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Performance Evaluation of a 800 kW Wind Power Project and Analysis of Factors Affecting Wind Power Generation

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ABSTRACT

The utilization of wind energy for power generation is becoming increasingly attractive and gaining a great share in the world power market. Wind is one of fastest growing energy source and is considered as an important alternative to conventional power generation. The energy production from a wind energy system depends on many factors namely characteristics of the wind profile, and most importantly, the operational parameters of the wind turbine generator itself. The suitability of a wind turbine to a site involves designing of wind turbine's operational parameters exactly according to the wind characteristics of the site. The present work is the analysis of energy generation of a 800kW wind project at Belagavi of the state of Karnataka, India. A mathematical model is developed to study the parameters that affect power generation. These include wind speed, air density, pressure, temperature, blade length, pitch angle etc. The study shows that the operational parameters have a direct effect on the power generation. This will lead the developers and researchers to focus on the highest priority parameters for manufacturing and optimizing the new generations of wind turbines. The method can be used in developing stage of wind energy system.

Introduction

Until very recently climate protection and energy security have been viewed as largely contradictory or separate matters. This scenario has changed in response to the ever-increasing energy demand in developing economies such as India, Brazil and China. In order to ensure a stable climate in a global sustainable development, while providing means for the improvement in our standards of life, we must make responsible decisions about our energy sources while searching for solutions to reduce the dependence on the fossil fuels in our energy matrix. [1]

India has the world's fifth-largest electricity generation capacity which currently stands at 243 GW. The power sector in India is highly diverse with varied commercial sources for power generation. The demand for power has been growing at a rapid rate and overtaken the supply, leading to power shortages in spite of manifold growth in power generation over the years. [2] The envisaged growth in the economy can be achieved by enhancing the availability & access to energy. The economic and social prosperity can only be bought by bridging the gap between the demand and supply.

Focused efforts are going on to bridge this demand-supply gap by way of policy reforms, participation from private sector and development of the Ultra Mega Power Projects. [3] In the last decades, a growing interest in renewable energy resources has been observed. It is envisaged in the twelfth plan that "Development cannot take place without additional energy and the energy requirement of development will have to be reconciled with the objective of protection of environment."[4]. Unlike other renewable energy sources, wind energy has become competitive with conventional power generation sources and therefore the application of wind turbine generators has the highest growth among other sources.

Wind is one of fastest growing energy source and it is considered as an important alternative to conventional power generating sources. The energy production from a wind energy system depends on many factors. These factors include the characteristics of the wind profile, and most importantly, the operational parameters of the wind turbine generator itself. The suitability of a wind turbine to a site involves designing of wind turbine's operational parameters exactly according to the wind characteristics of the site. One more applicable method is to match a specified site with a suitable wind turbine among existing ones. [5].

1.1 Need for Renewable Energy in India

Industrialization, urbanization, population growth, economic growth, improvement in per capita consumption of electricity, depletion of coal reserve, increasing import of coal, crude oil and other energy sources and the rising concern over climate change have put India in a critical position. It has to take a tough stance to balance between economic development and environmental sustainability. One of the primary challenges for India would be to alter its existing energy mix which is dominated by coal to greater share of cleaner and sustainable sources of energy. The total renewable energy potential from various sources in India is 2,49,188 MW. [2]

As of 31st March 2014, the total installed capacity from renewable energy, both grid-interactive and off-grid/captive power, was 32,730 MW. Thus the untapped market potential for overall renewable energy in India is 2,15,922 MW.[2] Figure 1 shows the total renewable energy potential in India.

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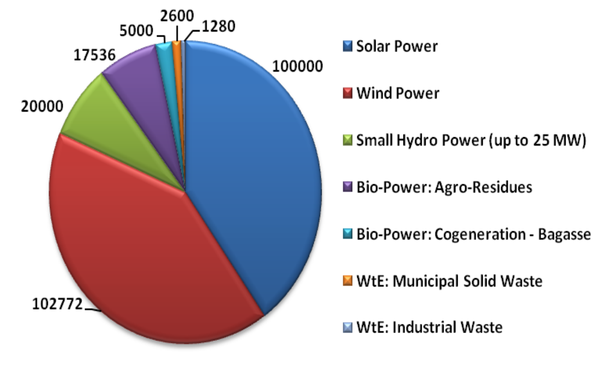

Figure 1. Renewable Energy Potential in India (MW) [2, 3]

1.2 Wind Energy for Power Generation

Wind power has experienced 26% annual growth in cumulative installations worldwide in the past 5 years and is expected to grow at 16% per annum in the next 5 years, despite increasingly turbulent economic conditions in the short term. Since 2010, Asia has been at the forefront of this growth, as wind energy installations in the region have outstripped both North America and Europe. While China and India have been the main drivers of growth, the projected investments in wind projects in the rest of Asia are expected to exceed US$50 billion between 2012 and 2020. Realizing the full potential of wind energy in the region, however, will require long-term, consistent policies and upgraded transmission and grid infrastructure. [6]. The challenges regarding Wind energy with respect to India are:

