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Designing and Modelling of Wind Turbine Simulation Using MATLAB / SIMULINK

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Abstract: The renewable energy, Malaysia hopes to lessen its reliance on oil and gas. Wind energy is one of the more promising renewable sources of electricity. Malaysia is situated in an area with low wind speeds, with an annual mean wind speed of 1.2-4.1 m/s, close to the equator. The northeast monsoon and the southwest monsoon are the two monsoon seasons that Malaysia experiences. While wind speeds during the northeast monsoon can approach 15 m/s, they can only reach 7 m/s during the southwest monsoon season. The potential for wind energy in Sarawak, Malaysia, has only received a limited amount of research and study. In this article, MATLAB/SIMULINK will be used for modelling and simulation of numerous wind energy conversion systems (WESC) utilizing different generators operating under the same conditionsin order to analysis the generators' efficiency. Although ultimately all of them are equally efficient, PMSG has shown tobe more efficient than SCIG and DFIG at lower wind speeds. SCIG, DFIG, and PMSG efficiency are, respectively, 66.25%, 69.38%, and 71.88% at the rated wind speed.
Keywords: Horizontal Axis Wind Turbine, Wind Energy, Induction generator, MATLAB Software.

I. INTRODUCTION

The kinetic energy of the wind is converted into the mechanical energy that turns the rotor blades of a wind turbine, which are connected to a low-speed shaft. This process is carried out by a wind turbine. After that, the mechanical energy will be transferred, with the help of a gearbox, into the high-speed shaft in order for the generator to be able to convert it into electrical energy [1]. Wind turbines with a horizontal axis revolve on an axis that is perpendicular to the directionin which the wind is blowing [2]. If the blades of the wind turbine are spun in such a way that they point in the direction that the wind is blowing, then it is possible to harness the power of the wind. In addition, HAWT often feature towers that are higher, which assists the turbine in meeting the challenges posed by a wind that is stronger. This is since the speed of the wind increases with height, and HAWT towers often have a greater altitude than average. It is feasible to extract the maximum amount of wind energy possible when employing wind turbines that have variable pitch angles. This is accomplished by adjusting the angle at which the blades rotate to either enhance or decrease the amount of power that is created by the wind turbine. Because of this, it is now feasible to harvest the greatest quantity of wind energy thatis practicable. Because HAWT models provide more accurate results, we will concentrate our modeling and simulation efforts on those models for the whole of this work. The characteristics of a wind turbine that are most often seen are shown in figure 1.1 below. These are some of the most crucial things to think about while shopping for an ideal turbine,so keep them in mind. The cut-in speed is the minimal wind speed necessary to overcome the friction of the turbine blades and spin the blades. This is the speed at which the blades begin to rotate. This is the speed at which the blades start to revolve after the fan has been turned on. When traveling at this speed, the blades will start to spin in the oppositedirection of a clockwise motion. The lowest wind speed at which the turbine can create the power output that is specified for its rating is referred to as the rated speed of the turbine. This is the minimum wind speed at which the turbine is ableto generate the power output.

II. CONVERSION WIND ENERGY SYSTEM

In order to generate mechanical energy, a wind energy conversion system, more often referred to as a WECS, is propelled by the force of the wind. After that, this kind of mechanical energy is transferred to an electrical generator so that it may be used in the process of producing electricity. The connection that can be made with a WECS is shown in figure 1.3. It is possible that the generator of the wind turbine is a permanent magnet synchronous generator (PMSG), adoubly fed induction generator, an induction generator, a synchronous generator, or one of the many alternative designsthat are feasible. The wind energy that is collected by the wind turbine and used by the generator is what makes up the source of the electricity. The WECS makes use of a pulse width modulation converter in order to keep the spinning speedof the generator at the optimal level so that it may produce the most amount of power that is technically possible.

The electricity that is produced by the generator is sent into the grid by means of an inverter that is located on the side of thegrid and a converter that is located on the side of the generator. Both devices are connected to each other through cables.Wind farms may be in a wide variety of environments, some of which include onshore, offshore, hilly terrain, and coastal locations. It is possible that the WECS DG may end up being the most important one in the not-too-distant future. This is something that can be expected to happen.

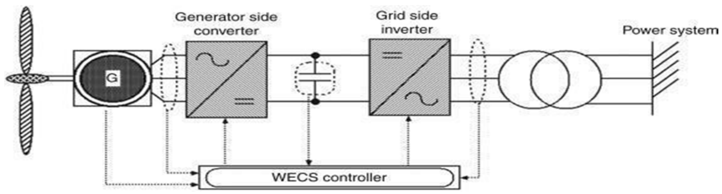

Fig:1- Wind Energy Conversion System.

