International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 11 Issue: 04 | Apr 2024 www.irjet.net p-ISSN: 2395-0072

Overview and Study of Wind Turbine Generators

Ms. Sneha Baliram Tambe[1], Mr. Samadhan A. Patil[2] , Ms.Naina Raut[3]

Ms. Sneha Baliram Tambe, Dept. of Electrical Engineering, YTIET ,Karjat, Maharashtra, India.
Mr. Samadhan A. Patil, Dept. of Electrical Engineering, YTIET , Karjat, Maharashtra, India.
Ms.Naina Raut, Dept. of Electrical Engineering, YTIET Karjat, Maharashtra, India.

---***---

Abstract - *The use of induction generators to generate electricity from unconventional sources has attracted considerable interest from energy researchers. Based on economy, high technical knowledge and environmental friendliness to provide electricity used for all development. Wind energy plays an important role in developing an environment friendly economy with low carbon footprint. This paper provides an overview of wind turbine generator technology and compares the advantages and disadvantages when applied to wind energy applications. Traditionally, DC motors, synchronous motors, and squirrel-cage induction motors have been used to generate small electrical currents. For medium and large wind turbines, doubly-fed induction generators are currently the dominant technologies, while permanent magnetic, switched reluctance and high-temp superconducting generators have been extensively researched and developed over many years. This paper discusses the topology and characteristics of these devices, including their practical considerations regarding design, control and operation.*

The paper presents a summary of wind turbine technology through a literature review of wind turbine systems followed by a discussion of systems applied on doubly fed induction generator wind turbines in particular.

Key Words*: *Doubly-fed induction generators, Synchronous Generator, Asynchronous Generator, Radial flux permanent magnet, Air core Generator.

1. INTRODUCTION

1.1 .Utilization of wind energy

Wind energy was used as early as 5000 B.C. when they sailed across the Nile. It is recorded that in 200 B.C. Since then, wind has been used as an energy source in ancient China and the Middle East to pump water, grind rice, and propel cars and ships. The first recorded windmill was built in the first century B.C. or the first century AD. Effectively, this wind turbine is used to convert kinetic energy into mechanical energy.

These wind turbines themselves tend to be small (less than 100kW) but can be designed for larger wind turbines (5MW or specified). Until the early 1990s, wind projects literally got off the ground, driven primarily by government and industrial policies. The 1990s also saw a shift in focus from onshore to offshore development in key wind developing countries, particularly in Europe, Offshore wind farms were first proposed in Germany in the 1930s, first installed in Sweden in 1991 and in Denmark in 1992. By July 2010, offshore wind turbines were installed 2.4 GW established in Europe Compared to onshore wind, offshore wind energy has some interesting properties such as wind speed.

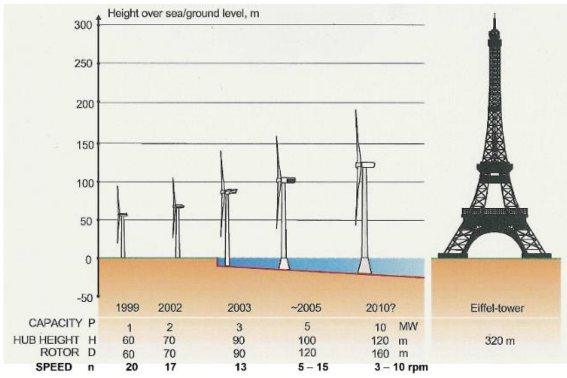

Fig -1: Ever-growing size of horizontal-axis wind turbines.