- Low wind speed and low average capacity factor. Most locations have class 2 winds (Wind power Density around 200 to 300 W/m^2) while the average capacity factor is in the range of 20%- 23% due to significant number of older and smaller wind turbine generators (WTG).
- Grid integration for rising wind based electricity generation is increasingly a challenge for state electricity utilities, especially in States like Tamil Nadu and Maharashtra. There is an urgent need for proper grid planning and modernization of the grid. [6]

Wind energy is a clean and eco-friendly energy source and increasingly accepted as a major complementary energy source for securing a sustainable and clean energy future in India. The official assessment shows that India has potential to generate over 100,000 MW of wind energy. Till May 2014, generation capacity of 21,268.3 MW has been created through wind, which places India in the fifth place globally.[7]

Wind turbines are designed to exploit the wind energy that exists at a location. Virtually all modern wind turbines convert wind energy to electricity for energy distribution. The modern wind turbine is a system that comprises three integral components with distinct disciplines of engineering science. The rotor component includes the blades for converting wind energy to an intermediate low speed rotational energy [8]. The generator component includes the electrical generator, the control electronics, and most likely a gearbox component for converting the low speed rotational energy to electricity. The structural support component includes the tower for optimally situating the rotor component to the wind energy source. Wind turbines are classified, in the basis of their axis in which the turbine rotates, into horizontal axis and vertical axis wind turbines. Because of the ability of the horizontal axis turbines to collect the maximum amount of wind energy for the time of day and season and to adjust their blades to avoid high wind storms; they are considered more common than vertical-axis turbines [9].

2. Modeling of Wind Turbine

The turbine in a wind energy conversion system consists of an induction generator and other electrical control power requirements. The wind turbine is effected by many parameters both internal (electrical connection, rotor size, copper and iron losses, efficiency of wind generator and blade shape) and external (wind speed, weather parameters, location and height of wind tower). Mechanical power of wind turbine is directly related to the wind speed as well as to the swept area of its blades. It should notice that the power is proportional to the cube of the wind speed and the square of the radius of the rotor blades. If the radius of the rotor blades is doubled, the swept area is quadrupled.

Also, the efficiency needs to be considered due to blade size and shape, number of blades, pitch angle, rotor speed, alternator efficiency, gear losses and other such factors. If the wind speed is reduced by half, the power is reduced to 1/8 of the original power. Thus, a light wind contains little power. [10]. Because wind speed generally increases and turbulence decreases with height, a tower helps the system increase its energy production and reduces turbulence-induced mechanical stresses, thus enhancing its economic benefit. The ability of a turbine to produce energy from the wind fundamentally depends on the wind resource and the swept area of the turbine. Simplifying somewhat, the power output of a turbine is proportional to the cube of the wind velocity and the square of the blade length.

A doubling of the wind speed thus yields an eight-fold increase in wind power while a doubling of a turbine’s blade length yields a four-fold increase in energy capture (all other things kept constant). Larger turbines with longer blades not only produce more energy for a given wind resource, they are also more capital cost-effective as well, as a result of inherent economies of scale as well as inefficiencies in the market for smaller turbines.[11]

As wind turbine power generation proliferates, designs are needed which are both efficient and minimally disruptive to surrounding communities, particularly in terms of additions to background noise. Design optimization is therefore needed to resolve the conflicting considerations of maximum power production and minimum noise generation. The facilities of MATLAB environment can be used for simulation, optimization of wind power generating systems based on renewable energies [12]. The basic goal of calculating effect of air's parameters in mechanical power (that later becomes electrical output power) is to show the generating sensitivity of wind generator to air characteristics variation at any wind speed value. A database for air effect of mechanical power can be created to use it in practical tests, installation and electrical generation.

2.1 Wind Turbine Operation

As wind flows through a turbine it forces the rotor blades to rotate, transforming kinetic energy of the wind to mechanical energy of the rotating turbine. The rotation of the turbine drives a shaft which through a gear box drives a power generator which generates current through the principal of electromagnetic induction. The shaft, gearbox and generator are located in the nacelle. The nacelle is able to revolve about a vertical axis so as to optimally direct the turbine to face the prevailing wind. The electric current thus generated is converted to a higher voltage via a transformer at the base of the tower. The power that can be harnessed from the wind is proportional to the cube of wind speed up to a theoretical maximum of about 59 percent. However, today's wind turbines convert only a fraction of the available wind power to electricity and are shut down beyond a certain wind speed because of structural limitations and concern for wear and tear. So far, it is considered cost optimal to start power regulation at 10-min wind speed of 9-10 m/s, have full regulation at mean wind speeds above 14-15 m/s and shut-down or idle mode at 25 m/s. Power regulation is the ability of a system to provide near constant voltage over a wide range of load conditions. To minimize fluctuation and to control the power flow, the pitch of the blades of offshore wind turbines is regulated. At lower wind speeds, variable rotor speed regulation is used to smooth out power output. The yaw of the turbine is also varied every 30-sec to 60-sec, to maximize operating efficiency which creates gyroscopic loads. The pitching and yawing creates non-linear aerodynamics and hysteresis which have to be modeled in turbine response calculations. [13]