Wind power is an alternative to the use of fossil fuels because it does not produce any emissions while it is functioning; it only requires a very small amount of land; it is abundant; it is renewable; it is widely scattered; it is clean;it is affordable; it is abundant; it is widely dispersed; it is clean; it is inexpensive; it is an alternative to the use of fossil fuels [14]. In general, the impacts on the environment are of far less concern than the problems that are caused by other traditional sources of electricity. The fluctuating wind speed causes the wind energy conversion system's output power to vary, which in turn has the potential to cause the frequency of the power grid to diverge in an unexpected way. Already, a sizeable amount of investigation has been carried out in the pursuit of finding a resolution to this issue in the not-too- distant future. The main data that was used for the 2013 edition of the World Wind Energy Report was gathered by an organization known as the World Wind Energy Association (WWEA). The global capacity for wind energy reached 318.5 GW at the end of 2013, which is an increase above the capacity of 282.2 GW that was reached in the previous year. Thereare now 103 nations throughout the world that allow the commercial use of wind power in some capacity. With a total capacity of 91.3 GW and a new capacity of 16 GW, China has retained its position as the most important participant in the worldwide wind industry.

A. Wind Turbine

There is a chance that the HAWT market might be further subdivided into wind turbines that operate at fixed speeds and wind turbines that operate at variable speeds [7]. This is an extra possibility that may be pursued. For one of the windturbines to be able to keep its speed consistent while it is operating, it is equipped with a component known as a squirrelcage induction generator, or SCIG for short. A wind turbine that has a speed that can be altered will always have the same rotational speed for its rotor, regardless of how quickly the wind is blowing. This is because of the speed's ability to be adjusted. This is because the pace may be adjusted. It is reliant on a variety of various elements, some of which include the frequency of the grid, the gear ratio, and the design of the generator.

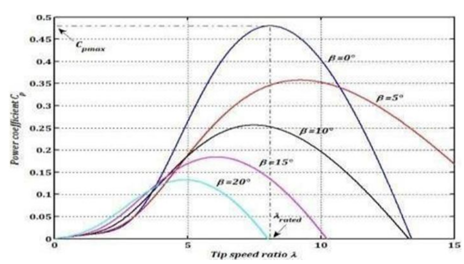

Fig:2- Power Coefficient Vs TSR for Wind Turbine.

B. Generator

One might further subdivide the term "electric generator" into "asynchronous generator" and "synchronous generator." These two categories of generators are both capable of producing electrical current. The most important distinction between the two is that synchronous generators do not need the power supply from the grid in order to excite their windings, in contrast to asynchronous generators, which do require the power supply from the grid in order to excite their windings. This is the most significant difference between the two types of generators. This is the primary point of distinction between the two distinct varieties of generators. This distinction between the two types of generators is the more significant of the two.

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Synchronous generators, on the other hand, do not need the power source that is supplied bythe grid in order to excite the windings of their machines. Synchronous generators can achieve this without the grid's assistance. The low rotational speed of the turbine blades must be increased by the gearbox to the greater rotating speedof the rotor shaft before the turbine can fulfill the duties for which it was designed. Because of this, the generator is nowable to accept power from the turbine. This came about as a direct result of the previous sentence.

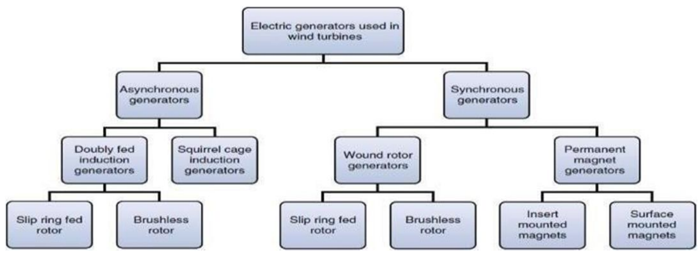


Fig:3-Types of Generators in WESC.

C. Block Diagram Of A Wind Turbine

The hub that is located at the base of the turbine blades is the component that oversees dictating the orientation of the blades. The blades are attached to the central hub with the help of a rotating mechanism that consists of gears, a small electric motor, and either a hydraulic or mechanical system for producing rotational motion. This arrangement ensuresthat the blades remain securely attached to the hub. Control of the system may be attained either electrically or mechanically, depending on how the system was planned out in the first place. The relative speedof the wind is what decides which direction the blades will rotate when they are turned on their axis. Pitch control is the term that describesthe approach in issue. It does this by ensuring that theblades of the wind turbine are aligned in the most efficient way possible in the direction that the wind is blowing in order to harvest the most amount of power possible from the wind.

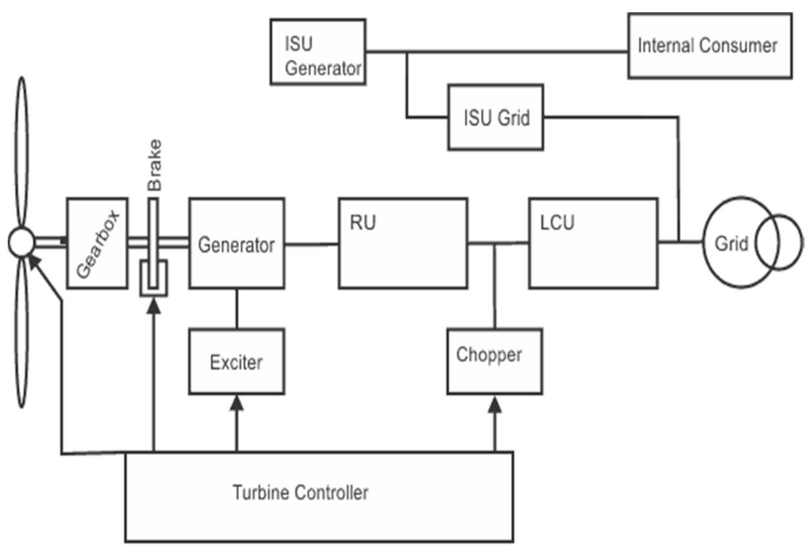


Fig:4-Block Diagram of a Wind Turbine.

