EMULATION OF WIND TURBINE USING DC MOTOR

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EMULATION OF WIND TURBINE USING DC MOTOR

A Thesis submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology in “Electrical Engineering”

By

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CERTIFICATE

This is to certify that the thesis entitled "Emulation of Wind Turbine using DC Motor", submitted by **LipsaPriyadarsini (Roll. No. 110EE0219)** & **Chandrani Das (Roll. No. 110EE0236)** in partial fulfillment of the requirements for the award of **Bachelor of Technology** in **Electrical Engineering** during session 2013-2014 at National Institute of Technology, Rourkela is a bonafide record of research work carried out by them under my supervision and guidance.

The candidates have fulfilled all the prescribed requirements.

The Thesis which is based on candidates' own work, have not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of Bachelor of Technology degree in Electrical Engineering

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ABSTRACT

Over the course of the past few decades, there has been a steady rise in the utilization of renewable energy resources. 238GW is the estimated global wind capacity at the end of 2011. India is the 5th largest harnesser of wind power with 16GW production. Wind energy is green and clean compared to non-renewable fossil fuels and thus wind energy based power generation has become a significant contributor to present power systems encouraging works on wind power based research.

Since it is troublesome to practice a true wind turbine for research requirements, it gets necessary to create a replica of a genuine wind turbine to be utilized for small scale works. This paper depicts the configuration of a test system working on a wind turbine's power-speed characteristics. It concentrates on the power-speed and torque-speed characteristics and models the wind turbine characteristics reproducing the same utilizing MATLAB-SIMULINK.

The work is on mathematical demonstration of test system of the Horizontal Axis Wind turbine. The corresponding static and dynamic characteristics recreations are done. Emulation of the wind turbine is done by working the DC motor to gauge the theoritical rotational velocity of the rotor of the wind turbine. A PI controller is utilized to tune the DC motor characteristics with the Wind Turbine characteristic curves. Taking into account the rotor characteristics of the wind turbine, a particular reference rotor pace is produced and the wind speed gives the mechanical wind power.

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NOMENCLATURE

ω_r - Rotor speed

λ - Tip Speed Ratio

C_p - Power coefficient

r_r - Rotor radius in meters

V_w - Wind speed in m/s.

P_r - Power extracted from turbine rotor

A - Area of the incident air stream

U - Velocity of air flow

ρ - Density of air flow

ϕ - Flux linkage

CHAPTER 1

Introduction

1.1. MOTIVATION

Pollution and global warming have become a burning topic of priority as greenhouse gas emissions increase in the atmosphere thanks to persistent dependence on fossil fuels. The long term consequences of pollution include increase in temperature and rise in sea levels. The melting of polar ice-caps, decrease in ozone layer, increase in level of poisonous gases in the atmosphere owe a lot of credit to the conventional, non-renewable energy generation techniques. Climate scientists continue to warn about the potential catastrophic effects of unchecked use of fossil fuels. The growth of carbon dioxide (the main cause of climate change) in the atmosphere, has accelerated inexorably, as countries continue using fossil fuels to power their economies. Thus the dire need of the hour is to have a mass shift of energy generation techniques to the renewable and pollution free form of energy. Added to the advantage of being eco-friendly, these forms of energy being unlimited at the source would never run out unlike conventional fossil fuels.

The past few years have experienced a fast rise in the electricity generation from wind energy resources. 10^{12} kWh per annum is the estimated maximum extractable energy from the 0-100 meters layer of atmosphere.

Advantages of using wind energy:

1. Being powered by wind, this is a clean fuel. It does not have harmful impact on environment unlike fossil fuels which extract energy from combustion of coal and natural gas. It is an eco-friendly source of energy without any form of greenhouse gas emissions.

2. Wind is available in abundance and thus is sustainable. This makes it reliable to be accessed and depend upon.

3. Winds are caused due to non-uniform heating of atmosphere by sun, earth's rotation and surface irregularities on earth. Thus it relies on renewable form of solar energy.

4. Apart from the initial establishing expenses, wind turbines are otherwise low-priced form of energy and can be built even on farms etc supporting rural locations at wind sites.

1.2. LITERATURE REVIEW:

Fixed pitch wind turbines are used in power generation systems for generating power varying from small to middle power. Presently, high and medium power systems use the variable-pitch wind turbines, while fixed pitch turbines finds its usage limited to various low-power applications. In large wind turbines, the power extracted is controlled by means of the blade pitch angle and the turbine speed. When the power range of the turbines is smaller, the power is controlled by either turbines that control the speed and not the pitch angle or turbines that change the pitch angle and not speed [2].

The mechanical power characteristics of a fixed-pitch turbine is expressed as a function of wind speed [3]. The maximum value of the power curve is obtained for each wind speed. A wind turbine emulator reproduces those power curves. Power electronic converter converts the turbine speed.

For the purpose of laboratory tests, a type of system is designed that emulates the operation and characteristics of a wind turbine. DC motors, permanent magnet motors or SCIMs are usually used [4-11]. The motor is controlled to have power curves similar to the wind turbine characteristics. Microprocessor-based control are used that takes turbine speed and wind speed as input parameters and thus the reference torque of the motor is calculated.

1.3.THESIS OBJECTIVES:

The following objectives are attained at the end of this project work:

1) Study of wind turbines, their types and method of their working.

2) Modeling of wind turbine and its analysis.

3) Power speed and torque speed characteristics obtained from the modeled wind turbine.
4) Modelling of separately excited DC motor and obtaining its characteristics.
5) Realisation of model for speed control of DC motor.
6) Comparing and controlling the DC motor model to obtain the wind turbine characteristics so that the DC motor can emulate the wind turbine in small scale applications.

1.4.ORGANIZATION OF THESIS:

The thesis is divided into five parts as follows:

Chapter1 deals with the introduction to the project. It puts forward the motivation that fueled the work on the topic. It provides the literature review of the topic and the research perspective. This chapter describes the objectives of the work and provides detailed documentation of proceedings of the report.

Chapter2 deals with the background details of wind energy conversion systems, wind turbines, equations governing energy conversion and various control strategy of wind turbines. This chapter provides with the pre-requisite knowledge required to work on the project. It sites different types of wind turbines and relevant terms associated with the energy extraction method.

Chapter3 deals with the theoretical analysis of separately excited DC motor. The equivalent circuit model, various parameters used and the basic concepts governing it’s operation is presented in this chapter.

Chapter4 presents Matlab simulation of various characteristics. IT deals with wind turbine modelling and DC motor modelling. Simulation of dumping wind turbine data on DC motor model. The C_p –TSRcharacteristics of the wind turbine is obtained and compared with the DC motor characteristics which is controlled till the desired outcome is reached.

Chapter 5 provides the conclusion of the work done

Chapter6 is about the future scopes and further improvements of the project.

CHAPTER 2

Wind Energy

2.1. WIND TURBINES

Over the course of the past few decades, there has been a steady rise in the utilization of renewable energy resources. 238GW is the estimated global wind capacity at the end of 2011. India is the 5th largest harnesser of wind power with 16GW production. Wind energy is green and clean compared to non-renewable fossil fuels and thus wind energy based power generation has become a significant contributor to present power systems encouraging works on wind power based research.

Since it is troublesome to practice a true wind turbine for research requirements, it gets necessary to create a relica of a genuine wind turbine to be utilized for small scale works. This paper depicts the configuration of a test system working on a wind turbine's power-speed characteristics. It concentrates on the power-speed and torque-speed characteristics and models the wind turbine characteristics reproducing the same utilizing MATLAB-SIMULINK.

In the wind energy conversion system, first the wind energy is captured by wind turbine. Using generator,it is converted into electrical power. So it is very important to study the characteristics of wind turbine. As the wind turbines are big in size and quite expensive, it is not at all possible to do the research work in the practical wind farm. For the research to be carried out on wind power technology, the need is to develop a simulator to simulate wind turbines which do not depend on natural wind turbine simulator and that reduces experimental cost to a large extent . It is very meaningful to develop in a laboratory a wind turbine simulator that can simulate the real wind turbine in both steady state as well as in dynamic state .

There are different designs of wind turbines and they are broadly classified in two categories which is based on orientation of the axis of rotation. They are -

1. Horizontal Axis Wind Turbines, or HAWTS.
2. Vertical Axis Wind Turbines, or VAWTS.

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Horizontal axis wind turbines

In Horizontal-axis wind turbines (HAWT), the rotor shaft and electrical generator are placed at the top of the tower facing the wind. The function of the gearbox is to turn the slow rotation of the blades into a speed that drives the electrical generator in a perfect way. Modern HAWTs consists of rotorsthat is similar to propellers of aircrafts, which basically operate on aerodynamic principles. In that, the air passes over the airfoil fashioned blades which develop a lifting force that helps in turning a rotor.