2.2 Project background

The site is located in Saundatti of Belgaum district in the state of Karnataka, India. The wind project is situated on a relatively flat plain, and treeless, and that is well exposed to the prevailing westerly wind for rain and other winds in the winter and summer seasons. Wind energy conversion systems of a capacity of 800 kW generations are installed at the site. Data collection was carried out through regular visits and interactions at the site.

2.3 Mathematical Model for Analysis

The kinetic energy of a mass in motions is given by:

$$E = \frac{1}{2} \times m \times v^2 \qquad (1)$$

Also, m = $\rho \times V$, and as V = $A \times l$,
we get m = $\rho \times A \times l$

Hence energy equation becomes,

$$E = \frac{1}{2} \times \rho \times A \times l \times v^3 \qquad (2)$$

Again as, $Pw = \frac{E}{t}$, it becomes

$$Pw = \frac{\frac{1}{2} \times \rho \times A \times l \times v^3}{t}$$

But $v = \frac{l}{t}$, Hence $Wind Power$,

$$Pw = \frac{1}{2} \times \rho \times A \times v^3 \qquad (3)$$

Mechanical Power,

$$P = \frac{1}{2} \times \rho \times A \times v^3 \times C_p \qquad (4)$$

Where, Pw = wind power (W), P = mechanical power (W), A= swept area (m^2), v = velocity (m/s), ρ = air density (kg/m^3), l=length of blades(m), C_p= power coefficient. The parameters that affect the power generated by wind turbines can be classified into two categories, namely, site parameters at the site in which the turbine will be installed, and the wind turbine itself as shown in Figure 2. [9]. In the present work the effect of wind parameters on power generation are analyzed.

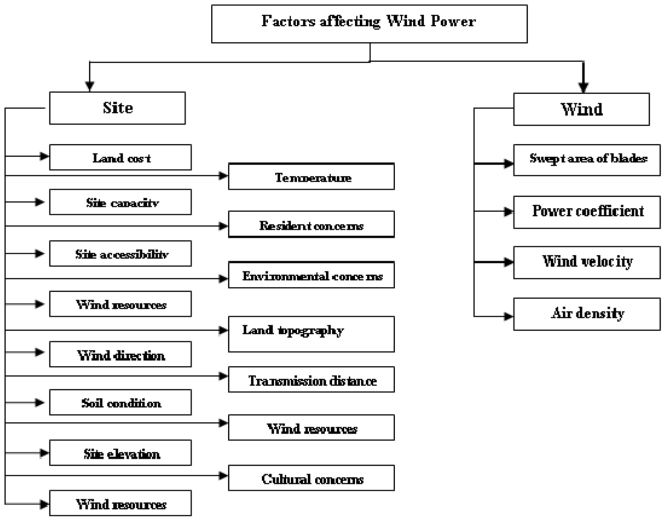

Figure 2. Factors affecting wind power generation.

A German physicist Albert Betz in 1919 concluded 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. To this day, this is known as the Betz Limit or Betz' Law. The theoretical maximum power efficiency of any design of wind turbine is 0.59 (i.e. no more than 59% of the energy carried by the wind can be extracted by a wind turbine). This is called the "power coefficient" : Cp_{max} = 59.3.[14]

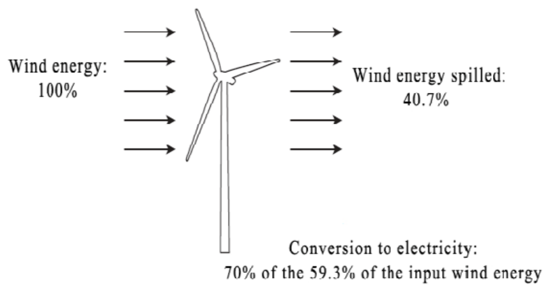

Figure 3. Betz Limit illustration.

