QUALITY IMPROVEMENTS IN WIND ENERGY GENERATION

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

By

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CANDIDATE'S DECELARATION

I hereby certify that the work which is presented in this dissertation entitled, "**QUALITY IMPROVEMENTS IN WIND ENERGY GENERATION**", in partial fulfillment of the requirement for the award of the degree of Master of Technology in "Alternate Hydro Energy Systems", submitted in Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee is an authentic record of my own work carried out during the period from September 2005 to June 2006 under the supervisions of Shri. Arun Kumar, Head and Chief Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee and Dr. R.P. Saini, Senior Scientific Officer, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee. The matter embodied in the dissertation has not been submitted by me for award of any other degree.

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ABSTRACT

Wind energy is a clean and renewable energy source whose applications exist worldwide. Sun is indirect cause of wind energy. Due to uneven heating of air on earth's surface wind blows. This energy can be harnessed through windmills for several applications of mankinds. Its use is expanding. Wind energy in India is fastest growing sector, with highest capacity addition of 1112 MW in last financial year. With 45% capacity addition India ranks 4^{th} in the world with highest growth rate. The problem associated with Wind Energy Conversion Systems (WECS) is related to the technology, which is being imported presently. No national standards for WECS in India are available as yet. This study involves an attempt to prepare a quality standard for WECS, which included: Selection of site, Mechanical equipments, Electrical components, Civil works, Installations, Operations and Maintenance for planning, designing and operation of wind farm. These components of quality standards are prepared on the basis of visiting wind farms and performance evaluation of a wind farm situated in Vijaydurg - Girye owned by MEDA, which is done on one-year generation and maintenance data collected from the site to find the expected increase in PLF by raising the height of the tower.

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NOMENCLATURE

Symbols and units:

rpm	revolutions per minute	-
P_a	Power available in the wind	W/m^2
P_r	Rated power	W/m^2
ρ	Air density	kg/m^3
D	Diameter of rotor	m
A	Rotor/Swept area	m^2
V	Wind speed	m/s
C_p	Power coefficient	-
c	Capacity factor	-
PLF	Plant Load Factor	-
TSR	Tip Speed Ratio	-
γ	Solidity	-
V_m	Mean wind speed	m/s
V_{in}	Cut-in speed	m/s
V_R	Rated wind speed	m/s
V_{out}	Cut-out speed	m/s
EPF	Energy Pattern Factor	-
V_r	Reference Velocity	m/s
V_d	Velocity at desired height	m/s
Z_r	Reference height	m
Z_d	Desired height	m
α	Power law exponent	-
Z_0	Surface roughness	m
p (V)	Weibull's probability distribution	-
v	Hourly wind speed	m/s
c	Scale factor	m/s
k	Shape factor	-
E_{wind}	Design daily energy from wind turbine	Wh

Abbreviations:

C-WET	Centre for Wind Energy Technology
IEC	International Electromechanical Commission
IEEE	Institute of Electrical and Electronics Engineers
MEDA	Maharashtra Energy Development Agency
MNES	Ministry of Non-conventional Energy Sources
PPA	Power Purchase Agreement
SNA	State Nodal Agency
WTGS	Wind Turbine Generator System

WIND ENERGY: AN INTRODUTION

1.1 Introduction:

With over a billion in habitants, in India has a population second only to China. As an emergent country with a strongly growing economy, India's energy intensity of the industrial sector is relatively high.

The Indian energy market is to a great extent state-controlled and is based mostly on the use of fossil fuels as coal, oil and natural gas. However, especially in rural areas traditional fuel such as wood, cattle dung cake play important role.

In 2002 the total output of India's electricity sector amounted to about 105 GW, with almost three-quarter of this capacity generated by fossil fuels and nuclear power stations. About a quarter of the installed capacity was provided by hydroelectric plants. The new renewable energies such as solar energy and wind energy currently make up just 4% of the output [1].

Experts estimate that the Indian electricity system has a permanent capacity deficit up to 10 % and peak periods this shortfall even amount to 20%. Moreover, the central energy system concentrates on providing large population centre with power. Large parts of the rural hinterlands are not connected to the electricity grid. There are 600, 000 villages in India. Of these, 80, 000 are still without electricity, and 18, 000 of these are in areas with difficult access. Wind energy could thus be used not only for industrial purposes in population centre but also for the electrification of remote areas.