Vertical axis wind turbines

The rotor shaft is vertically arranged. An important advantage of this arrangement is that the turbine need not point into the wind to be effective, when the wind direction is highly variable wind site. In VAWT arrangement, the gearbox and generator can be placed close to the ground, using a ground based gear box, which improves the access for maintenance. Further advantage of a VAWT over the counterpart HAWT is that Yaw mechanism is not needed because wind can be harnessed from any direction. The main disadvantages are low rotational speed with the higher cost of drive train because of higher torque, and the lower power coefficient.

As a turbine is positioned on a rooftop, the wind is redirected by the building over the roof which doubles the speed of the wind coming to the turbine. The efficiency is maximum if the height of the turbine tower mounted in the rooftop is around 50% of the height of the building.

2.2. SOME RELEVANT DEFINITIONS

Described below the explanations of some significant parameters associated with wind turbines. Control of the wind turbine models is facilitated by these parameters.

2.2.1. Solidity

The ratio of the blade area projection to the intercepted wind area is defined as solidity. The projected blade area here is denoted by the blade area seen by the wind or projected in the direction of the wind. The area intercepted by the wind is also defined as the swept area.

$$\text{Solidity} = \frac{\text{projected blade area}}{\text{rotor swept area}}$$

Study shows direct association of solidity with torque and speed. High-solidity rotors are characterized with greater torque and lower speed appropriate for jobs like pumping water. On the other hand, low-solidity rotors are characterized with greater speed and lesser torque. This is usually appropriate for electrical power generation.

Hence, only high speed propeller category and Darrieus category of wind turbines are well-matched for electric power generation.

2.2.2. Tip Speed Ratio (TSR)

λ or the Tip Speed Ratio (TSR) is the ratio of velocity of the rotor's blade tip to the air flow.

$$\boldsymbol{\lambda = \frac{\omega_r r_r}{V_w}}$$

where, r_r= rotor radius in meters, ω_r= angular speed in rad/sec and V_w= wind speed in m/s.

2.2.3. Coefficient of Performance

The power essentially taken from the wind turbine rotor, P_r, is some portion of the offered power, described by the coefficient of performance, C_p , that is basically a type of power conversion efficiency:

$$\boldsymbol{C_p = \frac{P_r}{P}} \tag{6}$$

Here C_p (power coefficient) signifies the efficiency of the blades to obtain the power in wind. It is the portion of power which is fetched from the wind to the turbine blades. The theoretical boundary of C_p is about 59.3%.

2.3. WIND TURBINE SIMULATORS

Due to the fast upsurge of wind power establishments, study close to wind energy structures is developed. Because of that equipment which can simulate effectively the purpose and operation of a wind turbine setup in a laboratory is of great importance. The primary purpose of this type of equipment, that possibly be termed as a wind turbine simulation device, is the capability to determine dynamic and static characteristics of an actual wind turbine.

There exists various categories of wind turbine simulators evolved using various types of motors and control practices. DC motors, induction motors and quite seldom, synchronous motors are utilized as the mechanical prime mover of the wind turbine simulators. Wind turbine simulating device employing separately exited DC motors generally utilize armature and field voltage control techniques to realize static characteristics of a fixed pitch wind turbine. These simulators are basic, unsophisticated and usually neglect the dynamic operations.

Few simulators employ permanent magnet synchronous motors as the mechanical prime mover with a voltage source converter. Like the prime movers, several categories of generators are employed at various wind turbine simulators. Induction generators are most widely used with the irregular use of DC and synchronous generators.

Wind, which is the normal motion of air in the atmosphere, is produced by pressure variations on the surface of the earth owing to the irregular warming via solar irradiation. From fluid mechanics, the air current can be examined as mass flow with kinetic energy [1] given by:

$$\frac{dm}{dt} = \rho AU \tag{1}$$

$$E_k = 0.5mv^2 \quad (2)$$

$$P_k = 0.5\rho A U^3 \quad (3)$$

here "A" is the area of the incident air stream, U and v the velocity and density of the flow respectively. Generally, "A", the stream area of interest is denoted as the area swept by the rotor of a wind energy conversion system (WECS). These systems transform the linear momentum of the air stream into a rotation of the WECS rotor, with a maximum possible efficiency of 59.26%, referred to as Betz limit. Additionally, it can be witnessed from (1) that the obtainable power in the wind surges at the cube of the air velocity, and from a substitution of "A" for the area of disk:

$$P_k = 0.5\rho\pi R^2 U^3 \quad (4)$$

Thus, a two fold escalation in the radius of a WECS' blade geometry consequences in a four-fold surge in captured energy.

2.4. WIND ENERGY CONVERSION SYSTEM

Till date, there have been a range of WECS' designs; but up till now the most common and extensively accepted is the horizontal axis wind turbine (HAWT). As made clear in the Introduction, the design of interest is the inexpensive, low-power HAWT design is widely used in rural and urban areas. Such systems are becoming increasingly popular due to increased concern over greenhouse gas emissions, and consist of following four main components [2]:

2.4.1. Rotor assembly:

Blades of the turbine along with the hub upon which the blades are mounted comprises the rotor assembly. The response of a wind turbine is critically affected by blade geometry, and in numerous designs, this factor is also the most costly part of the turbine unit.

2.4.2. Drive train:

Linking the rotor to the generator is the drive train. In larger wind turbine systems, the drive train comprises of gearing to escalate the velocity of rotation from the rotor into the generator. Small turbines lack this attribute; the drive train for those systems is merely a linking shaft.

2.4.3. Generator:

The generator transforms the mechanical rotation of the drive train into electricity. Small turbine generators are normally of the 3-phase, permanent magnet type; yet various generator classes are also employed.

2.4.4. Controller:

For shielding the system, apart from transforming the output of the generator to domestic voltages, the necessity of power electronic interface arises. As already mentioned, the working of a turbine is seriously affected by its geometry. Characterization of the performance is usually done with a Cp - λ curve; a plot of power coefficient to the tip speed ratio of the blades. The power coefficient Cp signifies the efficiency of the blades in taking out the power stored in the wind, whereas the tip speed ratio (TSR) is defined as the ratio of the blade speed to the air stream.

2.5. CONTROLLING TECHNIQUES OF WIND TURBINES

It is desirable that the power captured from the wind turbine should be maximized. Moreover, it is essential that under any circumstances, the safety of the wind turbine should not be compromised. Thus, proper regulation of power plays a very important role in the operation of wind turbine. In order to prevent any damage to the wind turbine in case of very high wind speed, it is important to limit the amount of power absorbed which can be done by regulating the aerodynamic forces acting upon the rotor. The commonly employed techniques to achieve the above objective are as follows

2.5.1. Pitch control

Pitch control helps the blades to be twisted into or out the wind. It results into deviation of the force exerted by the wind on the shaft of the rotor. This control has many advantages over other controls:

- power control is perfect,
- Aided startup, and
- Alternative stop.

Power output can be limited to the rated power of the generator using pitch control at higher wind speeds. The system complexity is one of the disadvantages in the pitch mechanism and one more disadvantage is greater power fluctuations at high wind speeds.

2.5.2. Stall control

a. Passive Stall control

The informal controlling method for a wind turbine is stall control and stalling will take place when the wind speeds crosses a certain limit . Thus, the lift force exerted on the rotor stops starting the turbine to stall and restrict them in a allowable speed limit. Therefore, the turbine is safe and secured at a very higher wind speeds. Power control is very smooth using this process. The disadvantage is that , at low wind speeds turbines operate at a lesser efficiency than the measured value . Moreover the reasons behind the disparities in steady state power extraction are due to the variation of grid frequencies and air density.

b. Active Stall Control

The active stall control was a replacement over passive stall control. Instead of using natural stalling, pitching was used by this system for controlling the stall of the blade actively. Therefore , maximum efficiency is achieved by pitching the blades in the same manner as that of pitch controlled wind turbine at low wind speeds and at higher wind speeds, to allow them into a deeper stall, the blades are oriented to some extent into the direction opposed to that of a pitch controlled turbine.

Various advantages of the above system are Power fluctuations will be less in case of obtaining smoother limited power. It can compensate differences in air density. It is quite easier for the system to obtain emergency stops and again starting up the wind turbine.

2.6. CHARACTERISTICS OF WIND TURBINE:

Different characteristics of a wind turbine are studied and plotted.

2.6.1. Power-Speed Characteristics:

Mechanical Power tranfered to the shaft is:

$$P = 0.5 * C_p A \rho {V_w}^3$$

where A is the capture area, ρ is the density of air and V_w is the wind speed.

The curves describe the relationship between mechanical power harnessed from the wind and the speed of the rotor at several wind speeds. For respectively wind speed there is an most favorable turbine speed at which extreme power is take out.
All those wind turbine curves are represented by a single dimensionless characteristic curve and are shown and the $C_p - \lambda$ is shown in the figure 2.1.