Over the past three decades, wind turbines have experienced tremendous growth as the global wind market continues to grow and accelerate. At the end of 2009, global capacity was 160 GW. The contribution of wind energy to the global electricity market is estimated to increase from 1% in 2008 to 8% by 2035. This can only be achieved by building larger wind turbines and putting more into the wind industry. In terms of scale, large megawatt wind turbines are starting to appear in the EU, the US, and now China and India. Typically the largest wind turbines installed in utility grids are 1.5-5 MW while 7.5 to 10 MW are in high development, as shown in Fig-1, Modern wind turbines are now Reliable, quiet, cost-effective and commercially competitive, while wind turbine technology has been demonstrated are also proficient. Current technical challenges are generally related to ever-increasing wind turbine size, power transmission, energy storage, energy efficiency, complex design and fault tolerance .Nowadays, it is widely recognized that wind power is the main source of economically viable renewable energy available. A global map of wind power potential is shown in Figure 2. However, wind power is variable in nature and such applications require high reliability and are mostly available when the market is still looking to reduce weight, challenges and operating costs.

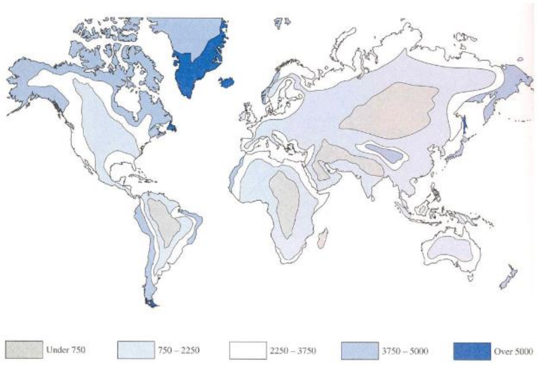

Fig -2: The world's energy potential for land-based wind turbines.

The main objective of this session is to study and design the proposed generator. The proposed generator is a radial flux permanent magnet generator with two rotor topology. The stator is metal-less or 'in air', hence the name. This generator is a single-sided generator, originally designed to use wind power.

Clearly, wind energy figures prominently in government and institutional agendas. However, there are some stumbling blocks in this widespread approach. Wind turbines come with different topologies, architectures and design features. The wind turbine generation system schematic is shown in Figure 3. Some options for wind turbine topologies are as follows.

• Orientation of the rotor axis: horizontal or vertical;
• Rotor position: upwind or downwind of the tower;
• Constant or variable rotor speed;
• Hub: solid, flexible, gimbal or hinged cable;
• Stiffness: mobile or brittle;
• Number of blades: one, two, three or more;
• Power control: stall, pitch, yaw or aerodynamic surface;
• Yaw control: enabled or disabled.

This paper focuses only on horizontal axis wind turbines (HAWTs), which is a standard wind turbine topology, as highlighted in Figure 4

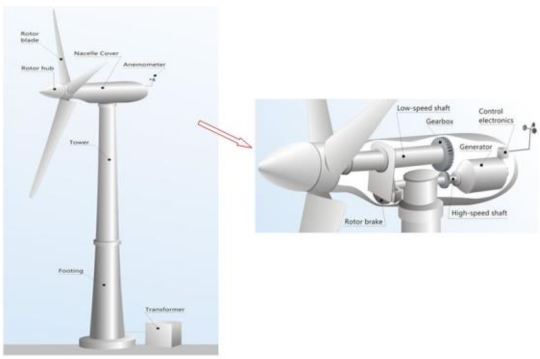

Fig -3: Schematic of a wind turbine generation system.

Wind turbines consist of turbine blades and rotors, critical mechanical parts, drive train and generators. More than 30% of the total capital expenditure goes to emissions from offshore wind projects. Wind turbines are often built in relatively inaccessible areas imposing certain design restrictions. In coastal areas, this is the only place you can go for cleaning once a year. Consequently, the fault tolerance of wind turbines is important for the development of wind turbines.

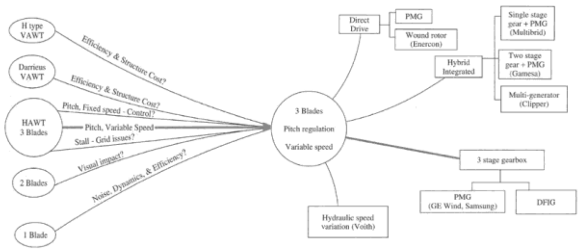

Fig -4: Commonly agreed wind turbine type and its divergence.

