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POWER, PERFORMANCE AND ENERGY GENERATION ANALYSIS OF HORIZONTAL AXIS WIND TURBINES

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ABSTRACT

The year 1973 has awakened the entire world from the energy crisis. Since then the entire focus of all developing countries turned towards non-conventional sources of energy. Of all the non-conventional energy sources wind energy is an inexhaustible, non-polluting, freely available energy. Enormous potential is associated with the kinetic energy of the wind. Previously the KE of the wind was utilized to drive wind turbines mostly for pumping water and grinding corns. The first wind turbine was employed for generation electricity in Denmark in 1890.India has started its power generation through (WEGs) from 1986. Later on number of wind electric generators (WEGs) has been installed every year. The next generation of wind turbines, developed by U.S.Dept. Of Energy, has to produce power at 25% lesser energy costs. In Tamil Nadu, Muppanthal is a place situated in the coastal region of Kanyakumari District. It is highly noted for its large number of wind turbines. Herein we have selected three different wind energy generators viz. NEPC, WINCO & TTG each of 250 kW capacities and undergone the power performance studies for each system and for different wind speed conditions. The density of air, total energy available in the wind, the energy actually converted by WEGs into electric power (Power co-efficient) are calculated and tabulated as per the wind energy standards IEC – 61400 –12. The characteristic curves such as wind velocity Vs power output (power curve), wind velocity Vs efficiency are plotted. The energy generation, technical availability, real availability, plant load factor, energy generation per square metre of rotor area and energy generation per kW installed capacity also calculated and the results are tabulated.

KEYWORDS : *Blade Design, Horizontal, and Vertical axis wind turbines, wind rotor, wind turbine*

I. INTRODUCTION

Renewable energy is expected a curable man impact in the production of electricity. Wind Power is globally the fastest growing energy source. Energy needs of man vary with life style, seasons, industrial progress etc.Rural man of today requires lower energy man the urban man. Urban man is dependent on electric energy. The renewable are available free of cost. Hence, consumption if renewable should be maximized. Wind electric generators (WEG is) harnessing the power of wind energy the clean natural power for India. In Muppanthal and Kayathar wind farm, several wind electric generator ranges from 80 Kw to 1250 Kw are installed. New Renewable Sources of Energy (NRSE) schemes under ministry of non-conventional energy, India has planned by 9th plan (1998 – 2003) 2000 Mw wind farms. Wind speed between 7 m/s and 25 m/s are favorable for the wind turbine generator.

Wind energy to electrical energy has become economically competitive in areas of favorable wind (e.g.) south zone of Tamil Nadu (Kayathar and Muppanthal) and wind electric energy systems are now in the forefront of renewable energy utilization projects sponsored by the Department of Non Conventional Renewable Branch (DNRB). In Muppanthal large wind turbine generators cover a wide ranges from 80 Kw to 1250 Kw. Wind energy is considered to be a very clear, cheap important renewable energy source particularly rural areas, remote on shore and off shore installation away from main electrical grid. Wind turbine generators ranges from 80 – 1250 Kw with 3 blades, horizontal shaft design mounted on a tower are being manufactured on commercial scale in several countries in the world. Such generators are commercially very successful initial technical snags have now been removed and reliable designed are in operations.

1.1. Wind power

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electrical power, windmills for mechanical power, wind pumps for water pumping or drainage, or sails to propel ships. Large wind farms consist of hundreds of individual wind turbines, which are connected to the electric power transmission network. For new constructions, onshore wind is an inexpensive source of electricity, competitive with or in many places cheaper than fossil fuel plants. Small onshore wind farms provide electricity to isolated locations. Utility companies increasingly buy surplus electricity produced by small domestic wind turbines. Offshore wind is steadier and stronger than on land, and offshore farms have less visual impact, but construction and maintenance costs are considerably higher. Wind power, as an alternative to fossil fuels, is plentiful, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little land. The effects on the environment are generally less problematic than those from other power sources. As of 2011, Denmark is generating more than a quarter of its electricity from wind and 83 countries around the world are using wind power to supply the electricity grid. In 2010 wind energy, production was over 2.5% of total worldwide electricity usage, and growing rapidly at more than 25% per annum.Wind power is very consistent from year to year but has significant variation over shorter time scales. The intermittency of wind seldom creates problems when used to supply up to 20% of total electricity demand, but as the proportion increases, a need to upgrade the grid, and a lowered ability to supplant conventional production can occur. Power management techniques such as having excess capacity storage, geographically distributed turbines, dispatchable backing sources, storage such as pumped-storage hydroelectricity, exporting and importing power to neighboring areas or reducing demand when wind production is low, can greatly mitigate these problems. In addition, weather forecasting permits the electricity network to be readied for the predictable variations in production that occur.

1.2. Wind energy

Wind energy is the kinetic energy of air in motion, also called wind. Total wind energy flowing through an imaginary area A during the time t is:

$$E = \frac{1}{2}mv^2 = \frac{1}{2}(Avt\rho)v^2 = \frac{1}{2}At\rho v^3,$$

Where ρ is the density of air; v is the wind speed; Avt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); $Avt\rho$ is therefore the mass m passing per unit time. Note that $\frac{1}{2}\rho v^2$ is the kinetic energy of the moving air per unit volume.Power is energy per unit time, so the wind power incident on A (e.g. equal to the rotor area of a wind turbine) is:

$$P = \frac{E}{t} = \frac{1}{2}A\rho v^3.$$

Wind power in an open-air stream is thus *proportional* to the *third power* of the wind speed; the available power increases eightfold when the wind speed doubles. Wind turbines for grid electricity therefore need to be especially efficient at greater wind speeds. Wind is the movement of air across the surface of the Earth, affected by areas of high pressure and of low pressure. The surface of the Earth is heated unevenly by the Sun, depending on factors such as the angle of incidence of the sun's rays at the surface (which differs with latitude and time of day) and whether the land is open or covered with vegetation. Also, large bodies of water, such as the oceans, heat up and cool down slower than the land. The heat energy absorbed at the Earth's surface is transferred to the air directly above it and, as warmer air is less dense than cooler air, it rises above the cool air to form areas of high pressure and thus pressure differentials. The rotation of the Earth drags the atmosphere around with it causing turbulence. These effects combine to cause a constantly varying pattern of winds across the surface of the Earth. The total amount of economically extractable power available from the wind is considerably more than present human power use from all sources. Axel Kleidon of the Max Planck Institute in Germany, carried out a "top down" calculation on how much wind energy there is, starting with the incoming solar radiation that drives the winds by creating temperature differences in the atmosphere. He concluded that somewhere between 18 TW and 68 TW could be extracted. Cristina Archer and Mark Z. Jacobson presented a "bottom-up" estimate, which unlike Kleidon's are based on actual measurements of wind speeds, and found that there is 1700 TW of wind power at an altitude of 100 metres over land and sea. Of this, "between 72 and 170 TW could be extracted in a practical and cost-competitive manner". They later estimated 80 TW. However, research at University estimates 1 Watt/m^2 on average and 2–10 MW/km^2 capacity for large-scale wind farms, suggesting that these estimates of total global wind resources are too high by a factor of about 4.

II. PREVIOUS WORK

Adigun et al (2010), in their project, carried out a study on the generation of electricity using a wind turbine. An analysis was carried out on a horizontal axis wind turbine designed for the environmental conditions of the University of Port Harcourt, Nigeria. The maximum power achievable was 322W at a wind speed of 10m/s from the result of analysis. This shows that a vertical axis wind turbine is more suitable for regions with low wind speed like Nigeria since it can attain a power range of 322W at a lower wind speed (5m/s to 6m/s).

Javier (2011), in his project, designed a small-scale vertical axis wind turbine rotor with solid wood as a construction material. "The aerodynamic analysis is performed implementing a momentum based model on a mathematical computer program. The results obtained indicate that wood is a suitable material for rotor construction and a further development of the computer algorithm is needed in order to improve the flow conditions simulation". The blade aerodynamic analysis is a very important aspect of a wind turbines performance and should always be carried out before any design of a wind turbine system.