Wind, a form of solar energy, is the atmosphere's response to air masses heated unevenly by the sun. These conditions create regional atmospheric pressure differences, causing wind to blow from areas of high pressure to low pressure. The larger the differences in pressure, greater the wind velocity.

We use wind turbines to turn the wind's energy into electricity. The blade, or floater, of a wind turbine is very similar in design to an aero plane wing. Its shape is very efficient in converting the wind force in to rotational energy. Turbulence, obstructions and sheltering all reduce the performance of wind turbines. Cold air is denser than hot air, meaning wind turbines can generate about five percent more power in the winter than in the summer. Modem wind turbines are available in sizes to meet the smaller electrical needs of homes, business, farms and ranches, or the larger demands of utility-scale power plants.

Wind electricity is affordable, environmental friendly and sustainable. Unlike conventional electricity production, wind electricity releases no air pollutants or greenhouse gases, and is an inexhaustible energy source. Saving of coal and saving of atmosphere from pollution with wind power generation as on end of December 2004 is given below in table 1.1:

Table 1.1: Saving of Coal and Saving of Atmosphere from Pollution with Wind Power Generation [1]

Item	Saving (Tons)
Coal	6,468,400
Sulphur di-oxide	105, 110
Nitrogen Oxide	72, 770
Carbon di-oxide	16,170,990

Installing a small wind turbine at a home or business offsets electricity purchased from a utility and reduces electricity bills. The wind energy industry is a growing source of jobs, helping local economics and reducing our dependence on fuel imports. Increases our use of local energy resources helps stabilize energy supplies and lower the risk of electricity price hikes. Comparison between fossil fuel and wind energy is given in Table 1.2.

Table 1.2: Comparison between fossil fuel and wind energy [2]

	Fossil fuels	Wind Energy
Availability	Have to be produced and made usable through laborious and environmentally damaging processes	Usable as it exits
Limitation On Availability	Limited in reserves, expected to get completely exhausted in the coming 60 years	Inexhaustible resource
Transportation	Have to be transported from the site for the further processing exposing	Used where it is available
Use in production	Used in producing electricity releasing green house gases	Zero emission
Geo-political	Over-reliance on oil as a resource has	Reduce our

implications	undermined our energy security, e.g. OPEC crises of 1973, Gulf war of 1991 and Iraq war of 2003	reliance on oil, safeguarding national security

