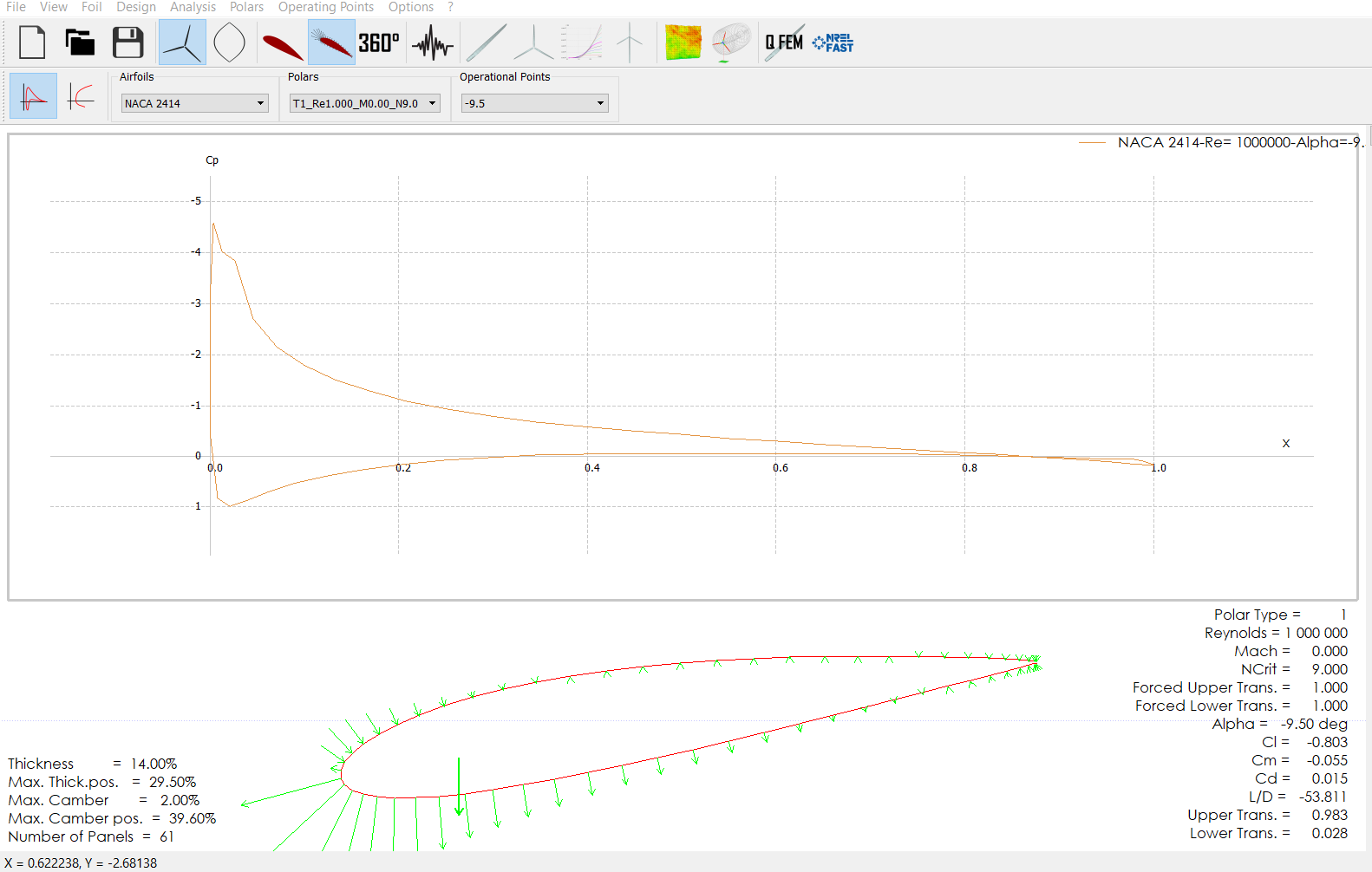
The software that is used to design blades or the airfoil of the blade is Q-blade. This software provides various simulation and designing tools that hold predefined values and data about the various types of airfoil structure that have been used commercially till this date. It also has an inbuilt Cl/Cd or a Cp calculator that can be used to find out the lift and drag ratio of that specific blade or airfoil. A 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.



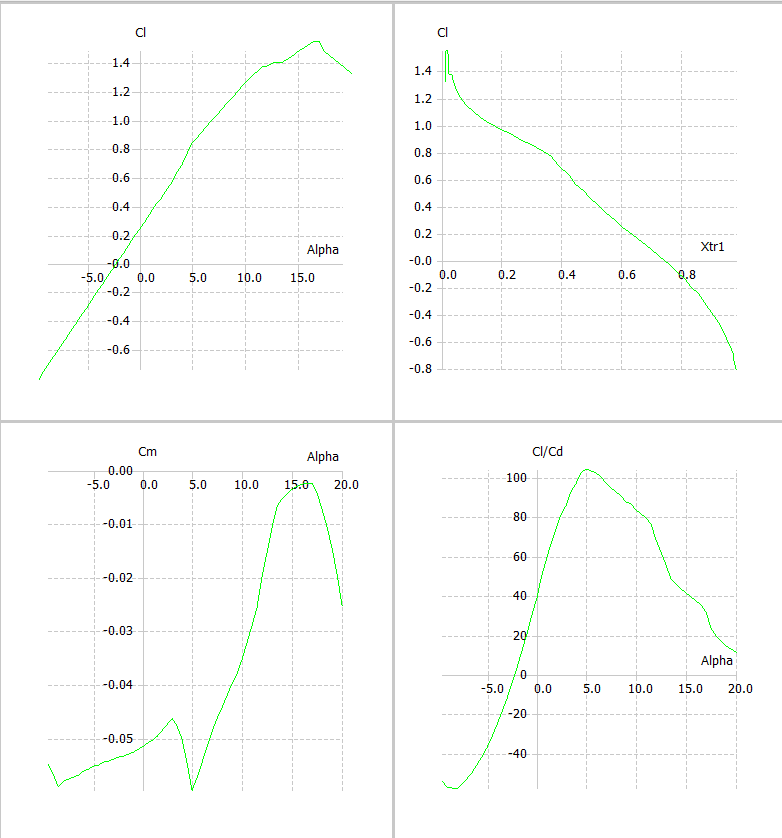
**Fig. (2.4): Different NACA airfoil designs**



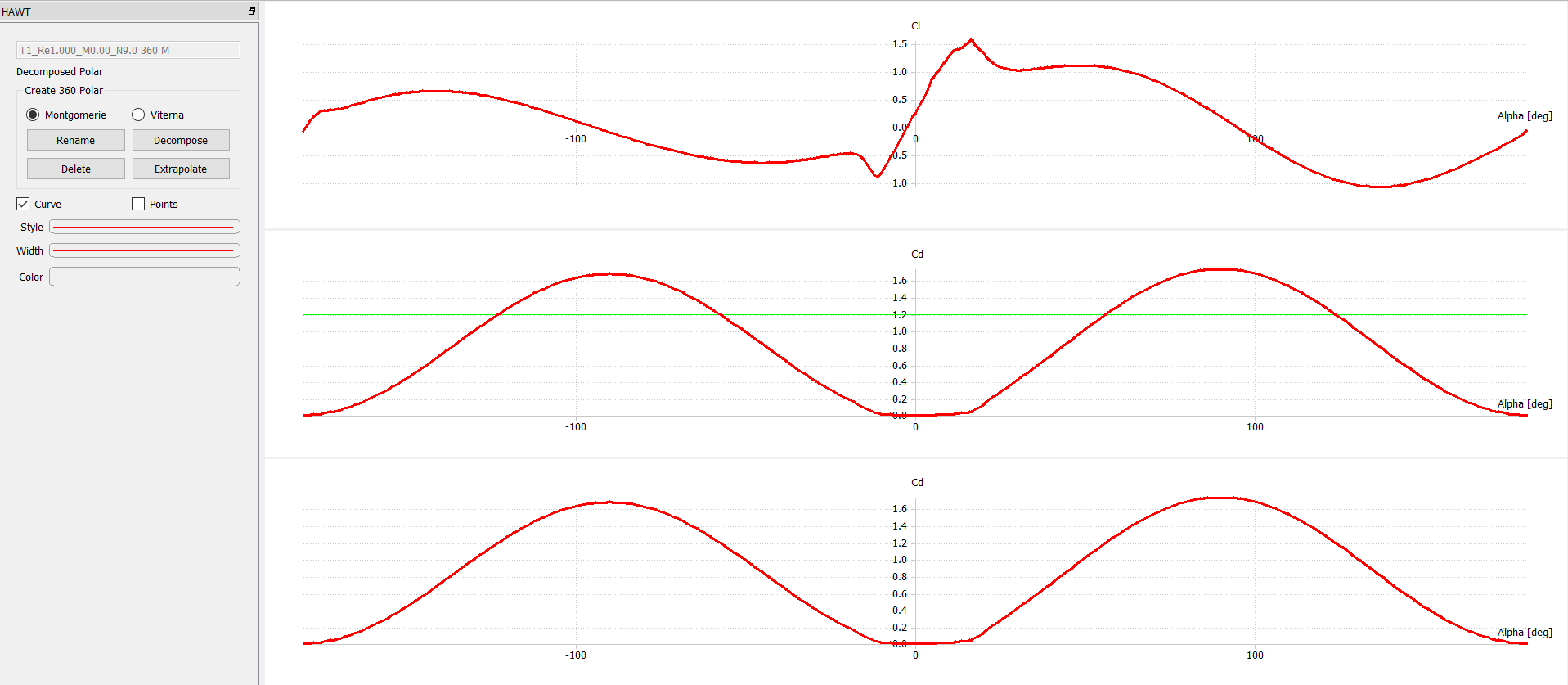
**Fig. (2.5): NACA 2414 airfoil design with the parameters**



**Fig. (2.6): This figure shows the Cp of the NACA 2414 curve along with how the wind will act on it along with the general wind direction represented with green arrows**

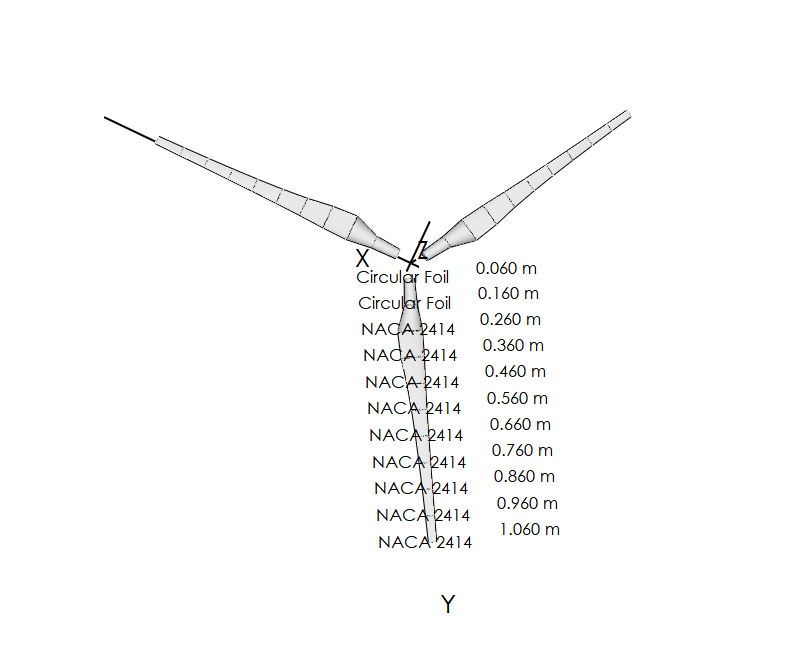


**Fig. (2.7): A graph of Cl and alpha, Cl and Xtr1, Cm and Alpha, Cl/cd and Alpha for NACA 2414**



**Fig. (2.8): Cl and Cd curves of the NACA 2414 airfoil are better compared to other airfoils Cl and Cd curves.**

Henceforth, based on the above parameter the following airfoil or blade design is obtained.



