MODELLING AND SIMULATION OF LOW SPEED WIND POWER GENERATION SYSTEM USING CAGE TYPE INDUCTION MACHINE

Thesis submitted to Jadavpur University, Kolkata towards fulfilment of requirements for the degree of

MASTER OF ELECTRICAL ENGINEERING (ELECTRICAL MACHINES)

submitted by

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MAY, 2019

DEDICATED TO

Guides, seniors and my dear colleagues for constant help and motivation during entire period, so that i could successfully complete the work.

CERTIFICATE

This is to certify that the thesis entitled "**MODELLING AND SIMULATION OF LOW SPEED WIND POWER GENERATION SYSTEM USING CAGE TYPE INDUCTION MACHINE**" submitted by **VIVEK KUMAR** in partial fulfilment of the requirements for the award of the degree of **MASTER OF ELECTRICAL ENGINEERING (ELECTRICAL MACHINES)** at Jadavpur University, Kolkata-700032, is a work carried out by him, under my supervision and guidance. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university or institute for the award of any degree or diploma.

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DECLARATION OF ORIGINALITY AND COMPLIANCE OF ACADEMIC THESIS

It is hereby declared that the thesis entitled "**MODELLING AND SIMULATION OF LOW SPEED WIND POWER GENERATION SYSTEM USING CAGE TYPE INDUCTION MACHINE**" contains literature survey and original research work by the undersigned candidate, as part of his degree in Master of Electrical Engineering.

All the information in this document has been obtained and presenter in accordance with academic rules and ethical conduct.

It is also declared that all the materials and results, not original to this work have been fully cited and referred throughout this thesis, according to rules of ethical conduct.

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ABSTRACT

This paper deals with the generation of power with the help of low speed wind turbine using squirrel cage induction machine. We have tried to generate power for low speed zone areas.

Due to the decrease in the stock of fossil fuels across the world, we had to shift towards renewable sources of energy, which should be environment friendly. So, in this paper we have worked upon wind power generation.

Till now, power generation for the wind speed in high and medium speed in the range of 8m/s to 25m/s, but we have tried to generate power with low speed range of around 4-5m/s. For the less maintenance and robustness, SCIM has been used. This scheme can be used in generation in even remote areas, so we have used capacitor for reactive power fulfilment of machine.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

As fossil fuels are diminishing day by day, or as its stock are limited, we are made to think upon alternative sources of electrical energy. Scientists and researchers are working on various alternate sources of electrical energy. Several renewable sources are hydropower, bio power, geothermal, solar energy, wind energy and ocean energy. As per GWEC report 2017, total renewable sources power capacity is around 2200 GW, which was around 1000 GW in the year 2007. Solar and wind energy are the trending topics to work upon. The energy production by wind turbine is increasing day by day, as it is environment friendly and world has enormous amount of wind power.

Wind energy production started in the year 1887 in Scotland, and in 2018, total installed capacity of wind power in the world is around 600 GW. Real acceleration in the installed capacity of wind energy took place after 1990's and installed capacity became more than four times from year 2000 to 2006 from 17GW to 74GW. The growth in the wind sector can be understood by the data that more than 50GW capacity was installed in the year 2014, and it even increased in 2015. Global Wind Energy council has predicted that total installed capacity by wind power will be around 700 GW by 2020 and it will even increase to 4050GW by 2050. In the year 2017, there has been maximum increase in the renewable energy generation and there has been decrease in the cost of those energies.

As per GWEC report, by the end of 2017, India is the 5th country in terms of renewable energy capacity. In terms of wind power generation capacity, India comes at 4th after China, USA and Germany. India has installed wind power capacity of 36.625 GW as on march 2019. Tamil Nadu has highest wind power capacity of around 8GW, followed by Gujarat and Maharashtra.

1.2 LITERATURE REVIEW

A new configuration for an energy conversion system using variable speed wind turbines to supply isolated loads was presented in [6]. 1kw SCIM is used, power converters and MPPT is used. The generated energy is being stored in a battery bank. A wind speed to 10.5 m/sec is taken for experimental data.

A renewable energy based micro-grid system has been developed using DFIG and PV system in [7]. The wind speed taken in this case is around 10m/sec.

A dynamic model of DFIG based wind energy generation in [8] coupled to a lithium battery. The battery is used to have a smooth power supply. Depending upon storage capacity, load can be changed.

A new control strategy for a grid-connected doubly fed induction generator (DFIG)-based wind energy conversion system (WECS) in [9]. It includes battery energy storage system to reduce power fluctuations, due to variations in wind speed. The paper deals with rated speed of 14m/sec.

CHAPTER 2: WIND ENERGY

The energy generated by rotating turbine with the help of flowing winds, is called as wind energy. Basically, wind's kinetic energy is used to provide mechanical power so that wind turbine should rotate and generator coupled to that turbine will generator will generate electric power.

Energy extracted from wind is directly proportional to cube of wind speed, so for wind energy generation, a depth knowledge must be there of the wind characteristics, variation in wind speed and direction variation. As well as there must be suitable sites identification, so that a feasible energy generation can take place. Wind is characterized by its randomness only, it is highly variable geographically, as well as it varies with space and time. All these are important as energy extracted is proportional to third power of velocity. These variations are also due to difference in climatic conditions of the world, and tilting of earth and its spinning also affect wind conditions. Wins speed variation is also affected by the ratio of land and water and presence of mountains in the area. Vegetation types also affect wind distribution by moisture absorption and reflection of sun's energy. Generally wind speed is more on the hilltop and mountains as compared to that of low level areas. Even wind speed is altered by the presence of trees and high buildings. Also, there can be variation in wind pattern annually. These variations are not easily understood, so predictions become difficult from economic point of view of wind farm establishments. Wind distributions can be predicted for short span of time. These variations should be understood because they affect generation of wind energy and also its connectivity to the grid.

2.1 POWER IN WIND TURBINE

Power generated by wind turbine is given by

$$P=0.5*\rho*A*C_p*(V)^3$$

where,

ρ = air density in kg/m^3 (approximately 1.225 kg/m^3 at 20$_o$ C at sea level)

A = area swept by the turbine blade

V = velocity of wind in m/sec (in the range of 4m/sec to 25m/sec)

Cp = power coefficient, which is a function of blade pitch angle(β) and tip speed ratio(λ)

Power coefficient is defined as the ratio of output power developed to the power available in wind.

BENZ LIMIT :- As per Benz Limit, No wind turbine is efficient enough to convert wind kinetic energy to shaft mechanical energy with efficiency greater than 59.3%. Thus Benz Limit is maximum possible theoretical value of Cp. The efficiency is considered in the range of 35-45% for a well designed turbine.

TIP SPEED RATIO:- It is defined as the ratio of the rotor tip speed to the wind speed. Mathematically it is written as

$$\boldsymbol{TSR(\lambda) = \frac{w * R}{V}}$$

Where, w= speed of rotor in radian/sec

R = radius of wind turbine

V= velocity of wind

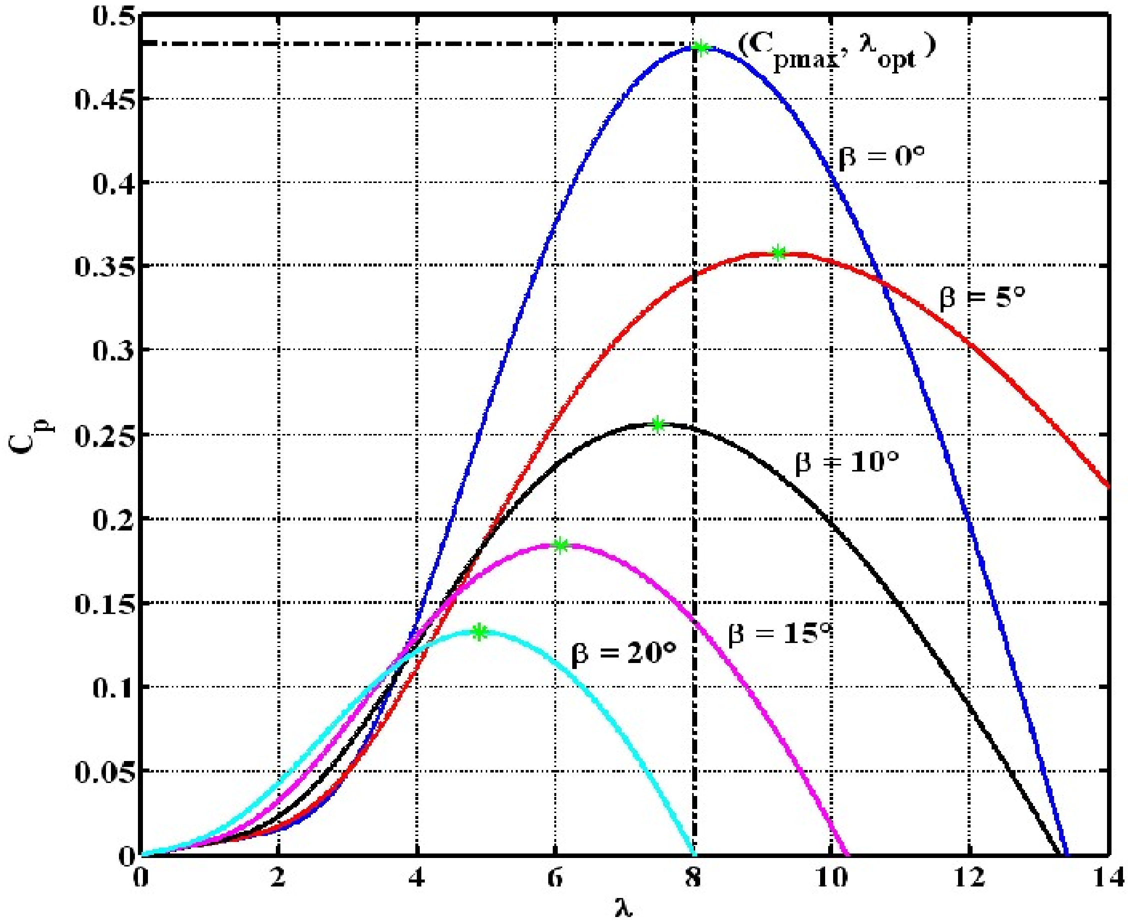

Fig2.1:- Power coefficient of a wind turbine with different pitch angle

2.2 WIND TURBINE

Wind turbine is a rotating device which converts wind's kinetic energy into mechanical energy, which can be further used by generator to generate electricity.

Based on the axis of rotation and alignment, wind turbine is basically divided into two types:-

1. Horizontal axis wind turbine (HAWT)

2. Vertical axis wind turbine (VAWT)

HAWT is commonly used due to its certain advantages, and VAWT is not much used, it is used for specific purposes.

