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Comparative Analysis of Types of Generators Uesd in Wind Energy Conversion System

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***Abstract*-Wind is a form of solar energy caused by the combination of three concurrent events-The sun unevenly heating the atmosphere, Irregularities of the earth's surface, rotation of the earth. Wind flow patterns and speeds vary greatly across the India and are modified by bodies of water, vegetation etc. Humans use this wind flow, or motion energy, for many purposes: sailing, flying kite and most important generating electricity.Wind turbine is an energy converter, which converts wind energy into electrical energy. It is manufactured n wide range for huge wind farms. The objective of this paper is to compare various generators used in wind farms.**

***Keywords*-wind turbine, energy converter, wind energy, electrical energy, and generators.**

I.INTRODUCTION

Nowadays, due to increase in demand of electricity and fast depleting resources, there is a need of other options or resources which are environment friendly and produce electricity. Some of the renewable sources are Solar, Wind, geothermal etc. Wind energy is one of the important resources. The wind mill contains three blades about a horizontal axis installed on a tower. A turbine connected to a generator, generators is an essential component of wind mill. But like the weather in general, wind can be unpredictable. It varies from place to place and from moment to moment. Wind turbines works on simple principle, turbines use wind to make electricity.
Wind turns the propeller-like blades of a turbine around a rotor, which spins a generator, which creates electricity.

1. Classification of wind mills:

- Horizontal axis - A horizontal axis machine has its blades rotating on an axis parallel to the ground.
- Vertical axis - A vertical axis machine has its blades rotating on an axis perpendicular to the ground.

1.1. Horizontal Axis:

- This is the most common wind turbine design.
- In addition to being parallel to the ground, the axis of blade rotation is parallel to the wind flow.
- Some machines are designed to operate in an upwind mode, with the blades upwind of the tower.
- In this case, a tail vane is usually used to keep the blades facing into the wind.
- Other designs operate in a downwind mode so that the wind passes the tower before striking the blades.
- Some very large wind turbines use a motor-driven mechanism that turns the machine in response to a wind direction sensor mounted on the tower.
- Commonly found horizontal axis wind mills are aero-turbine mill with 35% efficiency and farm mills with 15% efficiency

1.2. Vertical Axis:

- Although vertical axis wind turbines have existed for centuries, they are not as common as their horizontal counterparts.
- The main reason for this is that they do not take advantage of the higher wind speeds at higher elevations above the ground as well as horizontal axis turbines.
- The basic vertical axis designs are the Darrieus, which has curved blades and efficiency of 35%, the Giromill, which has straight blades, and efficiency of 35%, and the Savonius, which uses scoops to catch the wind and the efficiency of 30%.
- A vertical axis machine need not be oriented with respect to wind direction

2. Components used in a wind mill:

2.1. Anemometer: Measure the wind speed and transmits wind speed data to the controller
2.2. Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate.
2.3. Brake: A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies.
2.4. Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph.

International Journal of Scientific Research & Engineering Trends
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2.5. Gear box: Gear connect the low-speed shaft to the high speed shaft and increase rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm, the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploiting "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.

2.6. Generator: Usually an off-the-shelf induction generator that produces 60-cyclic AC electricity.
2.7. High speed shaft: Drives the generator.
2.8. Low-speed shaft: The rotor turns the low-speed shaft 30 to 60 rotations per minute.
2.9. Nacelle: The nacelle sits the lower and contains the gear box, low-and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.
2.10. Pitch: Blades are turned, or pitched, out of the wind to control the rotor speed and keep the rotor form turning in winds that are too high or too.
2.11. Rotor: The blades and the hub together are called the rotor.
2.12. Tower: Towers are made from tubular steel (shown here), concrete, or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.
2.13. Wind direction: This is an "upwind" turbine, so called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.
2.14. Wind vane: Measure wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.
2.15. Yaw drive: Upwind turbines face into the wind, the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind.
2.16. Yaw motor: Powers the yaw drive.