**Fig. (2.9): Scalar representation of the actual NACA 2414 blade/airfoil**

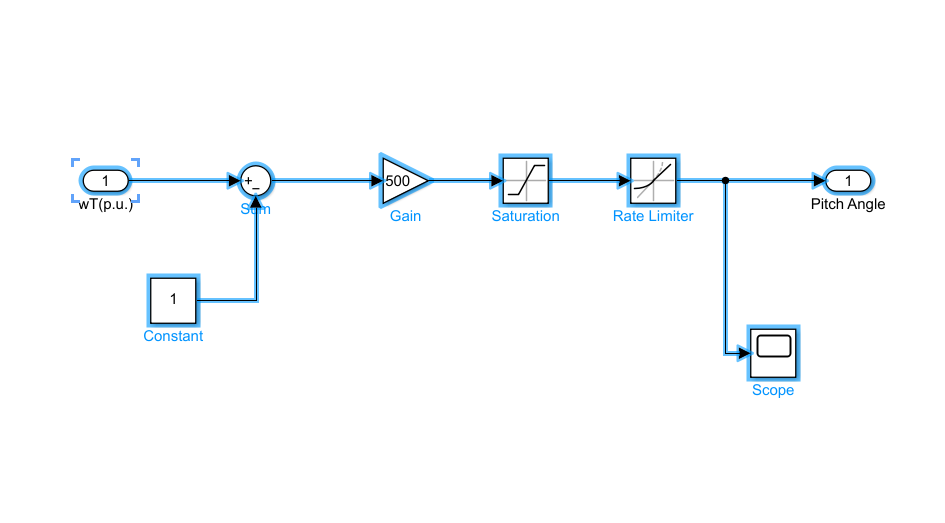
It gives the best overall input efficiency when used with the proposed turbine setup.

1. **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.

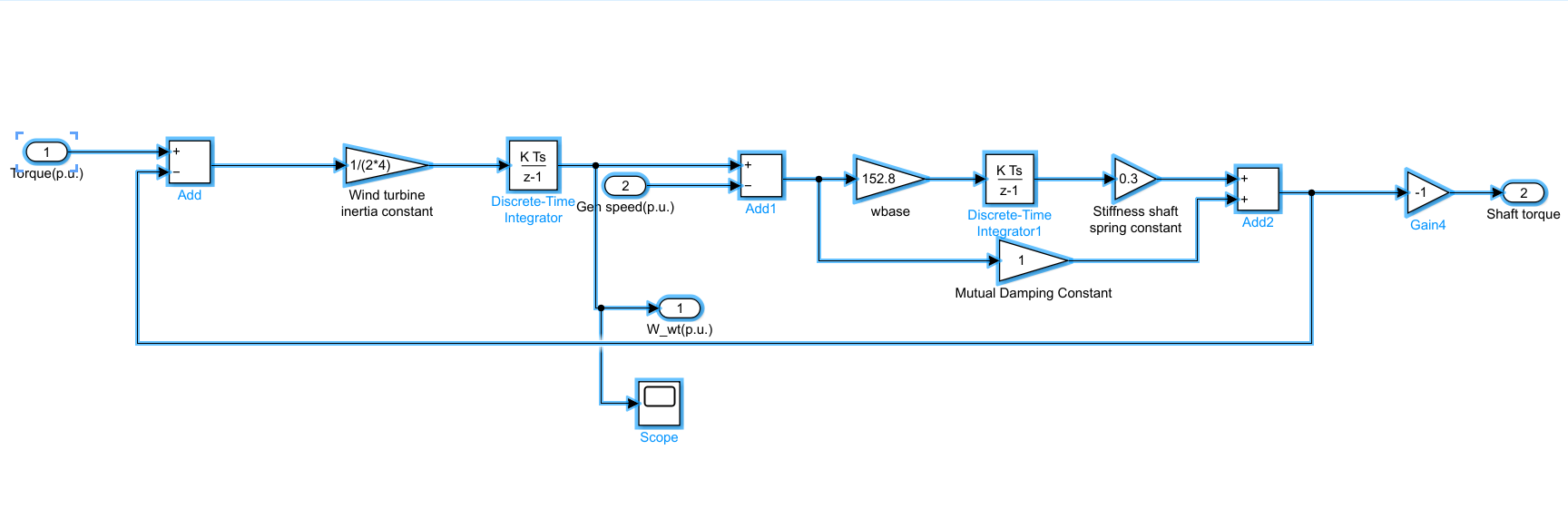
The components mainly have a wind turbine, two mass drive train, substations to get pitch angle, permanent magnet synchronous machine, three phase V-I measurement, three-phase series RLC branch, voltage measurement, current measurement, RMS for voltage and current, first order filter, two products, one 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.



**Fig. (2.10): Substation which gives pitch angle**

In the two-mass-drive train, the components used are one input as the torque of the wind turbine, two additions, a gain which is the wind turbine inertia constant, two discrete time integrator, a gain of 152.8, a gain of one which is a mutual damping constant, a gain of 0.3 for stiffness shaft spring constant, another input of the generation speed, a gain of -1 and a scope which gives the shaft torque and another output of the work done in the wind turbine.



**Fig. (2.11): Two-mass drive train**

* 1. **Pitch Angle Control**

Pitch control is the technology used to operate and control the angle of the blades in a wind turbine. The system is in general either made up by electric motors and gears, or hydraulic cylinders and a power supply system. The purpose of the control can be summarised in three aims as following:

1. Optimising the power output when a wind speed is less than rated wind speed.

2. Keeping the rotor power at design limits when the wind speed is above rated wind speed.

3. Minimize the fatigue loads of the turbine mechanical components.

The design of the controller must take into account the effect on loads

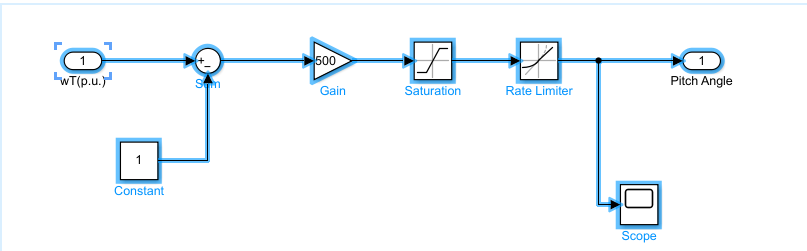
The pitch control method is a basic approach for controlling the rotational speed of wind turbine. The conventional blade pitch angle control strategies are developed in this part. The pitch angle reference is controlled by the input values. The direct measure of the wind speed makes this control strategy simple; however this is not a pertinent procedure, because it is difficult to measure the wind speed precisely. In fact, when the rotor speed exceeds the maximum rotor speed of turbine Ωtn, the pitch angle is increased to reduce the turbine torque Ct.

The reference rotor speed is compared with the controlled rotor speed. Then the reference pitch angle gets generated when the error signal is sent to the PI controller. It produces the reference pitch angle.

Diagram

Description automatically generated

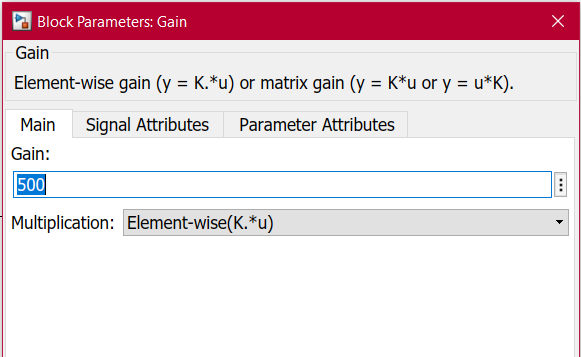
**Fig. (2.12): Pitch angle controller block diagram**



**Fig. (2.13): Proposed PAC design created using Simscape Library of Simulink**

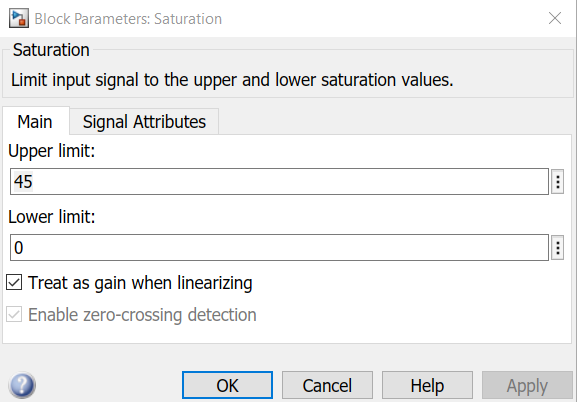
This circuitry consists of a reference input torque from the wind turbine or basically the variance in speed of the wind or rotation in blades which is positively summed to the gain of 500 which is element wise gain (y = K.\*u). This is then connected to a saturation block which just limits input signal 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 is 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 the mechanical energy and hence wind turbine systems are operated at its maximum power point. Hence it is very crucial to have a MPPT procedure, PAC in this case to make the turbine operate at its maximum power point or optimal power point.