Sina and Mahyar (2011), in their paper studied maximum power control of wind turbine using permanent magnet synchronous generator connected with two back to back voltage source converters to grid. In this paper; "The machine currents are controlled by indirect vector control method. In this method, generator side converter controls the maximum excitation (air gap flux) by machine's d-axis current and controls generator torque by machine's q-axis current. Permanent magnet synchronous generator speed is controlled by tip speed ratio upon the wind speed variations to generate the maximum output power. Grid side converter regulates the DC link voltage and injective active power by d-axis current and regulates the injective reactive power by q-axis current using simple control method". The P-Q Simulation results in the paper depicts that the proposed method operates properly. The control of a wind turbine working with varying speed using a converter model is very important when connecting the turbine to a grid. It should have a maximum power point tracking (MPPT) functionality to extract more power from wind.

Thomsen and Srensen (1999), analyzed the wind power plants installed in the early 1980s suffered structural failures chiefly because of incomplete understanding of the wind forces (especially the turbulence component) acting on these large structures and in some cases because of poor quality in manufacture. Failure of the rotor blades was one of the principal and most serious structural failures.

An investigation was performed by **De-Goeij *et al*. (1999),** for the implementation of bending-torsion coupling of a composite wind turbine rotor blade to provide passive pitch-control. Limited passive torsion deformation is realized with a structural coupling between flap wise bending and elastic twist of a constant speed rotor-blade. The blade and skin laminate configuration are analyzed with a FEM program, in which a complete blade with spar webs is modeled.A probabilistic model for analysis of the safety of a wind-turbine rotor blade against failure in ultimate loading is presented by **Ronold and Larsen (2000).** Failure in ultimate loading of wind-turbine rotor blades exposed to wind and gravity loading is a failure mode that needs to be considered when the rotor blades are designed.

Maalawi and Negm (2002), worked on the optimization strategy of maximizing the system natural frequencies, which are the true measure of the overall level of the stiffness-to-mass ratio. Higher natural frequencies are favorable for reducing both the steady state and transient responses of the structure being excited. The behavior of these frequencies and their variation with the selected optimization variables are investigated in detail. It is shown that global optimality can be attained from the developed structural model and a new concept for the exact placement of the system frequencies is also presented.

A rod model given by **Baumgart (2002)**, for slender, tapered, closed structures is presented and applied to a wind turbine blade. The mathematical model is solved as an eigenvalue problem and the results are compared with an experimental modal analysis. Even though the general model characteristics (position of nodal points, direction of motion) match quite well, the chord rotation for some mode shapes is significantly underestimated. The question remains as to what assumptions in the modeling process are the main sources of these differences (e.g., parameter uncertainties, unisotropic material, geometry, order of Taylor series expansion in x and y).

Ahmed *et al*. (2010), was to design 700 kw wind turbine hub. The conventional hub used so far is of circular type but problem with such hub is that many casting defects arise; so it was decided to use straight beams of standard cross sections and fabricate them to make skeleton of hub. Initially the simplest triangular hub was designed but due to space problem it was decided to select hexagonal hub. The concept of this hexagonal hub is totally new and was never used earlier. All the loads caused by wind and inertia on the blades are transferred to the hub, so mechanical strength of hub becomes very vital in the wind turbine design. The design has been done according to type's approval provision scheme. The mechanical as well as other safety considerations have been considered in this design. The analysis involves use of modeling and simulation software. The stress and deflection were also calculated in this study. This is a static analysis and preliminary stage of design, so many more improvement can be incorporated in future.

This work of **Tao et al. (1997)**, reports a progressive study of aerodynamic behavior of HAWT rotor blades (airfoil), focusing on modeling the stall-and post-stall characteristics as applied to the prediction of rotor performance under various field conditions. The methodology developed here may be generalized to provide a procedure used in the computer analysis.

There exist significant differences in airfoil aerodynamic characteristics between wind tunnel test data (Two Dimensional flow) and field test data (Three Dimensional flow). Through the Combined Experiment Program (CEP), efforts have been made to investigate proper approaches to analyze such differences so that it enables us to incorporate the results into wind turbine rotor performance codes to assist in optimal design of a horizontal axis wind turbine.

This study of **Ebert and Wood (1997)**, describes measurements in the wake of a small horizontal-axis wind turbine. The turbine had two constant-chords, constant-pitch blades which drove a hydraulic pump against a known load to extract power from the wind. This power was measured using a specially constructed dynamometer. The main limitation of the experiment was the high blockage so measurements were confined to the first two chord lengths downstream of the blades.

This study considered firstly the conventional mean velocities in the axial and circumferential direction for tip speed ratios of 2, 4 and 6. The axial velocity was nearly uniform at the operating condition closest to that giving maximum power as was the circulation determined from the circumferential velocity. Because of the small amount of wake expansion the bound circulation must also be nearly constant. To introduce the three-dimensional measurements, the downstream development of the circumferential profiles of the mean velocities and turbulent energy were presented for tip speed ratios of 2 and 4. These measurements were obtained in the region away from the tip and hub vortices and so are dominated, in terms of turbulence, by the wakes of the blades.

A variable-speed, fixed-pitch wind turbine control strategy was investigated by **Muljadi *et al*. (2000),** to evaluate the feasibility of constraining rotor speed and power output without the benefit of active aerodynamic control devices. A strategy was postulated to control rotational speed by specifying the demanded generator torque. By controlling rotor speed in relation to wind speed, the aerodynamic power extracted by the blades from the wind was manipulated. Specifically, the blades were caused to stall in high winds. In low and moderate winds, the demanded generator torque and the resulting rotor speed were controlled and the wind turbine operated near maximum efficiency. Turbine models were developed and simulations of operation in turbulent winds were conducted. Results indicated that rotor speed and power output were well regulated.

The rotational speed of the wind blades can be increased using steering aerofoil surrounding the blades. The blade profiles are designed using the theory of aerodynamics. The steering airfoils are fixed surrounding the wind blades at an optimum distance. The number of the airfoils and the angle of inclination (tilt) of the foils can be changed. In the experiment performed by **Varol and Varol (2001),** the ambient conditions are held constant. Because of the optimum adjustment of the distance and angle of the airfoils the rotational speed of the blades can be increased by 32% on the experimental device.

A method for determining the optimum design parameters for horizontal axis wind turbines was developed and tested by **Collecutt and Flay (1996).** These design parameters were the rotor diameter, rated power and tower height. The optimum values were found to be dependent on site wind regime. The results of the study indicated that it was, however, only the optimization of the relative combination of rotor diameter and rated power with respect to site mean annual wind speedthat afforded significant reductions in energy production cost. This optimization confirmed that presently available wind turbines were optimized for mean annual wind speeds in the range 6-8 m sec^{-1} and suggested that for windier sites the energy production cost may be reduced by up to 10% through the optimization of machine rated wind speed to suit such sites.

III. WIND TURBINE-ENERGY GENERATION

As the wind speed is fluctuating throughout the year, the energy generation readings of three WEGs namely NEPC, TTG and WINCON are taken for one year (May 2003 – April 2004) and the technical availability, real availability, plant load factor, generation in KWh / m^2 rotor area and generation is kWh/kW installed capacity are calculated on monthly basis, the values are tabulated in the tables and also plotted on graphs. The performance of WEGs is also measured in terms of technical availability, real availability and plant load factor. Technical availability is the fraction of time the WEG is ready for use except maintenance hours in a particular duration.

$$\text{Technical Availability} = \frac{\text{Total hours-Maint. Hours}}{\text{Total hours}}$$

Real availability is the fraction of time in a particular duration, the WEG is actually working.

$$\text{Real availability} = \frac{\text{Total hours-total stoppage hours}}{\text{Total hours}}$$

Plant load factor is the ratio of actual energy generated by a WEG in a particular duration to the maximum energy that can be generated at rated power.

$$\text{Plant load factor} = \frac{\text{Actual generation}}{\text{Max. generation at rated power}}$$

3.1. Horizontal wind turbine or horizontal axis wind turbine

A horizontal wind turbine **or** horizontal axis wind turbine has been modernized from the traditional windmill designs that have been around us for centuries. A nacelle installed perpendicular to the tower and horizontal with respect to the ground justifies the name of the turbine. Most common models for drawing energy from wind, the horizontal wind turbines offer a number of advantages. The main parts of a horizontal wind turbine are as mentioned below:

- Main rotor shaft
- Electrical generator
- Gearbox to boost the rotation speed of the blades.
- Turbine blades, having great stiffness to prevent them from being pushed into the post

A wind vane is used to point the small turbines, whereas, a wind sensor is used for a big horizontal wind turbine.