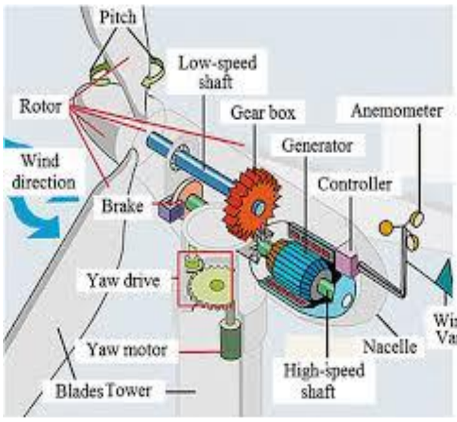

Figure 1. Components of wind mill.

II.TURBINE MODEL

A wind turbine consists of a rotor mounted to a nacelle and a tower with two or more blades mechanically connected to an electric generator. The gearbox in the mechanical assembly transforms slower rotational speeds of the wind turbine to higher rotational speeds on the electric generator. The rotation of the electric generator's shaft generates electricity whose output is maintained.

By a control system. There are two types of design models for wind turbines. The classification is made on the basis of their axis in which the turbines rotate: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). The VAWT is also called Darrieus rotor named after its inventor. HAWT have the ability to collect maximum amount of wind energy for timeOf day and season and their blades can be adjusted to avoid high wind storm. Wind turbines operate in two modes namely constant or variable speed. For a constant speed turbine, the rotor turns at constant angular speed regardless of wind variations.

One advantage of this mode is that it eliminates expensive power electronics such as inverters and converters. Its disadvantage however, is that it constrains rotor speed so that the turbine cannot operate at its peak efficiency in all wind speeds. For this reason a constant wind speed turbine produces less energy at low wind speeds than does a variable wind speed turbine which is designed to operate at a rotor speed proportional to the wind speed below its rated wind speed. The output power or torque of a wind turbine is determined by several factors. Among them are

- Turbine Speed,
- Rotor Blade Tilt,
- Rotor Blade Pitch Angle
- Size And Shape Of Turbine,
- Area Of Turbine,
- Rotor Geometry Whether It Is A Hawt Or A Vawt,
- And Wind Speed.

A relationship between the output power and the various variables constitute the mathematical model of the wind turbine. A mathematical model of wind turbine is essential in the understanding of the behavior of the wind turbine over its region of operation and also modeling enables control of wind turbines performance.

III.MATHEMATICAL FORMULATION OF TURBINE MODEL

Under constant acceleration a, the kinetic energy E of an object having mass m and velocity v is equal to the work done W in displacing that object fromRest to a distance s under a force F, i.e. $E = W = Fs$. According to Newton's Second law of motion

International Journal of Scientific Research & Engineering Trends
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$$F = ma \quad (1)$$

Thus, the kinetic energy becomes

$$E = mas \quad (2)$$

From kinematics of solid motion, $v2 = u2 + 2as$ where u is the initial velocityOf the object. This implies that $a = v2-u2 /2s$. Assuming the initial velocity ofThe object is zero, we have that $a = v2/2s$. Hence from equation (2) we have that

$$E=1/2\ mv2 \quad (3)$$

This kinetic energy formulation is based on the fact that the mass of the solid
Is a constant. However, if we consider wind (air in motion) as a fluid, both Density and velocity can change and hence no constant mass. For this reason

Reccab ET. Al formulates the kinetic energy law with a factor of 2/3 instead of 1/2. In this paper we shall assume that the density of air does not vary considerably
Even with variation in altitude or temperature and use the kinetic energy law In the form of equation (3). Hence the kinetic energy (in joules) in air of mass m moving with velocity vw(wind) can be calculated from equation (3) above.
The power P in the wind is given by the rate of change of kinetic energy, i.e.