* Gain Block



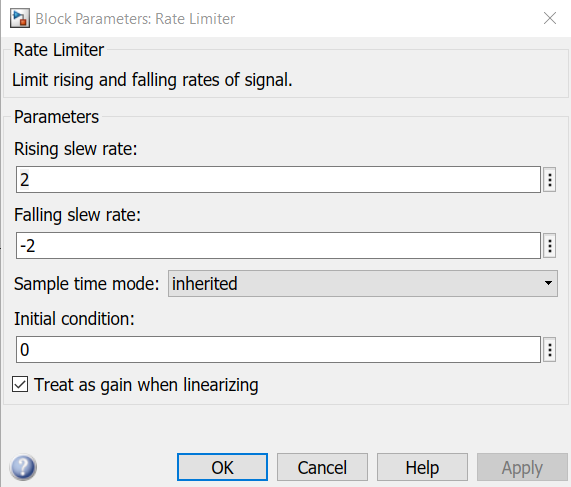
**Fig. (2.14): Gain block in Simulink**

* Saturation block

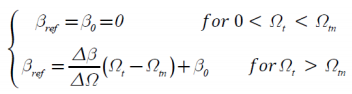


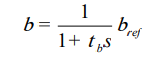
**Fig. (2.15): Saturation block in Simulink**

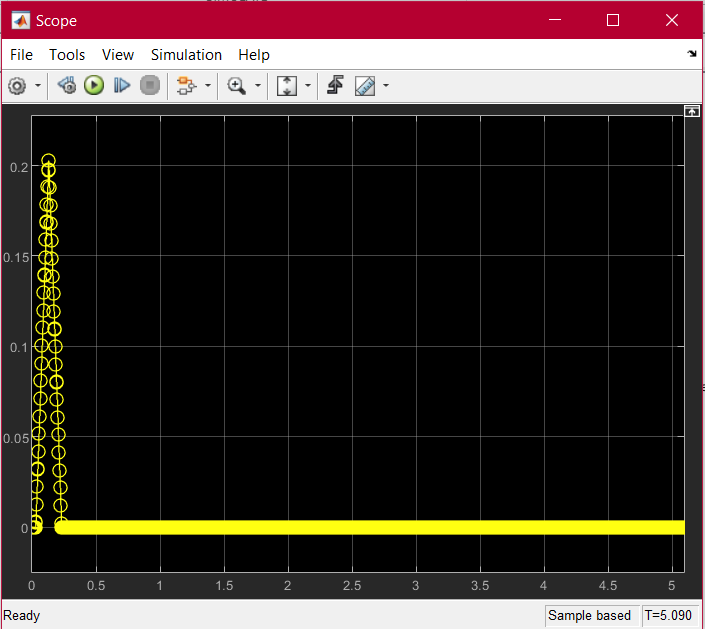
* Rate Limiter

****

**Fig. (2.16): Rate Limiter block in Simulink**

 (2.1)

 (2.2)



**Fig. (2.17): Graph showing the graphical output of the PAC controller.**

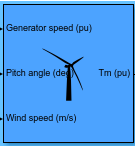
Chart

Description automatically generated

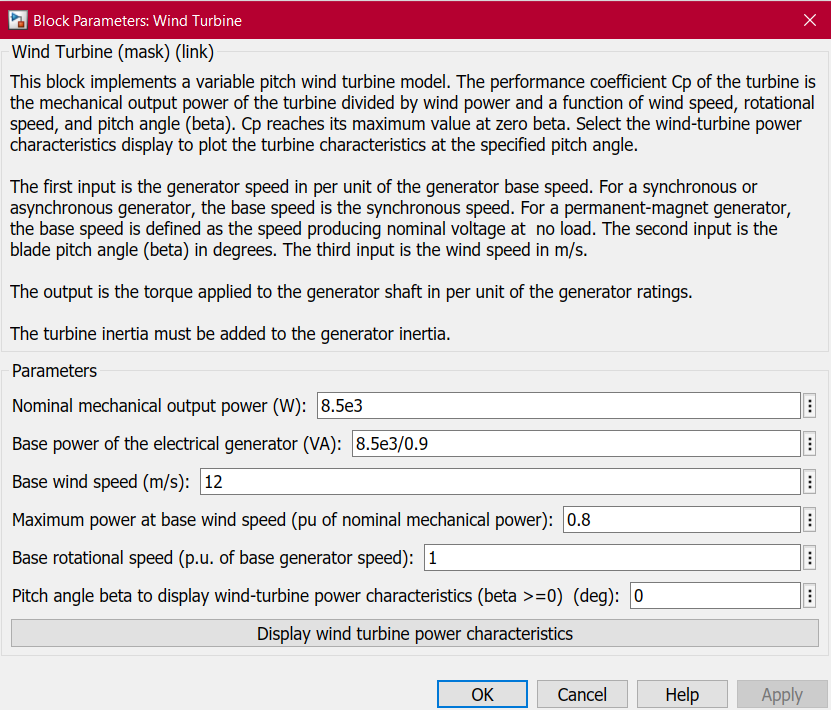
**Fig. (2.18): Graph showing the turbine power characterestics**

* 1. **Wind turbine function Block**

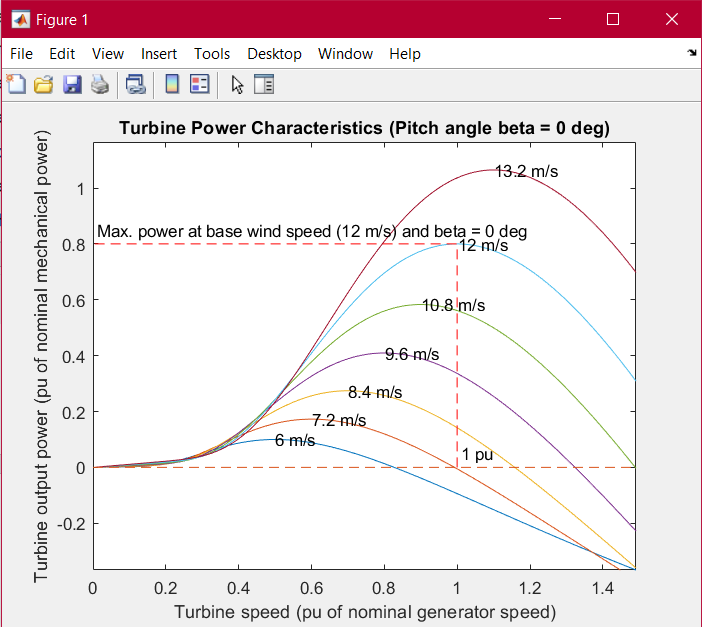
The MATLAB/Simulink 2021 offers a predefined function block that acts a wind turbine considering every parameter like wind speed(m/s), torque(pu), pitch angle(deg) and generator speed(pu).



**Fig. (2.19): Representation of wind turbine in Simulink**



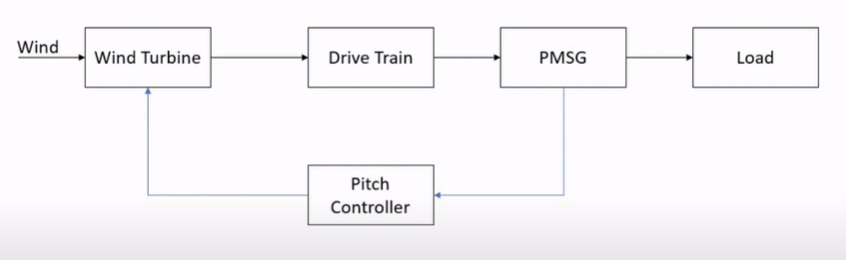
**Fig. (2.20): Wind turbine parameters block**



**Fig. (2.21): Turbine Power Characteristics Graph**

* 1. **Two-Mass Drive Train**

A drive train is there to help transfer the torque from the turbine blades to the generator.



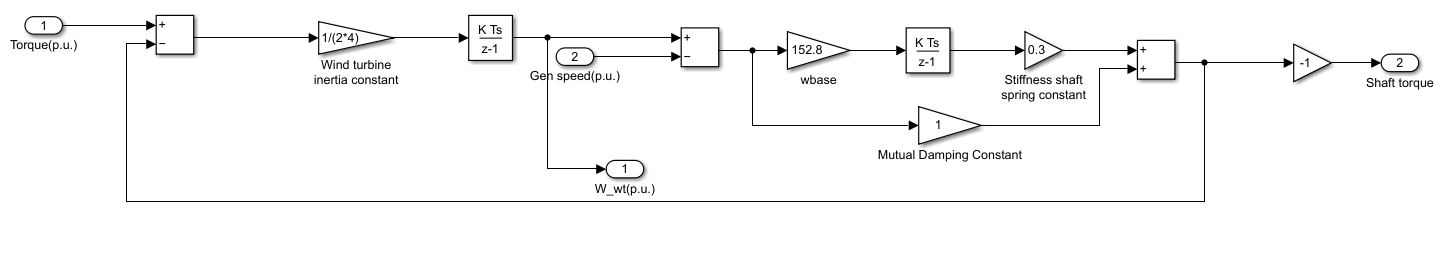
**Fig. (2.22): Wind turbine power generation system block diagram**

2Ht dwt/dt = Tm - Ts  (2.3)

(1/webs)(dθsta/dt) = wt - wr (2.4)

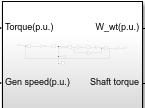
Ts = Kssθsta +Dt(dθsta/dt) (2.5)

Proposed model for drive train is shown below. The two inputs are torque(pu) and Gen. speed(pu) and the two output are shaft torque and W\_wt(pu).

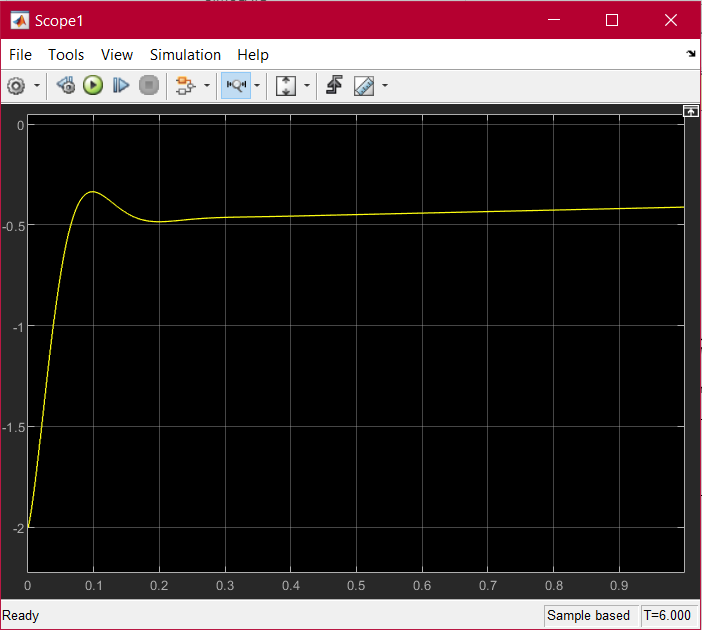


**Fig. (2.23): Two mass drive train in Simulink**

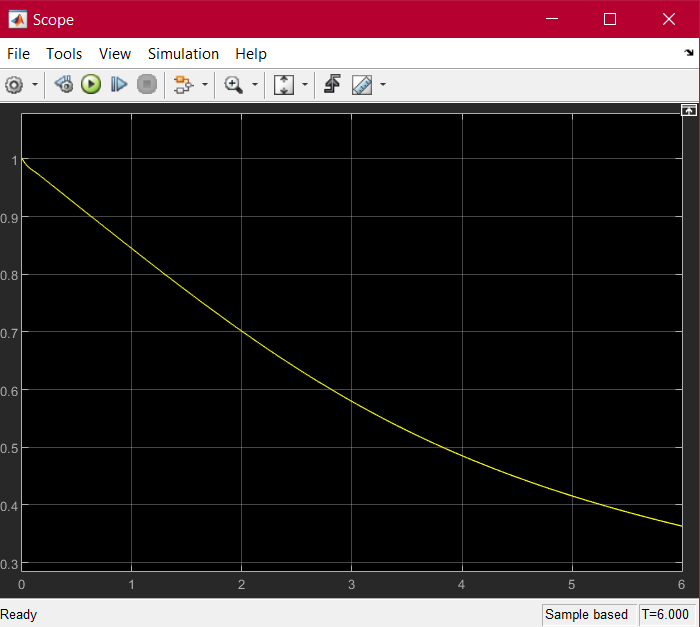
In the above model the torque input is given to the gain that is the wind turbine inertia constant which is then transferred to the wBase gain of the turbine which is then summed with mutual damping constant and the stiffness shaft spring constant, all of this along with the inverse gain is the shaft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