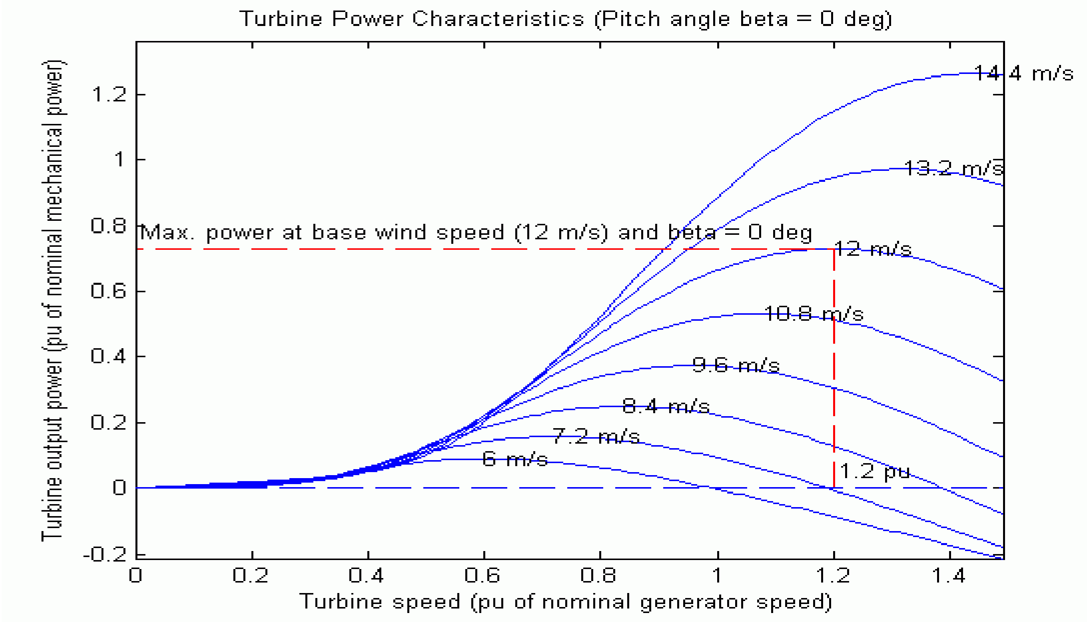

Fig 2.1. Turbine output power versus turbine speed characteristics

(fig. source: www.mathworks.com)

2.6.2. Torque Speed Characteristics

The characteristic curve between typical torque and speed of the wind turbine for a two blade wind turbine is shown in figure 2.2.

Mechanical torque of the Wind Turbine,

$$T_m = 0.5 * \rho A r_r \mathrm{C_M} {V_w}^2$$

Where ρ= air density in kg/m^3

A= area covered by the rotor blades (in m^2)

$C_M = \frac{C_p}{\lambda}$

C_M= torque coefficient

r_r= rotor radius in meters

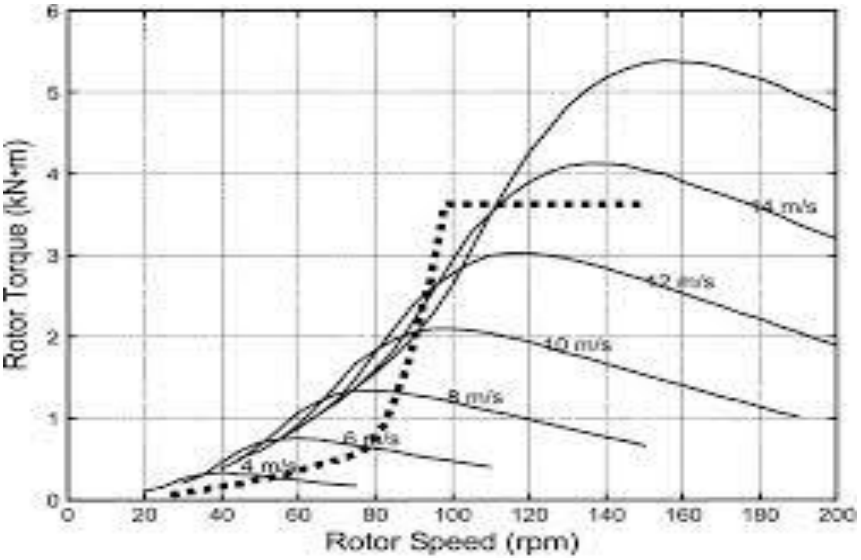

Fig 2.2. Torque speed characteristics of wind turbine

(fig. source: www.mathworks.com)

CHAPTER 3

DC Motor

DC motors make up most of the mechanical movement we see around us. They convert electrical energy in DC form to mechanical energy. Due to its simple operation and control and due to its availability at wide range of ratings it has been chosen for simulating wind in the wind turbine system.

3.1. ELECTROMECHANICAL ENERGY CONVERER DEVICE

It is basically a medium of transport between the input and output sides. Various types of electrical machines namely DC machine, induction machine and synchronous machine are employed widely for conversion of electromechanical energy. Conversion of electromechanical energy occurs whenever there is a variation in magnetising flux associating a coil, due to mechanical motion.

Electric Motor

The input to the system is electrical energy obtained from the supply while the output is in the form of mechanical energy given to the load. The system is described in Fig 3.1.

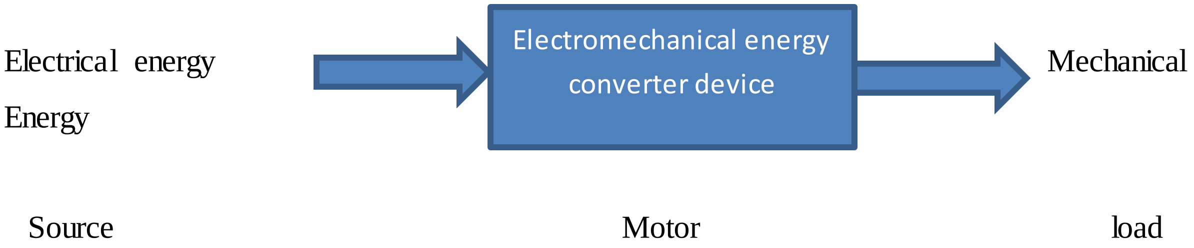

Fig. 3.1. Electrical motor

Electrical Generator

The system is described in fig 3.2.

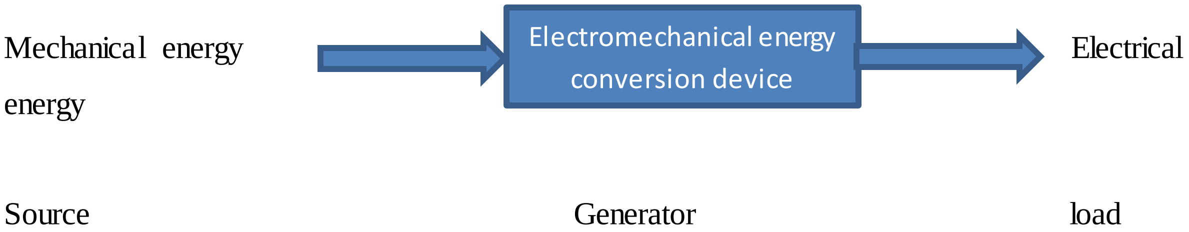

Fig.3.2. Electrical generator

3.2 SEPARATELY EXCITED DC MOTOR

Different supply voltage is provided to field and armature winding in a separately excited dc motor. Field flux to armature is facilitated by field winding. On application of dc voltage to motor, current is supplied to the armature winding via brushes and commutator. Since current carrying rotor is positioned in magnetic field, so it generates a back emf and a torque to equalize load torque at certain speed.

3.2.1Analysis of DC separately excited motor

When field current I_f is supplied to a separately excited dc motor and an armature current I_a circulates in the circuit, the motor generates a back EMF and a torque to equalize the load torque at a certain speed. The field current I_f does not depend on armature currentI_a. Separate excitation is provided to each winding. Armature current variation does not result in variation in the field current. Normally I_f is quite lesser compared to I_a.

The total emf induced in the motor is given by the equation

$$E = k_e \phi \omega_m$$

L_f and R denote the inductance and resistance of the field winding respectively. The magnetic field required for motor working is generated by the current I_f. In the armature (rotor) equivalent circuit, V is termed as the voltage put on athwart the motor terminals, I_a is the current circulating in the armature circuit, R_a refers to the resistance value of the armature winding, and E refers to the total voltage that is induced in the armature.

$$V = E + I_a R_a$$

For invariant field current in case of a separately excited DC motor, the flux can be expected to be constant.

$$T = k_e \phi I_a$$

From equations, it was found out that

$$T = KI_a$$

$$E = K\omega_m = V - I_a R_a$$

So,

$$\omega_m = \frac{V}{K} - \frac{R_a}{K}$$

$$\omega_m = \frac{V}{K} - \frac{R_a}{K^2} T$$

Now, using the above equation it can be clearly deduced that speed of DC motor is governed by applied voltage, armature current, armature resistance and field flux.

Thus, there are three methods of regulating speed of a DC motor.

1. Flux control method
2. Armature control method
3. Voltage Control method

1. Flux Control method

The speed can be improved by lessening the flux as well as vice versa holds true. The flux of a dc motor can be altered by varying I_f by fluctuating the input voltage.