As pictured in figure 3, the wind turbine converts 70% of the Betz Limit into electricity. Therefore, the Cp of this wind turbine will be 0.7 x 0.59 = 0.41. Hence this wind turbine converts 41% of the available wind energy into electricity. This is theoretically a good coefficient of power. Good wind turbines generally fall in the 35-45% range.[14]. Also, wind turbines cannot operate at this maximum limit. The Cp value is unique to each turbine type and is a function of wind speed that the turbine is operating in. Once the various engineering requirements of a wind turbine - strength and durability in particular are incorporated - the real limit is well below the Betz Limit with values of 0.35-0.45 common even in the best designed wind turbines. After taking into consideration the other factors of wind turbine system - e.g. the gearbox, bearings and generator only 10-30% of the power of the wind is ever actually converted into usable electricity. Hence, the power coefficient needs to be factored in equation and the extractable power from the wind is given by: Available Power = Power Coefficient * Wind Power.

Design parameter choice is critical for optimizing wind turbine performance. For any fixed diameter there are various parameters influencing energy production: rotor rotation velocity, blade number, airfoil chord distribution and longitudinal blade twist.

The wind power varies so greatly (with the cube of wind speed), the turbine must be able to generate power in light winds and withstand the loads in much stronger winds. Therefore, above the optimum wind speed, the blades are typically pitched either into the wind or away from the wind to reduce the generated power and regulate the loads. [15]

3. Factors Affecting Wind Turbine Power Generation

3.1 The wind turbine electricity production can be depending on the following factors, namely wind speed, air density and area swept by the rotor blades. The wind speed is further divided into 4 category based on the operation of wind turbine.

Start-up Speed

The speed at which the rotor and blade assembly begins to rotate.

Cut-in Speed

Cut-in speed is the minimum wind speed at which the wind turbine will generate usable power. This wind speed is typically between 7 and 10mph for most turbines.

Rated Speed

The rated speed is the minimum wind speed at which the wind turbine will generate its designated rated power. Rated speed for most machines is in the range of 25 to 35mph. At wind speeds between cut-in and rated, the power output from a wind turbine increases as the wind increases. The output of most machines levels off above the rated speed. Most manufacturers provide graphs, called "power curves," showing how their wind turbine output varies with the wind speed.

Cut-out Speed

At very high wind speeds, typically between 45 and 80mph, most wind turbines cease power generation and shut down. The wind speed at which shut down occurs is called the cut-out speed, or sometimes the furling speed. Having a cut-out speed is a safety feature which protects the wind turbine from damage.

Air Density

The denser the air, more is the energy received by the turbine. Air density varies with elevation and temperature. Air is less dense at higher elevations than at sea level, and warm air is less dense than cold air. All else being equal, turbines will produce more power at lower elevations and in locations with cooler average temperatures.

Power Coefficient (C_p)

The coefficient of power of a wind turbine is a measurement of how efficiently the wind turbine converts the energy into electricity. Power coefficient is simply the ratio of the power output from the turbine to the power available in the wind. [16]

Wind turbines extract energy by slowing down the wind. For a wind turbine to be 100 %efficient it would need to stop 100 %of the wind - but then the rotor would have to be a solid disk and it would not turn and no kinetic energy would be converted. On the other extreme, if there is a wind turbine with just one rotor blade, most of the wind passing through the area swept by the turbine blade would miss the blade completely and so the kinetic energy would be kept by the wind. [10]

Swept area of the turbine

The larger the swept area (the size of the area through which the rotor spins), the more power the turbine can capture from the wind. Since swept area is ($\pi/4 * D^2$), where D = diameter of the rotor, a small increase in blade length results in a larger increase in the power available to the turbine [17].

3.2 Parameters affecting the Performance of the Wind Turbine

Various parameters as indicated in figure 2 affect the performance of a wind turbine. The same are discussed in brief in following sections.

3.2.1 Effect of Blade Length

The effect of increasing the blade length is shown in Figure 4 with a constant air density of 1.2 kg/m^3. Initially power increases with the increase in wind speed as power is directly proportional to the cube of velocity. Later on power remains constant for a while & starts decreasing even if the wind speed increases further. This is because the value of C_p i.e. power coefficient starts decreasing after 9 m/s. As the wind speed increases further at a certain speed i.e. cutout speed the turbine stops generating power. Having a cut-out speed is a safety feature which protects the wind turbine from further damage.

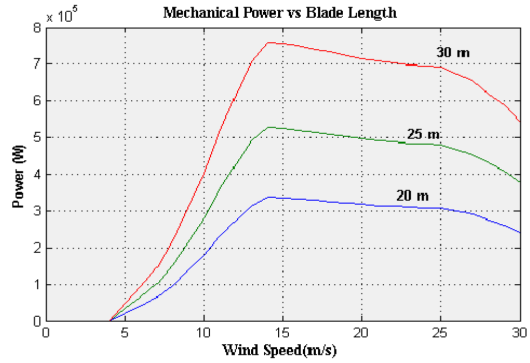

Figure 4. Turbine blade length effect on mechanical power.

From figure 4 it can also be observed that at wind speed of 10m/s, as the blade length is increased from 20m to 30m, the mechanical power increases from approximately 178 W to 402.kW T. Since power is directly proportional to swept area of the turbine, any increase in blade length results in manifold increase in swept area and hence the power. Table 1 shows the standard classification system for wind turbines and effect of diameter of power rating of wind generating [12].