**Fig. (2.24): Representation of two-mass drive train in Simulink**



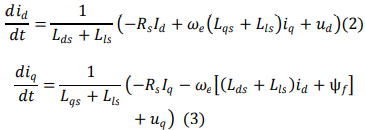
**Fig. (2.25):**

****

**Fig. (2.26):**

* 1. **Modelling of the 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 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:

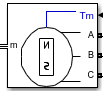


Here subscripts d and q refer to the physical quantities of rotating reference frame; Rs is the stator resistance, Ld and Lq are the d and q axis inductances of the generator, Lld and Llq are the d and q axis leakage inductances of the generator, ѱf is the permanent magnetic flux and ωe is the electrical rotating speed of the generator. The electromagnetic torque equation of the PMSG is given by [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 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.

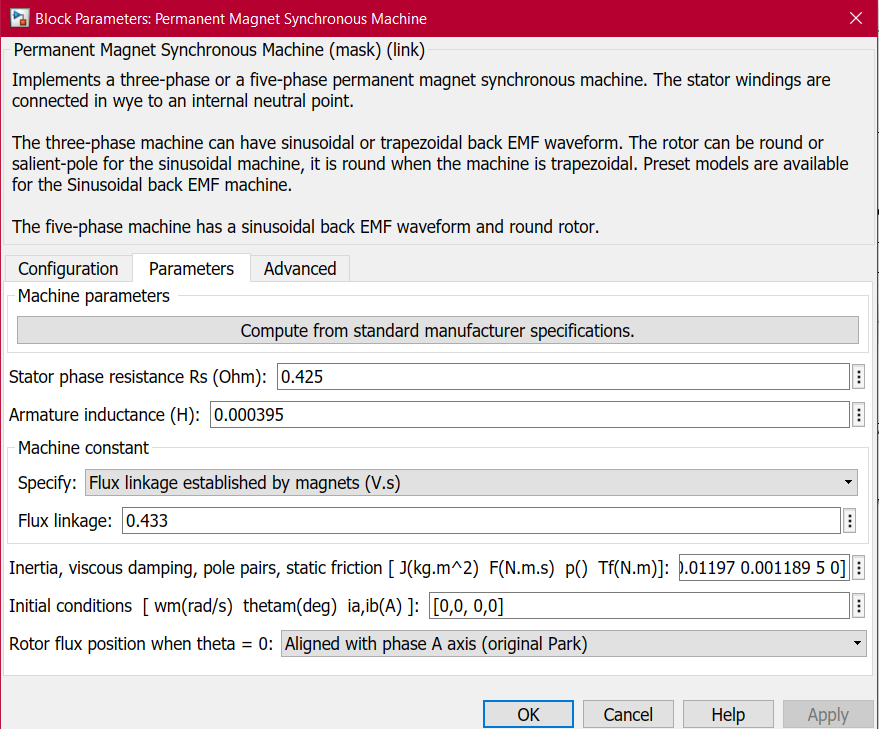
* PMSG function block



**Fig. (2.27): Representation of PMSG in Simulink**

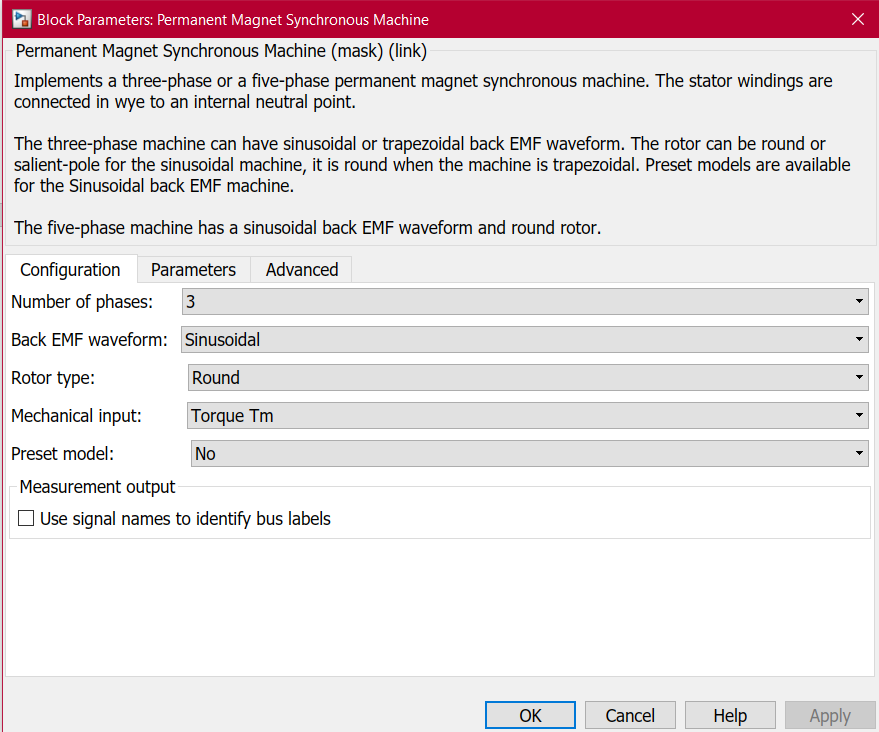
MATLAB/Simulink provide the following PMSG block, It has 3 phase output and a measurement bus and it takes torque from the shaft as the mechanical input

* PMSG Parameters



**Fig. (2.28): PMSG Parameters block**

* PMSG Configuration

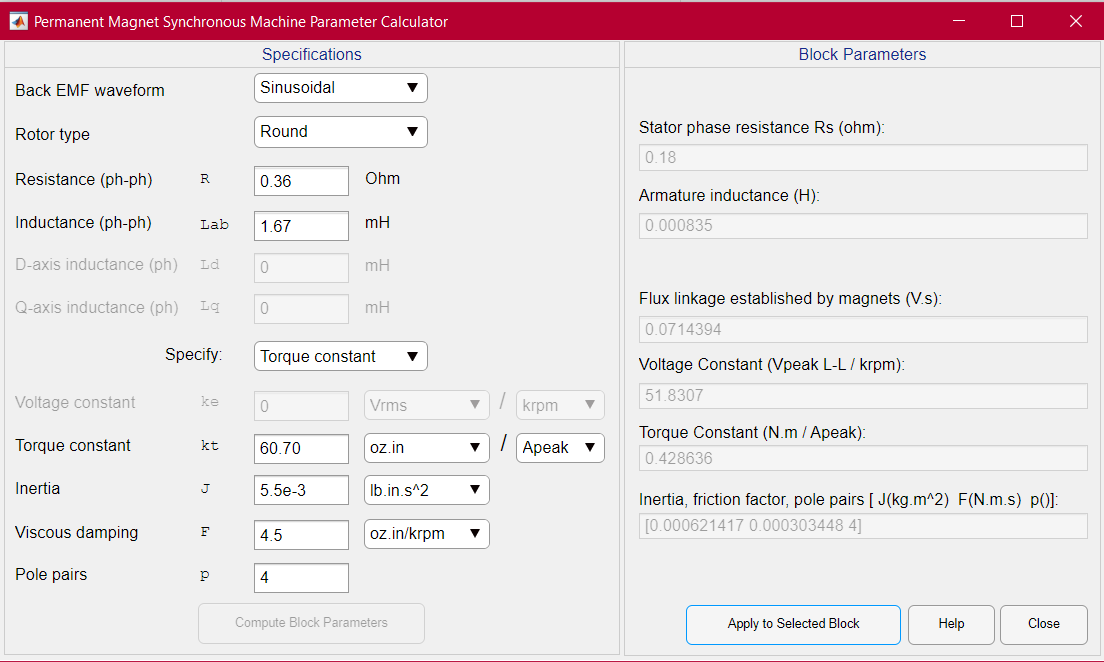


**Fig. (2.29): PMSG Configuration block**

* PMSG Specifications

|  |  |
| --- | --- |
| **PARAMETER** | **RATING** |
| Rated Power | 6 kW |
| Rated Line Voltage | 293.4 Vrms |