3.2. Types of Generators

Based on the types of generators, there are two varieties of horizontal wind turbines. The first one makes use of asynchronous generator in which the turbine is directly connected to the electric grid. The second variety of horizontal wind turbine has synchronous generator. In this, the turbine has a varying output, which needs to be passed through a rectifier and an inverter before being fed into the electric grid.

3.3. Types of Horizontal Wind Turbines

While tracing the history of horizontal axis wind turbine, you will come across its three types, used in different eras:

- A 12th century horizontal wind turbine consisted of four blades, and were used to grid grain and pump water. Most recently, this type of wind turbine was installed in the Netherlands to generate electricity.
- The 19th century horizontal windmill was used to pump water, fill railroad tanks and to generate power in the rural areas. These wind turbines consisted of multiple number of blades. One can still find these wind turbines used in areas where commercial power generation is expensive.
- Motor wind turbines are the modern form of horizontal wind turbine and are used to produce electricity at commercial level. These are generally 3-blade turbines and use computer-monitored motors for operation.

3.4. Advantages of Horizontal Wind Turbines

- Variable pitch of blades used for horizontal wind turbine allows it to collect maximum amount of energy form wind.
- Higher efficiency is offered by a horizontal wind turbine as it has blades in perpendicular to the direction of wind and hence receives more power for rotation.
- The traditional designs allow easy installation and easy maintenance as well.
- From home usage to application in hybrid systems, the horizontal wind turbines are popular options as sources of energy.

3.5. Wind Blades

Constant improvement in the design of wind blades has differentiated modern wind turbines to the traditional windmills. As a result, the new wind turbines are more compact, quieter and are capable of generating more power from less wind. Here is a complete discussion on various features of wind blades and how they contribute towards wind turbine efficiency.Figure 1 shows the differentiated modern wind turbines.

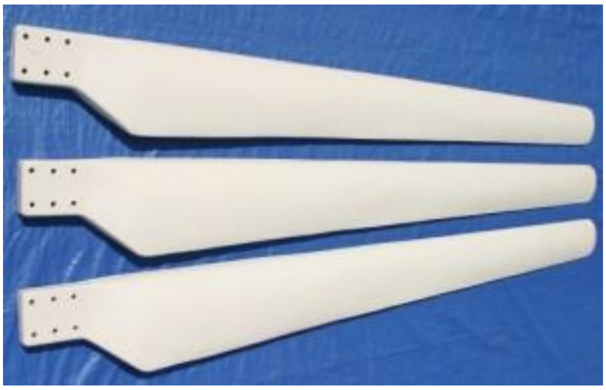

Figure 1wind blade

3.6. Material for Wind Blades

In earlier times, reed, cloth and wood were the materials employed for manufacturing wind blades. PVC pipes gained popularity as the manufacturing material for these blades in the beginning of modern era. Today, different experiments are conducted over different materials to support the energy extraction capability of turbines. Fiberglass, fiberglass enforced polymers, carbon enforced fibers and epoxy-based composites are some of the modern day options. Aluminum is popular for manufacturing household wind generator blade.

3.7. Number of Blades

The number of wind blades used in a wind turbine can decide a number of factors like aerodynamic efficiency. The modern wind turbines consist of two or three blades. The wind turbine with three blades has three percent better aerodynamic efficiency than those with two blades. However, increasing the number of blades further can lead to the sacrifice of blade stiffness. Noise and wear are generally lower in case of three-wind blade design.

3.8. Blades for Horizontal and Vertical Wind Turbines

A 3-blade design is preferred for horizontal wind turbines, as better rotor speed and stability balance are some of the advantages offered by it. For vertical wind turbine, the wind blades make use of wind drag and wind lift principles that arrange for good number of rotations for the turbines. Moreover, the blades for vertical wind turbines can rotate irrespective of the wind’s direction and thus, have advantage over horizontal designs.

3.9. Other Factors Associated with Wind Blades

The shape of wind blades is another contributing factor towards the overall performance of the turbine. The position of blades upwind or downwind can affect the noise emission of a wind turbine. Another factor associated with wind blade design is the weight carried by them. Tip speed ratio, which is the ration between wind’s speed and the speed of wind blades, is another factor that decides the efficiency of a wind turbine.

As you can see, the wind blades have among the most important roles to make a wind turbine work as per the expectations. The innovations for designing wind turbine blade have not stopped here, as new formulas and designs are being considered to improve their performance.

3.10.Wind Turbine Design

A successful wind turbine design is based upon a number of calculations and considerations. From load considerations to the development of control systems, many specifications can decide the efficiency of the final wind turbine design. The following discussion should help you learn about every aspect associated with the design of a wind turbine.

3.11. Load Calculations

A wind turbine design is based upon the consideration of the turbine’s strength to withstand extreme winds and high-speed winds. The design of wind blades contribute significantly towards this. Long and narrow blades are considered for modern day turbine designs. Moreover, the number of blades is limited to two or three, as more number of blades can lead to larger force exerted on turbine.

3.12. Structural Dynamics

A wind turbine is subject to fluctuating winds and thus, varying amount of forces is applied on it. Thus, an important consideration for wind turbine design is to analyze the forces that would be responsible for bending and stretching various components of the turbine. In addition, the individual as well as joint vibrations of different components need to be calculated in advance. All these things are studied as the structural dynamics for a turbine.

3.13. Power Control

Power control is important for a wind turbine design to protect a turbine against damage during wind blows at higher than rated speed. Stall control and pitch control are two useful methods in this direction.

3.14. Wind Blade Design

The design of blades attached with the rotor also contributes towards an effective wind turbine design. Apart from the shape and weight of these blades, it is also important to consider the material used for manufacturing them. As far as number of blades is concerned, two or three-blade wind turbines are the most popular ones in the industry.

3.15. Temperature Considerations

The wind turbine design has an important consideration in the form of temperature operating limits. It is an important aspect to consider, especially when the machine is to be installed in a low temperature area. For example, in cold climatic conditions, internal heaters are integrated with turbines to protect them against low temperature and snow.

3.16. Control Systems

Yaw control system is an important part of the wind turbine design, as it helps in minimizing non-symmetrical loads and increasing power output. Electrical braking and mechanical braking are other control systems to perform various tasks.Certification and testing of wind turbines is done before their installation to ensure that a good wind turbine design contribute towards production of energy.Figure 2 shows the Various parts of wind turbine. Table 1 shows the technical Specifications of Three wind Turbines.