III. DOUBLY FED INDUCTION GENERATOR

Doubly fed induction generator (DFIG), which is receiving a growing amount of interest for applications that needpower in the range of megawatts [13], is one solution. The windings onboth the stator and the rotor of this generator are set up in a three-phase arrangement, which is whythe generator is referred to as a three-phase device. After the rotor, thestator windings, and the back-to-back converters have been connected to the grid, it is the responsibility of the back-to-back converters to regulate the speed of the rotor. The grid will provide an electrical current that will excite the rotor windings, and the magnetic field that will be created by the rotor windings will revolve in time with the blades of the rotating turbine. This will be accomplished by the rotorwindings. Alternating current will be produced because of the interaction between the revolving magnetic flux and the stator windings in an electric generator. This interaction will produce alternating current.

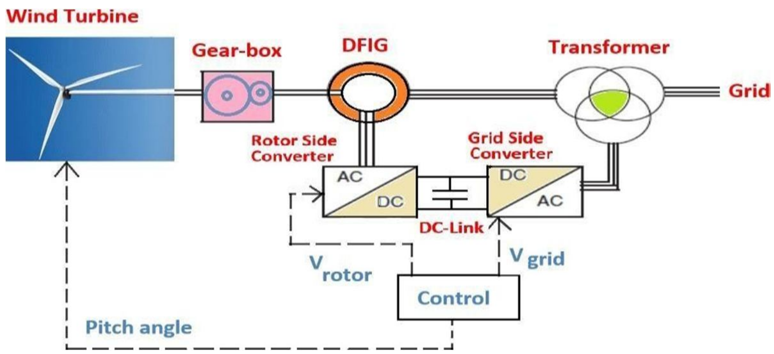


Fig:5- Doubly Fed Induction Generator.

Both the rotor's rotational speed and the frequency of the grid's rotation influence the rate at which the magnetic field ofthe stator rotates. It is important to condition the frequency of the grid signal that is operating on the rotor windings in order to keep the level of frequency that is being produced constant. This is done in order to maintain the current that isbeing created. This isdone so that there is no variation in the frequency of the current that is being carried. A back-to- back converter is made up of its two individual components, which are known as a machine-side converter and a grid- side converter. ADC voltage connection connects these two converters to oneanother so that they may work together.

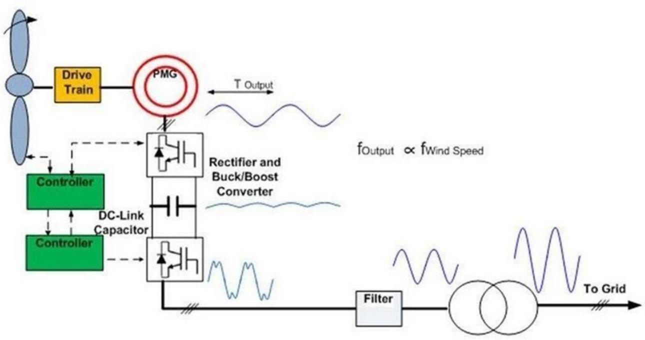


Fig:6- Permanent Magnet Synchronous Generator.

This effect is created by the wind turbine. One can achieve this objective by following thestrategy described in the previous paragraph. The presentation of the PMSG wind turbine model that is shown here in figure 3.7 should provide for an enjoyable viewing experience for you. The fact that modern computers have a basic organizational framework isone of the key reasons that has led to the widespread usage of these machines. [Case in point:] [C]computers have a fundamental organizational framework. Since the brushes, sliprings, and commutators of a WRSGare held in place by permanent magnets, disassembling and removing these components from theWRSG may be accomplished with relativeease. Disassembling a WRSG needs permanent magnets. This task may be completed in its entirety if one so chooses. As a result of this, the system's level of dependability will considerably increase, and as a direct consequence of this, it will become an alternative to the WRSG that is, in some circumstances, preferable. A PMSG's overall design must haveboth a rectifier and an inverter for the device to perform as intended whenput into operation. This is because the PMSG isa generator with variable speed.

IV. MODELING OF WIND TURBINE

An example of this would be a wind turbine, which is a piece of technology that converts the kinetic energyprovided by the wind into electrical energy. The rotor is one of the three primarycomponents that come together to produce the overall system that is the wind turbine. The bladesthat areresponsible for transforming thehigh-velocitywind energyintoa lower-velocity rotationalenergy are housed inside this component. The generator is the third and final component of the system. The second component is known as the generator, and it is made up of an electrical generator in addition toall the control circuits and gears that are necessary to convert the low- speed rotation into electric power. This second component is referred to as the generator. The structure is the very final part of the generator, and it is responsible for housing all the earlier partsinside its own boundaries. This structure, which consists of the tower as well as the nacelle, is thecomponent that brings the generator to its final form.