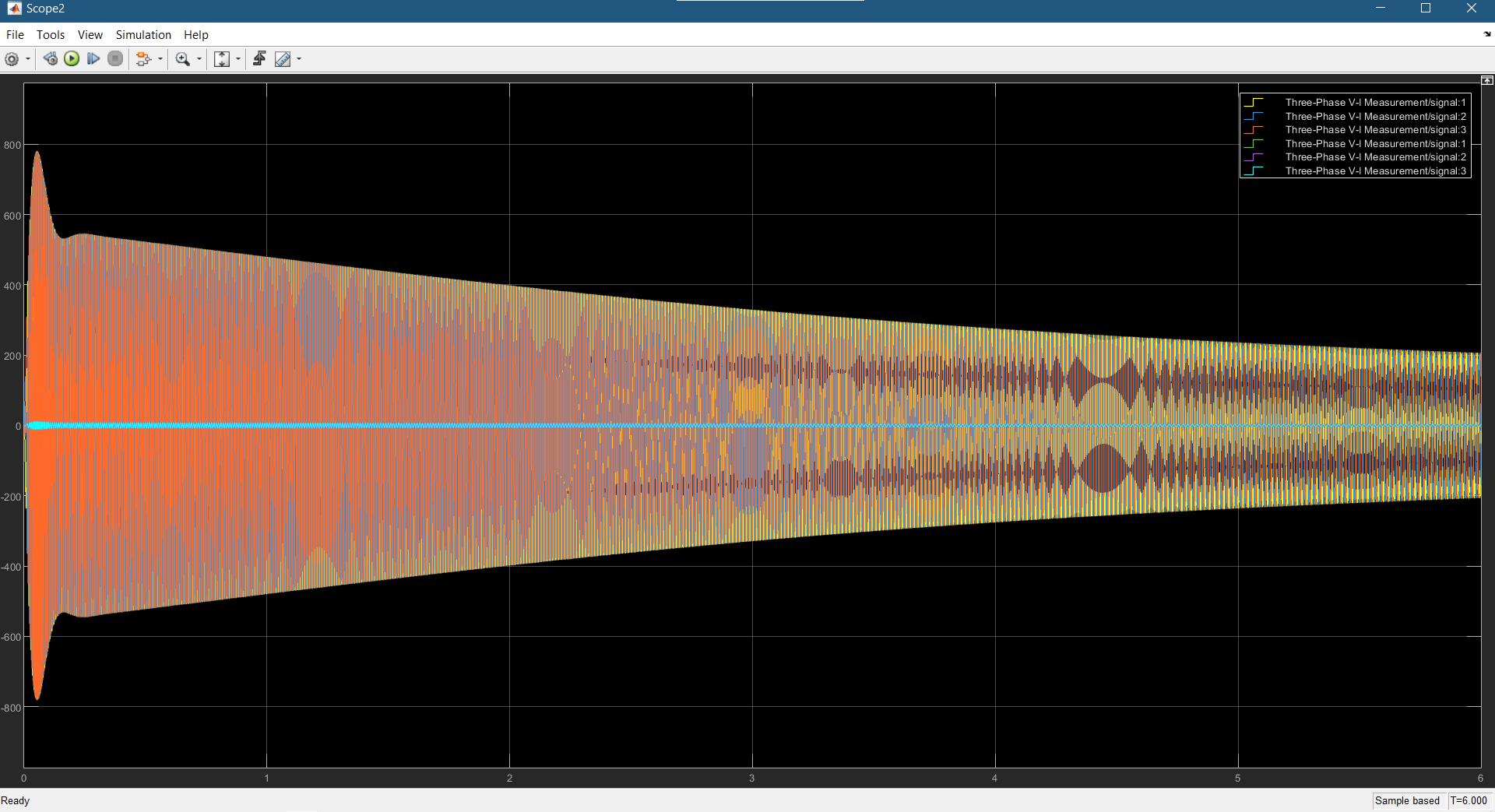
**Table (2.1): PMSG Specifications**



**Fig. (2.30): PMSG parameter calculator block**

* 1. **Measurement Block Voltage-Current**

The 3-phase output from the generator is recorded by a current and voltage measurement block that is connected to a scope where the current and voltage waveforms can be obtained.

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**Fig. (2.31): Voltage Current graph**

* 1. **Three phase series RLC Branch**

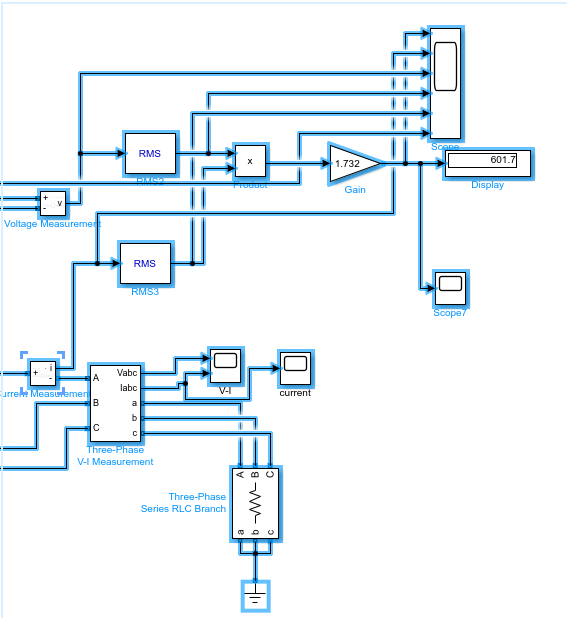
A three phase RLC Branch is used to filter out the harmonics and is connected to the V-I measurement block.



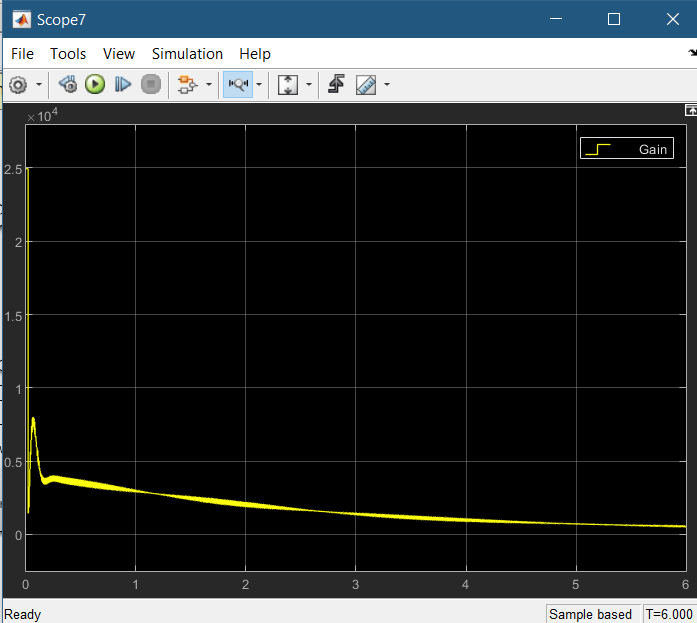
**Fig. (2.32): Reperesentation of RLC Branch in Simulink**

* 1. **Power Output**

The final power output is obtained by taking in voltage signal parts of output from the pmsg and the current from the V-I measurement block or from the pmsg itself and each of their respective rms value is obtained by connecting respective signal to the RMS function block and then their product is obtained using a product function block and then that signal is given a gain of 1.732 and the final power output is obtained.

****

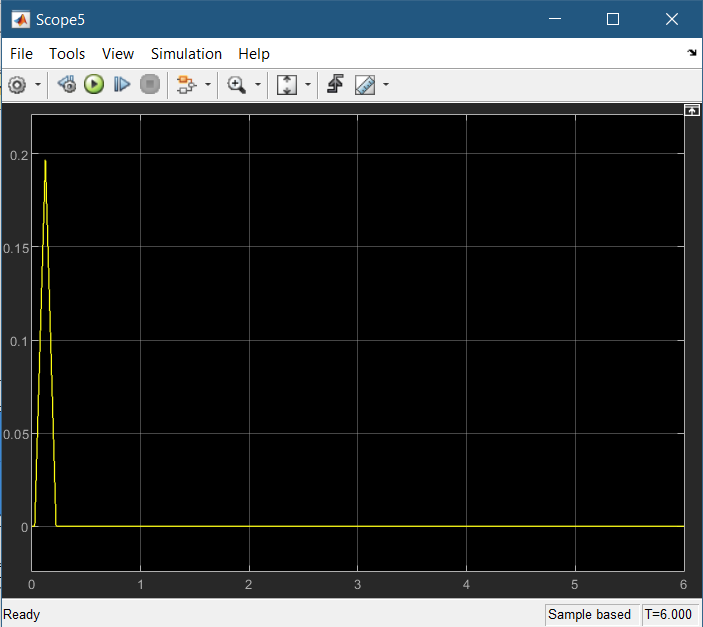
**Fig. (2.33): Power output in wind power generation system model in MATLAB**



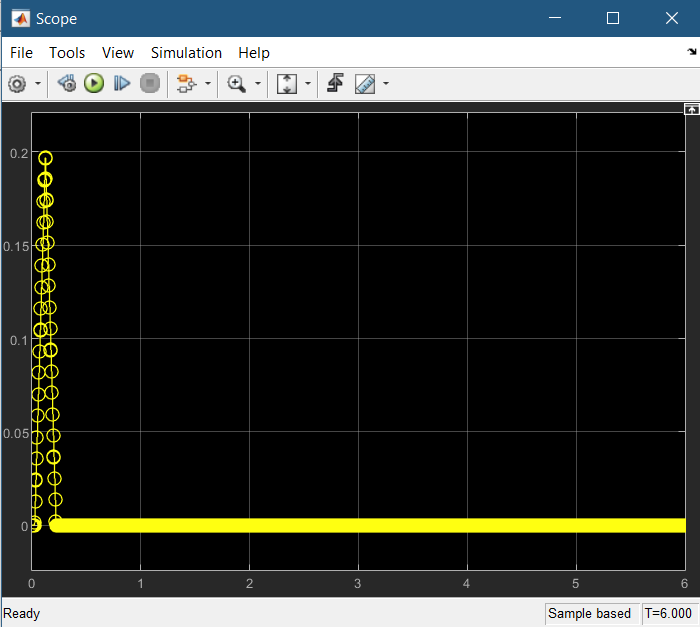
**Fig. (2.34):**

**SIMULATION RESULT**

1. **Pitch Angle Controller (deg.)**

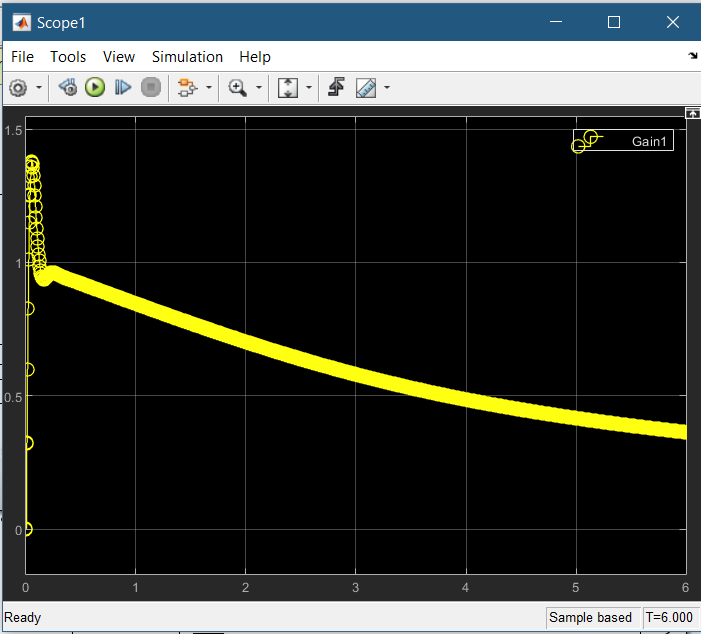
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**Fig. (2.35)**