1.2 Concept of wind energy:

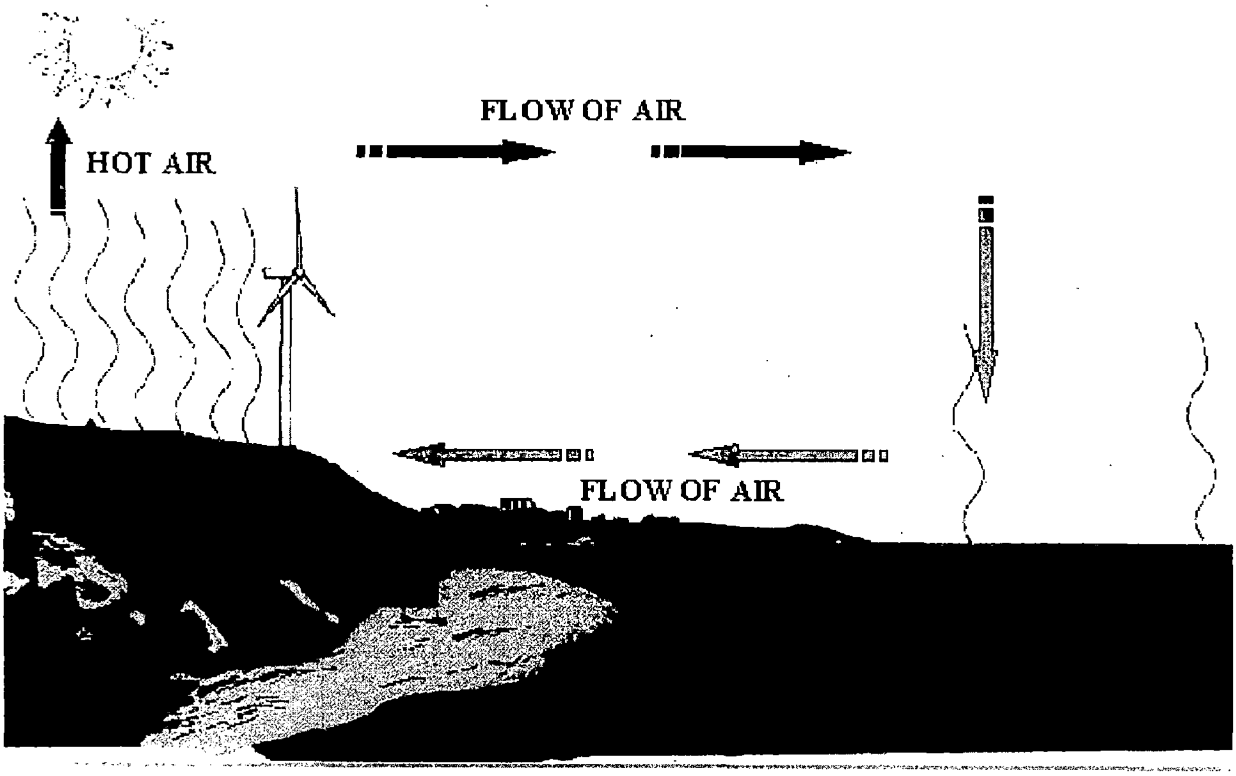


Fig. 1.1: Formation of Winds [2]

Primarily unequal heating of land and water causes winds on earth by the sun. The differences in temperature induce circulation of air from one zone to another. This air in motion is called wind. Wind has been recognised as a force of nature, ever since the planet came into existence. Human civilization has been harnessing the force of wind from time immemorial. However, the harnessing of wind energy for power generation commercially started only in the early 1970s and has continued to grow since then.

The macro-scale atmospheric flow of wind in tropical India is determined strongly by the strength of the monsoon winds. The monsoon period in India can be categorized into two:

1.2.1. South - West monsoon: The South-West monsoon begins in the month of April and is formulated in the Indian Ocean which later gradually moves in the North-East direction and first hits the state of Kerala by the second half of May. Wind gradually gains strength over the months and peaks during the month of July. During this period surface wind speed exceeding 20-30 km/h are found over Western India, Southern Tamil Nadu, Saurashtra, Kutch regions and coastal Bengal. Strong upper winds (150 m above ground) are observed in the forenoons over the interior Peninsula, Western Madhya Pradesh, Rajasthan and Saurashtra during the peak monsoon period.

1.2.2 North - East monsoon: During the winter months, the large-scale airflow reverses i.e., moves from the Himalayan belts towards the Indian Ocean which is called as the North - East monsoon. Wind speeds over 10 km/h are experienced during this period in Orissa, Saurashtra, Kutch and Southern Tamil Nadu.

1.3 Advantages and Disadvantages of wind energy [3]:

Wind energy offers many advantages, which explains why it's the fastest-growing energy source in the world. Research efforts are aimed at addressing the challenges to greater use of wind energy.

1.3.1 Advantages of wind energy:

Wind energy is fueled by the wind, so it's a clean fuel source. Wind energy doesn't pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind turbines don't produce atmospheric emissions that cause acid rain or greenhouse gasses.

Wind energy relies on the renewable power of the wind, which can't be used up. Wind is actually a form of solar energy; the heating of the atmosphere by the sun, the rotation of the earth, and the earth's surface irregularities cause winds.

Wind energy is one of the lowest-priced renewable energy technologies available today.

Wind turbines can be built on farms or ranches, thus benefiting the economy in rural areas, where most of the best wind sites are found. Farmers and ranchers can continue to work the land because the wind turbines use only a fraction of the land. Wind power plant owners make rent payments to the farmer or rancher for the use of the land.