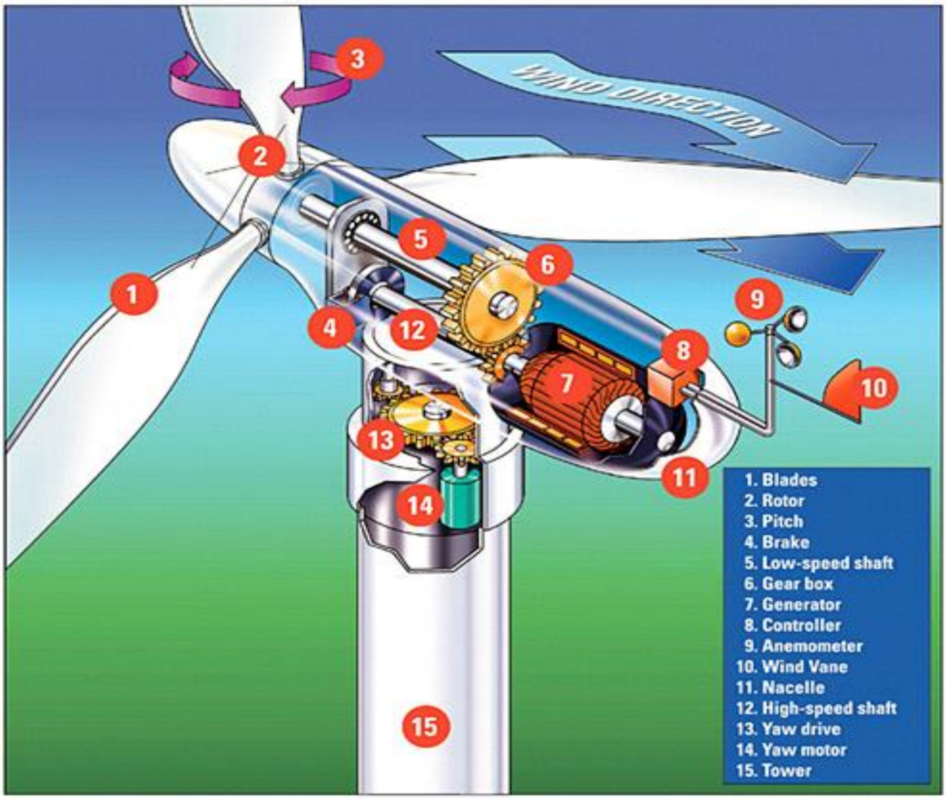

Figure 2 Various parts of wind turbine

IV. VARIOUS PARTS OF WIND TURBINE

4.1.The blades

Wind turbine blades are used to extract the kinetic energy of wind and convert to mechanical energy. These blades are made up of fiber glass-reinforced polyester or wood-epoxy. Wind turbines have one or two or three or multiple blades based up on the construction. Most of the HAWT have three blades. These are connected to rotor hub. Multiple blade concept is used in earlier days for pumping water and grinding etc.

4.2.The nacelle

The nacelle houses a generator and gearbox. The spinning blades are attached to the generator through a series of gears. The gears increase the rotational speed of the blades to the generator speed of over 1,500 RPM. As the generator spins, electricity is produced. Generators can be either variable or fixed speed. Variable speed generators produce electricity at a varying frequency, which must be corrected to 60 cycles per second before it is fed onto the grid. Fixed speed generators do not need to be corrected, but are not as able to take advantage of fluctuations in wind speed. A housing, which contains all the components, which is essential to operate the turbine efficiently is called a nacelle. It is fitted at the top of a tower and includes the gearbox, low- and high-speed shafts, generator, controller, and brakes. A wind speed anemometer and a wind vane are mounted on the nacelle.

4.3.Gearbox

Gear box used in wind energy systems to change low speed high toque power coming from a rotor blade to high speed low torque power which is used for generator. It is connected in between main shaft and generator shaft to increase rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1000 to 1800 rpm. Gearboxes used for wind turbine are made from superior quality aluminum alloys, stainless steel, cast iron etc.

The various gearboxes used in wind turbines are

1. Planetary Gearbox
2. Helical Gearbox
3. Worm Gearbox

4.4.Anemometers

Wind speed is the most important factor for determining the power content in the wind. The power content in the wind is directly proportional to cube of the wind velocity. Measuring wind speed is important for site selection. The device which is used for measuring wind speed is called anemometer. These are usually located on top of the nacelle.

4.5.Yaw Mechanism

yaw mechanism turns the rotor into the upwind direction as the wind direction changes. Electric motors and gear boxes are used to keep the turbine yawed against wind. This can be also used as controlling mechanism during high wind speeds.

4.6.Rotor

The part of the wind turbine that collects energy from the wind is called the rotor. The rotor usually consists of two or more wooden, fiberglass or metal blades which rotate about an axis (horizontal or vertical) at a rate determined by the wind speed and the shape of the blades. The blades are attached to the hub, which in turn is attached to the main shaft.

4.7.Drag Design

Blade designs operate on either the principle of drag or lift. For the drag design, the wind literally pushes the blades out of the way. Drag powered wind turbines are characterized by slower rotational speeds and high torque capabilities. They are useful for the pumping, sawing or grinding work that Dutch, farm and similar "work-horse" windmills perform. For example, a farm-type windmill must develop high torque at start-up in order to pump, or lift, water from a deep well.

4.8.Lift Design

The lift blade design employs the same principle that enables airplanes, kites and birds to fly. The blade is essentially an airfoil, or wing. When air flows past the blade, a wind speed and pressure differential is created between the upper and lower blade surfaces. The pressure at the lower surface is greater and thus acts to "lift" the blade. When blades are attached to a central axis, like a wind turbine rotor, the lift is translated into rotational motion.

4.9.Tip Speed Ratio

The tip-speed is the ratio of the rotational speed of the blade to the wind speed. The larger this ratio, the faster the rotation of the wind turbine rotor at a given wind speed. Electricity generation requires high rotational speeds. Lift-type wind turbines have maximum tip-speed ratios of around 10, while drag-type ratios are approximately 1. Given the high rotational speed requirements of electrical generators, it is clear that the lift-type wind turbine is most practical for this application.

4.10.A Generator

The generator is what converts the turning motion of a wind turbine's 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 turbine's blades because more energy is captured by longer blades.It is important to select the right type of generator to match your intended use. Most home and office appliances operate on 120 volt (or 240 volt), 60 cycle AC. Some appliances can operate on either AC or DC, such as light bulbs and resistance heaters, and many others can be adapted to run on DC.

4.11.Transmission

The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed. Generators typically require rpm's of 1,200 to 1,800. As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production. Some DC-type wind turbines do not use transmissions. Instead, they have a direct link between the rotor and generator. These are known as direct drive systems. Without a transmission, wind turbine complexity and maintenance requirements are reduced, but a much larger generator is required to deliver the same power output as the AC-type wind turbines.

4.12.Towers

A tower that supports the nacelle and rotor hub at its top. These are made from tubular steel, concrete, or steel lattice. Height of the tower is an important in design of HWAT. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity. Generally output power of the wind system increase with increase in height and reduces the turbulence in wind. The tower on which a wind turbine is mounted is not just a support structure. It also raises the wind turbine so that its blades safely clear the ground and so it can reach the stronger winds at higher elevations. Maximum tower height is optional in most cases, except where zoning restrictions apply. The decision of what height tower to use will be based on the cost of taller towers versus the value of the increase in energy production resulting from their use. Studies have shown that the added cost of increasing tower height is often justified by the added power generated from the stronger winds. Larger wind turbines are usually mounted on towers ranging from 40 to 70 meters tall. Towers for small wind systems are generally "guyed" designs. This means that there are guy wires anchored to the ground on three or four sides of the tower to hold it erect. These towers cost less than freestanding towers, but require more land area to anchor the guy wires. Some of these guyed towers are erected by tilting them up. This operation can be quickly accomplished using only a winch, with the turbine already mounted to the tower top.