Table 1. Standard Classification System for WT [18]

Standard Classification System for Wind Turbines		
Scale	Swept area diameter	Power Rating
Micro	Less than 3m	50W to 2kW
Small	3m to 12m	2kW to 40kW
Medium	12m to 45m	40kW to 999kW
High	46m and larger	More than 1.0MW

3.2.2 Blade Length effect on Mechanical Power.

Figure 5 shows the relation between mechanical power and the blade length at fixed wind speed of 10m/s. From figure 5 it can be inferred that, larger the blade length more is the power that can be extracted from the wind. This adds to mechanical stability and weight of the turbine

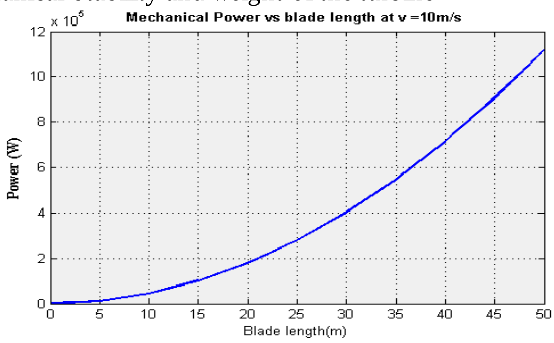

Figure 5. Effect of Mechanical Power at v=10m/s.

3.2.3 Effect of Wind Speed on Power Generated

The mechanical power (P) is harnessed with the wind speed (V). The wind speed of air is a measure of activity of wind generator and it has a greatest effect on the mechanical power. The wind turbine is characterized by the dimensional curves of the power coefficient (Cp) as a function of both the tip speed ratio (TSR- λ) and the blade pitch angle (B). The result is shown in Fig. 6 below.[Sallah]

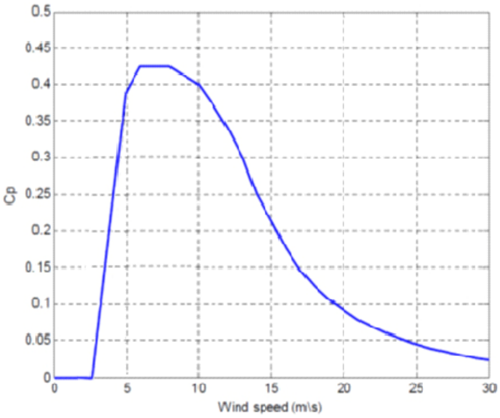

Figure 6. Power coefficient as a function of wind speed.

In order to fully utilize the available wind energy, the value of tip speed ratio should be maintained at its optimum value. Figure 6 shows the power coefficient as a function of wind speed. The tip speed ratio (λ) can be defined as the ratio of the angular rotor speed of the wind turbine to the linear wind speed at the tip of the blades; that is to say the behavior of mechanical power effectiveness by wind speed is determined by power coefficient.

$$Cp = Cp(\lambda, B) \quad \text{and} \quad \lambda = \frac{\omega t \times r}{V} \qquad (5)$$

where r = rotor radius, ωt = angular rotor speed of wind turbine.

Initially, wind speed is not useful until it reach to cut in speed of 2.54 m/s then the power begin initiates and grows with wind speed increasing. When wind speed increases up to 14m/s, the stability of mechanical power can be observed while the drop of mechanical power starts at cut off speed of 25m/s.

The TSR is a common and useful value for the scaling of parameters of a wind turbine. In addition, it is important to combine the aerodynamic effects of wind speed such as rotor size, power coefficient, and angular speed for a wind turbine. The power coefficient defines the response of a wind turbine under different operating conditions. From figure 6 it can be viewed that the power coefficient of the wind turbine depends on the TSR. Initially, as the TSR increases, the power coefficient increases. After the power coefficient reaches a maximum value at the specific value of the TSR, it begins to decrease. This can be explained as: for the small values of the TSR, almost all of the wind passes across the blades without the majority of power transfer to the WT due to the slow rotation of the blades, and, for the large values of the TSR, the blades act as a solid disk due to the rapid rotation of the blades; as a result, the power coefficient decreases. Ultimately, the TSR directly affects the generated power of the Turbine. Taking into account the best TSR is very critical for design of a turbine blade. While the TSR values of smaller wind turbines normally are between 7 and 10, this value is between 2 and 4 for many small-scale wind energy portable turbines. [19]

3.2.4 Effect of Air Density on Power Generated

An air density effect of mechanical power is remarkable and clarifies the wind stations work under air density variation with constant wind speed. Mechanical power of wind generator is directly proportional to air density. As air density increases from 1 kg/m^3 to 1.3 kg/m^3, the available power increases from 261 kW to 340 kW at wind speed of 10 m/s as shown in Figure 7. The denser the air, more is the energy received by the turbine. Air density varies with elevation and temperature. Air is less dense at higher elevations than at sea level, and warm air is less dense than cold air. All other things being equal, turbines will produce more power at lower elevations and in locations with cooler average temperatures.