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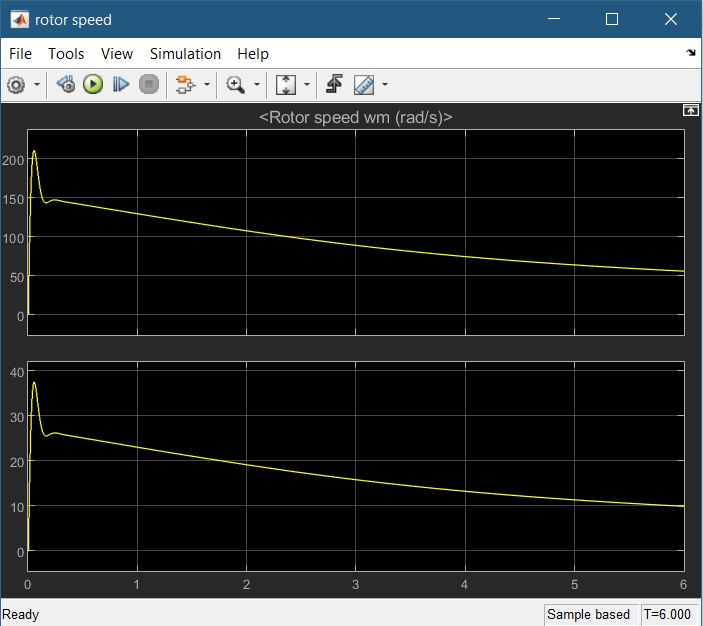
**Fig. (2.36)**

1. **Torque(W\_wT(p.u.)) obtained from Wind blades after going through CS or the input of the PAC**

****

**Fig. (2.37)**

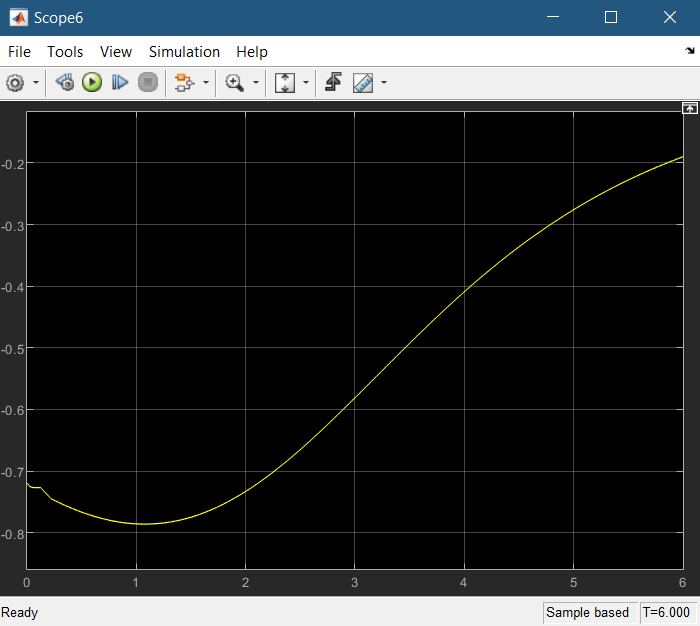
1. **Rotor Speed wm(rad/s)**

****

**Fig. (2.38)**

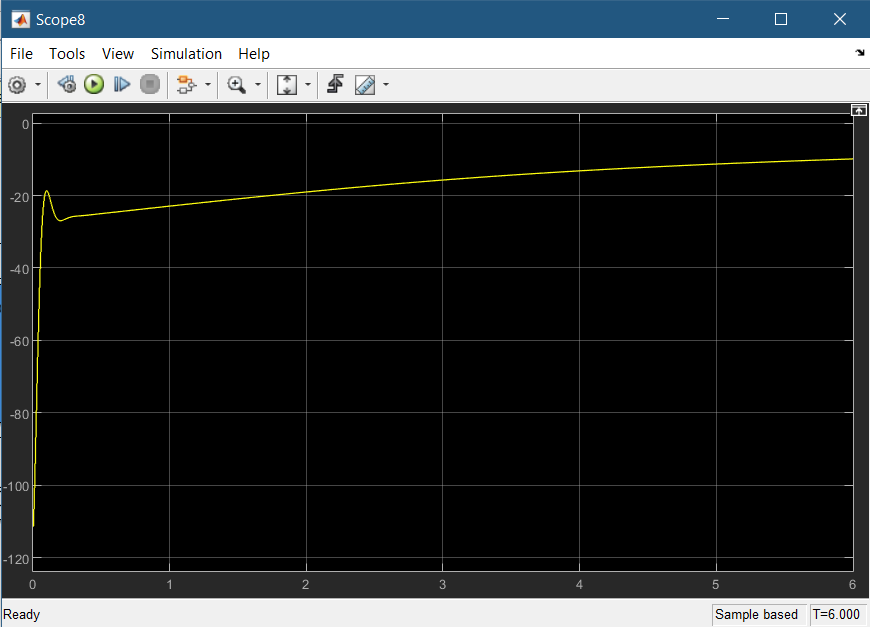
The First part of the graph shows the rotor seed after going through control system and the first order filter and the Second graph shows the output without the control system.