Table 1. Technical Specifications of Three wind Turbines

	WINCON	**NEPC**	**TTG**
GENERAL DATA			
Nominal power	250 KW	250 KW	250 KW
Rotor diameter	29.0 m	27.6 m	25.0 m
Swept area	661 m^2	598 m^2	491 m^2

OPERATIONAL DATA Cut-in, wind speed Nominal power, wind speed Cut-out, wind speed Survival, wind speed	4.5 m/s 18.0 m/s 25.0 m/s >52.0 m/s	4 m/s 16.5 m/s 25 m/s >60.0 m/s	3.5 m/s 16.0 m/s 25.0 m/s >49.0 m/s
ROTOR No. of blades Rotor position Rotor speed Tip-speed blade Power output regulation Weight-rotor	3 upwind 38.5 rpm 57.7 m/s 3,900 kg	3 upwind 41.5 rpm 56.5 m/s 4290 kg	3 upwind 41.5 rpm 28 m/s 2520 kg
ROTOR BLADE Type Profile data Length Material Weight	LM 13.4 NACA 63.4 XXY FFA.W3 13.4m fibre glass reinforced polyester 750 kg	LM 13.4 NACA 63.4 XXY FFA.W3 11.5m polyester reinforced fibre glass ---	LM fibre glass - 11.5 m ---
GEAR BOX Type Ratio Lubrication method Oil volume Weight	3 step, helical 01:39.5 splash 87 lts 2,000 kg	2 step, helical 01:36.5 splash 87 lts 2,000 kg	2 step with parallel shaft 01:24.1 electric oil pressure 80 lts 3300 kg
GENERATOR Type Nominal power Voltage Frequency synchronous speed Insulaion class	4-pole asynchronous/induction 250 KW 400V 50 Hz 1500 rpm F	4-pole asynchronous/3phase 250 KW 400V 52 Hz 1500 rpm F	Asynchronous, IP54, 6-pole 250 KW 415V 50 Hz 1000 rpm F
YAW SYSTEM Type Yaw brake Yas drives Controller	ball bearing el. Motors and permanent friction brake 2 el. Motors, planetary worm gear Wind vane	slewing system with gear motors yawing	-

MONITORING			
Power quality	Voltage, current frequency, power factor, power output	-	-
RPM	Rotor, generator	-	-
Temperature	Generator shaft and windings, thyristors, gear box		
Others	Wind speed and direction	-	-
TOWER			
Type	Tubular, conical (30 m) Lattice tower (50 m)	-	-
Height	30 m	-	-
Lightning protection	In accordance with IEC		
WEIGHT			
Nacelle	12,500 kg	8,000 kg	6,700 kg
Rotor	3,700 kg	4,290 kg	4,500 kg
Tower	16,000 kg	13,500 kg	14,500 kg
Total	32,200 kg	25,790 kg	25,700 kg

V. RESULTS AND DISCUSSION

The average efficiency of the WEGs varies for different type of systems. The studies show that the TTG machine operates at maximum efficiency of 58% at 6 m/s wind velocity. As compared to Wincon and NEPC machines, the TTG machine reaches maximum efficiency at lesser wind velocity of 6 m/s. As well as the cut-in wind speed is also very low for TTG machines. It implies that if the machine is designed for maximum efficiency at low wind velocities, the total energy generation, generation per m^2 rotor area and generation per kW capacity will be increased. As the wind turbines operates on low cut-in wind speed and low rated wind speed, the lull hours will be reduced which makes the plant to run at higher capacity factor. The technical availability of the TTG machine is comparatively higher. If the blade diameter of the rotor increases, the power generation also increases. Similarly if the tower height is increased by one unit around five percentage increases in generation is achieved. Figure 3 shows the Comparison of generation/Kw installed capacity during may2003-april2004.Figure 4 shows the comparison of generation/m^2 rotor area during may2003-april2004.

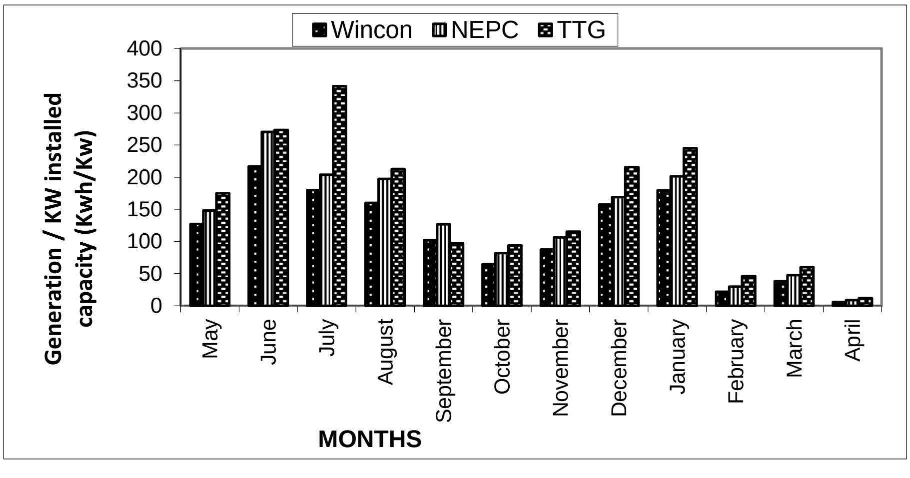

Figure 5. Comparison of Generation/Kw installed capacity during may2003-april2004