If we fluctuate I_f, flux ϕ will change, hence speed will change. For varying I_f an external resistance is linked in series with the field windings. When no external resistance is connected and rated voltage is applied across field coil, the field coil generates rated flux. The purpose of adding an external resistance is to limit the flux level by varying the former. Thus for controlling the speed above the base speed decrement of field current will result in increment in motor speed.

2. Armature Control Method

When there is requirement of speeds lower than the no-load speed the armature control technique is employed. Since the supply voltage is usually invariant, the voltage athwart the armature is varied by introducing a variable rheostat in series with the armature circuit. An increase in the controller resistance causes the voltage to decrease athwart the armature and hence decrementing the armature. For a constant load torque, speed is roughly proportional to the voltage athwart the armature. From the characteristic plot for speed vs armature current it is observed that the fall in the speed varies inversely with the value of resistance in the armature circuit.

3. Voltage Control Method

(a) Multiple Voltage Control:

According to this method, a fixed exciting voltage is impressed upon the shunt field of the motor. And using appropriate switch gear the armature is provided with various voltages by joining it athwart one of the different voltages. These different voltages will govern the armature speed because of the direct proportionality. The shunt field regulator is employed to achieve the intermediate speeds. Separately excited dc motors are best suited for this method. In this method of speed control, constant parameters are R_a and ϕ.

In normal operation, the drop along the armature resistance is quite small compared to E and therefore:

$$E = V$$

Since, $E = k_e \phi \omega_m$

Angular speed can be expressed as

$$\omega_m = \frac{V}{K} \qquad ,as \qquad k_e \phi = K$$

From this equation,

- The speed varies linearly with V provided flux is kept constant.
- The speed surges as the terminal voltage is risen and vice versa also holds true.

CHAPTER 4

Modelling

4.1. Modelling of Wind Turbine

The static model consists of the $C_p$vs.λ - curve and the generated torque. Inputs to the model are: angular speed (ω_r), wind speed (V_w) and pitch angle (β). Output of this model is the rotor torque (T_m).

The output extracted from the Wind turbine emulator model is governed by the following equations:

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{-\frac{C_5}{\lambda_i}} + C_6\lambda \quad (8)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \quad (9)$$

where,

C_1= 0.5176, C_2= 116, C_3= 0.4, C_4= 5, C_5=21, C_6= 0.0068

Mechanical torque of the Wind Turbine,

$$T_m = 0.5 * \rho A r_r \mathrm{C_M} {V_w}^2$$

where, $\mathrm{C_M} = \frac{C_p}{\lambda}$ (10)

The turbine power of a fixed pitch wind turbine is expressed as

$$P_t = 0.5 * A\rho {V_w}^3 C_p(\lambda,\beta). \quad (11)$$

4.1.1. Block Diagram: To plot the graph between coefficient of power and tip speed ratio, the value of constants are taken as mentioned above. The pitch angle is constant i.e. zero degree. Then $\lambda_i$is calculated and used in the equation of $C_p$to plot the graph. Multiplier and adder blocks are used at different places to get the characteristics. $C_p$vs lambda for various pitch angle also plotted i.e. pitch angle from 0 to 20. The power curve is also plotted for various values of wind speed. Block diagram is shown in Fig. 4.1. The sub-systems are represented in Fig.4.2 and Fig.4.3.

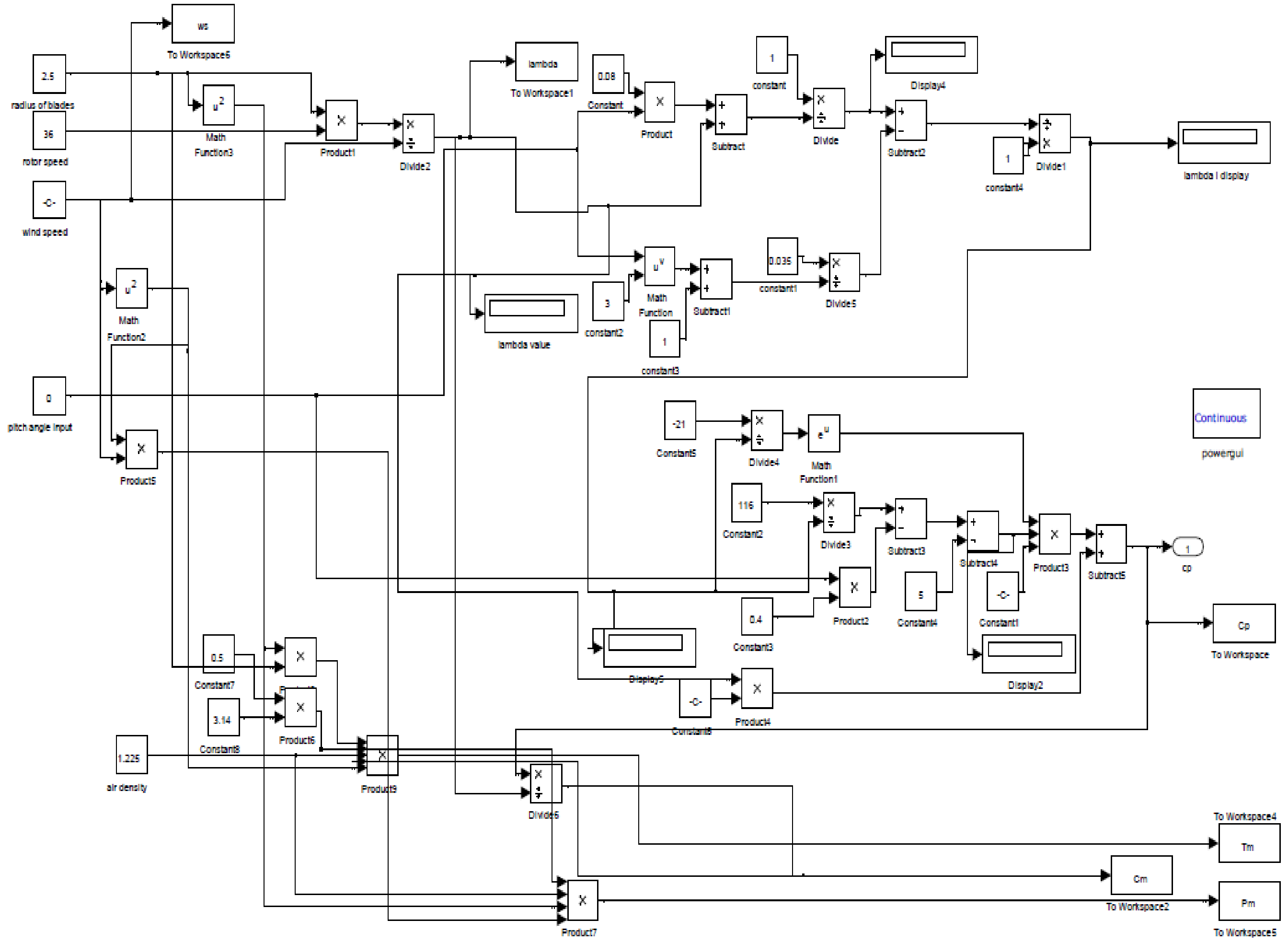

Fig 4.1. Simulink model of wind turbine emulation

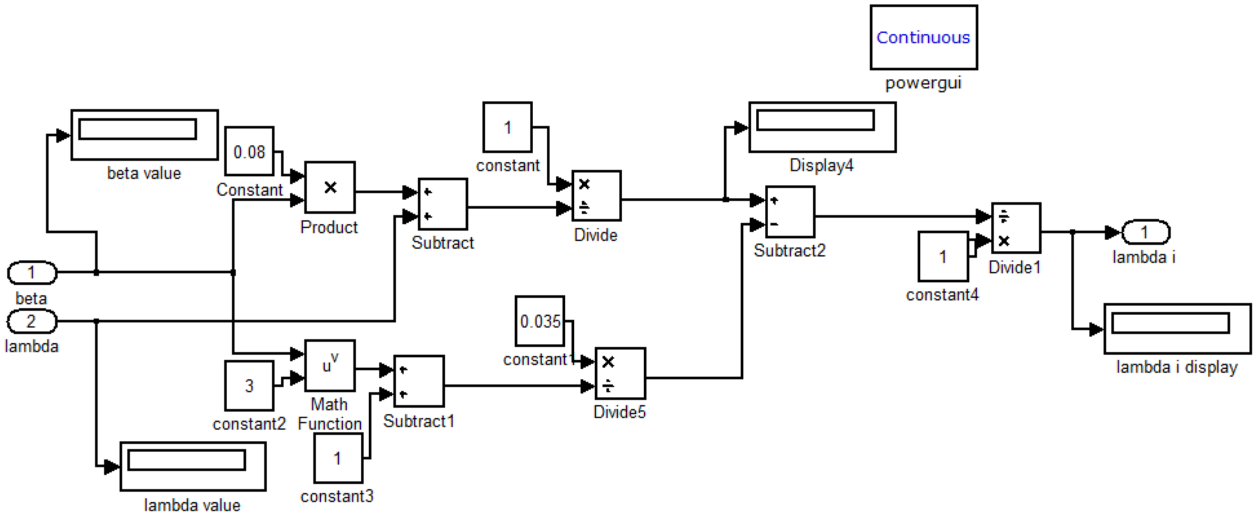

Fig 4.2. Subsystem of $\frac{1}{\lambda_i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1}$