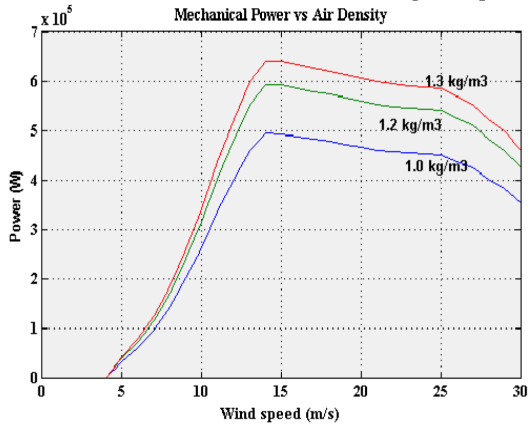

Figure 7. Effect of density of air on mechanical power.

3.2.5 Effect of Air Pressure on Mechanical Power

Air density is a function of air pressure. It increases when air pressure increases. The effect of pressure on the mechanical power is shown in Fig. 8 at a constant temperature of 25^0C.

From Figure 8 it can be inferred that as pressure increases from 0.8 bar to 1.1bar, power increases from 243 kW to 334 kW at wind speed 10 m/s. This can be attributed to increase in density of air with rise in pressure. Pressure decreases with increasing elevation. Therefore changes in elevation produce a profound effect on the generated power as a result of changing in the air density. To understand air density effect it is important to understand how the density changes with air status [12].

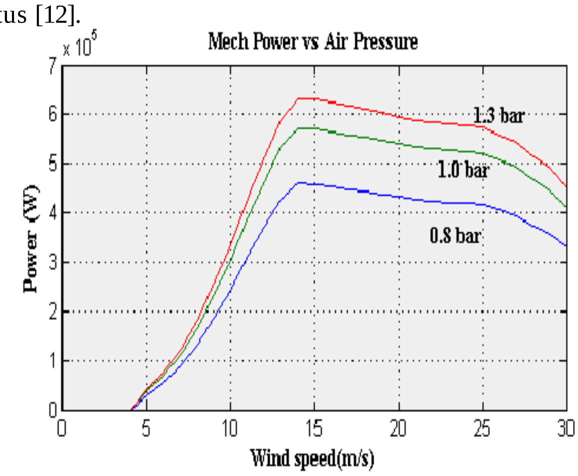

Figure 8. Effect of air pressure on mechanical power.

Air density (ρ) is the mass of the molecules of the gas in a certain volume(kg/m^3), which can be mathematically shown as:

$$\rho = P_a / RT, \qquad (6)$$

where p_a = air pressure, R = specific gas constant = 287 J/kgK, T = temperature, Kelvin [20]

3.2.6 Air temperature effect of mechanical power

Air density is a function of air temperature. It increases when the temperature decreases. The effect of temperature on the mechanical power is shown in Figure 9 at a constant pressure of 1bar. As the temperature increases from 25^{0}C to 45^{0}C, power decreases from 303.516kW to 285.199kW at wind speed of 10m/s. Temperature decreases with increasing elevation. Therefore changes in elevation produce a profound effect on the generated power as a result of changing in the air density.

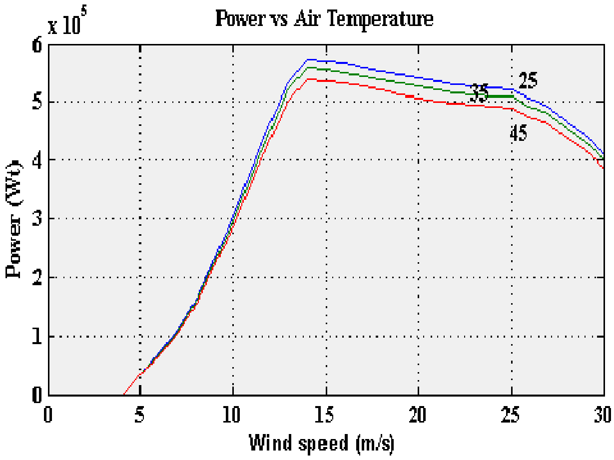

Figure 9. Effect of air temperature on mechanical power.

3.3 Power generation for the 800kW wind turbine

The technical specification of the 800 kW wind turbine is given in Table 2 and the power generation is presented in Table 3.