Internal components of a wind turbine, is shown below:-

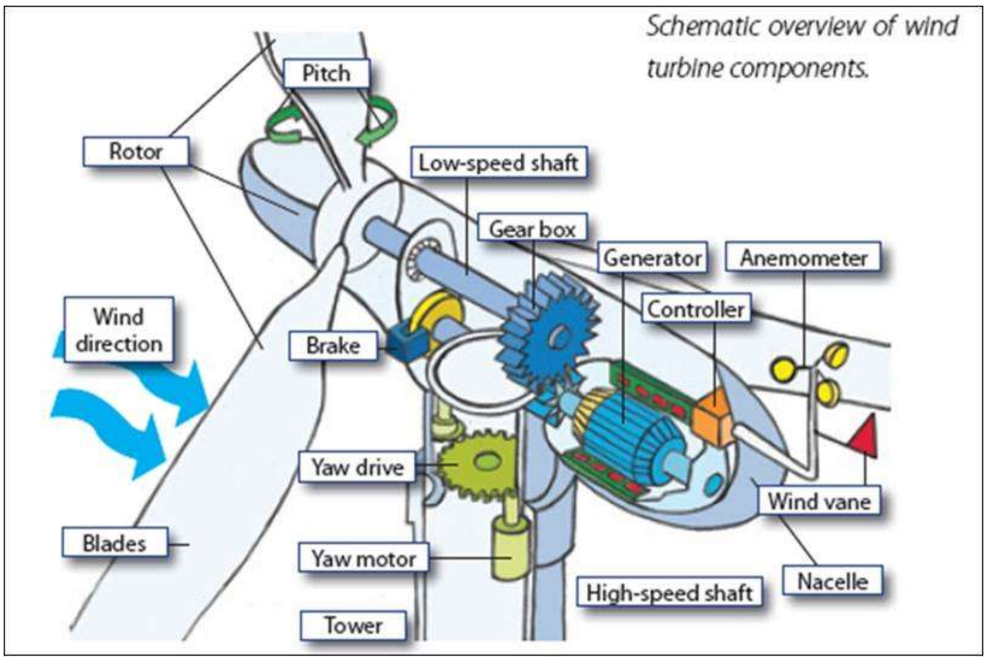

Fig2.2 wind turbine components

- ANEMOMETER :- Speed is measured using this device, and that measured speed is fed to controller for controlling pitch angle and yaw.
- BLADES :- These are aerodynamically designed structures such that when wind flows over them they are lifted as in airplane wings. For greater aerodynamic efficiency, these blades are slightly tilted.
- BRAKE :- These brakes are used for stopping wind turbine in case of very high wind conditions, for protection purposes.

- CONTROLLER :- From power output to pitch angle, everything is controlled by this device. It senses wind direction, wind speed, shaft speed, torque at different points. So it is most important part of wind turbine.
- GEAR BOX :- Generally wind speed is not that enough to be coupled directly to rotor of generator, so we require a gear box in between, such at a reasonable step up of speed can be done.
- GENERATOR :- Mechanical energy provided by blades are used by generator to generate electricity. It can be synchronous or asynchronous ac machine.
- HIGH SPEED SHAFT :- It is coupled to the rotor of generator, its work is to rotate the rotor for power generation.
- LOW SPEED SHAFT :- It is connected to blades and gear box, and it runs at a lower speed, by the force provided by wind.
- NACELLE :- It is enclosure for the low speed shaft, high speed shaft, gear box, generator, converter equipments etc. It is located at the top of tower and protects these equipments from surroundings.
- PITCH:- It adjusts angle of attack of rotor blades to the wind flow. According to wind speed and direction, pitch angle is changed. Changing the pitch angle changes weather the blades turn in or turn out of the wind stream.
- ROTOR :- The wind blades along with the hub are termed as rotor.
- TOWER :- It keeps entire structure at the top, it is made up of tubular steel or steel lattice. Also, power generated by wind turbine is also

dependent on the tower heights. More the tower heights, more the power generated, as wind speed also depends on heights.

- WIND VANE :- Its main job is to sense wind direction and communicate that to the yaw drive, so that turbine and blade direction can be changed accordingly.
- YAW DRIVE :- This controls the blade orientation so that maximum wind power can be accumulated, so it rotates the turbine in wind direction if blade is not in the wind flowing direction.
- YAW MOTOR :- It powers the yaw drive.

2.3 HORIZONTAL AXIS WIND TURBINE

As the name suggests, the axis of rotation of HAWT is horizontal in nature. Rotor shaft and generator are located at the top of the tower, and are pointed towards the wind direction. A gear system is present connecting blade shaft and generator shaft to maintain speed variability. The gear system provides constant speed operation providing constant frequency generation. For preventing blades from getting pushed into the tower, the blades are made stiff. Also the blades are placed distant from tower and are tilted a bit. Downwind machines have also been built, as they no longer require a yaw mechanism to keep them facing the wind, and also because in high winds the blades can turn out of the wind thereby increasing drag and coming to a stop. Most of the HAWTs' are upwind as downwind systems cause regular turbulence which may lead to fatigue.

A basic structure of horizontal axis wind turbine is given below

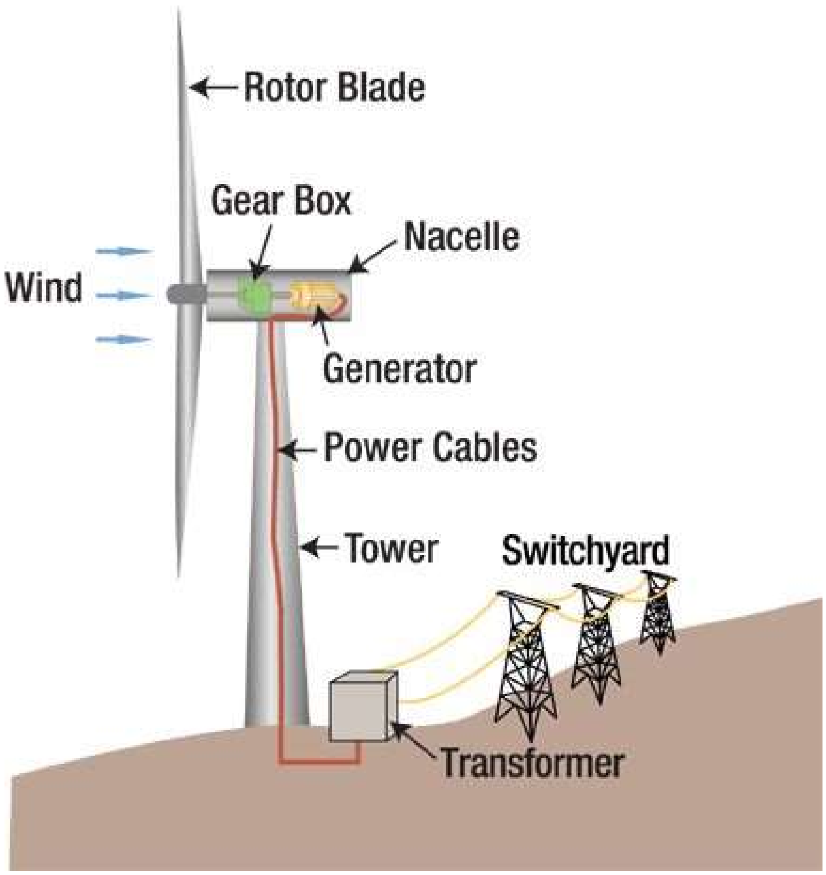

Fig2.3 Basic structure of HAWT

As generated voltage will be low, so that will be stepped up and then send to the grid or switchyard.

Depending upon purpose of wind turbine, number of blades varies in a horizontal axis wind turbine. Generally, multiple blades are used, but turbine with one blade and two blades are also used. Blades are generally made up of fiber glass reinforced polyester or wood- epoxy. Multiple blade concept is used in earlier days for pumping water and grinding etc.

SINGLE BLADE HAWT

It reduces the cost and weight of the turbine. These are rarely used due to tower shadow effects, needs counter weights on the other side of the blade, less stability. Power output will be in range of KWs.

Fig2.4

TWO BLADE HAWT

It requires more complex design due to sustain of wind shocks. It is also less stable. It saves the cost and weight of one rotor blade. Power output will be in range of MWs.

Fig 2.5

THREE BLADE HAWT

Generally three blades are used in wind turbine, as this structure has high strength to withstand heavy wind storms. As well as power output is more in case of three blades HAWT.

Fig 2.6

2.4 VERTICAL AXIS WIND TURBINE

As the name suggests, axis of rotation of such turbine is vertically oriented. Main advantage of such arrangement is that there would be no need for the wind turbine to be pointed in the direction of wind flow. This is advantageous for the places where wind direction is unpredictable. VAWTs can utilize winds flowing from any direction, so it does not require any yaw arrangement. In such arrangement, generator and gearbox is placed near to the ground, so tower does not need to support it, and generator and gearbox are more accessible for maintenance purpose. Drawbacks are that some designs produce pulsating torque. Drag can also be created when the blade rotates into the wind.

Vertical Axis Wind Turbine are used in area having low wind speed.

Vertical Axis Wind Turbine are basically of these types, namely Darrieus Rotor and Savonius Rotor

DARRIEUS VATS

In such rotor, to a vertical shaft, two or more flexible blades are attached. The blades are leaning outward, making a shape of parabola, and are symmetrical in nature. When it is stationary, no torque will be produced. As it has no starting torque, it has to be started by some external means.

Darrieus Rotor generates in the range of KWs.(few KWs to around 500KWs)

Fig2.7 :- 55KW Darrieus rotor

SAVONIUS ROTOR

In such type of rotor, two or more scoops (a kind of cup like structure) instead of blades are used which uses drag action to convert wind energy into torque to run the turbine of generator. When looked upon the rotor from top, a two scoop Savonius turbine will look like S shape.

When the wind blows, it creates a positive force in the scoop and a negative force on the back side of the scoop. This difference in force pushes the turbine around.

In a typical Savonius turbine, the wind comes from the front of the cylinder, causing rotation. However, wind also strikes the back of the other scoops, tending to slow the rotor.

FIG2.8 :- savonius rotor structure

Comparison between HAWT and VAWT

Advantages of HAWT

- Blade pitch can be varied to provide optimum angle of attack. By changing the angle of attack, we can have greater control over power generation and its efficiency also increases.
- As tower height is more, so it is accessible to strong winds.

Advantages of VAWT

- Installation cost will be less, as tower length is less and gearbox and generator are placed near to ground.
- Operation is independent of wind direction, so they don't require yaw mechanisms.
- They have lower start up speeds, so they can be used as low speed wind turbine.

Disadvantages of HAWT

- Higher installation cost, as tower length is more, and generator and gearbox are at the top of tower.
- Generator being at the top, maintenance cost will be more.
- Yaw control mechanism is required for the blade direction to be oriented towards wind direction.
- In case of downwind HAWTs, the regular turbulence produced leads to structural failure.

Disadvantages of VAWT

- Height of tower being low, it can capture only few wind power.
- Higher torque fluctuations and prone to mechanical vibrations.

Another form of classification of wind turbines also exist based on speed of rotation of wind turbine, namely:-

1. Fixed speed wind turbine(FSWT)
2. Variable speed wind turbine(VSWT)

2.5 FIXED SPEED WIND TURBINE

As the name implies, turbine speed is fixed for the time of operation, even if wind speed varies. The speed is determined by no of poles of generator, frequency of operation, and gear ratio. The turbine has to rotate at speed of generator. As speed of turbine is fixed and wind speed may vary so, Tip to speed ratio will change in case of FSWT. Also, the rotor aerodynamic performance would only be optimal at a given wind speed. The maximum conversion efficiency can be achieved only at a given wind speed, and the system efficiency degrades at other wind speeds. The wind turbine is protected by aerodynamic control of the blades from possible damage caused by high wind gusts.

2.6 VARIABLE SPEED WIND TURBINE

In case of Variable speed wind turbine, generator's rotor speed varies according to the wind speed in the range of cut-in speed and rated speed. . In doing so, the tip speed radio which is the ratio of the blade tip speed to the wind speed can be kept at an optimal value to achieve the maximum power conversion efficiency at different wind speeds. If wind speed is above rated speed, the, generator speed will be held constant. Also because of its wide range of operation, these turbines can achieve maximum energy conversion efficiency. Also due to use of converters, its cost will be more compared to FSWT.

3. GENERATORS CONNECTED TO WIND TURBINE

A generator is a device which converts mechanical power of the turbine into electrical form of energy. The generator is further connected to certain power electronic devices for proper synchronisation with grid.