There are essentially two different types of wind turbines, and the distinction between the two is based on the axis that the machine revolves around. One may make a distinction between a horizontal axis and a vertical axis when they are contained inside it.
There is a consensus among experts that wind turbines with a horizontal axis are more prevalent and ubiquitous in comparison to wind turbines with a vertical axis [1]. Wind energy may be harnessed and converted into usable forms ofpower via the use of adevice called a wind turbine. Wind power generation is the term used to describe this process. Thefollowing equation demonstrates how the air density, power coefficient, air density, and turbine swept area are all elements that impact the total amount of energythat is collected from the wind:

$$P = 0.5\times\rho\times Cp\times V3\times A \;\ldots.\; (1)$$

Where: P = Mechanical power in the moving air (Watt).
ρ = Air density (kg/m3).
A = Area swept by the rotor blades (m 2) V = Velocity of the air (m/s)
Cp= Power coefficient.

Scientist Betz made the discovery that the greatest amount of power that can be extracted from the wind by using an ideal turbine rotor with an infinite number of blades under ideal conditions is 59.26% (or 0.5926 times) of the power that is present in the wind. This maximum amount of power can be taken from the wind by utilizing an ideal turbine rotor with an unlimitednumber of blades. The limit in question is referred to as the Betz limit. Due to the structural requirements and economical constraints involved, wind turbines typically feature either two or three rotor blades depending on the size of the turbine. As a direct result of this, the amount of power that they can gather is closer to beingaround half (0.5 times) of the total amount of power that is available to them. Tip speed ratio (TSR) of a wind turbine isdefined as:

$$\lambda=(\Omega\times R)/V \;.. \qquad (2)$$

Where: Ω = Mechanical speed at the rotor shaft of the wind turbine (rad/s)R = Radios ofthe blade (m).
V = Velocity of the air (m/s).
The TSR, in addition to the blade pitch angle, which is represented by, is necessary in order to compute the rotor powercoefficient, which is denoted by the symbol CP. This is because the TSRis directly proportional to the rotor power coefficient. The following is a list of the mathematical computations that may be done in order to determine the rotor power coefficient:
Cp= (Extracted power)/(Power in wind) Cp=Protor / Pwind ... (3)Equation 1 can be written as:

$$Power = 0.5\times\rho\times Cp\,(\lambda,\beta)\times V3\times A$$

Wind turbines that are capable of running at changing speeds often come equipped with adevice that is known as a pitch change mechanism (pitch angle control). This device allows the pitch angle of the blades to be varied in order to producea more appropriate power coefficient profile [3, 4]. Wind turbines that are not capable of operating at varying speeds typically do not come equipped with this kind of device. The rotational speed of the turbine may be altered as a direct result of this feature of its design.

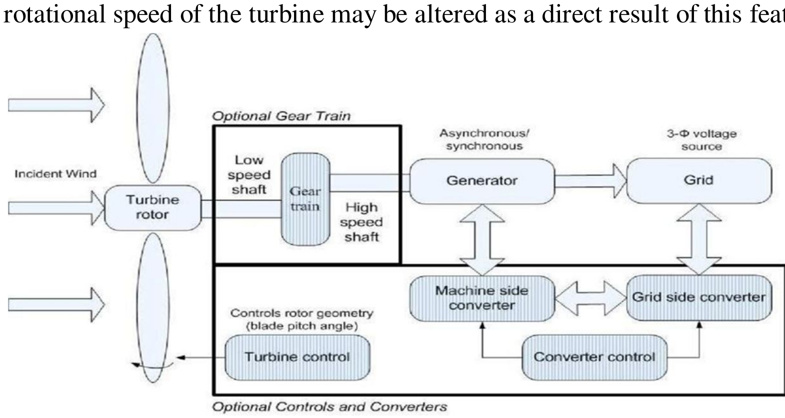


Fig:7- Modern Wind Turbine Diagram.

Wind turbines that can run at changing speeds often come equipped with adevice that is known as a pitch change mechanism (pitch angle control). This device allows the pitch angle of the blades to be varied in order to produce a moreappropriate power coefficient profile [3, 4]. Wind turbines that are not capable of operating at varying speeds typically do not come equipped with this kind of device. The rotational speed of the turbine may be altered as a direct result of this feature of its design.

V. RESULT AND ANALYSIS

The wind turbine generator is the most important component of a wind turbine (WT) system since it is the component that is accountable for transforming the mechanical energy that is produced by the turbine into electrical energy. Most of the time, problems that occur with windturbines are due to components in the generator being damagedin some way. As a direct result ofthis, the analysis of the generator model in wind turbines is developing into a subject of research that is becoming more important. This is because, in order to avoid problems with wind turbines,it is vital tobe aware of the special attributes of the generator. The objective of this study is to construct a mathematical model of agenerator that can easily be adjusted to account for any faultthat may occur in the generator. This research will be used to conduct research on WT dynamic systems, and the goal of this study is to contribute to that research. The primary objective of this line of study is going to be the formulation of a mathematical model of a generator that is appropriate for implementation in wind turbines. This is a result of the fact that the most of the WT models that have been developed up to this point either include protection for intellectual property or are relatively straightforward in the generator modeling that theyuse. Both MATLAB and Simulink were used throughout the whole of the process of constructing themathematical model of the wind turbine-based induction generator for the purpose of this project. The model of a wind turbine that was built includes not only an aerodynamic model but also a model of an induction generator and a drive train for the wind turbine that is based on a model with two masses. The construction of the induction generator was based on electrical equations that were arranged inside Park's reference system. The building of the model incorporatesnot just one but two distinct subsystems: a mechanical one and an electrical one. Thesuggested model of the wind turbine fitted with an induction generator was verified by means of aMATLAB software simulation of a wind farm fitted with adetailed model of a doubly-fed induction generator (DFIG).