$$P= dE/dt=1/2\ dy/dx\ v2 \quad (4)$$

But mass flow rate dm/dt is given by $dm/dt= = \rho Avw$ where A is the area through which the wind in this case is flowing and ρ is the density of air. With this expression, equation (4) becomes

$$P =1/2\rho Av3w \quad (5)$$

The actual mechanical power Pw extracted by the rotor blades in watts is theDifference between the upstream and the downstream wind powers [1], i.e.

$$Pw = 1/2\ \rho Avw\ (v2u- v2d) \quad (6)$$

Where vu is the upstream wind velocity at the entrance of the rotor blades in m/s and vd is the downstream wind velocity at the exit of the rotor blades in m/s. We shall see later that these two velocities give rise to the blade tip speed ratio. Now from the mass flow rate, we may write

$$\rho Avw =\rho Avu+vd/2 \quad (7)$$

vw being the average of the velocities at the entry and exit of rotor blades of turbine. With this expression, equation (6) becomes

$$Pw = ½\ pA\ vu/2\ (vu2-vd2)+vd/2\ (vu+vd)$$

Which may be simplified as follows:

$$Pw = 1/2\rho AV\ 3u\ Cp \quad (8)$$

Where $Cp =1- (vd/vu)2+(vd/vu)- (vd/vu)3 /2$or

$$Cp =(1 + vd/vu)(1 - (vd/vu)2)/2 \quad (9)$$

The expression for Cp in equation (9) is the fraction of upstream wind power captured by the rotor blades. Cp is often called the Betz limit after the Germany physicist Albert Betz who worked it out in 1919. Other names for this quantity are the power coefficient of the rotor or rotor efficiency. The power coefficient is not a static value. It varies with tip speed ratio of the wind turbine. Let λ represent the ratio of wind speed vd downstream to wind speed vu upstream of the turbine, i.e.

$$\lambda = (vd/vu) \quad (10)$$

or

$$\lambda = \text{blade tip speed/wind speed} \quad (11)$$

λ is called the tip speed ratio of the wind turbine. The blade tip speed in meters per second can be calculated from the rotational speed of the turbine and the length of the blades used in the turbine, i.e.

$$\text{Blade tip speed} = \text{angular speed of turbine } (\omega) \times R/\text{wind speed} \quad (12)$$

Where R is the radius of the turbine and ω is measured in radian per second.
Substitution of equation (10) into equation (9) leads to

$$Cp = (1 + \lambda)\ (1 - \lambda 2)/2 \quad (13)$$

Differentiate Cp with respect to λ and equate to zero to find value of λ

That makes Cp a maximum, i.e. $dCp/d\lambda = (1+\lambda).\ (-2\lambda)+ (1-\lambda 2).1/2 = 0$ yielding $\lambda =-1$ or $\lambda = 1/3$. Now $\lambda = 1/3$ makes the value of Cp a maximum. This maximum value is 16/27. Thus the Betz limit says that no wind turbine can convert more than 16/27 (59.3%) of the kinetic energy of the wind into mechanical energy turning a rotor, i.e. $Cpmax = 0.59$. Wind turbines cannot operate at this maximum

Limit though. The real world is well below the Betz limit with values of 0.35 − 0.45 common even in best designed wind turbines. If the rotor of a wind turbine turns too slowly most of the wind will pass through the openings between blades with little power extraction. If on the other hand the rotor turns too fast, the rotating blades act as a solid wall obstructing the wind flow again reducing the power extraction. The turbines must be designed to operate at their optimal wind tip speed ratio λ in order to extract as much power as possible from the wind stream. Theoretically the higher the λ the better in terms of efficient operation of the generator.

There are disadvantages however. High λ causes erosion of leading edges of the blades due to impact of dust or sand particles found in the air. This would require use of special erosion resistant coating material that may increase the cost of energy. Higher λ also leads to noise generation, vibration; reduced rotor efficiency due to drag and tip losses and excessive rotor speeds can lead to turbine failure. Other factors that impede complete energy conversion in a complete turbine system are things such as gearbox, bearings, number and shape of blades etc.Only 10− 30% of the power of the wind is ever actually converted into usable electricity.