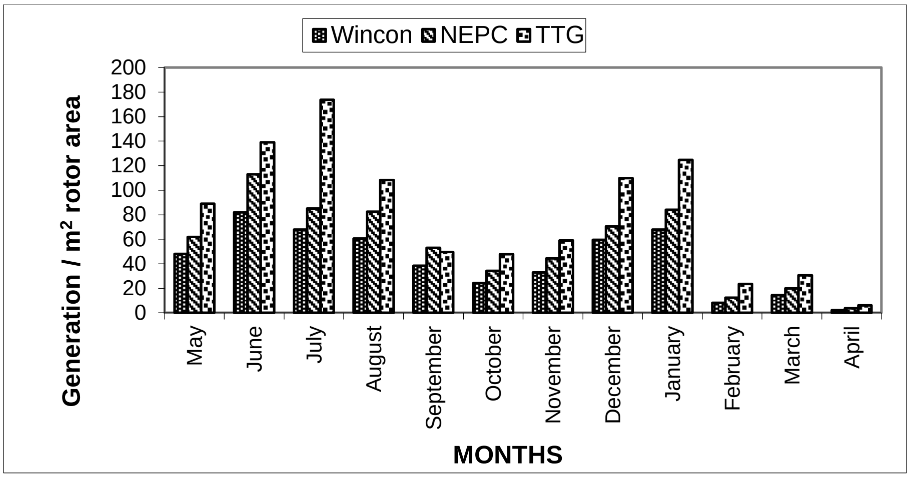

Figure 6. Comparison-Generation/m^2 rotor area during may2003-april2004

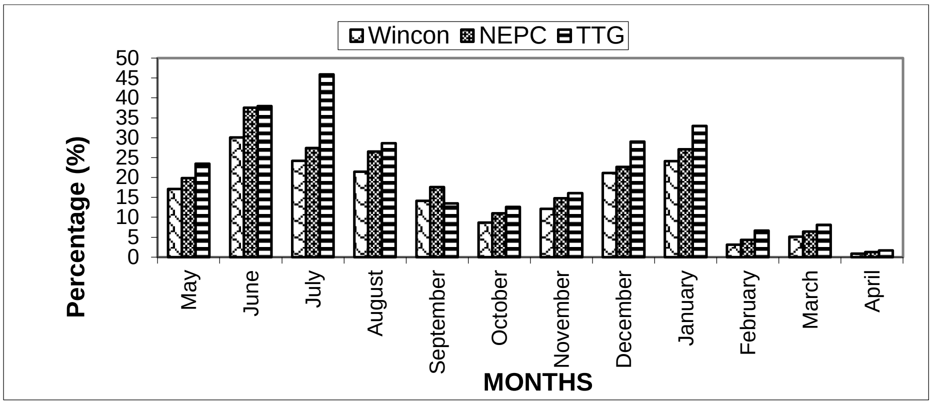

Figure 7. Comparison-plant load factor during may2003-april2004

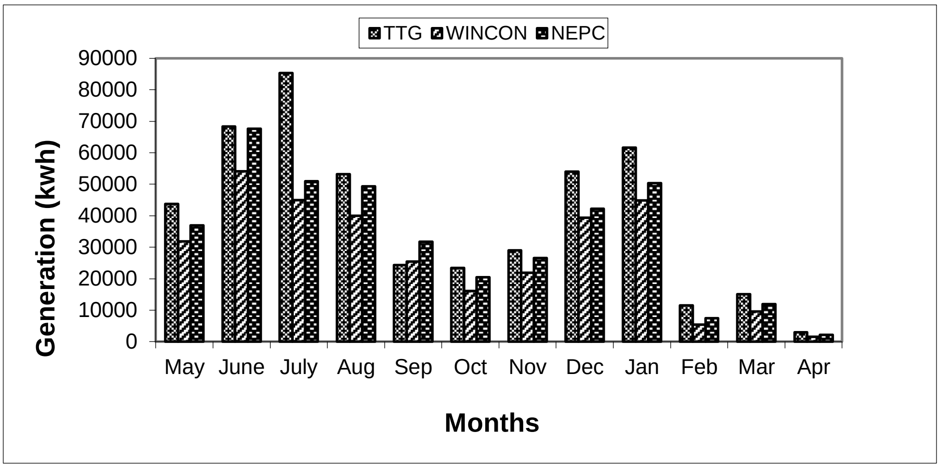

Figure 8 Comparison of monthly energy generation TTG, WINCON, NEPC

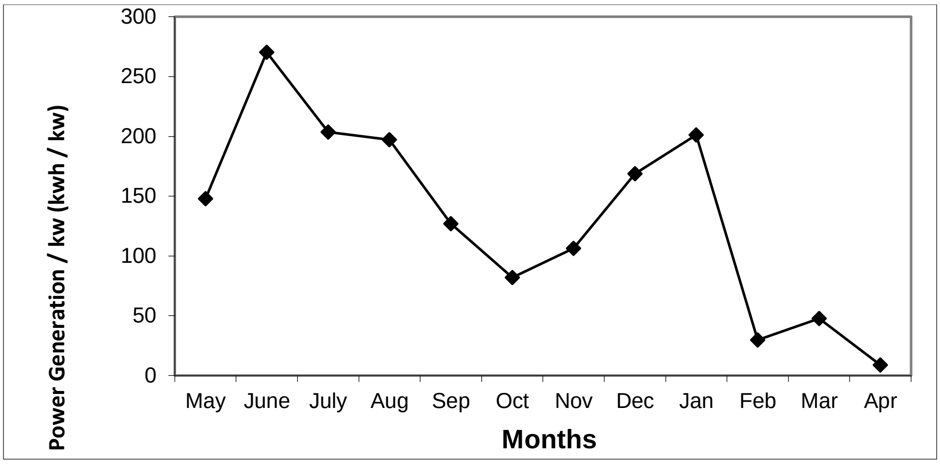

Figure 9 Power generation in kwh/kw installed capacity-NEPC during may 2003-april 2004

The calculated value of the performance studies of WINCON, NEPC, and TTG has been shown in table2.Figure 10 shows the comparison of plant load factor during may2003-april2004. Figure 11 shows the comparison of monthly energy generation TTG, WINCON, NEPC during may2003-april2004.Figure 12 shows the power generation in kwh/kw installed capacity of NEPC during may 2003-april 2004.

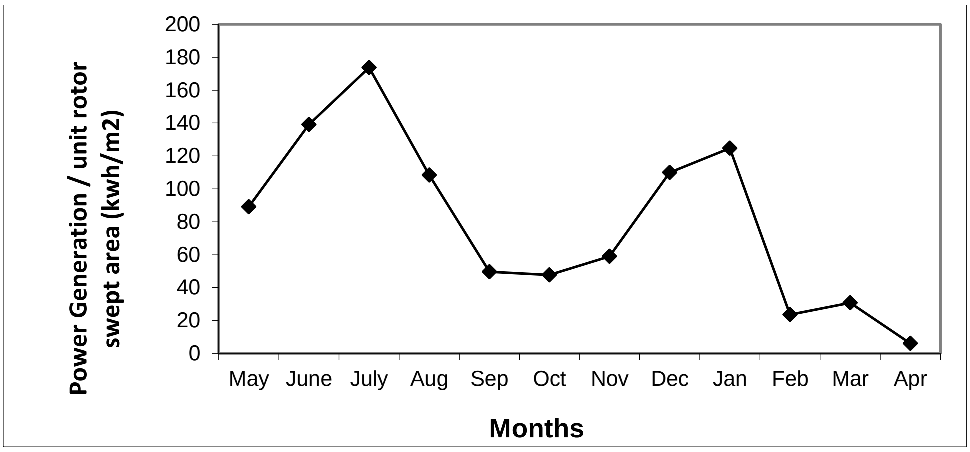

Figure 13 Power generation in kwh/unit rotor swept area-TTG during may2003-april2004

The technical availability also plays an important role in energy generation. It is found that the technical availability of the machine is around 97 – 98 % during the high windy months. By increasing the technical availability such that preventing the possibilities of breakdown maintenance in high windy seasons.

Table 2. Calculated values of WINCON, NEPC, and TTG

S.No	Description	WINCON	NEPC	TTG
1.	Average Efficiency (%)	24.06	30.85	36.01
2.	Cut-in wind speed (m/s)	3.5	3	3
3.	Rated wind speed (m/s)	17	16.5	16
4.	Max. Efficiency (%)	42.08	57.14	58.21
5.	Wind speed at n_{max} (m/s)	8	7	6
6.	Tip-speed ratio at n_{max}	7.9	8.25	8.29
7.	Annual Generation (kWh)	334984	397696	472198
8.	Breakdown hrs	232	60	232
9.	Lull hrs (annual)	2674	2450	2134

10.	Teach. Availability (%)	97.34	99.315	98.82
11.	Real availability (%)	63.08	66.30	69.48
12.	Plant load factor (%)	15.17	18.02	21.37
13.	Generation in kWh/m^2	42.22	55.42	80.13
14.	Generation in kWh/kW	111.59	132.56	157.39

Figure 14 shows the power generation in kwh/unit rotor swept area of TTG during may2003-april 2004. Figure 15shows the analysis of technical availability, real availability and plant load factor for WINCON during may 2003-april 2004.Similarly figure 16 shows the comparison of Generation/kw installed capacity during may 2003-april 2004. Figure 17 shows the comparison of Generation/m2 rotor area during may2003-april2004.Figure 18 shows the comparison of plant load factor during may 2003-april 2004.

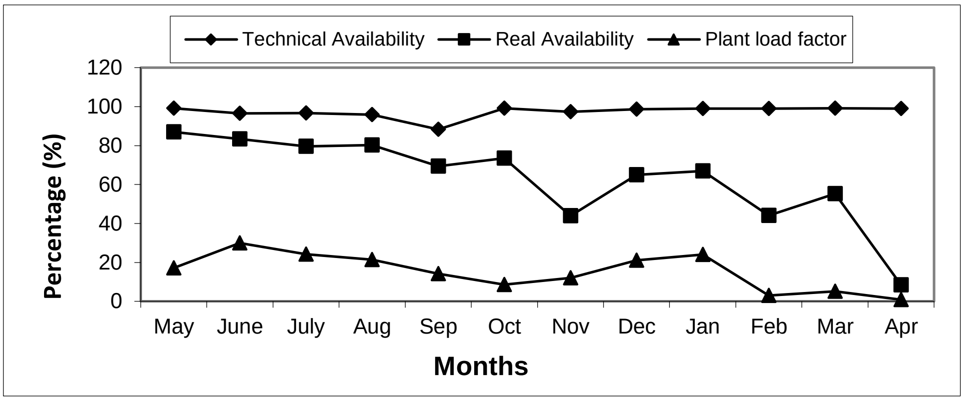

Figure 19. Analysis of technical availability, real availability, plant load factor for WINCON during may2003-april2004