A. *Methodology Of The Wind Turbine*

With several simulations, we are going to present several distinct WECS in this part. The following building pieces are utilized to construct the simulation's portrayal of the wind speed, asseen in Figure 8. The modeling of the simulation will be done using these pieces. Between the timet = 1 second and t = 10 seconds, the speed of the wind is going to growfrom a speed of 0 meters per second to a speed of 9 meters per second. This increase is going to take place. After t = 15seconds, it will then begin to raise its speed to 15 meters per second, having previously been at 9 meters per second. This will take place after the initial speed of 9 meters per second has been maintained.

Up until the time equals thirty seconds, there is not going to be any change at all in the speed of the wind. This simulation's goal is to investigate the performance of a variety of generators when subjectedto three distinct levels of wind speed: 0 meters per second (the "zero wind speed" condition), 9 meters per second (the "base wind speed"), and wind speeds that are greater than the "rated wind speed." All these aspects are evaluated, including the apparent power, the apparent reactive power,the rotor speed, the mechanical torque, and the pitch angle. Measurements are taken, and records are kept. The actual power output, the rotor speed, and the pitch angle are all aspects of the wind turbine that will be the subject of conversation.

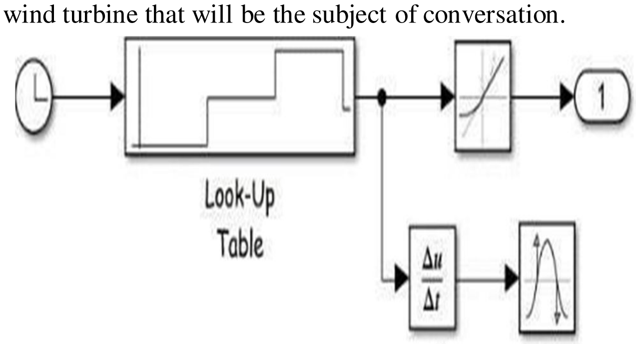


Fig:8-Simulation Model of Wind Turbine Generator.

B. *SCIG Wind Turbine*

Figure :9 provides a visual representation of the modeled SCIG wind turbine that was created using SIMULINK. Together with the 30-kilometer transmission line, the 575V/25kV step-up transformer and the 25kV/120kV step-up transformer make it possible for the 1.5 MW inductiongenerator to be directly connected to the power grid. We will be using the SIMULINK model of the wind turbine in order to offer the required quantity of mechanical torque for movingthe rotorof the generator. After SCIG has transformed the mechanical torque into electrical power, that power will be delivered to the grid through the stator windings. The VI-measurement blocks are going to take readings of the voltage,current, active power, and reactive power.

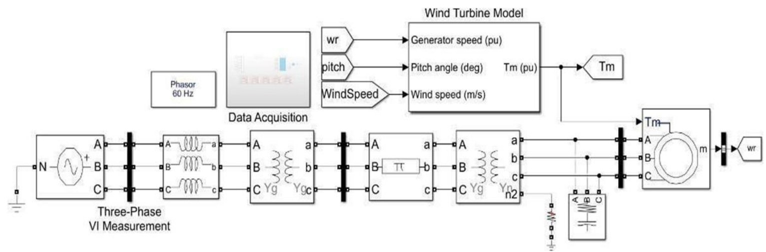


Fig:9-Simulink Model of SCIG Wind Turbine.

C. DFIG Wind Turbine

Figure 10 presents a DFIG model that is quite comparable to the SCIG model. This comparison may be seen by comparing the two models. The sole difference between the two models is the way in which step-up transformers and power converters link the rotor windings of the DFIG type to the grid. This is the only difference between the two versions. Transformers areused so that a connection may be made between the stator windings and the grid of the power supply. Because there is no other source, the reactive power that is necessary to activate the generator stator will be drawn from the grid. This is because the grid is the onlysource that is nowaccessible. When a rectifier and an inverter areplaced inside of a universal bridge, the process ofmodeling a DFIG wind turbine is said to be complete.