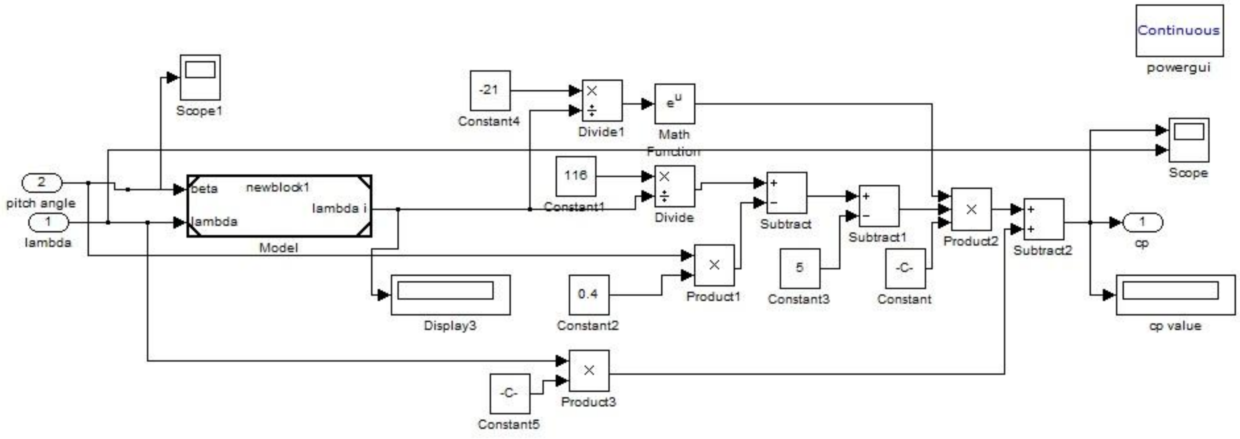

Fig 4.3. The subsystem of $C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{-\frac{C_5}{\lambda_i}} + C_6\lambda$

4.1.2. Characteristics (C_p vs. λ Curve): Both TSR and C_p are calculated and taken to workspace and the graph plotted between C_p and λ. Output is as shown in Fig.4.4.

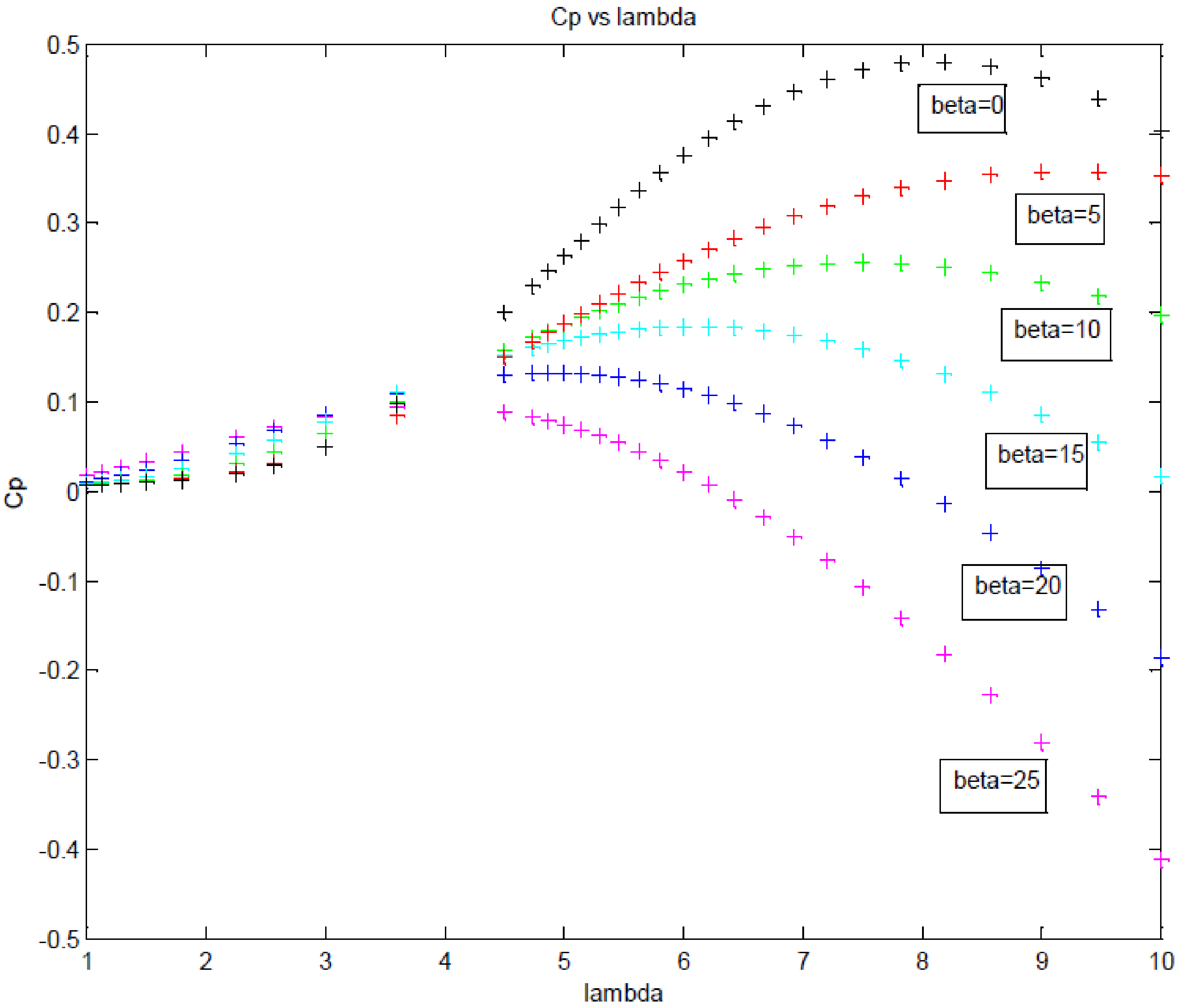

Fig 4.4. C_p vs λ curve characteristics

The graph shows the variation of Tip Speed Ratio with power coefficient at different beta values.

4.1.3. Power Speed Characteristics Of Wind Turbine:

The output obtained is shown in Fig. 4.5. The graph between power generated from the wind turbine and the wind speed shows that increases proportionate to the cube of the wind speed.

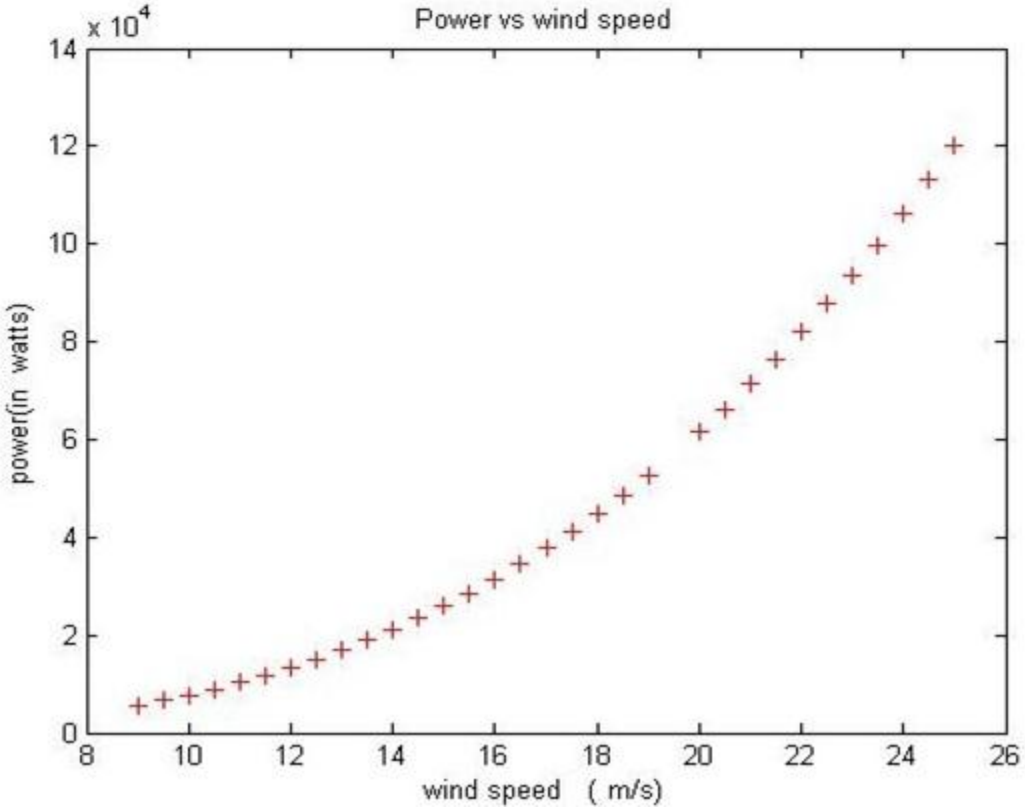

Fig 4.5. Power vs Wind speed

4.2. DC Motor Modelling

The DC motor is modeled using the equations and the blocks of the simulink. The gain blocks with different values were chosen and the above circuit is made. Two integrators are used as they are required to implement the equation.