The main component of a wind turbine is its drive train that connects the aerodynamic rotor to the electrical output. Optimization of wind turbine generators cannot be achieved without considering the mechanical, structural, hydraulic and magnetic performance of the drive train. Generally, they can be divided into four categories according to their structure:

• Conventional: high-speed gearbox and generator with fewer twin poles.
• Direct drive: Drive train without a low-speed gearbox and generator.
• Hybrid: Drive train with gearbox and generator speed between the above two types.
• Multiple generators: Drive train with more than one generator.

Drive train topologies can raise issues such as rotor and gearbox/ bearing integration, separation of gear and generator shafts from bending load machines, integrity, and load paths although it can be easy to service wind turbine components if separated like gearbox, bearings and generator is largely in favor of the planning of Drive train components.

1.2 Wind Turbine Generators

One of the limiting factors for wind turbines is the engineering of their generators. Academics and industry disagree on the optimal wind turbine technology. Traditionally, there are three main types of wind turbine generators (WTGs) that can be considered for wind turbine systems, these are direct current (DC), alternating current (AC) synchronous, AC asynchronous. Generators are also available and can in principle be either fixed or variable speed. Due to variable wind forces, variable speeds are operated in the WTG which reduce the physical strain on the turbine blades and drive train, improving the aerodynamic efficiency, torque and transient behavior of the system.

1.3 DC Generator technologies

Generally in conventional DC motors, the field is on the stator and the armature is on the rotor. The stator consists of several poles that are energized by permanent magnets or DC field coils. If the device is electrically powered, it usually follows the concept of a shunt-wound DC generator.

In general, these types of DC WTGs are rare in wind turbine applications unless the power demand is low where the load is physically close to the wind turbine, for thermal applications or battery.

1.4 AC Synchronous Generator Technologies

Since the early development of wind turbines, considerable effort has been devoted to the use 3 phase synchronous machine. AC synchronous WTGs can take constant or DC excitation from constant magnets or electromagnets and are called PM synchronous generators (PMSGs) and electrically excited synchronous generators (EESGs) respectively. For fixed-speed synchronous generators connected to the grid through the medium, the rotor speed must be maintained at synchronous speed otherwise synchronization will be lost. Synchronous generators are a proven machine technology because their efficiency in electricity generation has been studied and widely accepted for a long time. A cutaway diagram of a conventional synchronous generator is shown in Figs. 7. In principle, the reactive power characteristics of synchronous WTGs can be easily controlled by field circuits for electrical excitation despite being transmitted through the power grid, synchronous WTGs have a low damping effect so that the power of drive train transients will not be absorbed. As a result, an additional damping element (e.g. flexible coupling of the drivetrain) is required, or a gearbox assembly mounted on springs and dampers, which requires a smooth operation to synchronize their frequency with the grid frequency when installed in the grid. In addition, they are generally more

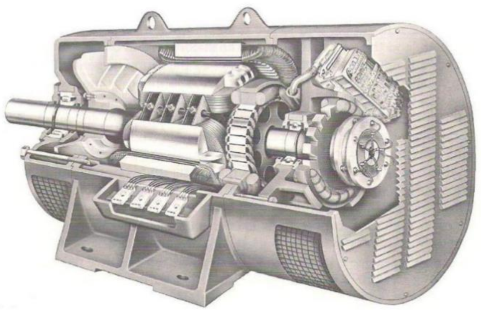

Fig -7: Cutaway of a synchronous generator.