Table 2. Specification of Wind Turbine

Rated Power	830kW
Cut-in power	2.54 m/s
Rated wind speed	12 m/s
Cut-out power	28 m/s
Blade Length	26.5 m
Swept Area	2206.18 m^2
No. of blades	3

The actual power output considering the wind speed and air density has been calculated using equations 1 to 4. The theoretical power was calculated using betz equation and it was compared with the actual power. The actual power was found to be less as compared to theoretical power. Wind turbines are optimized by considering wind speed, swept area and air density in terms of local area conditions to extract maximum power. The output power of a wind turbine is directly proportional to cube of wind speed, air density and swept area of its blades.

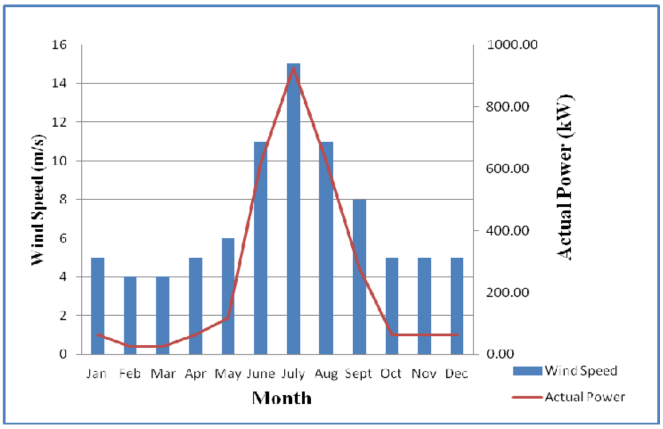

Figure 10. Effect of wind speed on power output

The larger the diameter of its blades, the more power can be extracted from the wind. Figure 10 shows that, the power output is directly proportional to the wind speed. The maximum power output for the turbine under study is attained in the month of July which also records maximum velocity. The wind velocity is maximum during the months of June to September.

Air density has a significant effect on wind turbine performance as depicted in Fig 11. The power available in the wind is directly proportional to air density. As air density increases the available power also increases. Air density is a function of air temperature. It increases when air pressure increases or the temperature decreases. Both temperature and pressure decrease with increasing elevation. Consequently changes in elevation produce a profound effect on the generated power as a result of changing in the air density.

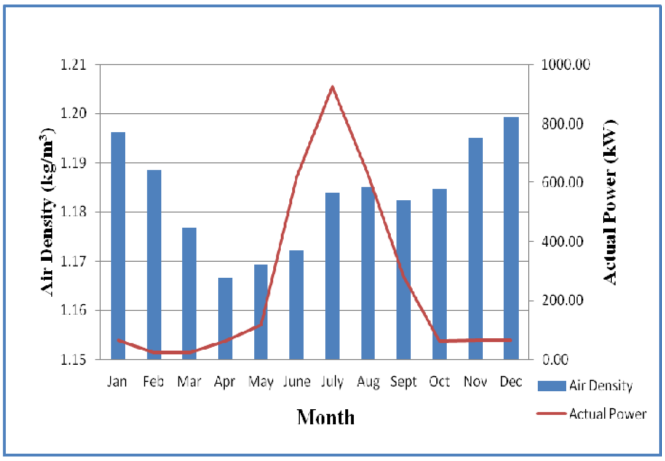

Figure 11. Effect of air density on wind power output.

Table 3. Power Generation for the 800kW Wind Turbine.

Month-2014	Speed (m/s)	T (K)	P (kPa)	Density (kg/m^3)	Swept Area (m^2)	Power (kW)	Power (kW)
Jan	5	295	101.3	1.20	2206.18	97.32	64.33
Feb	4	296	101.0	1.19	2206.18	49.51	25.18
Mar	4	299	101.0	1.18	2206.18	49.02	24.92
Apr	5	301	100.8	1.17	2206.18	94.91	62.74
May	6	300	100.7	1.17	2206.18	164.39	118.41
June	11	299	100.6	1.17	2206.18	1015.34	619.53
July	15	296	100.6	1.18	2206.18	2600.67	925.66
Aug	11	296	100.7	1.19	2206.18	1026.65	626.43
Sept	8	297	100.8	1.18	2206.18	393.98	280.46
Oct	5	297	101.0	1.18	2206.18	96.38	63.71
Nov	5	295	101.2	1.20	2206.18	97.22	64.27
Dec	5	294	101.2	1.20	2206.18	97.55	64.49

4. Summary of Results.

Wind turbines should be optimized, by taking swept area into consideration, in terms of the local area conditions to capture power as maximum as possible. As evident from the results, the output power of a wind turbine is directly related to the wind speed as well as to the swept area of its blades. The larger the diameter of its blades, the more power can be extracted from the wind. The power produced by the wind turbine increases from zero at the threshold wind speed (cut in speed) (usually around 4-5m/s but varies with site) to the maximum at the rated wind speed. Above the rated wind speed, (15 to 25 m/s) the wind turbine continues to produce the same rated power but at lower efficiency until shut down is initiated if the wind speed becomes dangerously high, i.e. above 25 to 30m/s. Air density has a significant effect on wind turbine performance.