4.2.1. Block Diagram:

In the block diagram in Fig. 4.6., different gain parameters are used. Values of different gain blocks are: Gain : 1/0.5, Gain1: 1/0.01, Gain2: 0.01, Gain3 :0.01, Gain5:0.01

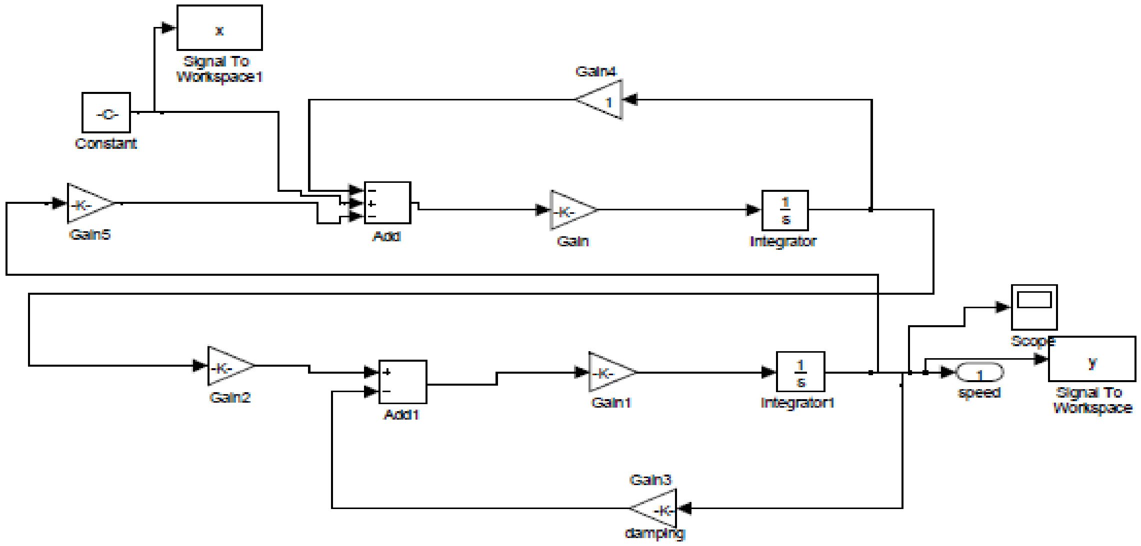

Fig 4.6. Simulink model of separately excited DC motor

4.2.2. Output Characteristics: Output is speed and it is taken to a workspace. Output characteristic has been plotted between speed and time for different inputs. The graph is shown in Fig.4.7. where speed variation is plotted.

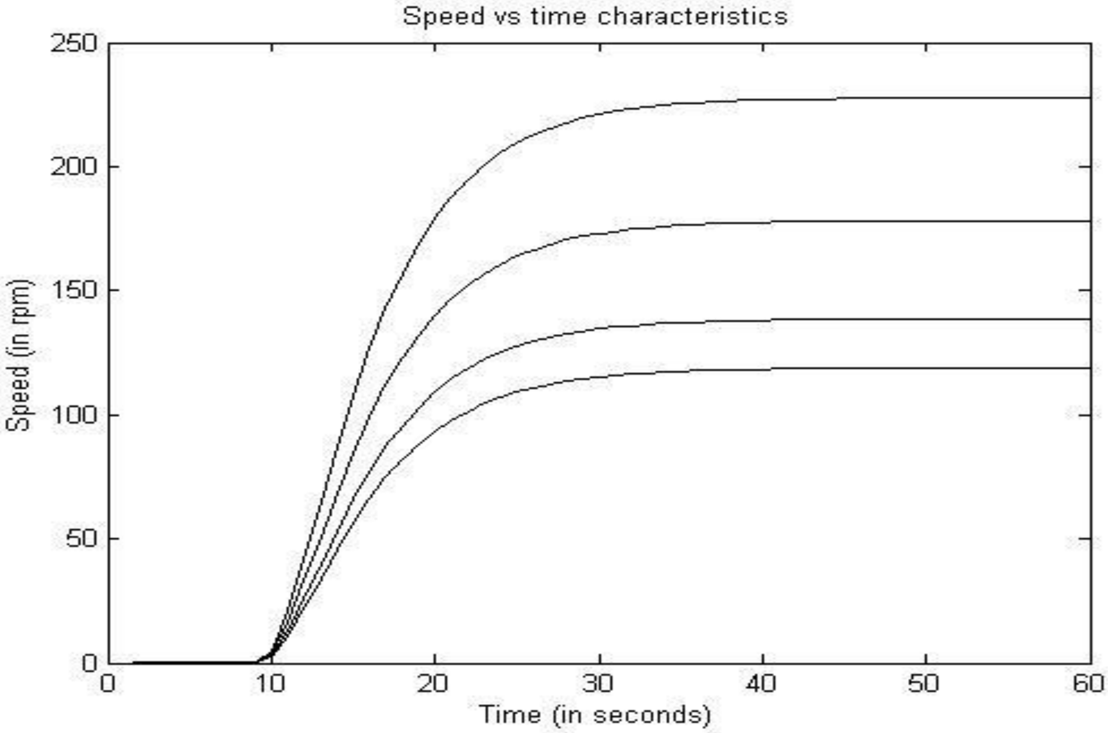

Fig 4.7. Output Characteristics of DC Motor

4.3. Speed Control of DC Motor

The wind turbine model takes the wind speed, pitch angle and angular speed as inputs. Gear ratio conversion is applied to the angular speed. The torque constant is multiplied with the calculated reference torque in the model and the reference current is calculated. This reference current is equated with the armature current of the DC motor. The current error is lessened by a tuning a proportional-integral controller. The block diagram of this system is shown in Fig. 4.8.

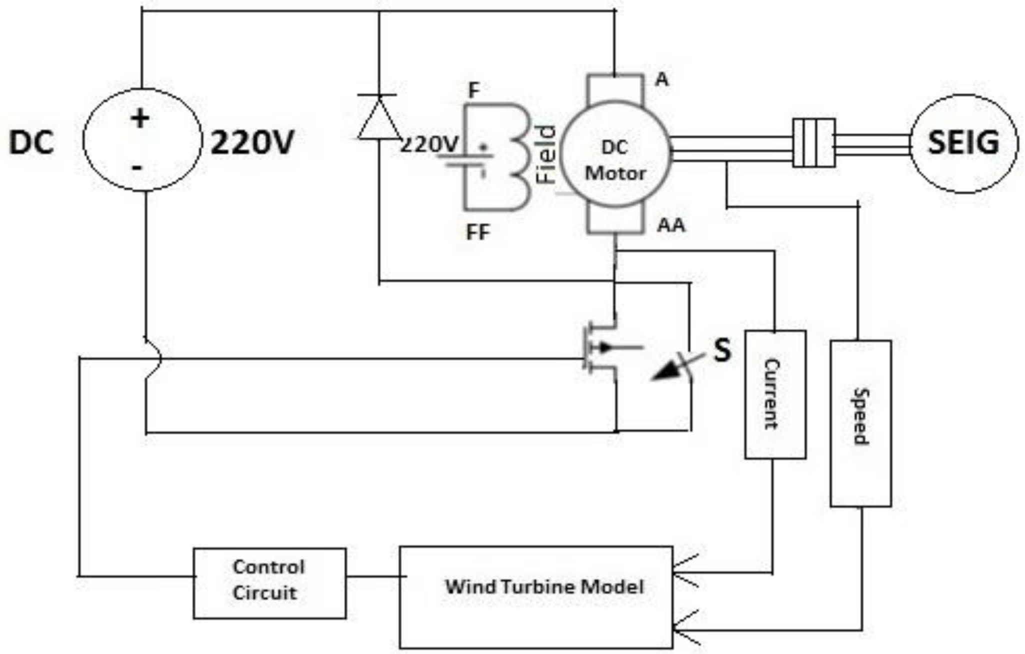

Fig.4.8. Schematic representation for speed control of DC motor to emulate wind turbine characteristics

Under steady state, the emulator power and current matches with the reference power and current, respectively. However, the shaft speed varies in accordance with the wind speed variation. The investigations of the emulator action under various wind profile ensures the effectiveness of the WTE.

4.3.1. Block Diagram:

Speed control of dc motor using PI controller is presented in Fig. 4.9.