Broadly we have two types of three phase generators:-

1. Asynchronous generator or induction generators
2. Synchronous generators

3.1 ASYNCHRONOUS GENERATOR

As the name given ASYNCHRONOUS; it basically means that it won't run at synchronous speed. Synchronous speed of an ac machine is given by

$$Ns = \frac{120 * f}{P}$$

where ,

Ns= synchronous speed

f= frequency of machine

P= no of poles of machine

The other name of asynchronous machine is INDUCTION MACHINE, because the principle of operation is based on ELECTROMAGNETIC INDUCTION.

Like other machines, induction machine also consists of on outer static part called as STATOR, and the inner rotating part called as ROTOR. The stator is wound with a three phase winding and a three phase voltage is supplied to the stator windings. This creates a uniform magnetic field in the stator which is found to rotate in space around the periphery of the stator. The uniform speed at which magnetic field is rotating around the stator is called as synchronous speed. The rotor also has a multi phase winding embedded in the slots provided on a cylindrical armature structure. These rotor windings are short circuited among themselves and no supply is given to the rotor. There is no electrical connection between the stator and the rotor. The rotating flux created by the stator when links with the rotor, induces an alternating EMF in the rotor which causes current to flow in the rotor windings. This current is due to magnetic induction, and hence the name induction motor. The current flowing in the rotor interacts with the magnetic flux created by the stator to produce a torque and makes the rotor to rotate. The rotor rotates at a speed lower than the synchronous speed, and hence induction motors are called asynchronous motors.

In case of induction motor, speed of rotation is always less than that the synchronous speed and the lag in the speed is termed as slip.

Mathematically slip is given by

$$s = \frac{Ns - Nr}{Ns}$$

where,

Ns= synchronous speed

Nr= actual speed of rotation

so, slip is 1 when rotor is blocked, and tends to 0 when running at no load.

TORQUE SLIP CURVE OF INDUCTION MACHINE

Torque of induction motor is given by the equation

$$T=\frac{3}{Ws}*I_2^2*\frac{r_2}{s}$$

where,

W_s= synchronous speed in rad/sec

I_2 = rotor current

r_2 =rotor resistance

s= slip

Putting the values of current, developed torque can be rewritten as

$$T=\frac{3}{Ws}*\frac{v^2}{((r_1+\frac{r_2}{s})^2+(x_1+x_2)^2)}*\frac{r_2}{s}$$

In the above equation it can be clearly seen that torque is a function of slip, so by varying slip, we will get different values of torque.

At high speeds or low slips, as S will tend to zero, then by various approximation we can see that

$$T \propto s$$

torque is directly proportional to speed, so it will be a straight line.

At low speeds or at high slips , as slip tending to 1, we can see that

$$T\propto\frac{1}{s}$$

Thus, at high slip values, when induction motor is running at low speeds, torque is inversely proportional to slip. So, torque slip characteristics will be rising parabola in low speed zone.

The torque slip characteristics of an induction machine is shown in the figure given below

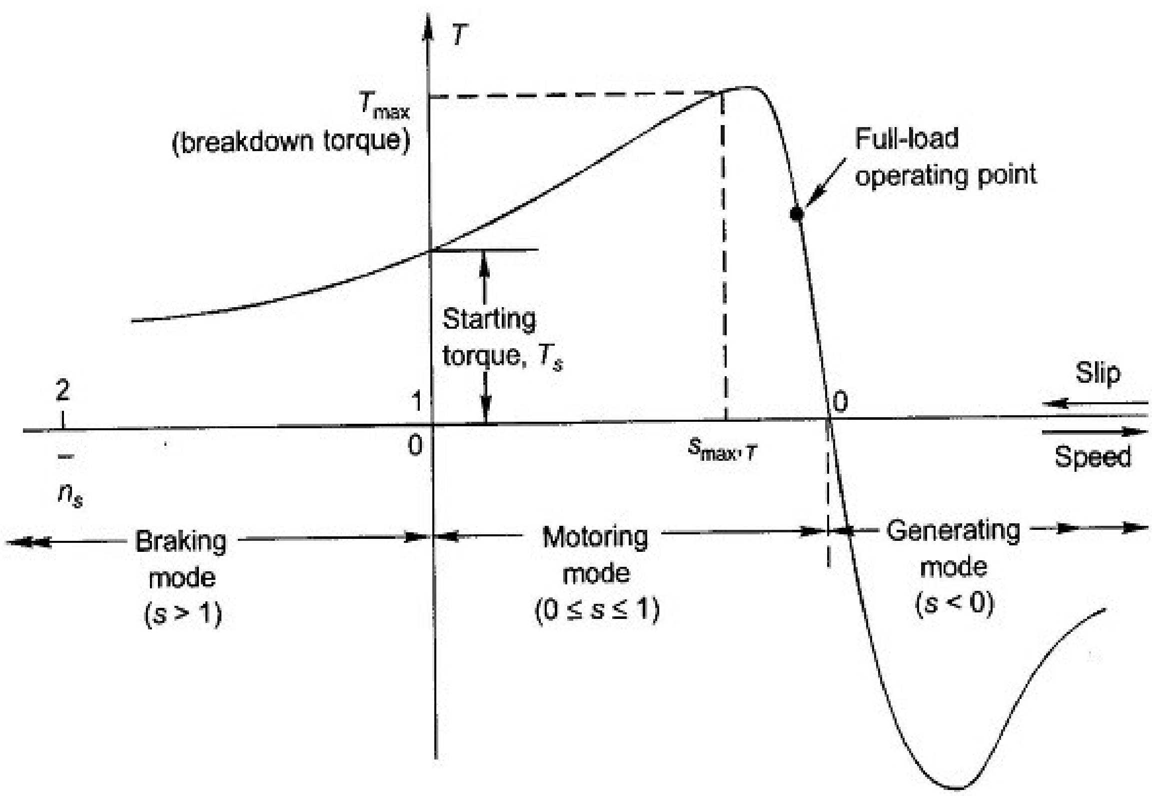

Fig 3.1 Torque slip characteristics of induction machine

From the above figure, it can be seen that we have three ranges of operation:-

1. MOTORING MODE

2. GENERATING MODE

3. BRAKING MODE

MOTORING MODE OF OPERATION

In this mode, the rotor rotates in the same direction as of stator rotating magnetic field rotates, and the slip ranges from 1 to 0. In this region, motor is able to deliver torque to the load, as indicated by the positive values of torque in this range.

GENERATING MODE OF OPERATION

In this mode, the rotor is rotated by an external mechanical prime-mover at a speed above synchronous speed of the machine and rotated in the direction of RMF. The stator terminals, however, needed to be connected to a constant frequency three phase voltage source so that RMF can be generated in the stator. While the stator terminals draw magnetizing current from the three phase power supply, it in turns delivers active electrical power generated to the same power lines to be delivered to electrical loads. In generating mode as speed varies from N_s to $2N_s$, the slip varies between 0 to -1. In generating mode, developed torque is negative, which indicates that induction motor accepts torque from the prime mover, rather than delivering torque to mechanical load.

But sometimes, we can't have the accessibility to the grid, in such cases, for power generation, we can get reactive power from capacitor banks. The mechanical torque will be provided by the prime mover connected to turbine. This is the case of generation of electricity with wind turbine, and such generators are commonly called as standalone generators.

BRAKING MODE OF OPERATION

It is also known as plugging mode. In this mode, the rotor is made to rotate in a direction opposite to the rotating magnetic field causing a slip range of 1 to 2. In this region, the torque is positive while speed is negative. This mode of operation is generally used to stop an induction motor quickly. If the motor is rotating in forward direction, it can be stopped quickly by interchanging the connections of two of the three phases. Interchanging any two of the three supply lines results in changing the direction of rotation of the stator magnetic field (RMF) . This effectively puts the machine into braking mode with its rotor rotating in a direction opposite to RMF.

The types of induction generators used in wind energy generation are as follows:-

1. Squirrel cage induction generator (SCIG)

2. Wound rotor induction generator (WRIG)

3. Doubly fed induction generator (DFIG)

Because of wide speed range, Induction generators are widely used in case of wind energy generation. Standalone Induction generator with fixed capacitor banks are used for fixed speed wind turbine. But DFIG is the most common used induction generator among the all three, because of its advantages over others.

SQUIRREL CAGE INDUCTION GENERATOR

Its rotor has solid bars of conducting material, which are placed in rotor slots and are shorted at the ends. In large machines alloyed copper bars are driven in the slots and are brazed onto the copper end-rings, while smaller ones have dicast aluminium bars. Also the rotors bars are skewed to prevent the rotors from magnetic locking.

The schematic diagram of SCIG used in wind power generation is given below:-

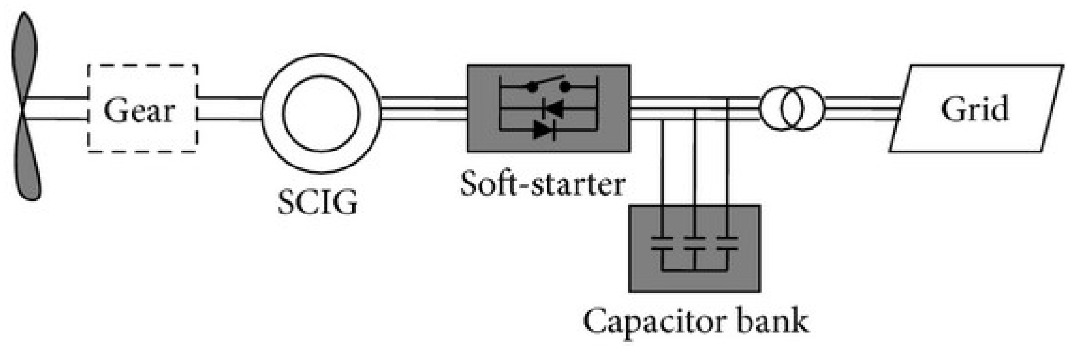

Fig3.2 SCIG used in wind power generation

The capacitor banks shown over here are used to provide the reactive power to the induction generator. Soft starter are used to disrupt the heavy inrush of current while starting from the grid. As wind speed is not much high, a gear arrangement is made, so that speed can be made super-synchronous. Then generator provides active power to the grid.

A pole changeable SCIG can be used to achieve wide range of speeds.(1)

Advantage of this scheme is rotor is robust and maintenance free.

WOUND ROTOR INDUCTION GENERATOR

The basic difference between SCIG and WRIG is the rotor structure. Its rotor has poly-phase coils places in slots made in rotor core. The winding is similar to that of stator. The rotor is wound and star connected with leads brought out of machine via slip rings placed on the shaft. External resistance can be used to reduce starting current. Having flexible rotor circuit, WRIG can be effectively used for wind power generation applications.

The schematic diagram of this scheme is given below

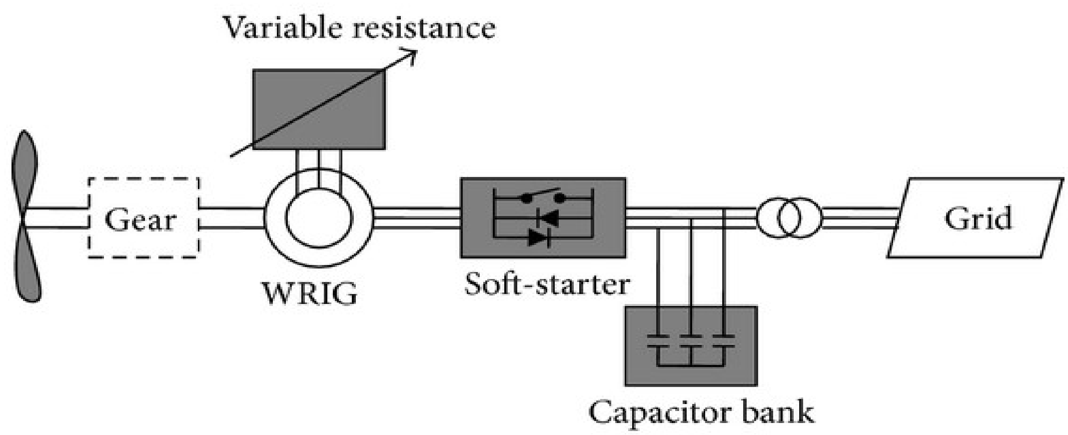

Fig3.3 Wound rotor induction generator connected to wind turbine

By changing the value of resistance, operating speed can be changed, as slip of the machine will change. So compared to SCIG, it will have a wide range of speed application. But being employed resistance in the scheme, there will be power loss in the resistance, so this scheme will be less efficient compared to that of SCIG. Also even in this scheme capacitor banks are required to supply reactive power to the generator.