In recent decades, PM generators are increasingly being used in wind turbine applications due to their high efficiency and low size. These devices are generally referred to as permanent magnet synchronous generators (PMSGs) and are considered the device of choice in small wind turbine generators. The design of the generator is quite simple. As in Figure 8. A solid PM is placed on the rotor to create a constant magnetic field and an electrical energy is taken from armature (stator) by using a commutator, slip ring or brush. Sometimes the PM is made of cylindrical cast aluminum -They can reduced cost by adding cost to the rotor. The principle of operation of the PM generator is similar to the synchronous generator except that the PM generator can operate asynchronously. The advantage of PMSG is that commutators, slip rings and brushes are removed making machines more robust, reliable and simple. The use of PM eliminates field winding (and its associated power loss) but field control is not possible and the cost of PM can be prohibitively high for large machines

Because the actual wind speed fluctuates, PMSGs cannot generate fixed-frequency electricity. As a result, the power grid must be connected with an AC- DC-AC conversion driven by a power converter. That is, the generated AC voltage (of variable frequency) is first rectified to fixed DC, and then converted back to AC voltage (of fixed frequency). Use of this permanent magnet device for direct drive application is also very attractive. Obviously in this case the pesky gearboxes that cause most wind turbines to fail can be eliminated.

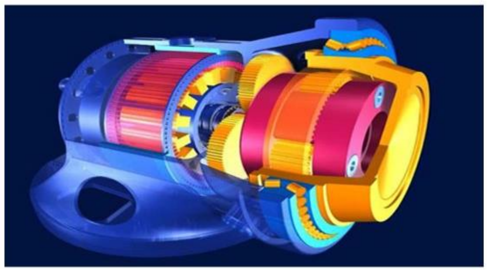

Fig -8: Cutaway of a permanent magnet synchronous generator.

One possible type of synchronous generator is a high temperature superconducting generator. See Figure 9 for a multi-MW, low speed HTS synchronous generator system. The device includes stator back metal, stator copper winding, HTS field coil, rotor core, rotor support system, rotor cooling system, cryostat and external refrigerator, electromagnetic shield and damper, bearing, shaft and housing Stator keeps HTS coils warm the lower operating conditions in machine design , rotor, cooling and gearbox design can pose particular challenges.

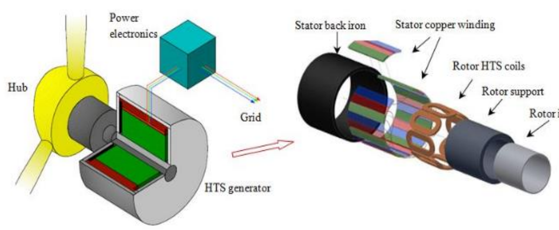

Fig -9: Schematic of a HTS synchronous generator system.

Superconducting coils can carry 10 times more current than conventional copper wires with little tolerance and losses of conductor. Superconductors will certainly eliminate all field circuit power losses and superconductivity's ability to increase current density allows higher magnetic fields, greatly reducing the number and size of wind turbine generators. The company "Siemens" offers the world in the first superconducting wind turbine generator of 4 MW synchronous generator was installed successfully. However, many technical challenges are encountered, especially for long-lived, low-maintenance wind turbine system. For example, cryogenic systems require constant maintenance so that cooling and recovery time after shutdown is another issue.

1.5 AC Asynchronous Generators

While traditional electricity generation uses synchronous machine, modern wind power systems increasingly use induction machines. These induction generators are of two types: fixed speed induction generators (FSIGs) with squirrel cage rotors (sometimes referred to as squirrel cage induction generators-SQIG and double-fed induction generators (DFIGs) with wound. The cross-sectional images of the squirrel-cage induction generator and the double-fed induction generator are shown in Fig. 10 and Fig. 11, respectively, and their configuration topologies are further shown in Fig. 12

When a three-phase AC voltage is supplied to the stator, a rotating magnetic field is produced in the air gap. When the rotor rotates at a speed different from the synchronous speed, slip occurs and the rotor circuit is energized. Induction devices are generally simple, reliable, inexpensive, and well-designed. They have high damping and can absorb variable rotor speeds and drive train transients (i.e. fault tolerance). But induction machines draw reactive power from the grid so some reactive power compensation is needed such as the use of a capacitor or power converters. In a fixed-speed induction generator where the stator is connected to the grid through a transformer and the rotor goes to a wind turbine via gearbox. The rotor speed is assumed to be fixed (of course varying over a small range). Until 1998, most wind turbine manufacturers developed constant-speed induction generators of 1.5 MW and less. These generators typically operate at 1500 revolutions per minute (rpm).