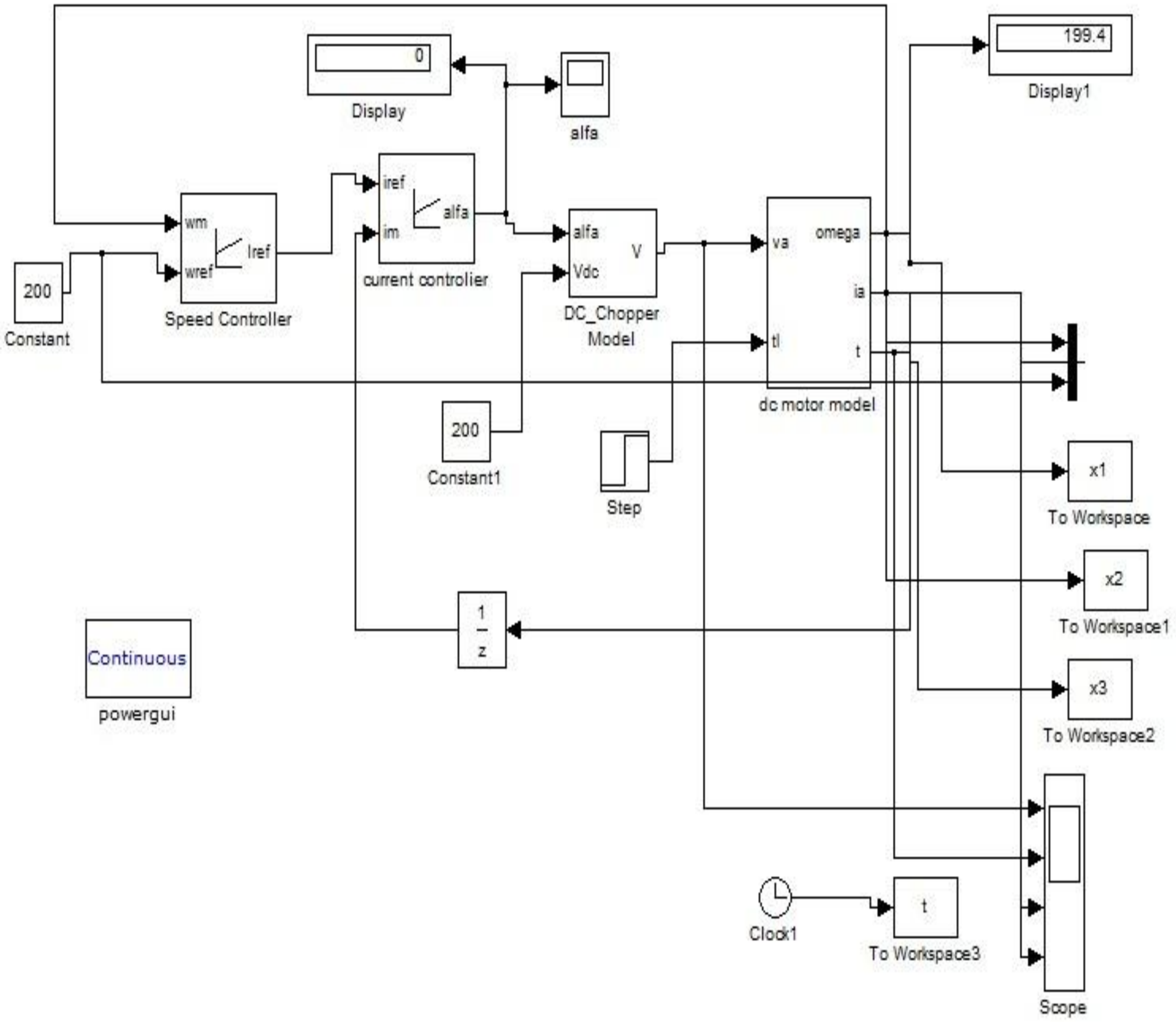

Fig.4.9. Simulink model for speed control of DC Motor

The DC Chopper Model: The subsystem shown in Fig.4.10 represents the chopper model

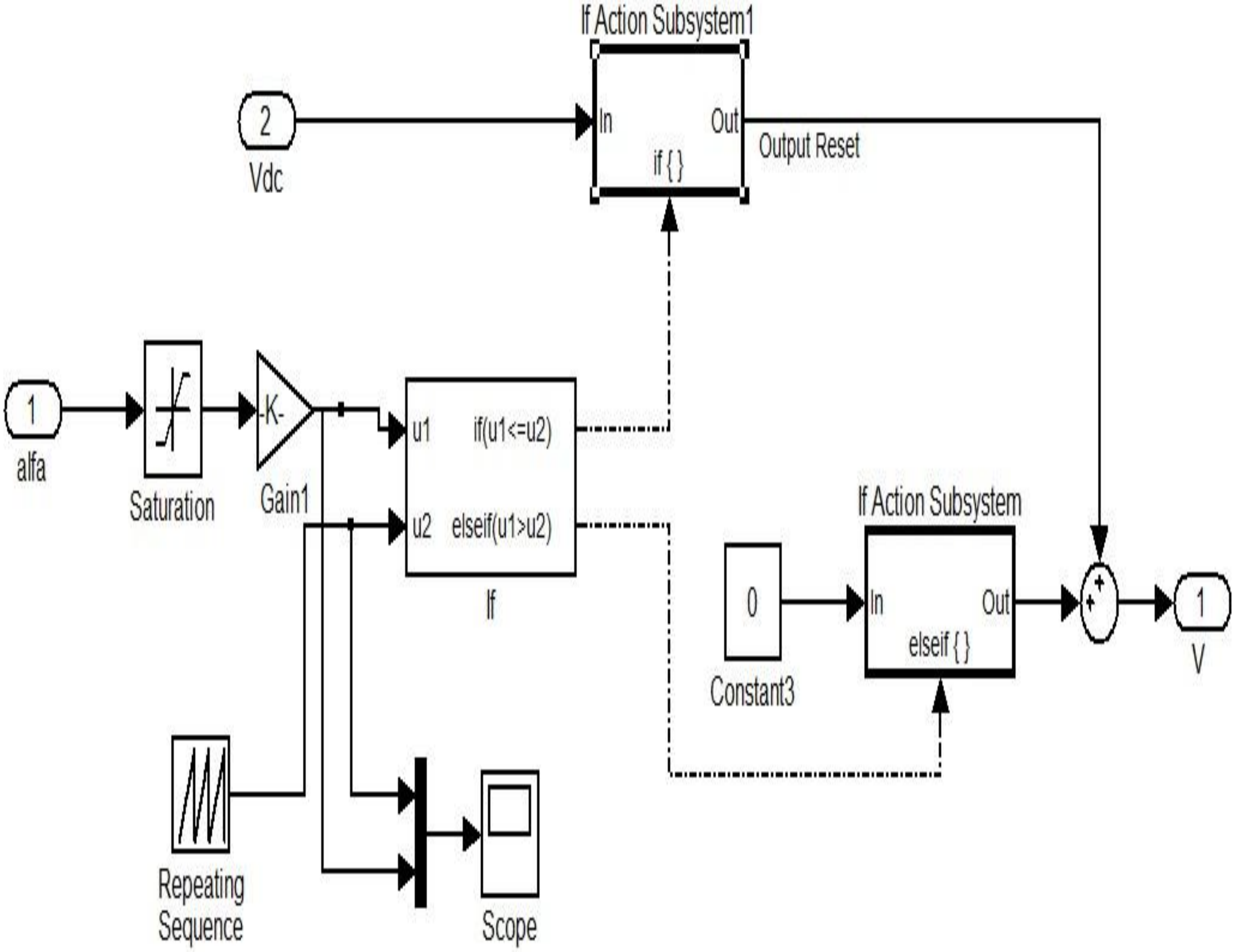

Fig.4.10. Simulink model for DC Chopper subsystem

4.3.2. Output:

The output curves are shown in Fig 4.11 :