The total number of components is now upto four as a result of this. After first converting the fluctuating AC electrical power that is producedinto stable DC power with the help of a rectifier, the DC power will then be transformed back into AC electrical power with the assistance of an inverter. While the rectifier control system overseesdetermining the speed at which the generator spins, the inverter control system oversees controlling the amount of electricity that is sent out to the grid. Alternating current will be produced as a direct result of the interaction between the spinning magnetic flux andthe stator windings of the generator. This will take place as a direct consequence of the interaction. Both the rotor's rotational speed and the frequency of the grid's rotation influence the rate at which the magnetic field of the stator rotates. It is important to condition the frequency of the grid signal that is operating on the rotor windings in order to keep the level of frequencythat is being produced constant. This is done in order to maintain the currentthat is being created. Thisis done so that there is no variation in the frequency of the current that is being carried. A back-to-back converter is madeup of its two individual components, which areknown as a machine-side converter and a grid-side converter. A DC voltage connection connectsthese two converters to one another so that they may work together.

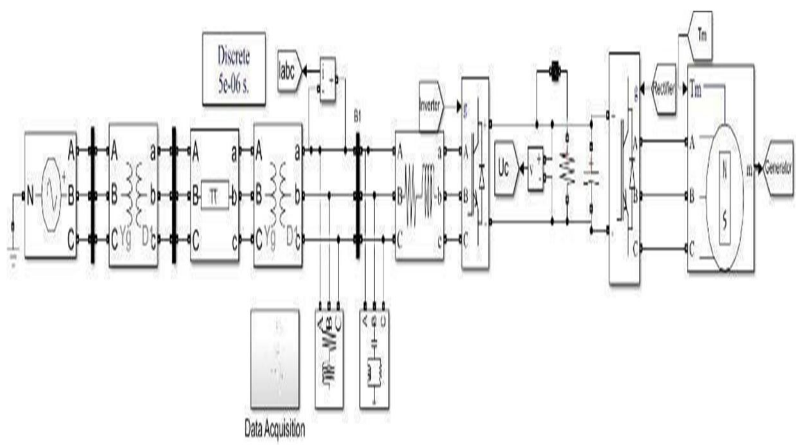


Fig:10-Simulink Model of DFIG Wind Turbine.

D. PMSG SIMULINK Model in Wind Turbine

The PMSG SIMULINK model, which is fairly like the SCIG and can be seen in Figure 5.4, may be downloaded here. The fact that the generator in the PMSG model does not need a feedfrom the grid for its windings to be excited is the primary contrast that can be made between the two models. Because a PMSG is a wind turbine that may run at differentspeeds, it is required to include power converters. These speeds can range from very slow to very fast. In contrast, the stator windings will be directly linked to the grid via the use of a rectifier, an inverter, step-up transformers, and a transmission line that is thirty kilometers in length. The rotor windings will beexcited by permanent magnets.

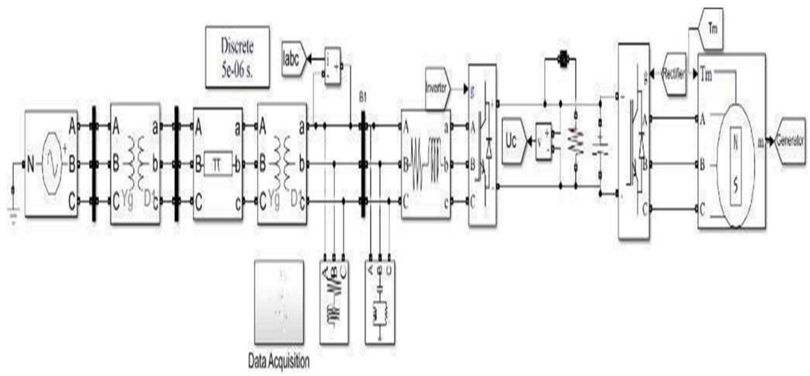


Fig:11-Simulink Model of PMSG Wind Turbine.

E. Simulation Circuit Diagram Of Wind Turbine Generator

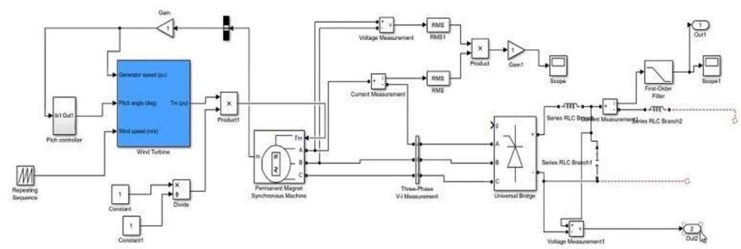
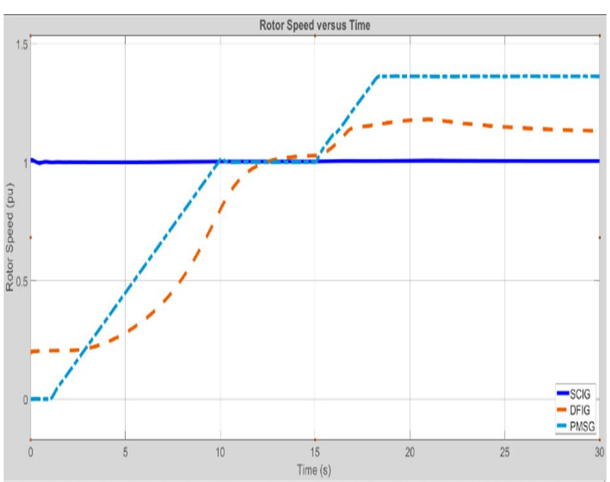
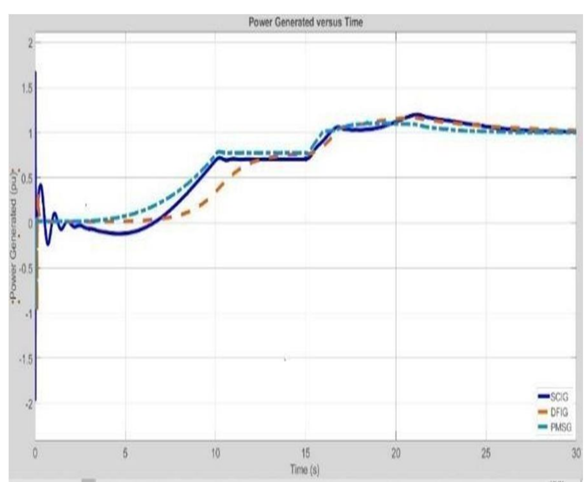