DOUBLY FED INDUCTION GENERATOR

In this type of arrangement, everything is same to SRIG, except that rotor of DFIG is also fed from grid through use to some power electronics devices.

The schematic diagram of DFIG connected to wind turbine is shown below:

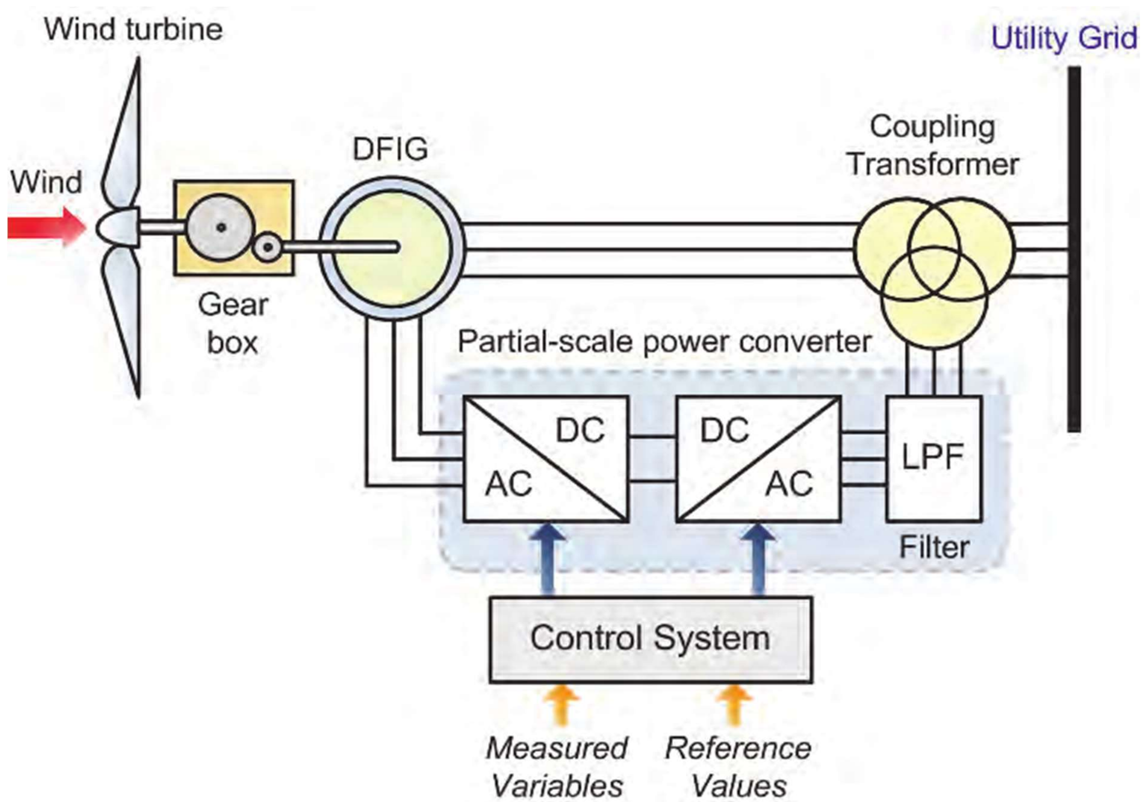

Fig 3.4 DFIG connected to wind turbine

In this scheme, stator is directly connected to grid, and rotor is connected to grid through converter based on IGBT. This scheme has a full control over active and reactive power. The main reason for the popularity of DFIG connected to the national networks is their ability to provide power at constant voltage and frequency while the rotor speed varies.

In large wind farms, DFIG based generation is used. The converter connected to rotor has two components, rotor side converter and grid side converter. A capacitor is connected in between the two converter which acts as a DC voltage source. The wind power captured by the wind turbine is converted into electrical energy by the induction generator and is transferred to the grid by stator and rotor windings. The control system gives command for pitch angle control and voltage commands for the rotor side converter and grid side converter to control the power of wind turbine, Dc bus voltage and reactive power or voltage at the grid terminals.

In this scheme, slip power control is done. At high speeds, the slip power is delivered to the grid, so overall efficiency of system increases. Since the mechanical torque is positive for power generation and since the rotational speed of the magnetic flux is positive and constant for a constant frequency grid voltage, the sign of the rotor electric power output is a function of the slip sign. Rotor side converter and grid side converter have the capability of generating or absorbing reactive power and can be used for controlling the reactive power or the grid terminal voltage. The pitch angle control is used for controlling the generator output power to its normal value for high wind speeds.

All these advantages make it a preferable choice for WECS.

3.2 SYNCHRONOUS GENERATORS

As the name suggests SYNCHRONOUS, which means rotor will be rotating at synchronous speed. The basis of operation of synchronous generator is faraday law of electromagnetic induction.

In this case, we have to provide dc source voltage to the stator or permanent magnet will be connected to rotor, and the rotor will be rotated at synchronous speed by some external source and three phase windings present on stator will be connected to grid. When the flux generated by rotor will cut the stator based windings, three phase voltage will be induced and power will be transferred to grid or the load connected to stator three phase windings.

Synchronous generators are of two types:-

1. Wound Rotor Synchronous Generator (WRSG)

2. Permanent Magnet Synchronous Generator (PMSG)

WOUND ROTOR SYNCHRONOUS GENERATOR

It is also known as electrically excited synchronous generator.

In this generator, windings will be provided in the rotor and DC voltage is supplied to the rotor for excitation purposes. The voltage's amplitude and frequency can be controlled fully by the power electronics converter at the generator side, so that the generator is fully controllable over a wide range of speeds. Also the excitation current can be controlled by the rotor side converter.

The schematic model of this scheme is given below

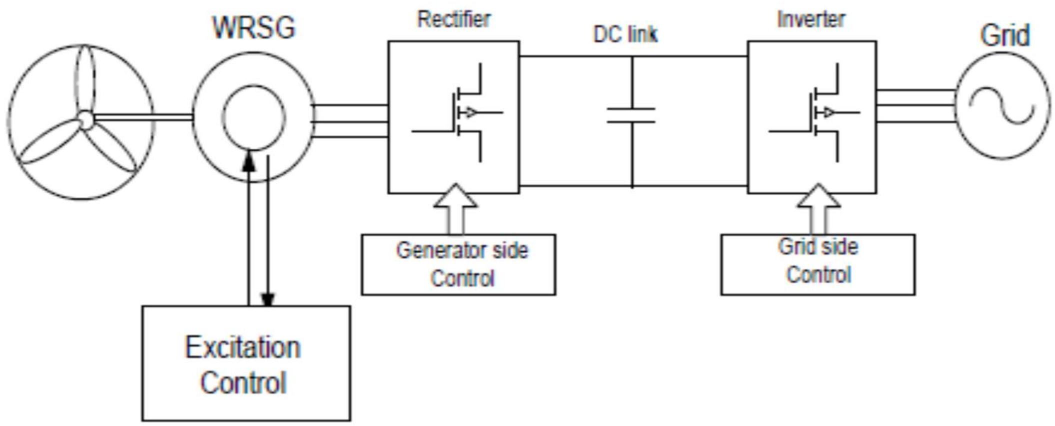

Fig 3.5 WRSG connected to wind turbine

It has an independent control over active and reactive power. Also it can be used in large power generation.

PERMANENT MAGNET SYNCHRONOUS GENERATOR

Everything will be same to that of WRSG, except that we will have permanent magnet attached to the rotor for generating flux, so we can't have excitation control in this case.

The schematic diagram is given below

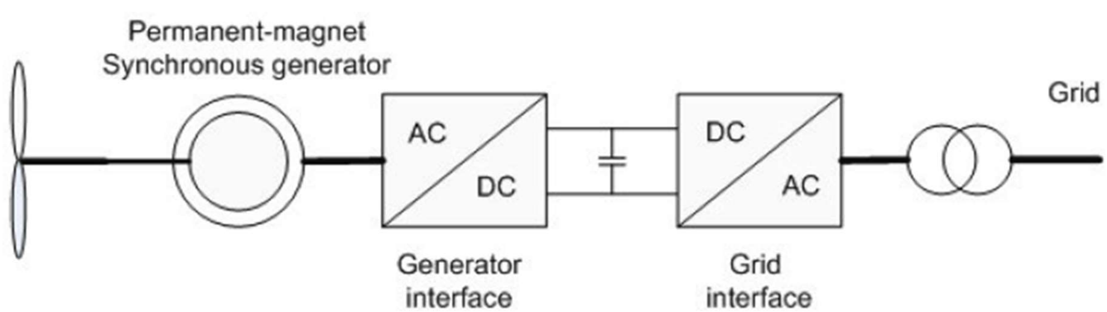

Fig 3.6 PMSG connected to wind turbine

4. MATLAB MODELLING

4.1 PROPOSED SCHEME

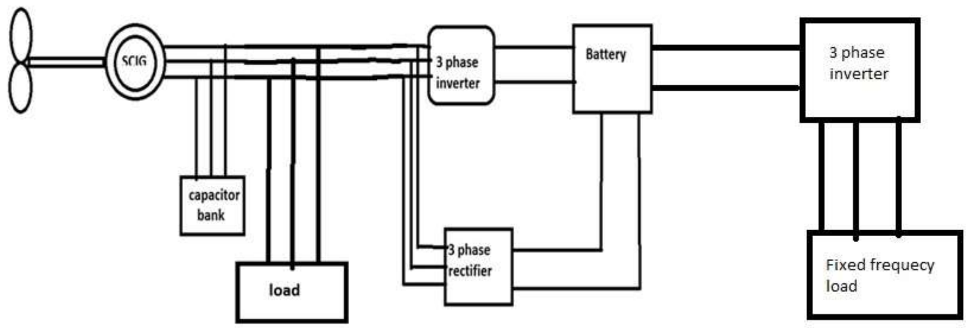

Fig 4.1 Proposed scheme

In this scheme, we have coupled squirrel cage induction machine with wind turbine. And for the reactive power, required for the induction machine to run, we have used charged delta capacitor connected across its terminals. The voltage generated across its terminals are further rectified and fed to the battery storage, which can be further used by the inverter if it needs extra power. Further we have made induction machine to run at low speeds by decreasing the synchronous speed of the system. Also the load connected is variable frequency load.

Later if generated power is more, we can use that to supply to fixed supply loads after being inverted by a rectifier.

4.2 MODELLING OF SPWM INVERTER IN MATLAB

Inverter circuit converts DC voltage into AC voltage. This conversion is done by controlled switching of IGBTs. The output of inverter is square or quasi-square wave not sinusoidal. Ideally, it should be sinusoidal.

The controlling of IGBT is done by comparing reference signal with carrier signal (of higher frequency). In the below case reference signal is sinusoidal wave and carrier signal is saw-tooth wave.