Air density ρ is another flow input quantity at the rotor system. ρ is a function of both air pressure and temperature. When air pressure increases ρ increases. When air temperature decreases ρ increases. This is in accordance with the equation of state

$$P = \rho RT \quad (14)$$

where R is the gas constant. Both temperature and pressure decrease with increasing elevation. Hence site location is important as elevation has major effect on power generated as a result of air density variation. At atmospheric pressure, Patm = 14.7psi, temperature is T = 600F and density is ρ = 1.225kg/m3. Temperature and pressure both vary with elevation. Thisaffects the air density. propose the following relation

$$\rho = \rho 0e{-}0.297/3048\ Hm \quad (15)$$

where Hm is site elevation in metres. At high elevations the air density corrections can be important.

IV.GENERATORS OF WIND MILL

The generator is what converts the turning motion of wind turbines blades into electricity. Inside this component, coils of wire are rotated in a magnetic field to produce electricity. Different generator designs produce either alternating current (AC) or direct current (DC), and they are available in a large range of output power ratings. The generator's rating, or size, is dependent on the length of the wind turbines blades because more energy is captured by longer blades. It is important to select the right type of generator to match intended use.

It is attached to the electrical grid; the generator has to work with a power source (the wind turbine rotor) which supplies very fluctuating mechanical power (torque). On large wind turbines (above 100-150 kW) the voltage (tension) generated by the turbine is usually 690 V three-phase alternating current (AC). The current is subsequently sent through a transformer next to the wind turbine (or inside the tower) to raise the voltage to somewhere between 10,000 and 30,000 volts, depending on the standard in the local electrical grid.

Large manufacturers will supply both 50 Hz wind turbine models (for the electrical grids in most of the world) Traditionally, there are three main types of wind turbine generators which can be considered for the various wind turbine systems, these being direct current (DC), alternating current (AC) synchronous and AC synchronous generators.

1. DC Generator

DC generators gives out a direct current, which means the current only flows one way, unlike AC which alternates. The main principle is to convert mechanical energy into electrical energy. The way it produce energy is that is based on fundamental principle of faraday's law of electromagnetic induction, in which when a conductor moves in a magnetic field of any strength it cuts magnetic lines of force due to which an EMF is induced in the conductor. The EMF will cause the current to if the conductor circuit is closed. This means the magnitude of this induced EMF depends upon the rate of change of flux linkage. This means the essential parts of the generator are magnetic field and conductors which move inside the magnetic field.

Inside a DC generator there is a main outside frame called the Yoke which is the casing for the generator as well as providing support for the poles, connected to the Yoke are many Pole Cores that spread out the flux in the air gaps and reducing resistance of the magnetic path. On the Pole Cores are Pole Coils that will have lots of copper wire wrapped round the frame to produce the magnetic flux once a current is passed through the coil. Moving directly to the centre of the Yoke is the Armature Core which houses the Armature Conductor that looks much like long gear cogs that are die cut and inside these cogs there are air gaps, as well as a keyhole these are the parts that rotate in the centre to cut lines in the magnetic force.

The Armature Windings are then wrapped round the core to make a coating. At the end of the Armature Core is the Commutator this piece of equipment facilitates the collection of current from the Armature Conductors which then coverts the AC current into unidirectional current. Finally, the last component is the Brushes which collect the current that is in the commuter and the bearings. All these components together including the air gap between the Pole Cores and the Armature Core make up the magnetic circuit. The Armature Cores are mounted over the rotating part or otherwise known are the Shaft.