50 Hz utility grid, with three-stage gearbox.

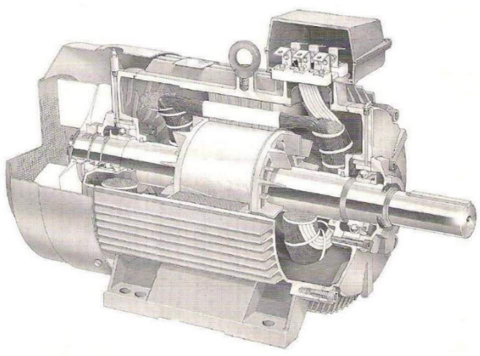

Fig -10: Cutaway of a squirrel-cage induction generator.

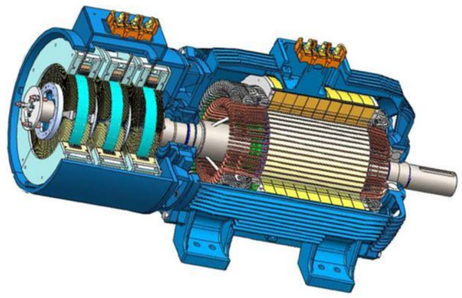

Fig -11: Cutaway of a doubly-fed induction generator with a rotary transformer.

SCIGs can be used in variable wind speeds, such as synchronous machines. However, the output voltage cannot be controlled and the reactive power must be supplied externally. Obviously, fixed-speed induction generators are limited to operate only in a very narrow range of differential speeds. Other mechanical drawbacks are related to mechanical size, noise, low performance and reliability. These machines have proven to cause significant performance failure and subsequent maintenance.

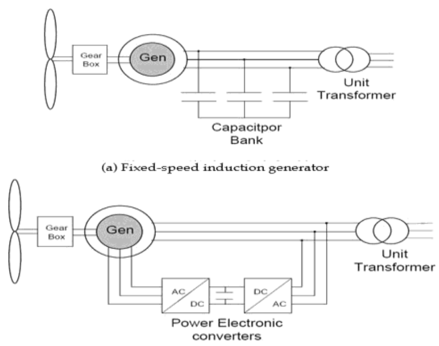

Fig -12: Schematic of two induction generator systems.

SCIGs have led the wind turbine market over the past millennium, which surpassed the widely adopted DFIG. More than 85% of the currently installed wind turbines use DFIG and with DFIG the maximum capacity of commercial wind turbines has increased to 5 MW in operation. In the DFIG topology, the stator through a transformer and rotor and connected directly to the grid connected to the grid via PWM power converters –It can control rotor circuit current, frequency, and phase-angle changes. Such induction generators can operate over a wide slip range (typically ±30% of synchronous speed). As a result they offer many advantages such as high power output, reduced mechanical stresses and variable, controllable power output.

Reactive power for the magnetic circuits must be supplied to the entire induction generator from a grid or local capacitor. Induction generators are susceptible to unstable voltage. When capacitors are used to compensate for the power factor, there is a risk of self-excitation. Additionally, the damping effect can cause power losses in the rotor. There is no direct control of terminal voltage (and thus reactive power), nor is there a continuous fault current.