Inverter modelling involves two parts:-

1. Modelling of power circuit

2. Modelling of control circuit

MODELLING OF POWER CIRCUIT

Power circuit consists of 6 IGBTs. It has three limbs , each limb has 2 thyristors, each conducting for 180^0. Let the 6 switches be named as S1, S2, S3, S4, S5 and S6. S1 is connected to S4, S3 is connected to S6, S5 is connected to S1.

Power circuit of inverter is given below

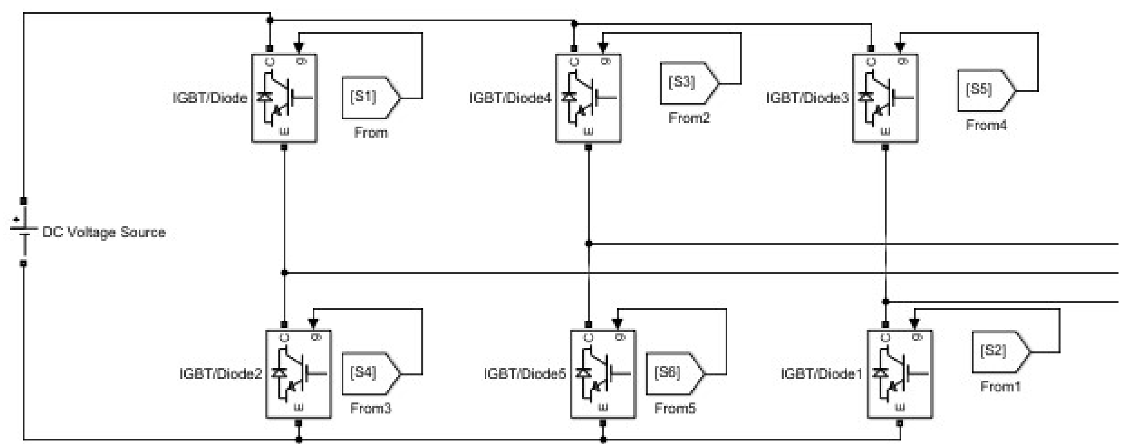

Fig 4.2 Power circuit of SPWM inverter

Input of the inverter being fixed DC voltage. Firing of the gate pulses will be done at an interval of 120^o, which simply means, S1 will be fired at 0^o, S3 at 120^o, S5 at 240^o.

Firing table is given below

Modes	S1	S2	S3	S4	S5	S6
0-60^o	ON	OFF	OFF	OFF	ON	ON
60^o-120^o	ON	ON	OFF	OFF	OFF	ON
120^o-180^o	ON	ON	ON	OFF	OFF	OFF
180^o-240^o	OFF	ON	ON	ON	OFF	OFF
240^o-300^o	OFF	OFF	ON	ON	ON	OFF
300^o-360^o	OFF	OFF	OFF	ON	ON	ON

The above table shows that IGBTs connected to a single limb conduct alternatively, which simply means when S1 is conducting S4 is off, and when S4 is conducting, S1 is off.

DESIGN OF CONTROL CIRCUIT

In control circuit we compare reference signal with carrier signal, and signals will be generated depending upon signal is greater or carrier is greater, and those generated signals are fed to the gate of IGBTs, so that they can conduct accordingly.

Control circuit for spwm inverter is given below

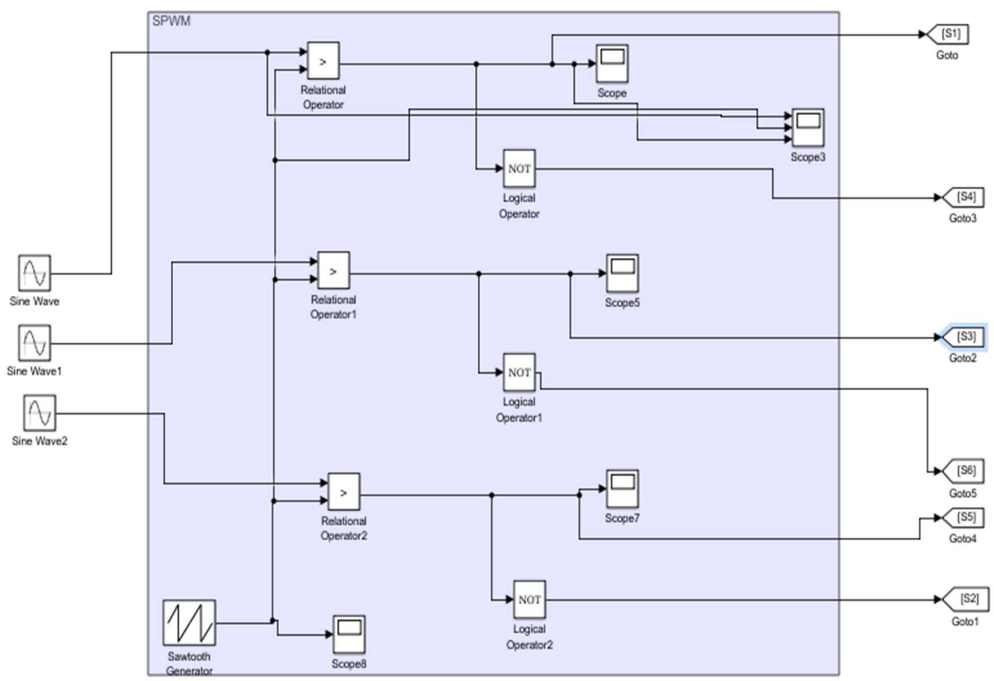

Fig 4.3 Control circuit of SPWM inverter

OUTPUT VOLTAGE OF SPWM INVERTER IS SHOWN BELOW

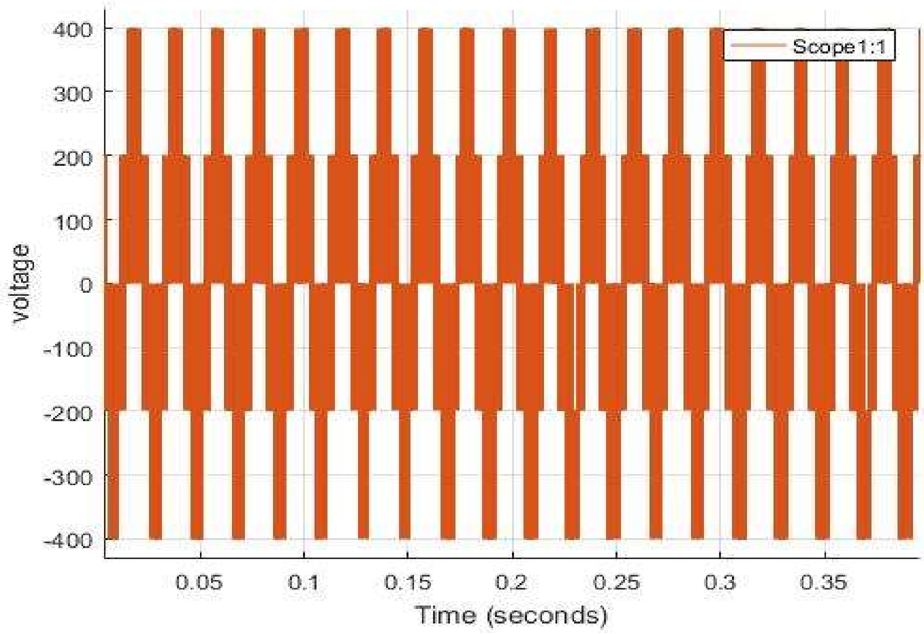

Fig 4.4 SPWM inverter output voltage

4.3 MODELLING OF THREE PHASE UNCONTROLLED RECTIFIER

The model of rectifier is shown below

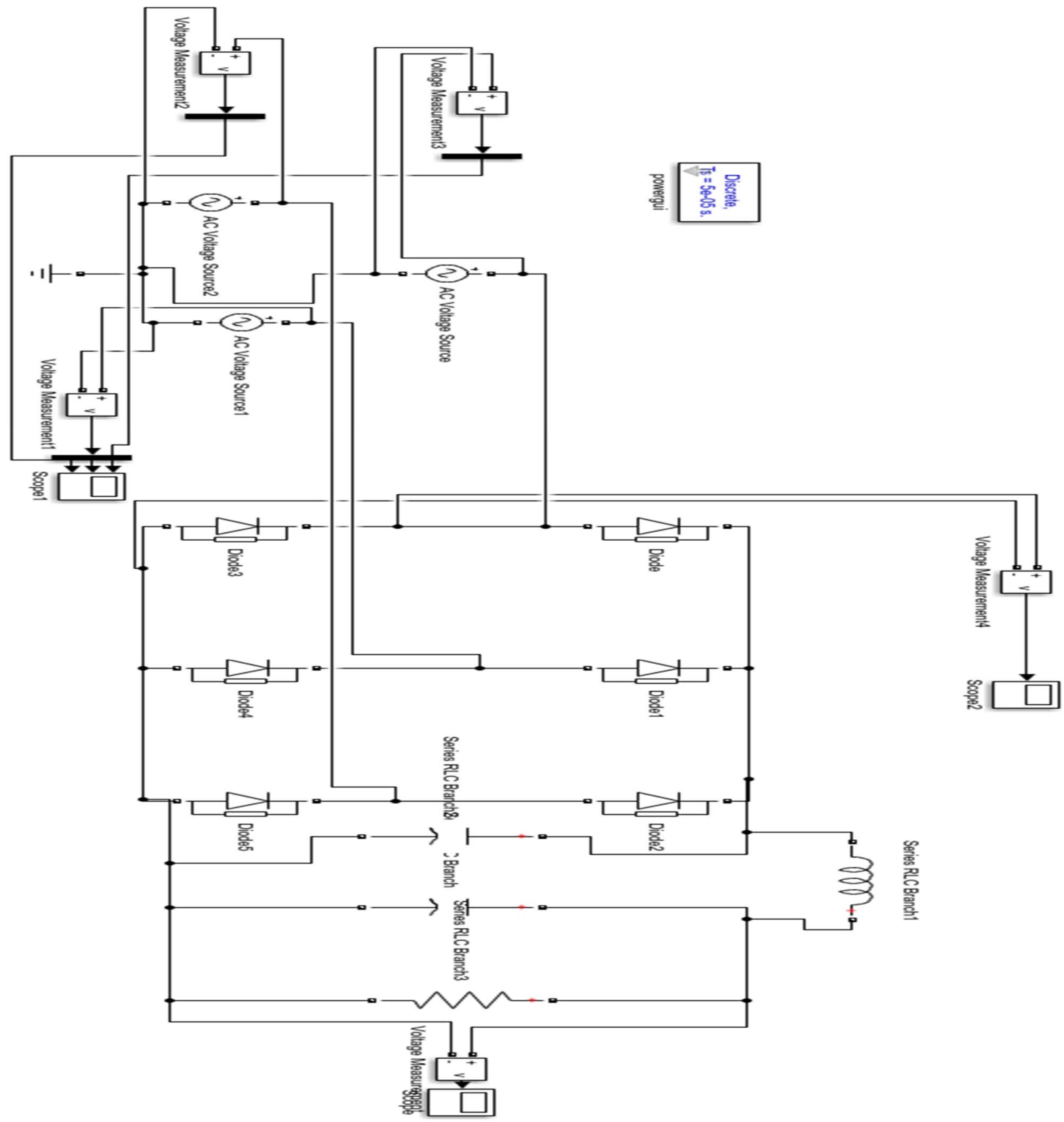

Fig 4.5 Three phase uncontrolled rectifier

It consists of 6 diodes, 2 in each limb. So, it has 3 limbs. Three phase ac voltage is applied to it and output after diode rectifier was pulsating dc so we passed that signal through LC filter and hence a kind of DC voltage is obtained.