Fig:12-Simulink Diagram of Wind Turbine Generator.

The information necessary to understand the total power output of SCIG, DFIG, and PMSG was supplied by the SIMULINK models. These details were extracted from the corresponding model. When the generators are used in research, it is feasible to examine how the behavior of each generator fluctuates in response to various degrees of wind speed. This is made possible sincethe generators may be used as research instruments. This is made feasible by the fact that the generators may be used in many ways, including as research tools. Since the SCIG does not includeany form ofpower converter into its design, it is possible to see a large rise in the SCIG's initial current from time = 0s to time = 1s. This is because the SCIG does not have a power converter. This is because the SCIG does not include any kind of power converter into its design, therefore this explanation cannot be given. This is because the SCIG does not include any otherkind of power converter and instead maintains a direct link to the power grid. Because of this, this outcome was produced. This is the rationale behind why things are the way they are.



(A)



(B)

(A) Fig:13- Simulation of Rotor Speed for Different Types of Generators.
(B) Fig:14- Simulation of Power Generation for Different Types of Generators.

The grid will suffer considerable voltage disruptions because of this increase in the initial current. Because of this, a soft starter is necessaryto regulate the high beginning current of the generator in order to reduce these voltage disturbancesandguarantee that the grid continues to work in the proper way. This is because a lack of control over the high starting current might lead the generator to fail. As a direct consequence of the occurrence, the grid will be subject to major voltage disturbances on account of the rise in the initial current that it will be experiencing. DFIGs' windings, regardlessof whether they are on thestator or the rotor, are simply linked to the grid in the same way. This is the case regardless of which side of the device theyare on. Because of this, the generator may be managed with a greaterdegree of precision in terms of both its active and reactive power. This applies to both aspects of the generator's power. This is true for both theamount of electricity it generates and the amount ofpower it uses. At the absolute least, the power converter has the capacity to exercise some degreeof control on the quantity of power that is generated by the DFIG. This is the case because of the power converter's ability to convert one kind of energyto another.

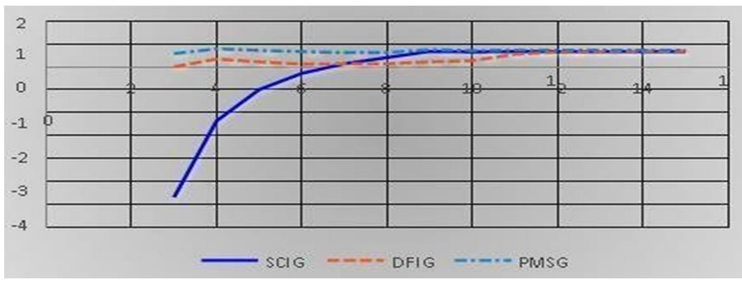


Fig:15-Efficiency of Generators.

The number of particles per unit area in the atmosphere, with A referring to the entire surface area that is covered by therotor and v referring to the speed at which the air is traveling. If we proceed with the evaluation of the generator based on the presumption that the pitch controller will be engaged as soon as t = 15 s, then we will be able to evaluate its performance upto that time. if the actual wind speed reaches a level that is greater than the wind speed that the sailwas designed to withstand. The data on efficiency that was collected between t = 0s and t = 3s hadto be excluded from the research since SCIG experiences a current spike during those times because it is directly coupled to the power grid anddoes not have a soft starter installed. This meant that the data could not be included in the study. Because of the dynamicsof the circumstance, it was imperative that this be done. The SCIG will draw electricity from the grid during the intervals of time ranging from t = 3s to t = 7s in order to excite the windings in advanceof the beginning of the generator's process of manufacturing energy. This will allow the windingsto be excited in preparation for the beginning of the process. This will occur between the periods of t = 3s and t = 7s, inclusive. This sheds light on the factors that contribute to the generator's lowefficiency rating, which was previously unknown to me.

VI. CONCLUSION

Up to this moment, effective simulations of the SCIG, DFIG, and PMSG wind turbines' SIMULINK models have been carried out within the limitations of the restrictions imposed by thisresearch project. When contrasted with variable-speed wind turbines that employ DFIG and PMSG, the structure of an SGIG turbine is a great deal simpler andmuch simpler to grasp. On theother hand, variable-speed generators provide a variety of advantages that fixed-speed generatorsdo not have, including a higher level of reliability and overall efficiency. Even though all of themeventually reach the same level of efficiency, the simulation that was run indicated that PMSG is more efficient than SCIG and DFIG even when the wind speed is low. This was the case even though all of them eventually attain the same level of efficiency. This is the case regardless of whether all of them finally attain the same level of productivity.