1. **Torque(pu) input to the Two mass drive train**

****

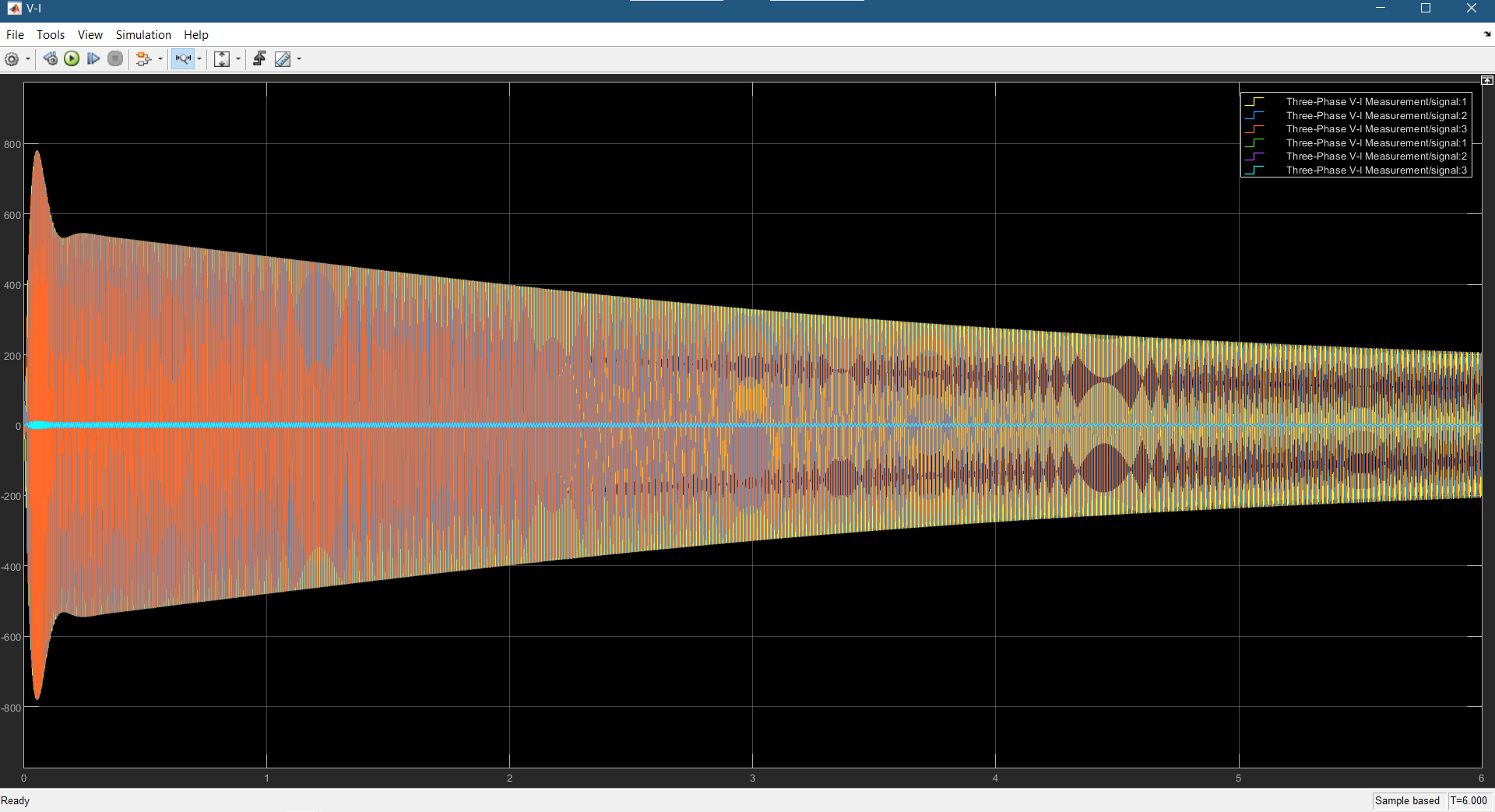
**Fig. (2.38)**

1. **Torque(pu) input of the PMSG or the output of the two mass drive train**

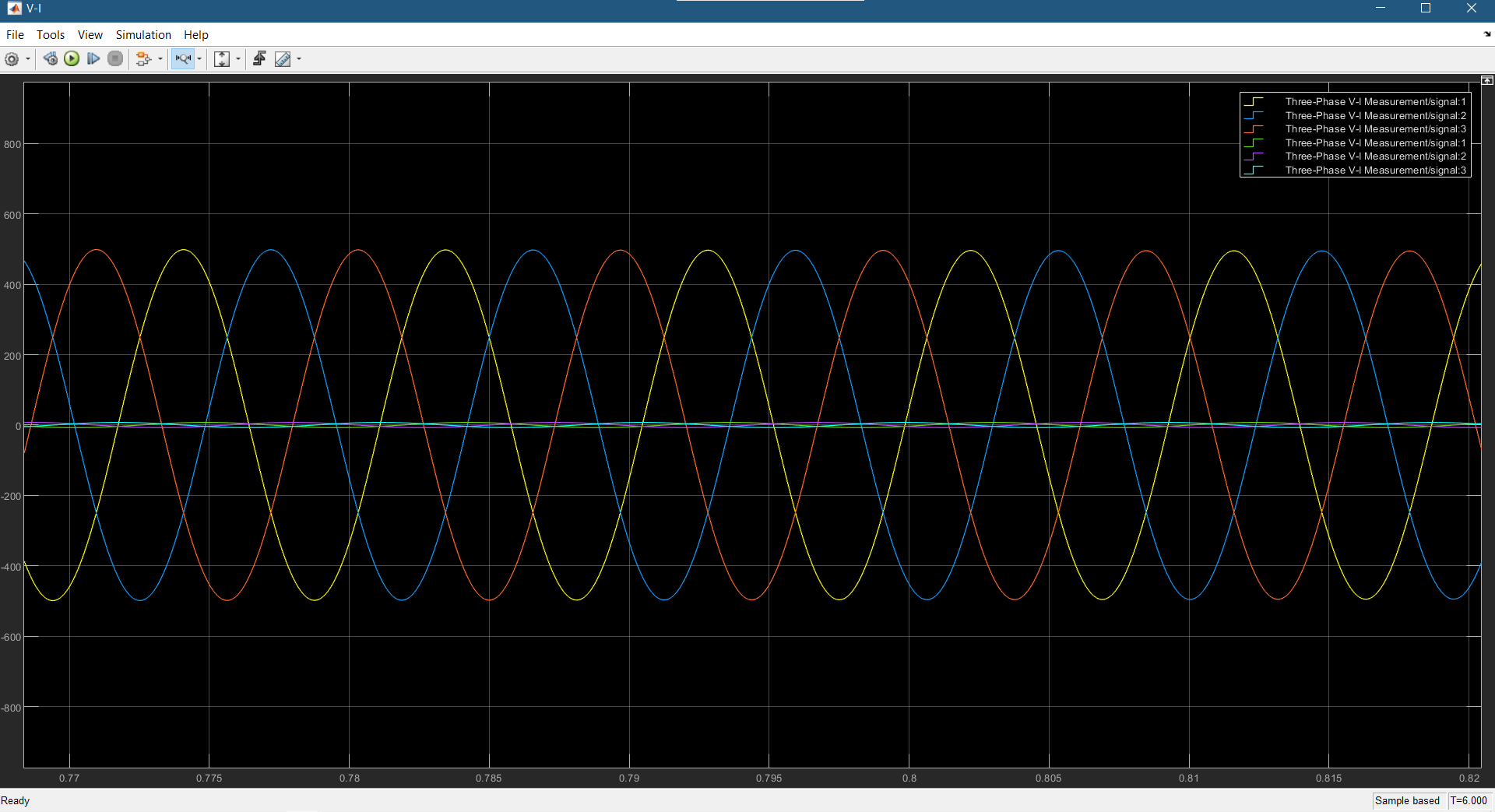
****

**Fig. (2.39)**

1. **Voltage(V) Output of the PMSG**

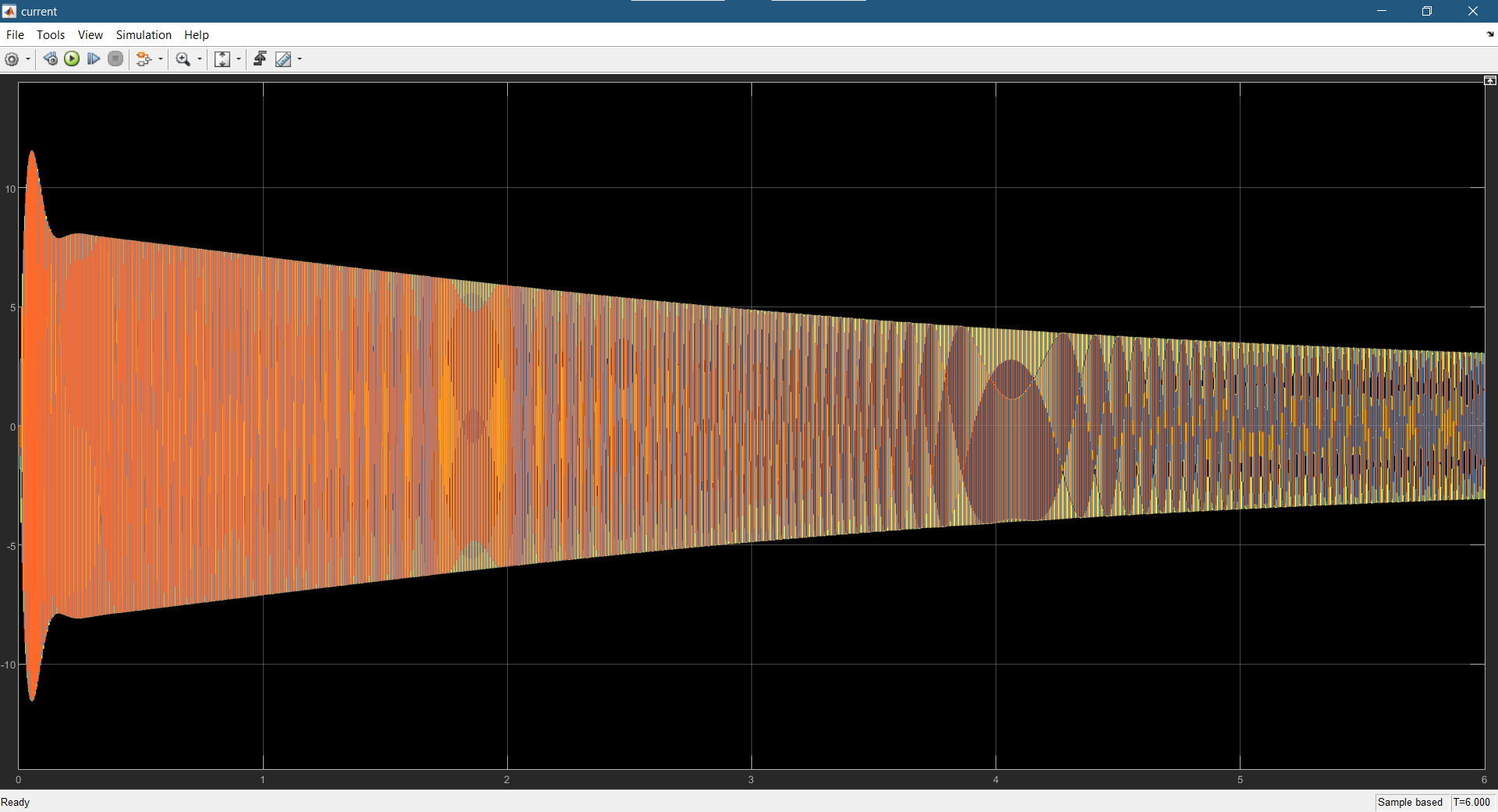
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**Fig. (2.40)**

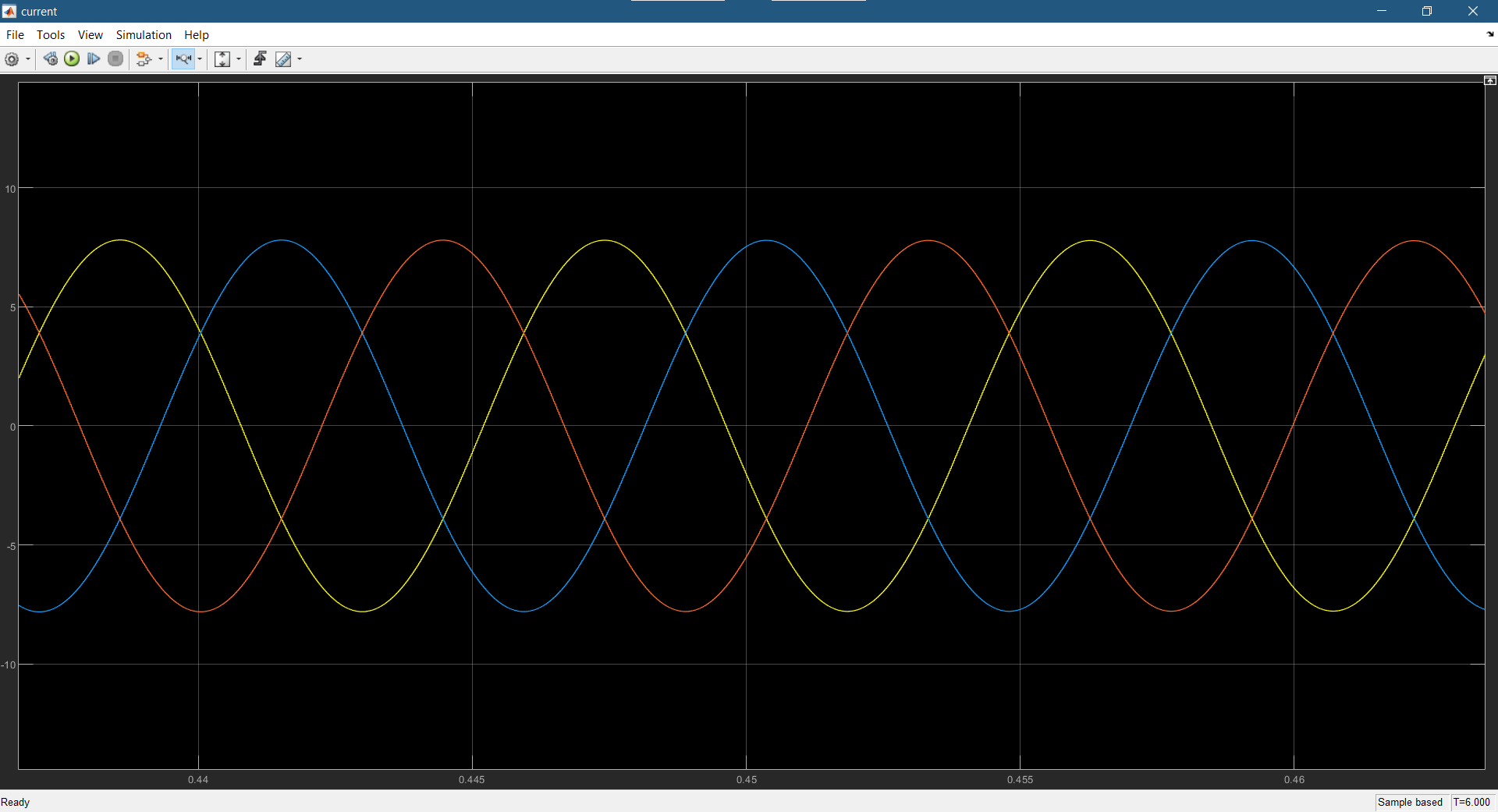
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**Fig. (2.41)**

1. **Current(A) Output of the PMSG**

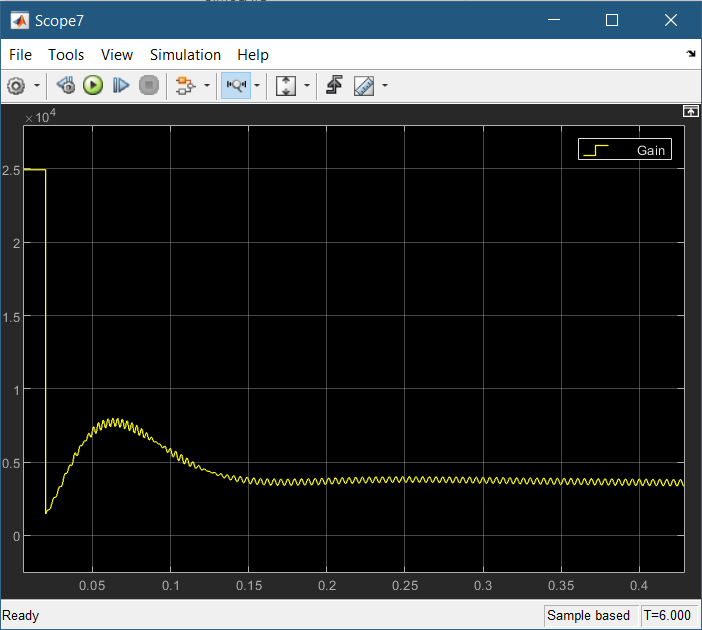
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**Fig. (2.42)**