1.3.2 Disadvantages of wind energy:

Wind power must compete with conventional generation sources on a cost basis. Depending on how energetic a wind site is, the wind farm may or may not be cost competitive. Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a higher initial investment than fossil-fueled generators.

The major challenge to using wind as a source of power is that the wind is intermittent and it does not always blow when electricity is needed. Wind energy cannot be stored (unless batteries are used); and not all winds can be harnessed to meet the timing of electricity demands.

Good wind sites are often located in remote locations, far from cities where the electricity is needed.

Wind resource development may compete with other uses for the land and those alternative uses may be more highly valued than electricity generation.

Although wind power plants have relatively little impact on the environment compared to other conventional power plants, there is some concern over the noise produced by the rotor blades, aesthetic (visual) impacts, and sometimes birds have been killed by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

1.4 Objectives of the Dissertation work:

Literature review reveals that there is lot of potential of wind energy in India. Some states are encouraged by Government of India for trapping this potential. The problem associated with wind energy exploitation is related to the technology, which is being imported. There is no quality standard of WECS is available. Keeping in this in view, an attempt has been made to prepare a quality standard for WECS. The quality standard is prepared on the information/data collected by visiting three wind farms in the state of Maharashtra and conducting the performance evaluation of a wind farm.

LITERATURE REVIEW

2.1 General:

Wind power happens to be the fastest growing industry in the world with annual growth rate of about 20%. Today there are 50,000 MW of wind power generation capacity all over the world and in India we have nearly 4,200 MW of installed capacity. India ranks 4th in terms of total installed capacity and third in terms of current market size. Germany with about 17,000 MW of wind power is the leading country followed by Spain and US. Refer Fig. 2.1. Of all the renewable energy projects in the world, wind power in grid connected mode accounts for nearly 50% [1].

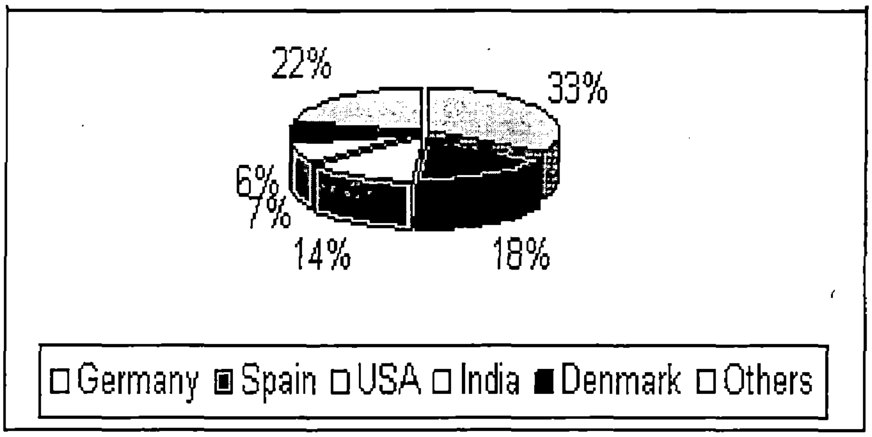


Fig. 2.1 Percentage contribution by top five countries to the total installed capacity to the world as on March 31, 2005 [1]

The Wind power programme in India was initiated towards the end of the Sixth Plan, in 1983-84. A market-oriented strategy was adopted from inception, which has led to the successful commercial development of the technology. The broad based National programme includes wind resource assessment activities research and development support implementation of demonstration projects to create awareness and opening up of new sites involvement of utilities and industry development of infrastructure capability and capacity for manufacture, installation, operation and maintenance of wind electric generators and policy support.

2.2 Wind resource assessment:

India has been endowed with vast wind resources. Onshore wind power potential is 48,199 MW assuming 1 % of land availability for wind power generation in ten potential States. However, technical potential is limited to only 14,775 MW assuming 20% grid penetrations, which will go up with the augmentation of grid capacity in the potential states. Figure 2.2 and 2.5 shows Gross and Technical potentials available in nine states of India and wind power density map of India [4].