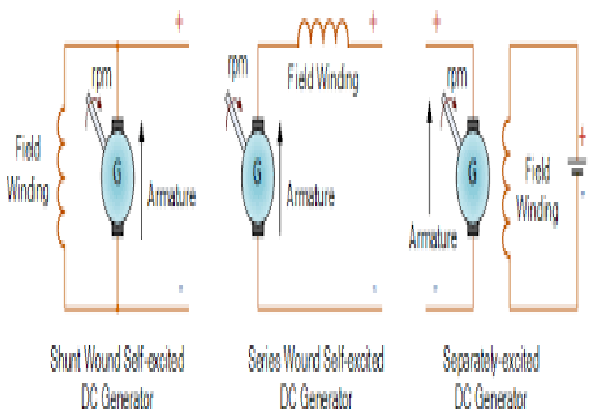

Figure 2. DC generators.

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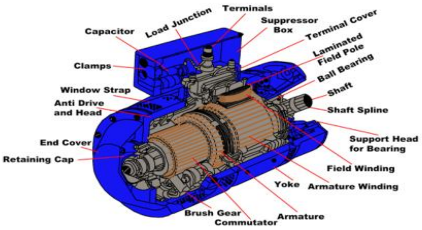

Figure 3. construction of DC generator.

Disadvantages of DC generator:

- It is not very robust
- It is very expensive
- It is not for longer utilization
- Only used in low power demand situation

2. AC Synchronous Generator

AC synchronous generator can take constant or DC excitations from either permanent magnets or electromagnets and are thus termed PM synchronous generators (PMSGs) and electrically excited synchronous generators (EESGs). When the rotor is driven by the wind turbine, a three phase power is generated in the stator windings which are connected to the grid through transformers and power converters. For fixed speed synchronous generators, the rotor speed must be kept at exactly the synchronous speed.

Otherwise synchronism will be lost. Basically, the synchronous generator is a synchronous electro-mechanical machine used as a generator and consists of a magnetic field on the rotor that rotates and a stationary stator containing multiple windings that supplies the generated power. The rotors magnetic field (excitation) is created by using either permanent magnet mounted directly onto the rotor or energized electromagnetically by an external DC current flowing in the rotor field windings.

This DC field current is transmitted to the synchronous machine's rotor via slip rings and carbon or graphite brushes. Synchronous generators do not require complex commutation. It has to synchronize with the electrical grid before it can generate electricity.

2.1. Disadvantages of synchronous generator:

- It is more complex and costly
- It is prone to failure

Figure 4. AC synchronous generator.

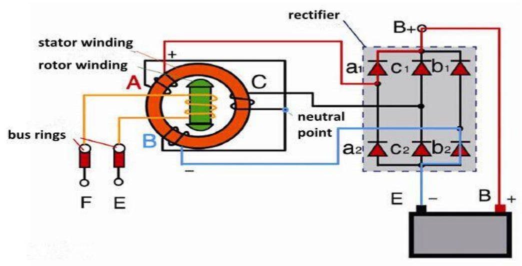

Figure 5. construction.

3. AC Asynchronous Generator

Rotating electrical machines are used in wind energy systems and most of these electrical machines can function as either a motor or generator. Asynchronous generator has fixed stator winding arrangement which, when energized by a rotating magnetic field produces a three phase voltage output. This generator is based on the very common squirrel cage motor type machine as they are cheap, reliable, and readily available in wide range of electrical sizes from fractional horse power to multi megawatt capacities making them ideal for both domestic and commercial wind power application. It can be connected directly to the utility grid and driven by the turbines rotor blades at variable wind speed.

For economy and reliability many wind power turbines use asynchronous generators which are driven through a mechanical gearbox to increase their speed of rotation, performance and efficiency. It requires reactive power in individual wind turbine.The generator rotates above synchronous speed. So, when rotated faster an asynchronous generator produces AC electricity. It synchronize directly with the main utility grid i.e. produces electricity at the same voltage and frequency – no rectifiers and inverters are required.