The fact that they each finally reach the same degree of efficiency does not alter the fact that this continues to be the case even ifit may seem like it should change. In a wind turbine, the kinetic energyof the wind is transformed intothe mechanical energythat is required to spin the rotor blades, which are attached to a low-speed shaft. This operation isoften carried out using a wind turbine. This is how the wind's kinetic energy is converted into usable electrical energy. After that, the gearbox will be used to transmit the mechanical energy intothe high-speed shaft so that it may be convertedinto electrical energy by the generator [1]. After the preceding stage has been finished, we shall go on to the next one. Wind turbines with a horizontal axis revolve around an axis that is perpendicular to the direction in which the wind is flowing [2, 3]. It will be able to harness the power that is provided by the wind if the rotors are positioned in such a manner that they face in the direction that the wind is blowing. In addition, HAWT often includes towers that are taller, which helps the turbine to better combat a greater wind. This is one of the advantages of using HAWT.

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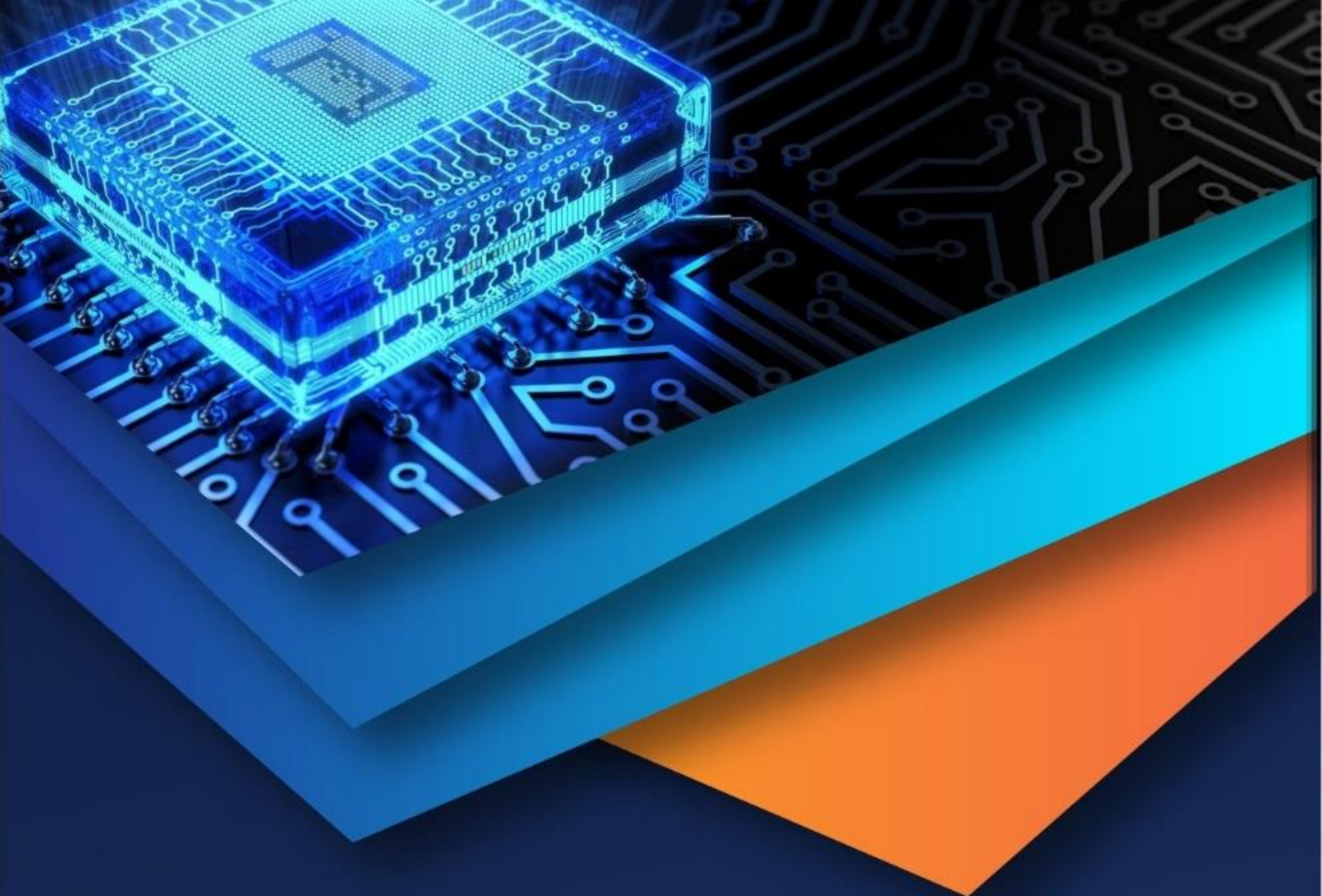

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