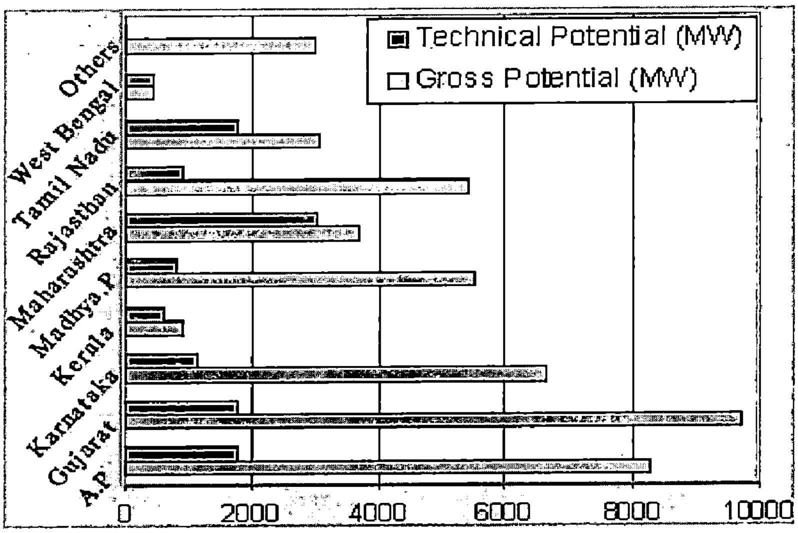


Fig. 2.2 Technical and Gross potential available in India [1]

Wind Resource assessment programme is being implemented in the country through the Centre for Wind Energy Technology (C-WET), an autonomous Institution of the Ministry, in co- ordination with State Nodal Agencies (SNAs). Around 1150 wind monitoring/mapping stations were set-up in 25 States and Union Territories, out of which 50 Wind monitoring stations are in operation with the remaining stations having been closed after collection and analysis of data. 97 master plans have been completed taking into account the zone of influence around each mast. 211 wind monitoring stations in 13 states and Union Territories having a mean annual wind power density greater than or equal to 200 W /m^2 at 50 m height above ground level has been identified for wind power development. Wind resource and wind shear assessment at five selected wind locations with 120 m anemometry mast is under implementation.

2.3 Potential exploited:

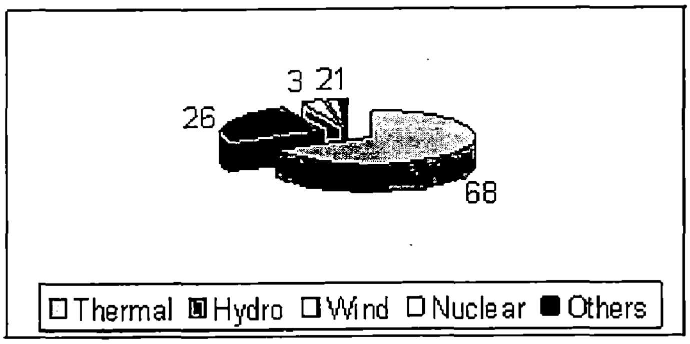


Fig. 2.3 Percentage contribution by different sources of energy to the installed capacity in India [1]

A total wind power capacity of 4,228 MW has been installed which is about 3% of the installed capacity through conventional sources in the country (Refer Fig. 2.3) out 25% of exploitable technically potential. Wind power capacity of 1111 MW was added during 2004-05 in Andhra Pradesh Gujarat, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamil Nadu. Comparison of wind power development with other forms of energy source and year wise capacity addition of wind power is shown in the Figure 2.4. The Table 2.1 below shows the state wise power installed in India:

Table 2.1: State wise installed capacity of India as on September2005 [1]

State	Installed Capacity (MW)
Andhra Pradesh	120.60
Gujarat	257.50
Karnataka	443.40
Kerala	2.00
Madhya Pradesh	28.90
Maharashtra	581.20
Rajasthan	359.80
Tamil Nadu	2432.20
West Bengal	1.10
Others	1.60
Total	4228.20