3.1. Disadvantage of asynchronous generator:

It requires additional capacitors connected to windings of self excitation

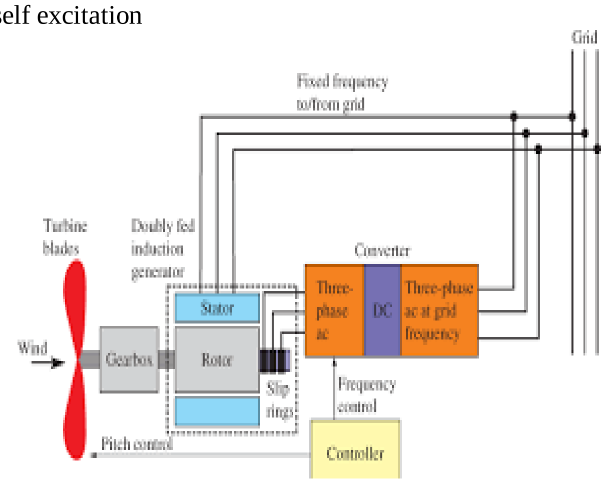

Figure 6. AC asynchronous generator.

International Journal of Scientific Research & Engineering Trends
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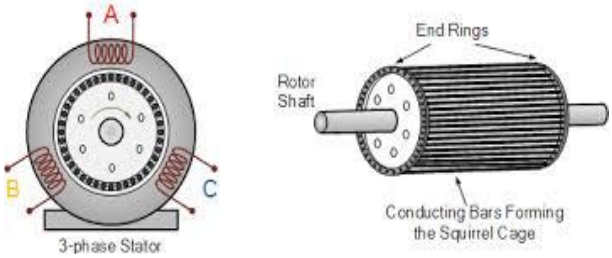

Figure 7. stator and rotor.

V.SUBTYPES OF GENERATORS

1. Permanent Magnet DC Generator

It is used as a simple wind turbine generator. It can be considered as a separately excited DC brushed motor with a constant magnetic flux .These DC machines have a stator having rare earth permanent magnets such as neodymium or samarium cobalt to produce a very strong stator field flux instead of wound coils and a Commutator connected through brushes to a wound armature as before. The main advantage over other DC generator is that the permanent magnet DC generator responds to changes in wind speed very quickly because their strong stator field is always there and constant.

PMDC are lighter than wound stator machines for given power factor and has better efficiency. It is a good choice for small scale wind turbine as they are reliable can operate at low rotational speed and provide god efficiency especially in light wind conditions.

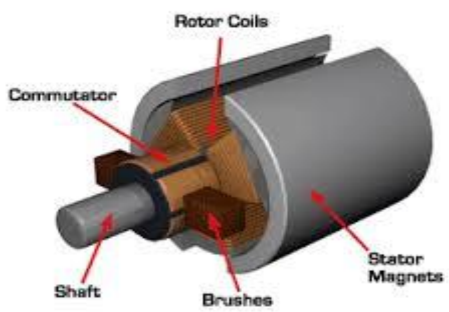

Figure 8. permanent magnet DC generator.

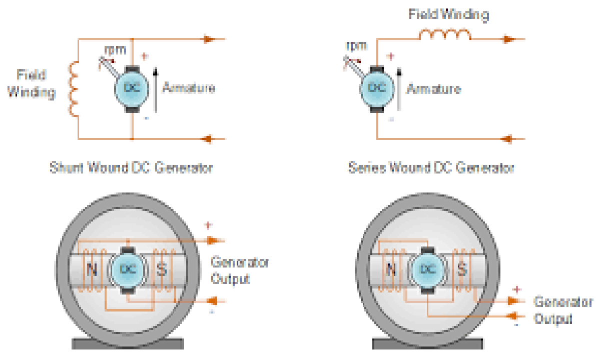

Figure 9. types of DC generator.