As shown in Fig. 12, the rotor of the DFIG is mechanically connected to the wind turbine through a drive train system, which can have high and low speed shafts, bearings, and gearboxes. The rotor is fed by the bi-directional voltage-source converters. The speed and torque consumption of the DFIG can therefore be controlled by controlling the rotor side converter (RSC). Another feature is that DFIGs can handle sub-synchronous and super-synchronous states. The stator constantly transmits power to the grid while the rotor can handle power in both directions. The reason for the latter occurs because PWM converters can deliver voltage and current at different phase angles. In sub synchronous operation, the rotor-side converter acts as an inverter and the grid-side converter (GSC) acts as a rectifier. In this case, the active power flows from the grid to the rotor. In super-synchronous mode, the RSC acts as a rectifier and the GSC acts as an inverter. Consequently, the reactive power energy flows from the stator as well as from the rotor to the power grid.

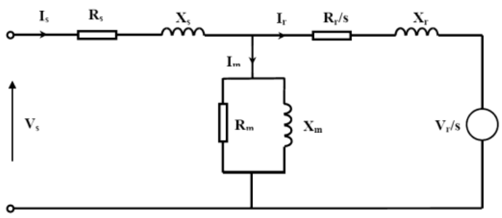

Fig -13: Per-phase equivalent circuit of the DFIG.

To analyze the performance of a DFIG, it is always necessary to take its counter phase equivalent circuit, as in Fig. 13. From this figure, we can see that the DFIG differs from the conventional induction machine in which a rotor circuit is used voltage is included in order to apply voltage to the rotor circuit. The actual d-q control of the DFIG is similar to the amount of voltage applied to the circuit and the phase control.

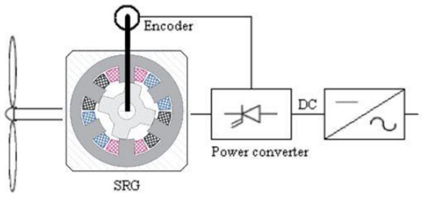

Fig -14: Schematic of a switched reluctance generator system.

The reluctance rotor is made of laminated steel and has no electrical windings or permanent magnets. As a result, the reluctance machine device is simple, easy to manufacture and assemble. One obvious aspect is their greater reliability as they can operate in a harsher environment or at higher temperatures. Since reluctance torque is only a fraction of electrical torque, switched reluctance rotors tend to be larger than others with electrical excitations for a given rated torque. If reluctance machines are combined with direct drive features the device would be larger too much and heavy, making it unsuitable for wind energy.

2. Design Considerations and Challenges

Wind turbine generators can be selected from commercial electric motors with or without minor modifications. When it is necessary to tailor the Wind turbine generating system to a specific location, there are some basic points to consider.

These include:

- Choice of machines
- Type of drive train
- Brush topology
- Rated and operating speeds
- Rated and operating torques
- Tip speed ratio
- Power and current
- Voltage regulation (synchronous generators)
- Methods of starting
- Starting current (induction generators)
- Synchronizing (synchronous generators)
- Cooling arrangement
- Power factor and reactive power compensation (induction generators)
- Power converter topology
- Weight and size
- Protection (offshore environment)
- Capital cost and maintenance.

2.1 Reasons for air core generator being used

- ➢ Efficiency is high due to absence of losses (iron & field cu losses).

- Does not require gearbox for speedup i.e. omitting the gearbox.
- Eliminate the need for gearbox repairs, gearbox maintenance and complex installation procedures.
- Noise is less.
- Due to absence of iron core cost is less.
- Power to weight ratio is high.
- Due to light weight installation is easy.
- It has very less cogging effect.

3. Problem Definition & Objective:

3.1 Definition:

i. The normal wind turbine is suitable for min 10m/s wind velocity & they are using either Star or Delta type of winding for their generator so generator get only one output (pair of wire +,-) .

ii. If wind velocity less than 10m/s this turbine cannot rotate generator because for starting generator torque is insufficient so in max. part of India we cannot install wind turbine.