Ac voltage applied to the three phase uncontrolled rectifier

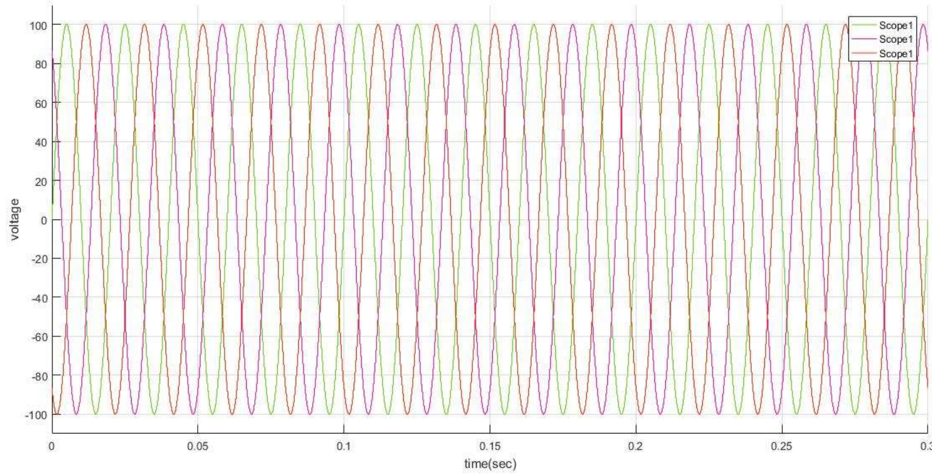

Fig 4.6 Input voltage to rectifier

Rectified voltage is shown below

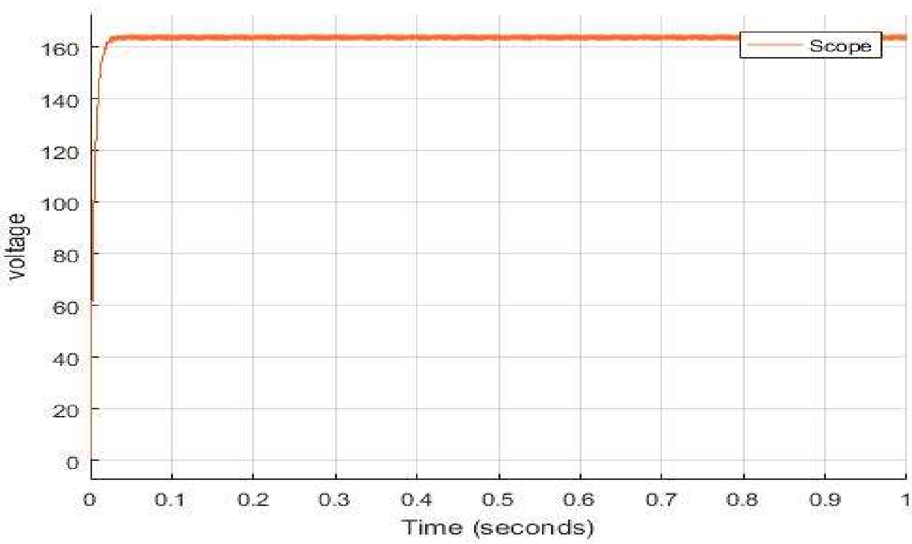

Fig 4.7 Rectified voltage

5. MODELLING AND SIMULATION OF LOW SPEED WIND POWER GENERATION USING INDUCTION MACHINE

Simulation, being the primary stage in any of the projects to be completed on ground, or in a physical manner. By doing simulation of any model in software, we come across the errors which may occur in future, when we are going to implement that in real world. So simulation plays an important role in the work of researchers. I have used MATLAB R2016b for the simulation purpose. At first, SPWM inverter is modelled and connected to the available model of 1kw SCIM. Later on, inverter is disconnected and connected to a capacitor, and negative torque is applied using wind turbine. EMF is generated across terminals of generator and then load is applied. The results and explanations are shown below.

The generator is connected to SPWM inverter till T=3, and then it is disconnected and capacitor is connected and load is connected at T=4.

We have tried to run the generator at three speeds, 100rpm, 150 rpm, and 200 rpm .

The MATLAB model is shown below

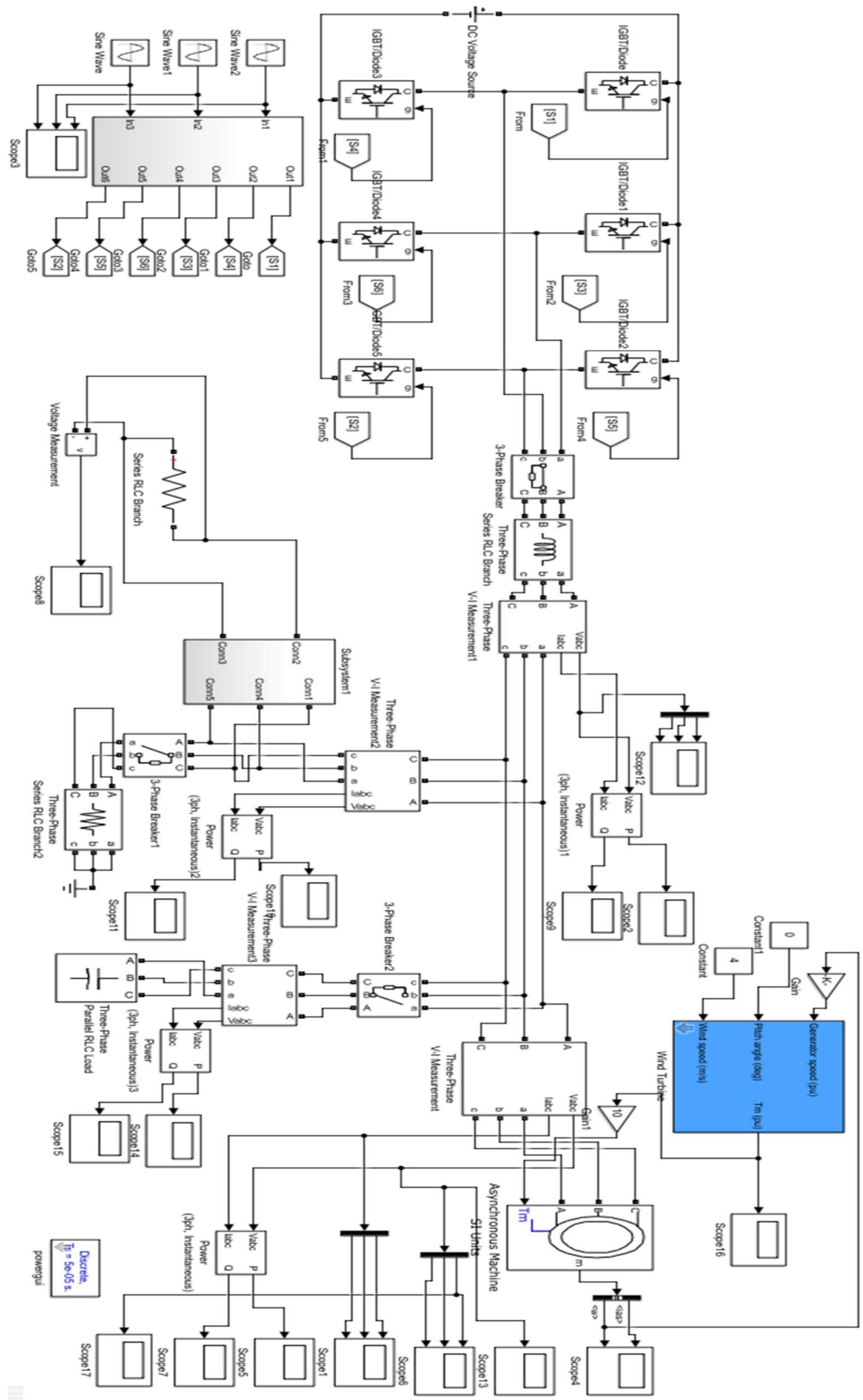

Fig 5.1 MATLAB model

INDUCTION MOTOR SPECIFICATION

Input dc voltage	160v
power	1kw
voltage	400v
frequency	50 Hz
pole	8 pole
phase	3
Motor type	SCIM

The SPWM has reference signal of 10Hz, and since motor is 8 pole, so synchronous speed for entire process will be

$$N_s = 120*f/P$$

$$Ns = 120 * \frac{10}{8}$$

$$N_s=150rpm$$

For rad/ sec, the given speed is multiplied by pie/30,

solving we get, N_s=15.7 rad/sec

For synchronous speed of 100 rpm(10.47rad/sec), the synchronous frequency will be 6.66Hz and for speed of 200 rpm(20.94rad/sec), the frequency will be 13.33Hz.