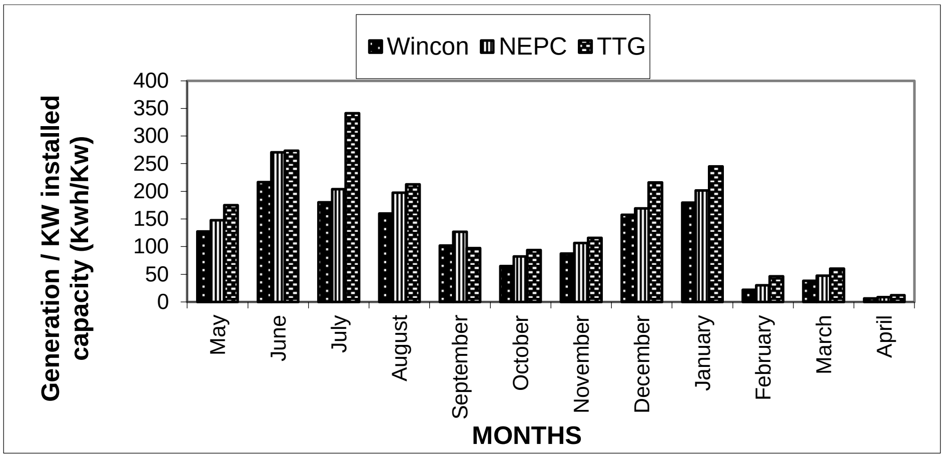

Figure 20 Comparison of Generation/kw installed capacity during may2003-april2004