5. Conclusions

As the level of penetration of the wind power into the electricity domain is increasing, it is necessary to analyze and evaluate the impacts the factors which affect their performance. The good exploitation of wind energy may enhance the renewable power generation capabilities, maximize its capacity factor, and participate in generating electricity at good costs. Wind turbines are optimized by considering wind speed, swept area and air density in terms of local area conditions to extract maximum power. The output power of a wind turbine is directly proportional to cube of wind speed, air density and swept area of its blades. The larger the diameter of its blades, the more power can be extracted from the wind. The power output is directly proportional to the wind speed. From the calculated data it is evident that the maximum power output is attained in the month of June and July. Air density has a significant effect on wind turbine performance. The power available in the wind is directly proportional to air density and as air density increases the available power also increases. Air density is a function of air temperature and both temperature and pressure decrease with increasing elevation. Consequently changes in elevation produce a profound effect on the generated power as a result changing in the air density. The exact specifications for energy capture by the turbine depend on the distribution of wind speed over the year at the individual site.

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References

[1] Solar and Wind Energy Resource Assessment in BRAZIL, National Institute for Space Research – INPE Sao Jose dos Campos, 1st Edition - May, 2008.

[2] GREEN –Global Renewable Energy Summit-India Renewable Energy Status Report, Green Summit, Bangalore, India, June 2014.

[3] www.mnre.gov.in/schemes/grid-connected/solar-thermal-2/

[4] Twelfth Five year plan-India, Sustainable growth, Economics, Social Factors – Planning Commission (Government of India) ,Sage Publications India Ltd, New Delhi-2013

[5] Ciprian Nemes, Florin Munteanu, Operational parameters evaluation for optimal wind energy systems development, U.P.B. Scientific Bulletin, Series C, Vol. 74, Iss. 1, ISSN 1454-234x, 2012

[6] ADB, Wind Energy Future in Asia, A Compendium of Wind Energy Resource Maps, Project Data and Analysis for 17 Countries in Asia and the Pacific. ADB-GWEC Report - 2012

[7] Deepak Sangroya, Jogendra Kumar Nayak, Development of Wind Energy in India, International Journal Of Renewable Energy Research, Vol.5, No.1, 2015

[8] Omar Badran, Emad Abdulhadi, Rustum Mamlook "Evaluation of parameters affecting wind turbine power generation" Al-Balqa Applied University, The Arabic Academy for Banking and Financial Science Amman-Jordan. 2008

[9] Omar Badran, Emad Abdulhadi, Evaluation Of Factors Affecting Wind Power Generation In Jordan, The Seventh Asia-Pacific Conference on Wind Engineering, November 8-12, 2009, Taipei, Taiwan

[10] Khambalkar V P, Karale D S, S R Gadge, " Performance evaluation of a 2 MW wind power project ", Journal of Energy in Southern Africa, Vol 17 No 4, November -2006

[11] The Cost and Performance of Distributed Wind Turbines, 2010-35, U.S. Energy Information Administration Distributed Generation System Characteristics and Costs in the Buildings Sector, ICF International, June -2010

[12] Salih Mohammed Salih, Mohammed QasimTaha, Mohammed K. Alawsaj. "Performance analysis of wind turbine systems under different parameters effect", International Journal Of Energy And Environment, Volume 3, Issue 6, 2012, PP.895-904.

[13] Sanjeev Malhotra, Selection, Design and Construction of Offshore Wind Turbine Foundations, Parsons Brinckerhoff, Inc.United States of America, www.intechopen.com

[14] Betz limit, "Understanding Coefficient of Power (Cp) and Betz Limit", Kidwind science snack:

[15] Abdullateef A. Jadallah, Dhari Y. Mahmood and Zaid A. Abdulqader, Optimal Performance of Horizontal Axis Wind Turbine for Low Wind Speed Regime , International Journal of Multidisciplinary and Current Research, Jan/Feb -2014

[16] Gary L. Johnson, Wind Energy Systems, Electronic edition. Manhattan. November 21, 2001

[17] C. Marimuthu, V. Kirubakaran, "A critical review of factors affecting wind turbine and solar cell system power production", International Journal of Advanced Engineering Research and Studies Jan.-March,2014/143-147. , 2014

[18] "Wind Turbine Information", Renewable Energy Education Lab, Internet Survey, www.learnonline.com.

[19] Hayati MAMUR, Design, application, and power performance analyses of a micro wind turbine, Turkish Journal of Electrical Engineering & Computer Sciences, doi:10.3906/elk-1401-174, 2015

[20] Richard Shelquist, "An Introduction to Air Density and DensityAltitudeCalculations",wahiduddin.net/calc/density_altitude.htm.