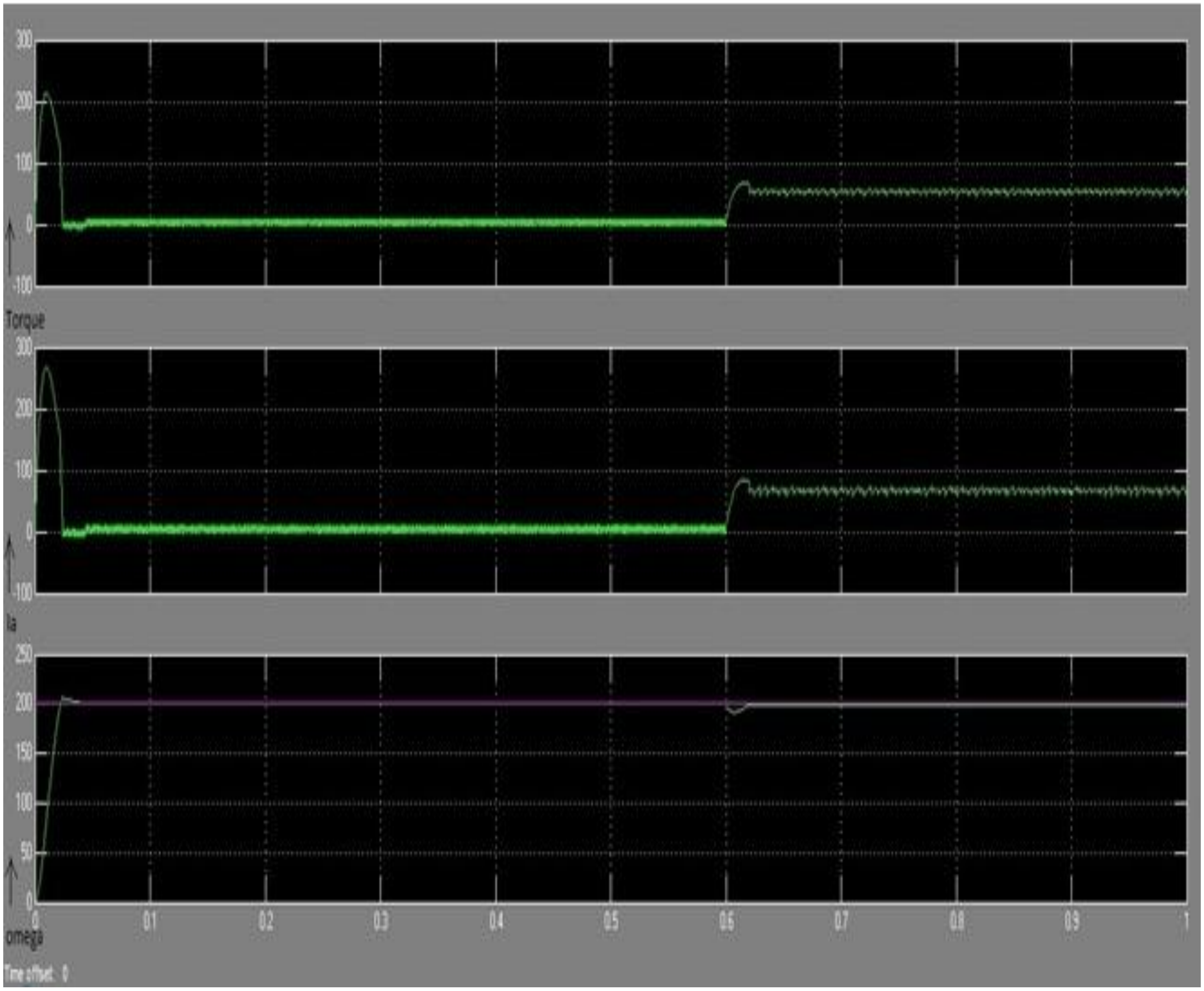

Fig 4.11.Output of speed control of DC motor

These curves in Fig.4.12 obtained for dofferent votage values, resembles with the Cp vs Tip-speed-ratio characterisitcs of the modelled wind turbine for different pitch angles.

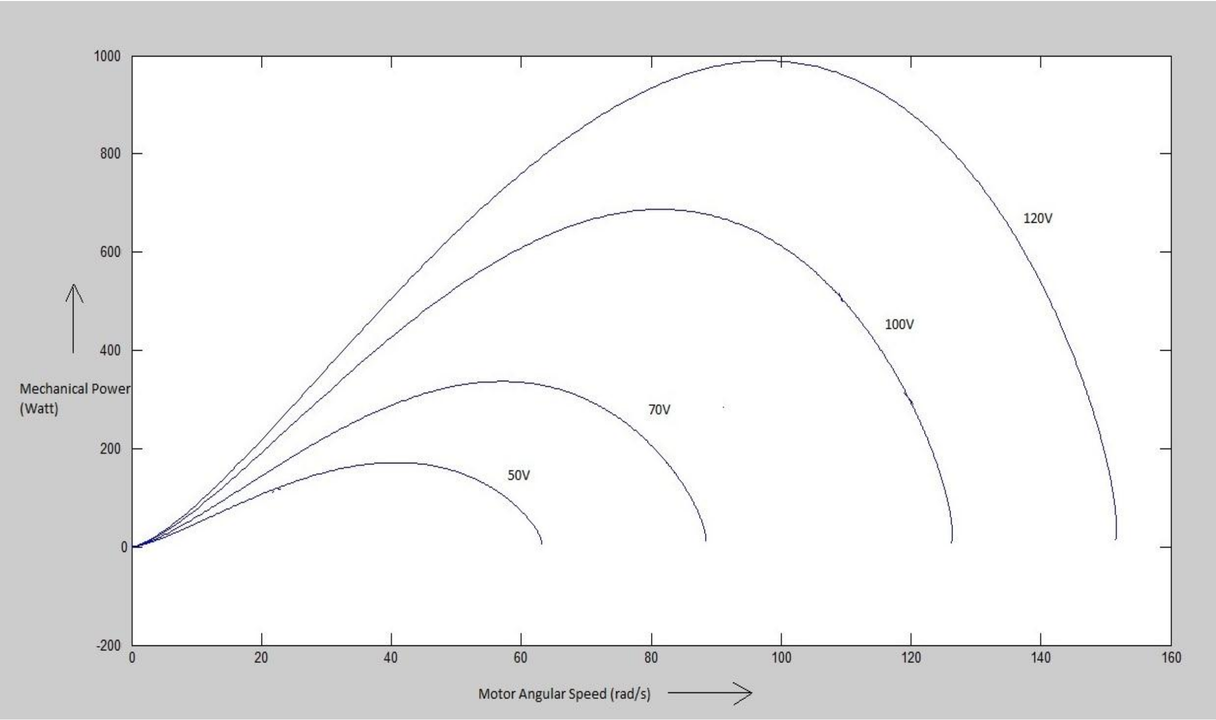

Fig 4.12. Curve for mechanical power vs motor angular speed

4.4. The WECS System

The wind speed, pitch angle and angular speed are taken as inputs to the wind turbine model. The angular speed is encounters conversion through gear ratio. The calculated reference torque is used to estimate the reference current. This is compared with the armature current of DC motor. The current error is tuned by a proportional-integral controller. At steady state conditions, the emulator current and emulator power is same as the reference current and power. The wind speed variation determines the shaft power variation. The effectiveness of the Wind Turbine Emulator is determined by emulator action at various wind profile. The motor is coupled to the induction generator. The power generated is supplied to the grid.

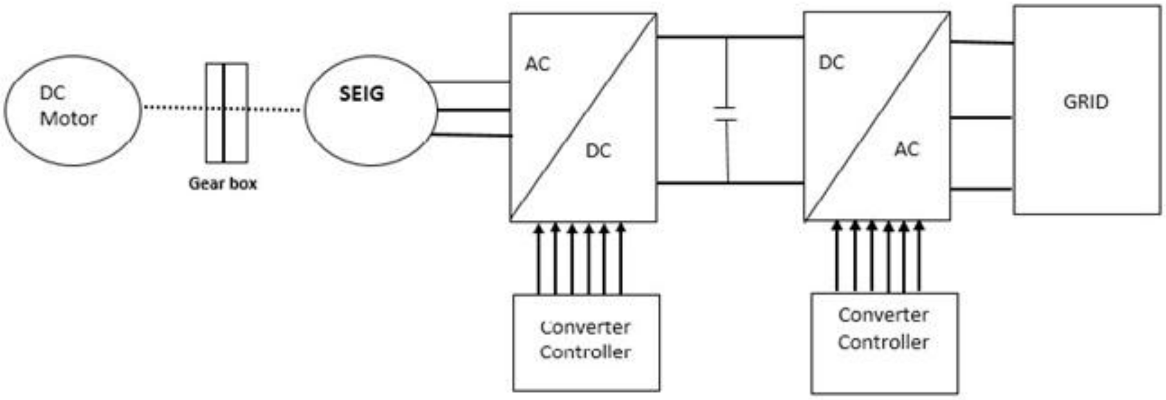

Fig. 4.13. Wind Energy Conversion System

CHAPTER 5

Conclusion

The concept of wind turbine was studied in detail and the modelling in MATLAB/SIMULINK was done. The project develops a wind turbine emulator that provides characteristics of wind turbine based on wind speed and other gradient factors. It verifies the modeling of wind turbine as a speed source that can be further used for development of more efficient energy converters for extraction of power from wind turbine. Such emulators are vital for development of WECS to encounter all sorts of unpredictability in wind and environment in order to ensure the continuity of wind energy hence contributing to more encouragement of Wind Energy. The project implements speed control of DC motor using PI controller. DC choppers are used. The characteristics of wind turbine with DC motor are obtained by using PI controller. This operational wind turbine emulator could be used for research on a small wind energy conversion system and thus form a test-bed to experiment and develop other control strategies.

Chapter 6

Scope of Future Work

- The emulated wind turbine model developed in the present work can be redesigned to operate in transient conditions and the required characteristic plots can be obtained for a more realistic approach.

- The control method of the DC motor can be improvised to have a more efficient model that can emulate well the real characteristic operation of a wind turbine.

- The wind model can be dumped on the DC motor using microcontroller programming or FPGA program etc. to have the hardware implementation of the emulation model.

- The emulated turbine may be coupled with an induction generator to build a stand-alone system that can be used for various small scale applications.

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