2. Doubly Fed Induction Generator

It is the most commonly used wound rotor induction generator, stator of DFIG is directly connected to the grid and rotor across a partially rated converter. Due to difference between the speed of stator and rotor a gearbox is needed to couple the rotor to the generator. Most commonly used configuration includes variable frequency and back AC/DC/AC and AC/AC voltage source type. Rotor side and grid side convertors are used made up of power electronics devices such as IGBT, MOSFET etc. the rotor voltage is applied from the power converters. Active and reactive powers as well as harmonics cab be controlled from the rotor slide convertor (RSC)

Advantages of DFIG

- Limited speed range -30% to 30% around synchronous speed
- Small capacity PMW inverter
- Rugged and brushless
- Active and reactive power can be controlled completely
- Full speed range
- High efficiency and energy yield

Limitations

- Need of gearbox
- Need of slip rings
- Medium reliability

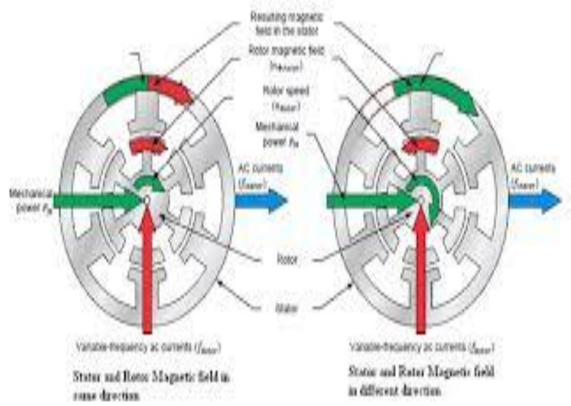

Figure 10. Doubly fed induction generator.

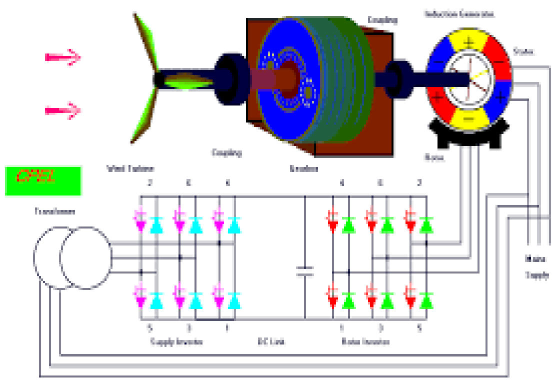

Figure 11. construction of PMDC.

3. Switched Reluctance Generator

It has features such as strong rotor and stator. With the rotor's rotations, the reluctance of the magnetic circuit linking the stator and rotor changes. It then, in turn, induces current in the winding on the armature. The reluctance rotor is built from laminated steel sheets, and it does not have any electrical field windings or permanent magnets. For this reason the generator is simple, easy to produce, and assemble. It is highly reliable because they can work in harsh or high temperature environment. Due to the fact the fact that the reluctance torque is only fraction of electrical torque, the rotor of a switched reluctance generator is usually larger than the other with electrical excitations for a given rate of torque.

Figure 12. switched reluctance generator.

VI.PERFORMANCE COMPARISON AND CONCLUSION

The efficiency of permanent magnet synchronous generator is higher than doubly fed induction generator Because of the fact that excitation can be provided without energy supply. The other Advantage of permanent Magnet Synchronous generator is that according to conditions power can be generated at any speed. The stator of the latter is wound and rotor consists ofPermanent magnet pole system. On the other side the materials used for manufacturing permanent magnets are expensive and also are sensitive to temperature therefore they require cooling systems. Another issue with this type of generator is problem encountered during start up due to its synchronous nature and hence there will be difficulty in getting constant voltage.

Doubly Fed Induction Generator (DFIG) on the other hand has good control over generating Reactive power which can be delivered to the stator by grid side converter. Due to presence of Gearbox in DFIG there is additional maintenance cost and hence less reliable than PMSG. Variable speed operation is attractive in today's world because of the fact that machine with this technology exhibits more power capture and less mechanical stress. A short introduction Followed by different wind turbine topologies and wind turbines from electrical point of view. Is presented in this paper. Comparison of different types of generators in wind turbines is presented

Whose performances are improving due to new advancement in power electronic devices? Which provide solution in wind power installations by improving power system stability and Control.

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