5.1 SIMULATION RESULTS

GENERATOR SPEED

For 100rpm

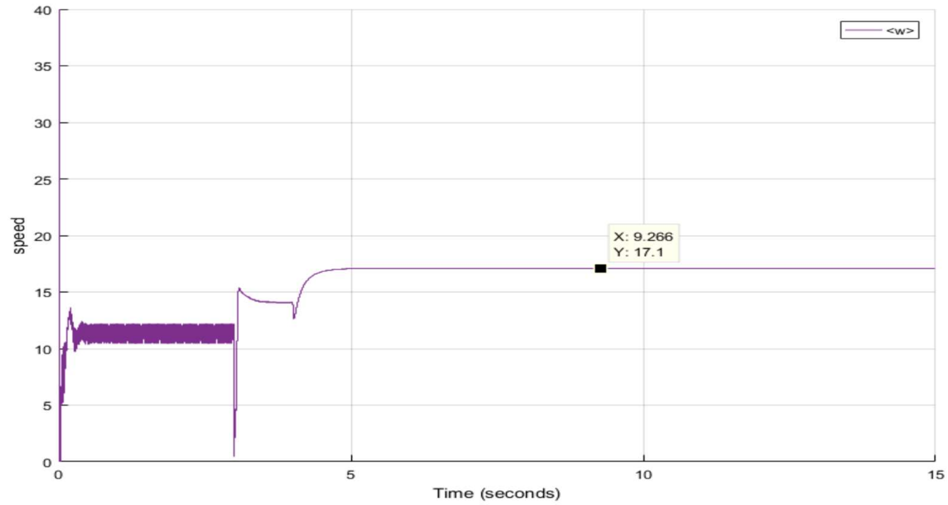

Fig 5.2 Generator speed at 100rpm

For 150rpm

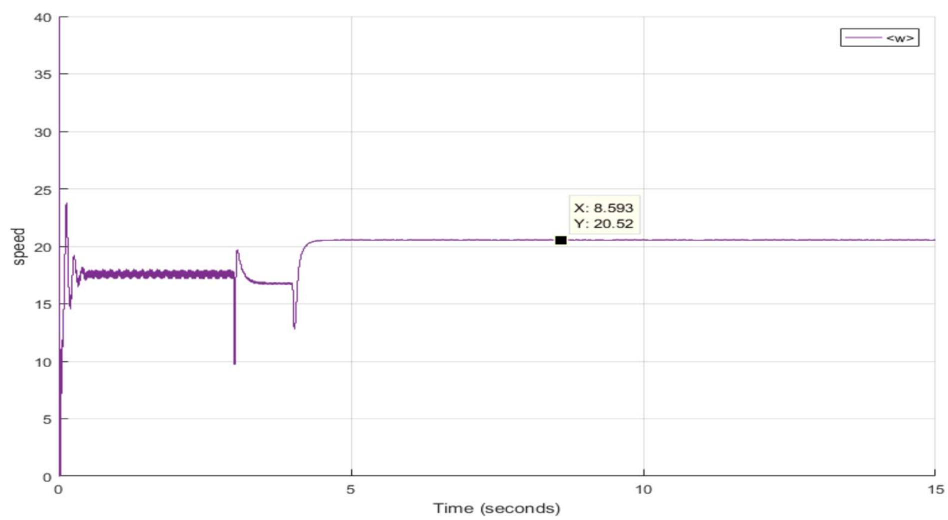

Fig 5.3 Generator speed at 150 rpm

For 200 rpm

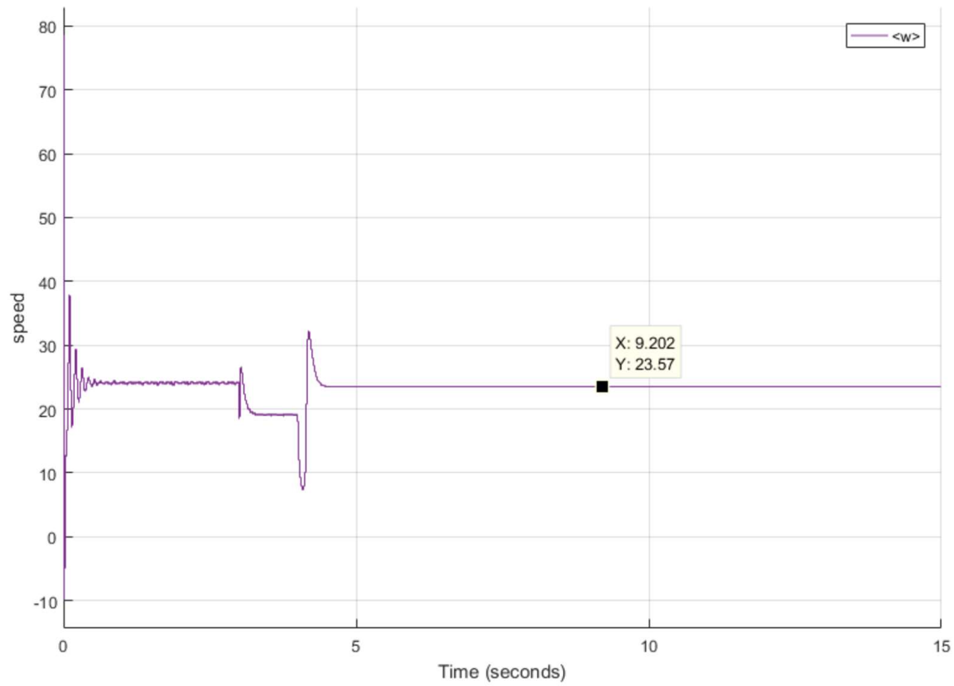

Fig 5.4 Generator speed at 200 rpm

It can be clearly seen from the above figures that speed is above synchronous speed in all the three cases, which means that machine is running in super-synchronous mode.

For 100 rpm, synchronous speed is 10.47 rad/sec, speed of machine is 17.1 rad/sec. For 150rpm, synchronous speed is 15.7 rad/sec, speed of machine is 20.52 rad/sec. For 200 rpm, synchronous speed is 20.94 rad/sec, speed of machine is 23.57 rad/sec.