3.2 Objective

1) Objective of our project is to make a smart generator, i.e. according to wind speed it should change the required torque to rotate the generator.
2) To increase the zones for installing the wind turbine by reducing the required air velocity for windmill.
3) To design a special type of circuit which will sense the air velocity and accordingly operate the relay.
4) To make such a wind mill which will activate and deactivate the winding according to wind velocity.
5) To make the project in possible low cost.

4. Description and Concept

4.1 Generation of EMF by faraday's law:

Electrical generators are devices that convert mechanical energy into electricity and are well known. The underlying working principle of these generators is found in Faraday's law which states in its basic form that an electrical difference occurs between the edges of an electrical conductor running perpendicularly through a magnetic field. In this experiment Faraday uses a magnet and a coil and connecting galvanometer around the coil. Initially the magnet is at rest, so there is no deflection in the galvanometer ie. the needle of the galvanometer is centered or at zero. When the magnet moved towards the coil, the needle of the galvanometer turns in one direction. When the magnet is stationary, the galvanometer needle returns to zero at that point. Now when the magnet moves away from the coil, there is a slight deflection in the needle but in the opposite direction and again when the magnet is stationary at that point about the coil, the galvanometer needle returns to zero and as the coil moves away and towards the magnet holding the magnet still It can be seen that, the faster the magnetic field changes, the greater the emf or voltage induced in the coil will be. More specifically, that the electromagnetic field (EMF) induced in any closed circuit is equal to the time change of the magnetic flux through the circuit.

But according to Faraday's law of electromagnetic induction, the rate of change of flux linkage is equal to induced emf.

$$E = N\frac{d\phi}{dt}$$

Lenz's law states that when an emf is generated by a change in magnetic flux according to Faraday's Law, the polarity of the induced emf is such, that it produces an current that's magnetic field opposes the change which produces it. The negative sign used in Faraday's law of electromagnetic induction, indicates that the induced emf (ε) and the change in magnetic flux ($\delta\Phi_B$) have opposite signs. Considering Lenz's Law.

$$E = -N\frac{d\phi}{dt}$$

Reason for opposing, cause of currents according to Lenz's Law-

Lenz's law obeys the law of conservation of energy and if the direction of the magnetic field that creates the current and the magnetic field of the current in a conductor are in same direction, then these two magnetic fields would add up and produce the current of twice the magnitude and this would in turn create more magnetic field, which will cause more current and this process continuing on and on leads to violation of the law of conservation of energy. If the induced current creates a magnetic field which is equal and opposite to the direction of magnetic field that creates it, then only it can resist the change in the magnetic field in the area, which is in accordance to the Newton's third law of motion.

5. Disadvantages of Conventional Wind Generators

Conventional wind generators suffer from a number of disadvantages. One such disadvantage is that the majority of such generators utilize iron core stators. Apart from the high cost associated with iron cores, they are also heavy and require additional resources and support to install, stabilize and maintain. Iron core stators also suffer from cogging torque, which is the torque resulting from the interaction between the permanent magnets of the rotor and the stator slots of a PM machine. It is also known as detent or "no-current" torque. Cogging torque is an undesirable component for the operation of iron-core electric generators. It is especially prominent at lower speeds and manifests itself in stuttered rotation.

A further disadvantage of conventional wind generators is the cost associated with their repair and maintenance. In particular, where windings on either the rotor or stator become worn or defective, highly skilled technicians are required to conduct repair or maintenance. The weight and unwieldiness of conventional iron-core stators also often require the use of machinery or teams of technicians to conduct even routine maintenance.

6. Advantages of Proposed Model

6.1 Advantages of permanent magnets:

Permanent magnet excited machines have a series of economic and technical advantages over the electrically excited type. Some of these advantages can be summarized as follows:

a) No additional power supply for the magnet field excitation.
b) Improvement in the efficiency and thermal characteristics of the motor due to absence of the field losses.
c) Higher reliability due to absence of mechanical components e.g. slip rings.