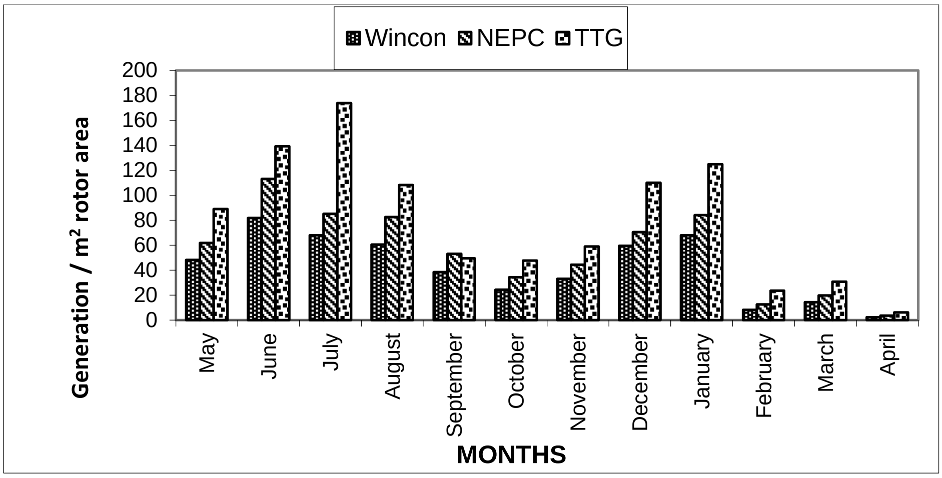

Figure 21 Comparison of Generation/m2 rotor area during may2003-april2004

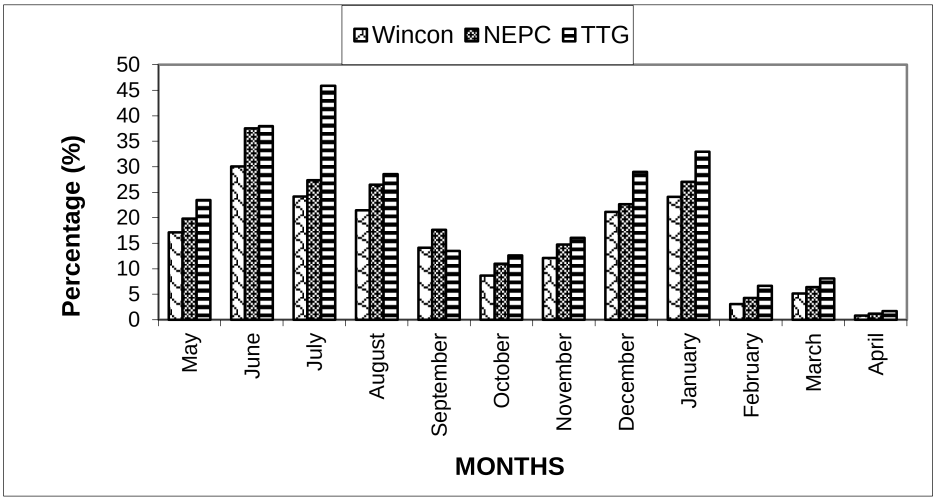

Figure 22 Comparison of plant load factor during may2003-april2004

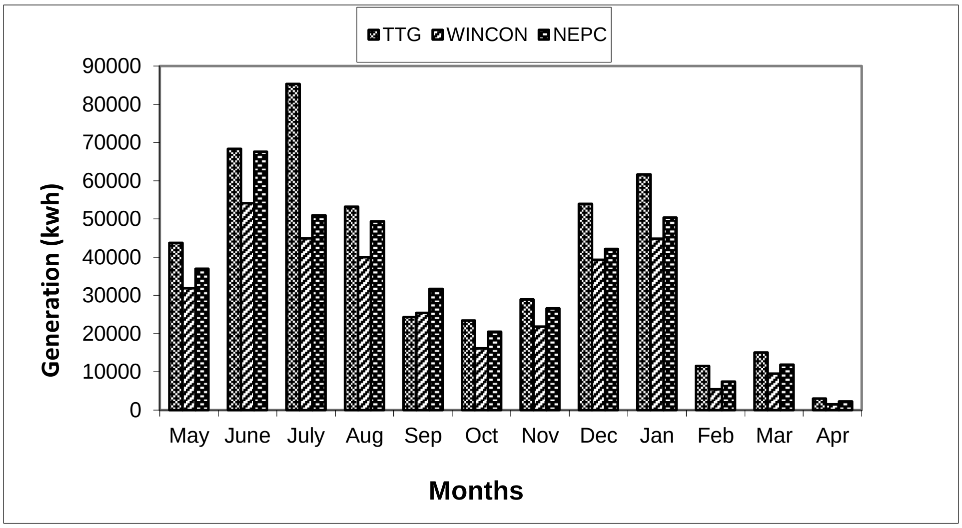

Figure 23.Comparison of monthly energy generation for TTG,WINCON,NEPC

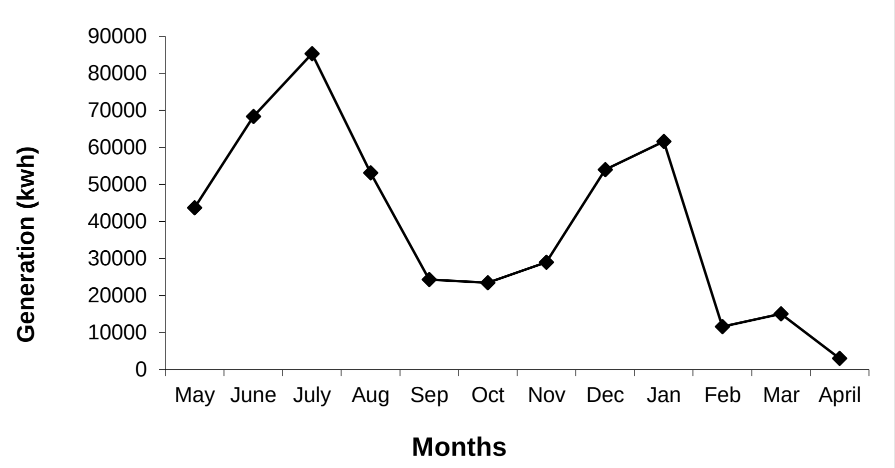

Figure 24. Monthly energy generation of TTG during may2003-april2004

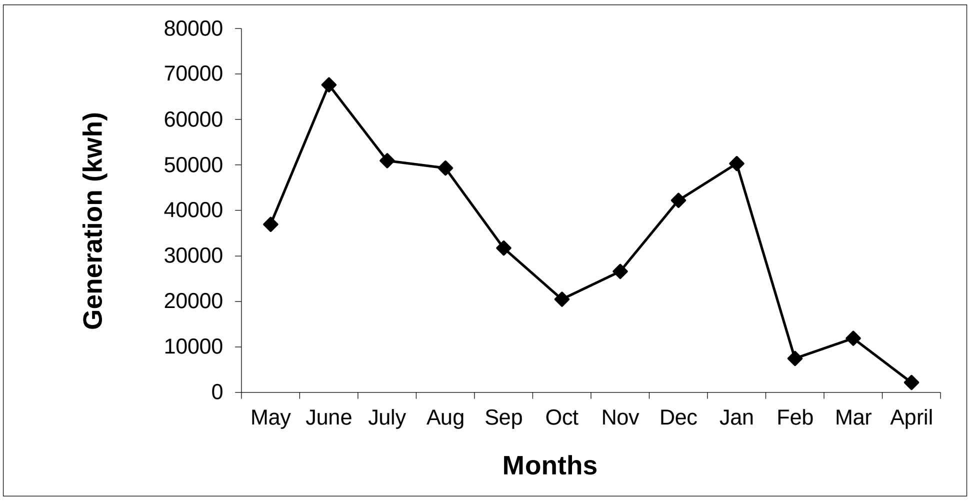

Figure 25.Monthly energy generation of NEPC during may2003-april2004

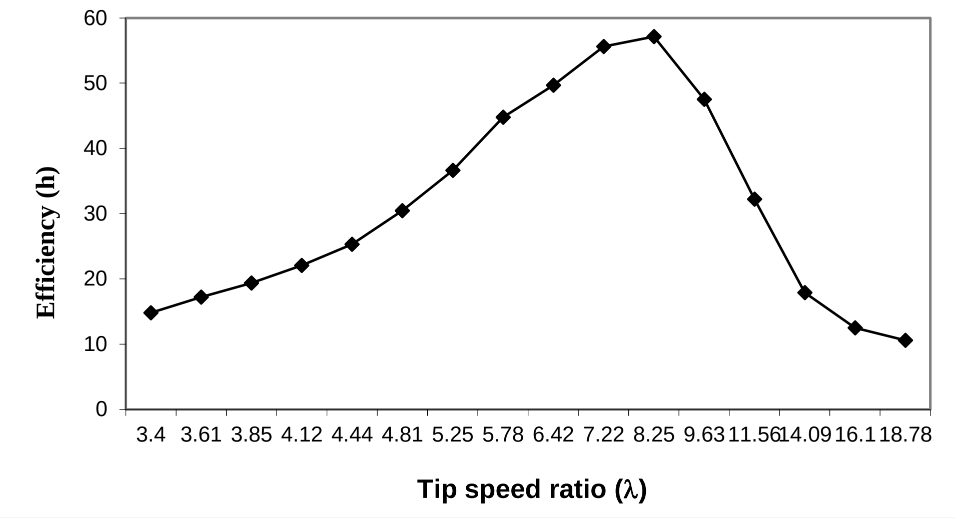

Figure 26 Tip ratio Vs efficiency(NEPC)

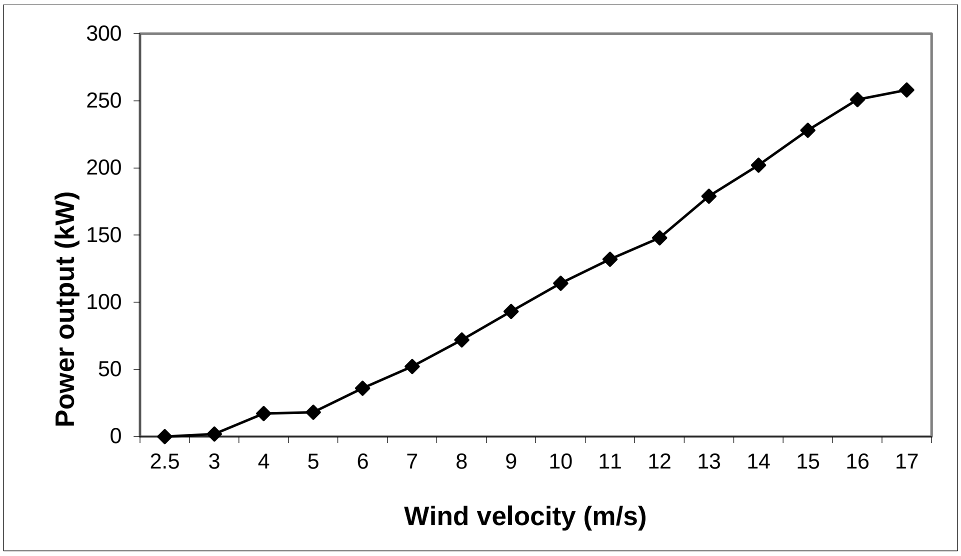

Figure 27 Wind velocity Vs power output (TTG)

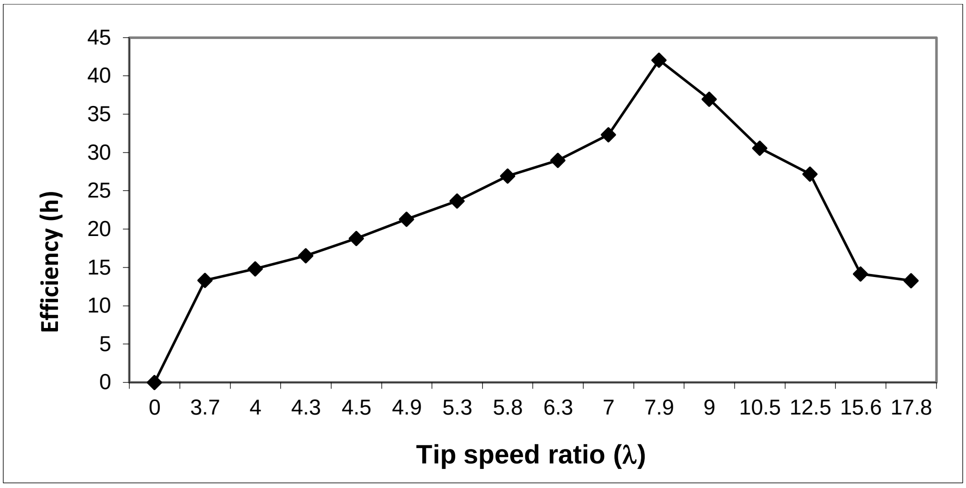

Figure 28 Tip ratio Vs efficiency (WINCON)

By increasing the rotor blade diameter and tower hub height of the WEGs, the energy can be generated at 25% lower cost in near future. If the WEGs can be manufactured to last 25-30 years due to research and developments, the energy cost as well as the payback period of the wind turbine generators becomes low. Figure 29shows the comparison of monthly energy generation for TTG, WINCON, and NEPC. Figure 30shows the monthly energy generation of TTG during may2003-april2004. Figure 31shows the monthly energy generation of NEPC during may2003-april2004. Figure 32 shows the Tip ratio Vs efficiency (NEPC). Figure 33 shows the Wind velocity Vs power output (TTG). Figure 34 shows the Tip ratio Vs efficiency (WINCON).

VI. CONCLUSION

From the power performance studies carried out so far, we have been under the inference that still enormous potential in the wind remains untapped. By suitable developed technologies in blade design, material features, the life span of the system can be well improved and thereby the cost of energy generation can still be minimized. The outstanding constraint in the wind-power generation is the initial investment cost, which can be very well minimized by suitable planning of the generator capacity and improved design features of the WEGs.

The feature prevailing in the decrease of technical availability is the poor maintenance schedule followed. Hence preventive maintenance procedure could be adapted to avoid breakdowns and thereby increase the technical availability. Proper training and suitable incentives can improve the labour quality so that the WEGs can be successfully launched in the sustainable future.

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