CURRENT IN A PHASE

For 100rpm,

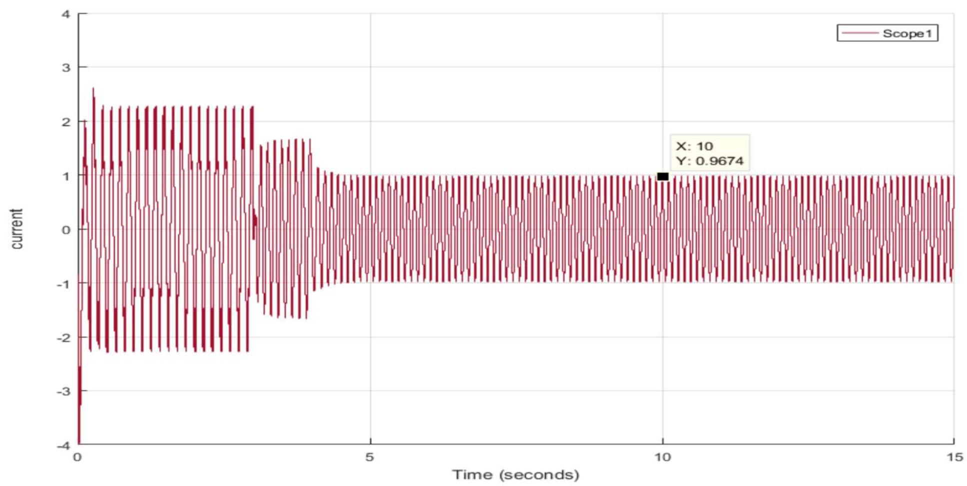

Fig 5.5 Current generated at 100 rpm

For 150rpm,

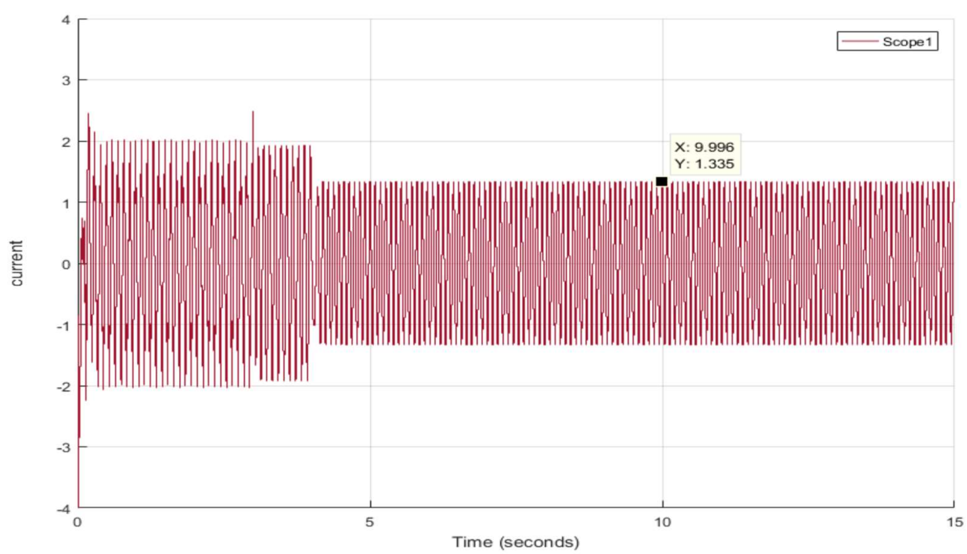

Fig5.6 Generated current at 150rpm

For 200 rpm

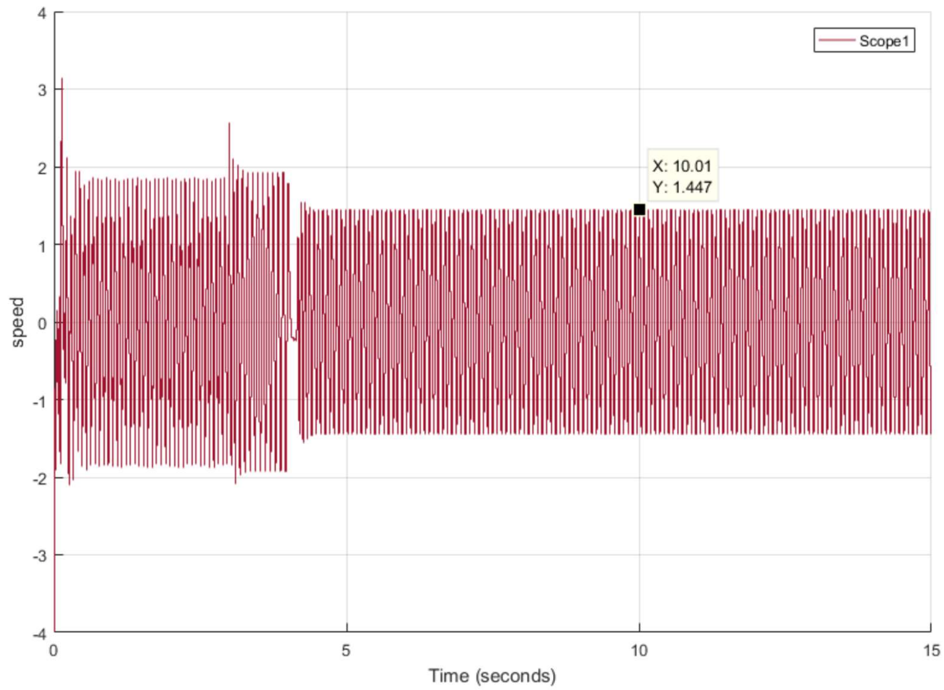

Fig 5.7 Generated current at 200 rpm

With increase in speed, generated current is increasing

GENERATED VOLTAGE

FOR 100rpm

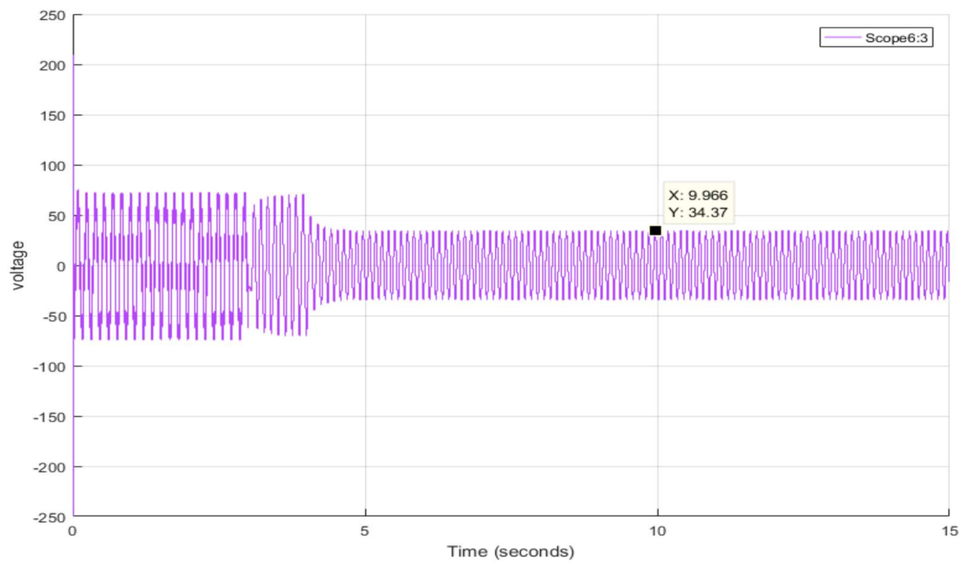

Fig 5.8 Generated voltage at 100rpm

For 150 rpm

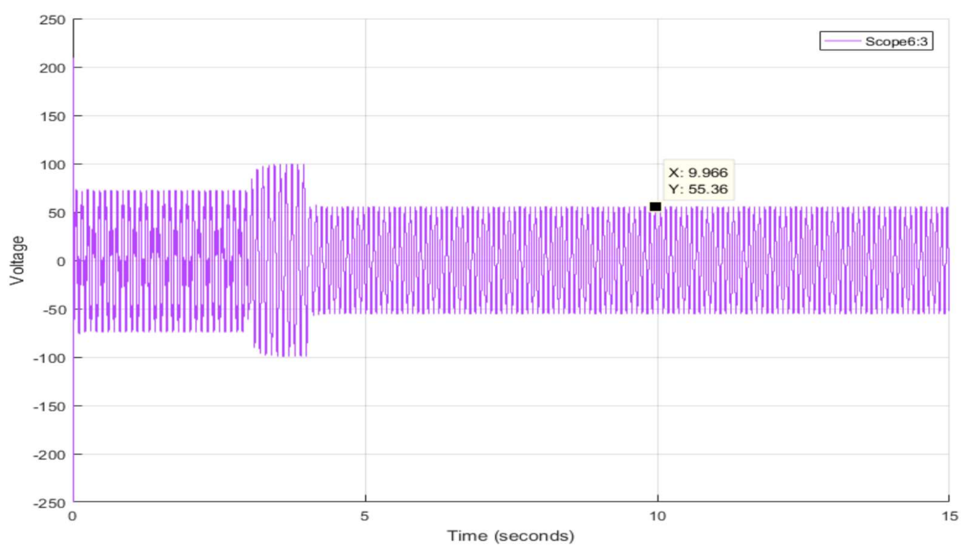

Fig 5.9 Generated voltage at 150 rpm

For 200rpm

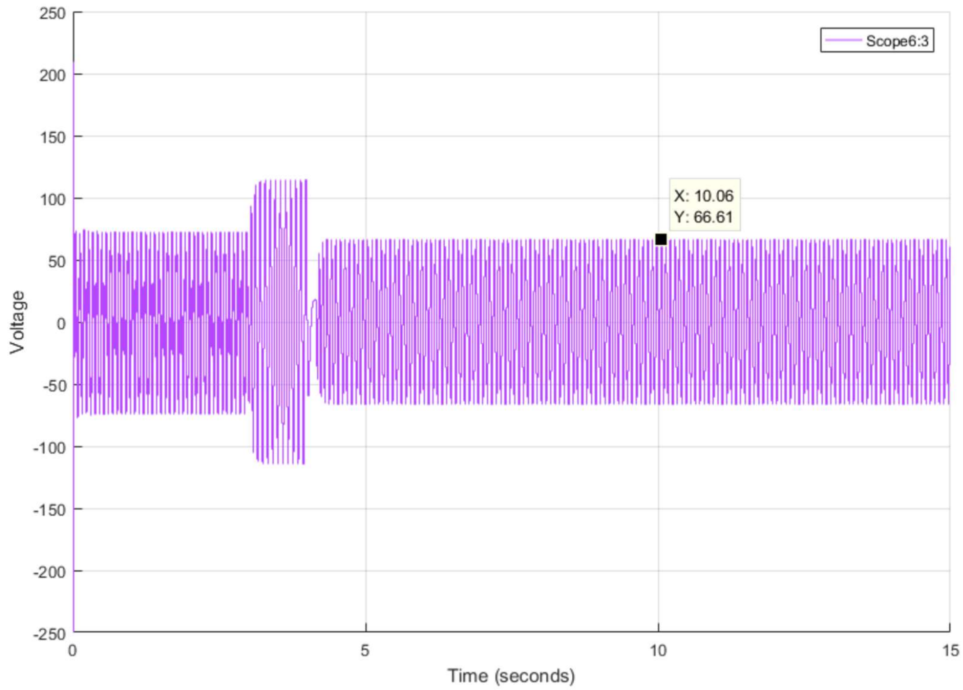

Fig 5.10 Generated voltage at 200 rpm

ACTIVE POWER GENERATED BY MACHINE

For 100 rpm

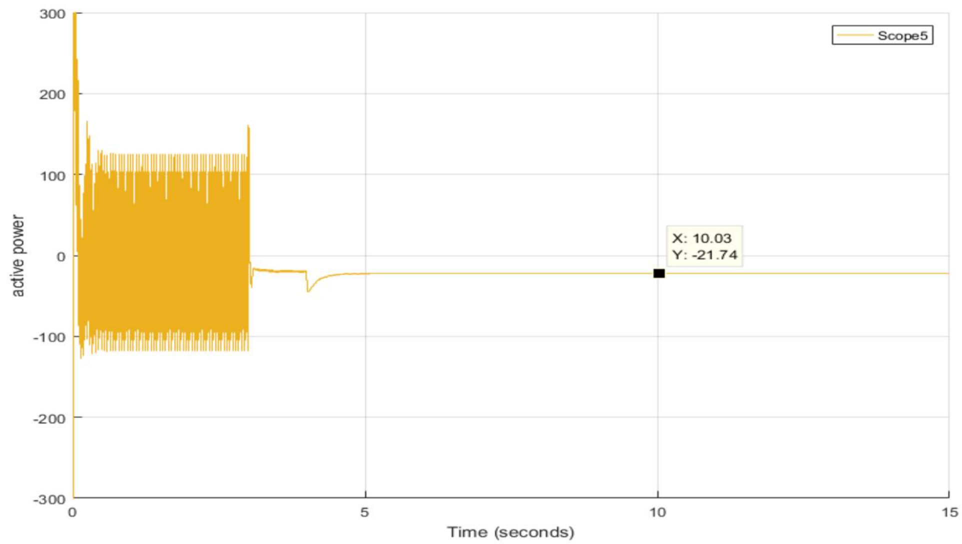

Fig 5.11 Generated power at 100 rpm

For 150 rpm

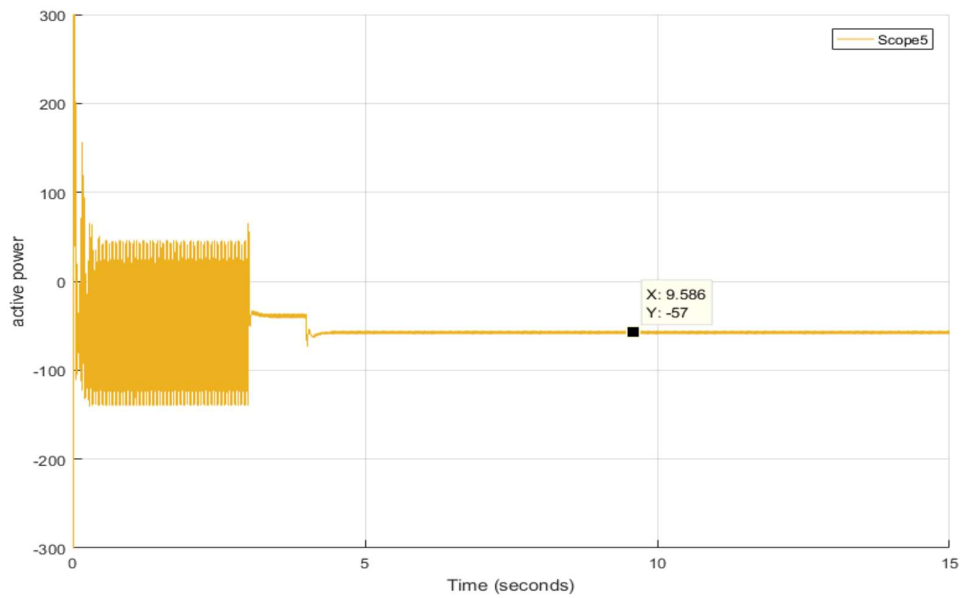

Fig 5.12 Generated power at 150 rpm

For 200 rpm

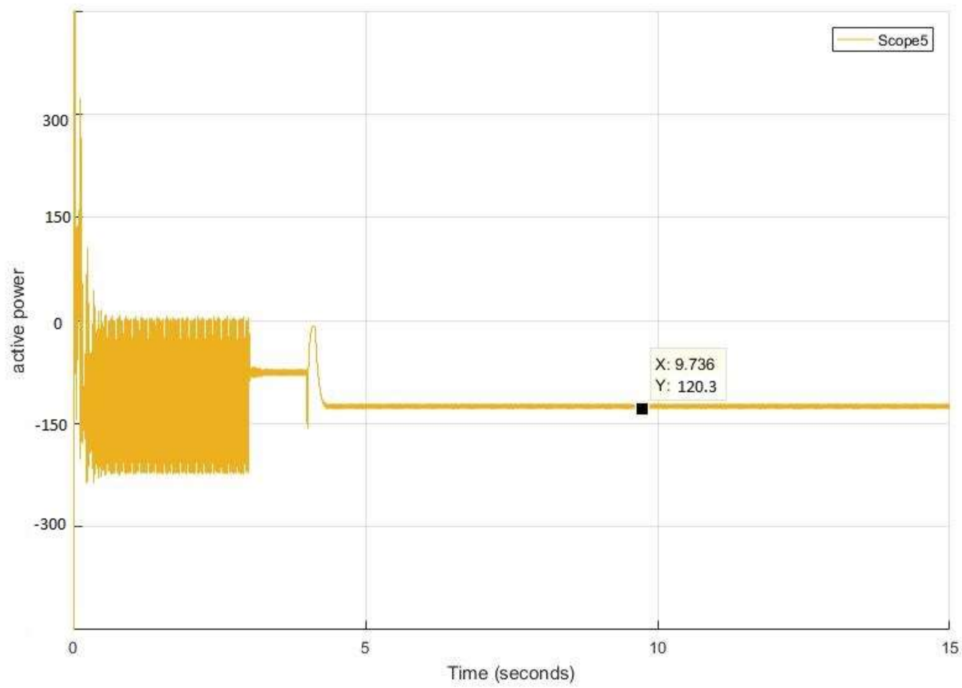

Fig 5.13 Generated power at 200 rpm

Negative value of active power shows that machine is delivering power to the load.

Also active power generated by the machine is increasing with the increasing speed.

Comparison of data at different speeds

Speed(N_s)	Generator speed	Voltage(peak)	Active Power
100rpm	163.3rpm	34v	21w
150rpm	196rpm	55v	57w
200 rpm	225rpm	67v	120w

5.2 CONCLUSION

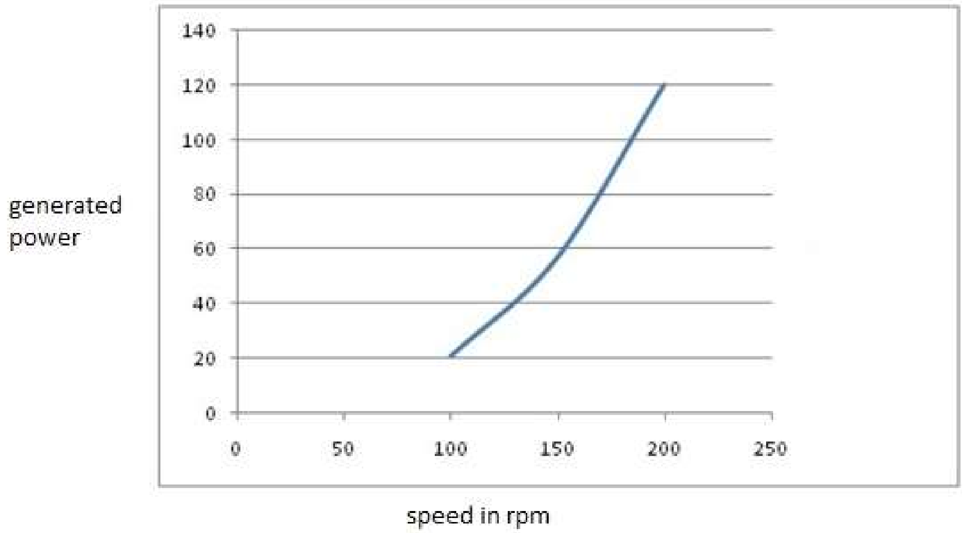

Fig 5.14 Speed vs active power graph

It can be clearly seen from the graph that active power is increasing nonlinearly with increase in speed.

Here, SCIM has been used for the generation of power using low speed winds (Generator speed 100rpm, 150rpm and 200 rpm). The simulation results clearly shows that power can be generated with low speeds in the range of around 4-6 m/sec.

This scheme can be used for generation of power in the areas which does not have connectivity to the grid and has ample amount of wind speed which were being wasted till now. Also the generated power can be stored in battery bank for further use.

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