Higher power to weight ratio. Permanent-magnet machines allow a great deal of flexibility in their geometry. Based on the direction of flux penetration, permanent magnet machines can be classified as: radial flux, Axial-flux and transversal-flux machines.

6.2 Advantages of a radial flux machine:

The permanent magnets of radial-flux machines are radially oriented. Radial-flux Permanent-magnet machines can be divided mainly into two types, surface-magnet and Buried-magnet machines. The simple way of constructing the rotor with high number of poles is by gluing the permanent magnets on the rotor surface of the machine.

7. Material Selection

The proper selection of material for the different part of a machine is the main objective in the fabrication of machine. For a design engineer it is must that he be familiar with the effect, which the manufacturing process and heat treatment have on the properties of materials. The Choice of material for engineering purposes depends upon the following factors:

- Availability of the materials.
- Suitability of materials for the working condition in service.
- The cost of materials.
- Physical and chemical properties of material.
- Mechanical properties of material.

In engineering practice, the machine parts are subjected to various forces, which may be due to either one or more of the following.

1. Energy transmitted
2. Weight of machine
3. Frictional resistance
4. Inertia of reciprocating parts
5. Change of temperature

The selection of the materials depends upon the various types of stresses that are set up during operation. The material selected should with stand it. Another criteria for selection of metal depend upon the type of load because a machine part resist load more easily than a live load and live load more easily than a shock load.

Selection of the material depends upon factor of safety, which in turn depends upon the following factors.

1. Reliabilities of properties.
2. Reliability of applied load.
3. The certainty as to exact mode of failure.
4. The extent of simplifying assumptions.
5. The extent of localized.
6. The extent of initial stresses set up during manufacturing.
7. The extent loss of life if failure occurs.
8. The extent of loss of property if failure occurs.
9. For Base plate, motor support, sleeve and shaft Material used is **Mild steel.**

8. Solution

This paper provides an overview by comparing the advantages and disadvantages of different types of wind turbine generators including DC, synchronous and asynchronous wind turbine generators. If the wind turbine generators have to be further improved, especially the calculation -More in -depth analysis in wind turbine design, control and operation using research and testing methods is essential but despite continuous research and development efforts, wind power systems still face technological, environmental issues has faced many financial challenges. In summary, there may not be an optimal wind turbine generator technology to tick all the boxes. The selection of complex wind turbine systems is highly dependent on capital and operating costs because wind markets are particularly cost-sensitive Essentially, the decision always comes down to comparing material costs to land sitting exist between magnets, superconductors, copper, iron or other reactive materials.

We are developing a special generator that can also operate at lower torque so if the wind speed is 2m/s our turbine will generate power so that we can use it at lower speeds as well.

REFERENCES

[1] Abo-Khalil, A. G. (2011). A new wind turbine simulator using a squirrel-cage motor for wind power generation

systems. IEEE Ninth International Conference on Power Electronics and Drive Systems (PEDS), 750-755.M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

[2] Al-Majed, S. I., & Fujigaki, T. (2010). Wind power generation: An overview. The Inter- national Symposium on Modern Electric Power Systems (MEPS), 1-6. K. Elissa, "Title of paper if known," unpublished.

[3] Aly, H. H., & El -Hawary, M. E. (2010). An overview of offshore wind electric energy resources. 23rd Canadian Conference on Electrical and Computer Engineering CCECE, 1-8.

[4] Bansal, R. C., Zobaa, A. F., & Saket, R. K. (2005). Some issues related to power generation using wind energy conversion systems: an overview. Int. J. Emerging Electr Power Syst., 3(2), Article 1070.

[5] Abrahamsen A B, Mijatovic N, Seiler E, Trholt C, Norgard P, Pedersen N, Andersen N and Ostergard J 2010 Supercond Sci. Technol. 23 034019.

[6] Wind in power 2015 European statistics EWEA.