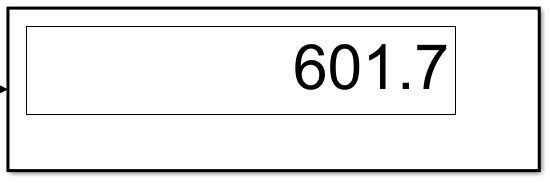
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**Fig. (2.43)**

1. **Power Output**

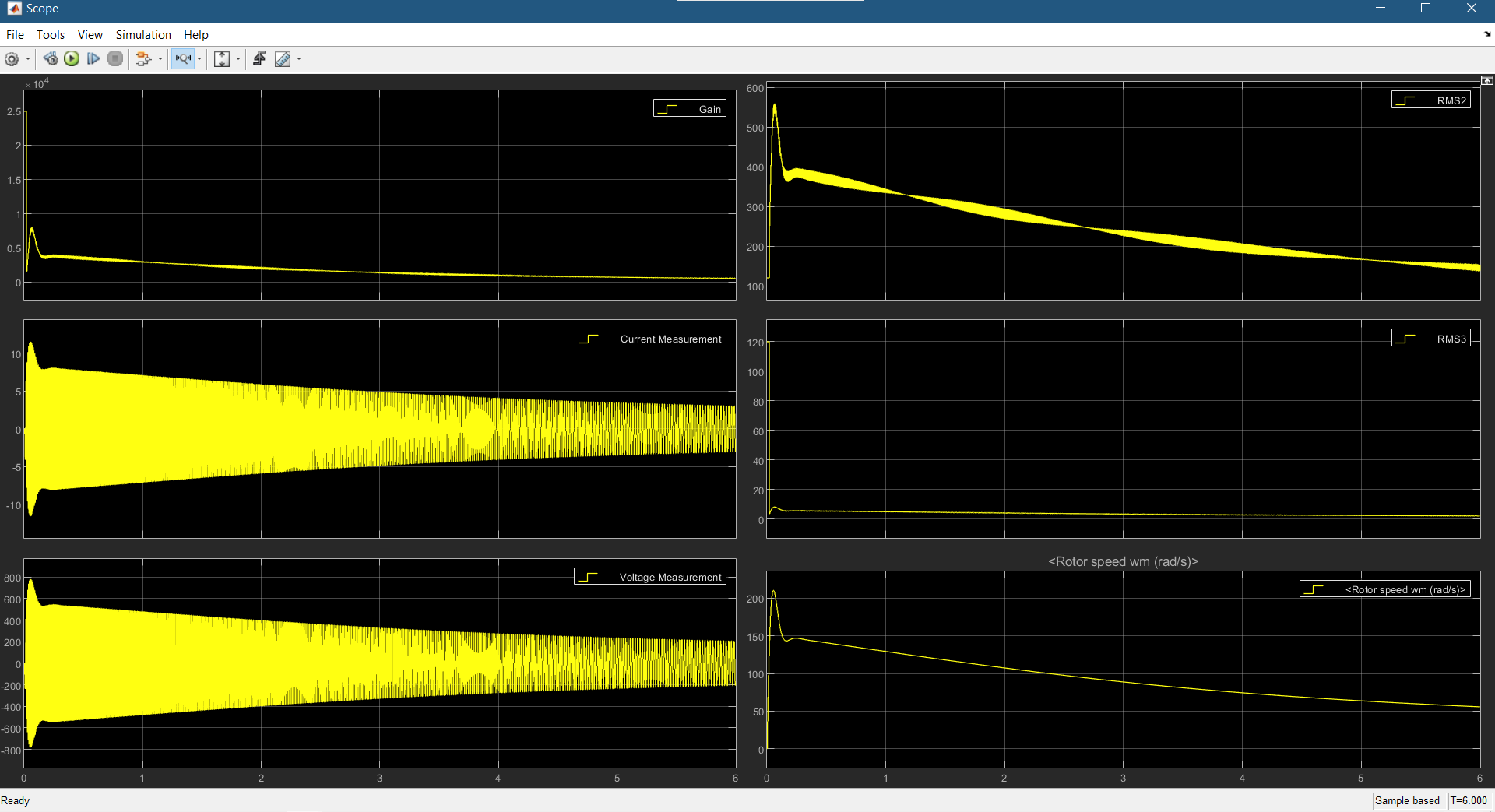
****

**Fig. (2.44)**

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**Fig. (2.45)**

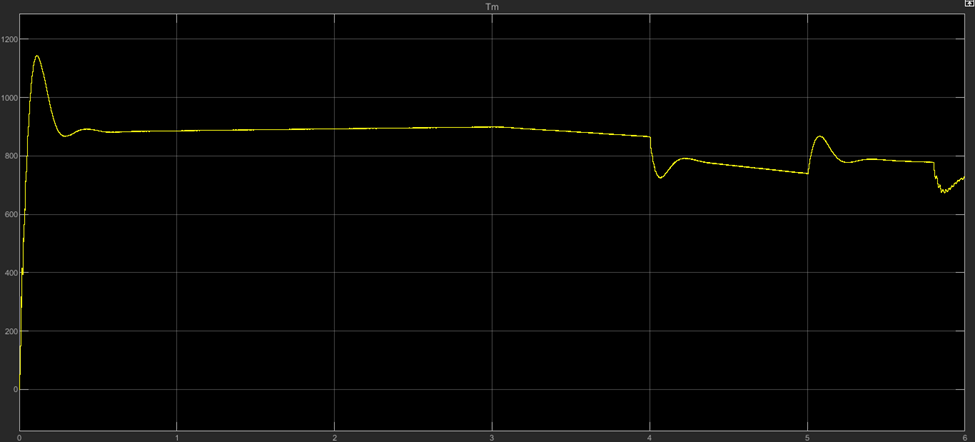
1. **Generalised Graph**

****

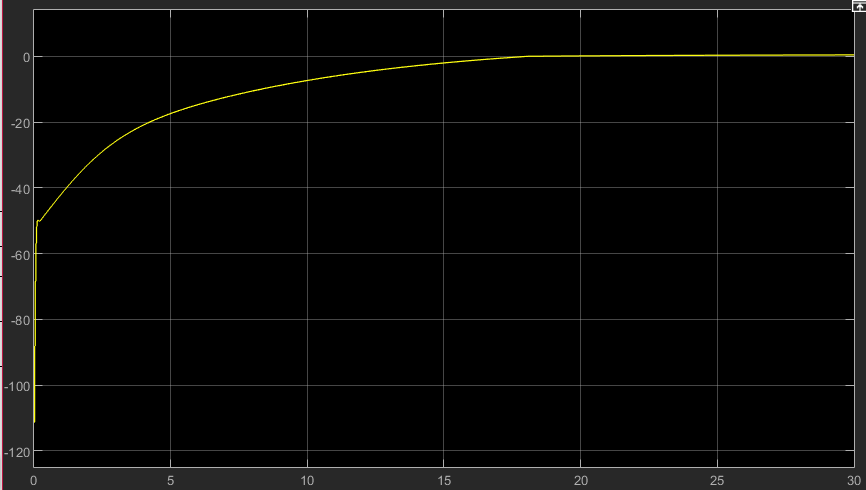
**Fig. (2.46)**

**CONCLUSION**

In this Project the 6 KW wind turbine was designed and simulated successfully and it’s parameters and simulation results were recorded successfully. The comparison between a standard 6 KW wind turbine designed with the trivial approach and the proposed wind turbine discussed in this report is depicted graphically down below:



**Fig. (2.47)**



**Fig. (2.48)**

It is clear from the graph that the proposed design of the 6 KW wind turbine is producing a more stable output as compared to the one which is designed according to the trivial standard approach.

**LIST OF REFERENCES**

* **The WEI6K, a 6-kW 7-m Small Wind Turbine: Final Technical Report by** Wetzel, Kyle K, McCleer, Patrick J, Hahlbeck, Edwin C, and DOE Project Office - Keith Bennett. *The WEI6K, a 6-kW 7-m Small Wind Turbine: Final Technical Report*. United States: N. p., 2006. Web. doi:10.2172/887056.
* **Dynamic Modeling, Control and Simulation of a Wind and PV Hybrid System for Grid Connected Application Using MATLAB** D. Mahesh Naik , D. Sreenivasulu Reddy , Dr. T. Devaraju
* **Pitch Controller Design of Wind Turbine Based on Nonlinear PI/PD Control by** Feihang Zhou and **Jun Liu**
* **Pitch Angle Control for Variable Speed Wind Turbines by** Mouna BEN SMIDA, Anis.SAKLY Research Unit: Industrial systems study and renewable energy (ESIER),
* **Modeling and simulation of windgenerator with fixed speed wind turbine under Matlab-Simulink by** a Djohra Saheb-Koussa , Mourad Haddadi , Maiouf Belhamel,a Mustapha koussa &a Said Noureddine
* **Dynamic Modeling and Performance Analysis of Grid Connected PMSG based Variable Speed Wind Turbines With Simple Power Conditioning System by** Jayalakshmi N. S., D. N. Gaonkar, Member, IEEE and K. Sai Kiran Kumar
* **Stochastic modeling to represent wind power generation and demand in electric power system based on real data by** Humberto Verdejo, Almendra Awerkin , Eugenio Saavedra , Wolfgang Kliemann , Luis Vargas
* **Design, modeling and economic performance of a vertical axis wind turbine by** Sahishnu R. Shah , Rakesh Kumar , Kaamran Raahemifar , Alan S. Fung

**APPENDIX**

* **Cut in Speed**

The speed at which the wind power generation starts is termed as the cut in speed in this project it is 12m/s.

* **Cut out Speed**

The speed at which the wind power generation ceases in order to protect the wind turbine equipment and exceeding the fixed values or the rated values is called the cut out speed, in this project it is 27 m/s.

* **TSR**

TSR (tip speed ratio) can be defined as the ratio between the wind speed and the speed of the tips of the turbine blades. This is important for the wind turbine system because too less TSR, and the kinetic energy of the wind will not be fully utilised and if the TSR is too much, then the blades will rotate in the previous kinetic energy and will not harness energy from the new wind.