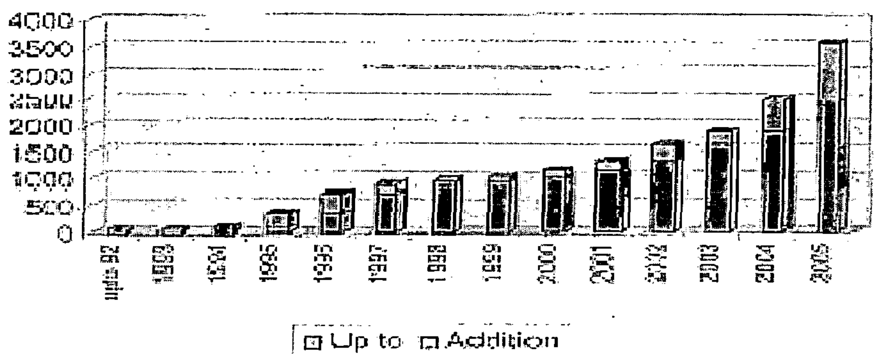


Fig. 2.4 Year wise capacity addition of wind power in India [1]

2.4 Literature review:

2.4.1 Robert Gross, Matthew Leach, Ausilio Bauen (2002) [5] states that, Wind power is well-developed, with a rapidly expanding global market and substantial technological advances over the last decade. As a result, costs at the best sites onshore are already close to competitive with fossil fired alternatives. There is some evidence to suggest that the rate of cost reduction could slow down over the next 10–20 years, but considerable further cost reductions are widely predicted. The key challenge for policy is to facilitate continued market expansion and ensure that cost reductions are delivered. If this succeeds then there is good reason to expect that wind will indeed converge with fossil fuelled alternatives, but this is likely to require both developments offshore and considerable expansion into parts of the world that have, as yet, seen little wind energy deployed.

2.4.2 V. H. Morcos (1994) [6] stated that, i. The power and thrust coefficients of wind turbines increase with the increase of tip-speed ratio and solidity, and with the decrease of ratio of drag coefficient to lift coefficient and blade angle. As the rotor solidity increases, the maximum power and thrust coefficients occur at lower tip-speed ratios. So, low speed wind turbines (multi bladed type) have a high number of blades, while high-speed wind turbines (propeller-type) have a low number of blades. The maximum power coefficient occurs at a lower tip-speed ratio than that of maximum thrust coefficient for the same solidity. This helps in getting maximum power at a lower thrust than the maximum.

ii. The torque coefficient decreases with the increase of tip-speed ratio, drag coefficient to lift coefficient ratio and blade angle. It increases with the increase of solidity at low tip-speed ratios. So, low and high-speed wind turbines need high and low starting torques, respectively. The tip-speed ratio range of variation for circular- arc airfoil blade section is smaller than that of flat-plate and symmetric airfoil blade sections. Therefore, flat-plate and symmetric airfoil blade sections are recommended for wind energy conversion systems. Simple flat-plate airfoil blade sections are easy to manufacture, and small size wind turbines can use them without marked loss of performance. If strength considerations dictate some profiling for large size wind turbines, symmetric airfoil blade sections are recommended.

2.4.3 G.M. Joselin Herbert, S. Iniyan, E. Sreevalsan, S. Rajapandian (2005) [7] concluded that, Remarkable advances in wind turbine design have been possible due to developments in modern technology.

- The factors such as selection of site, height, choice of wind generators, wind velocity, wind power potential have been considered as an objective function of probabilistic models. These mathematical models are used to determine the energy output of the wind turbine system.
- Weibull, Rayleigh distribution and Markov chain model were found suitable to predict wind speed data for the site. Selection of windy site for wind power generation requires meteorological data for installation of wind generator.
- Experimental and theoretical methods are used to analyze vibration problems of wind turbines. Rain flow counting, a linear Goodman fit and Miner summation are used for lifetime prediction of wind turbine blades. The aero elastic and structural dynamic aspect helps in understanding various loads used for design and fatigue damage.
- Aero acoustic tests are used to find noise in the aerofoil. Computer-based supervisory control is used to identify operating characteristics of wind turbines.
- Static reactive power compensator is used to improve stability of large wind farms. Parato analysis and simulation models are used to analyze grid-related problems.
- Wind field modeling is an important part of a structural analysis of wind turbines.

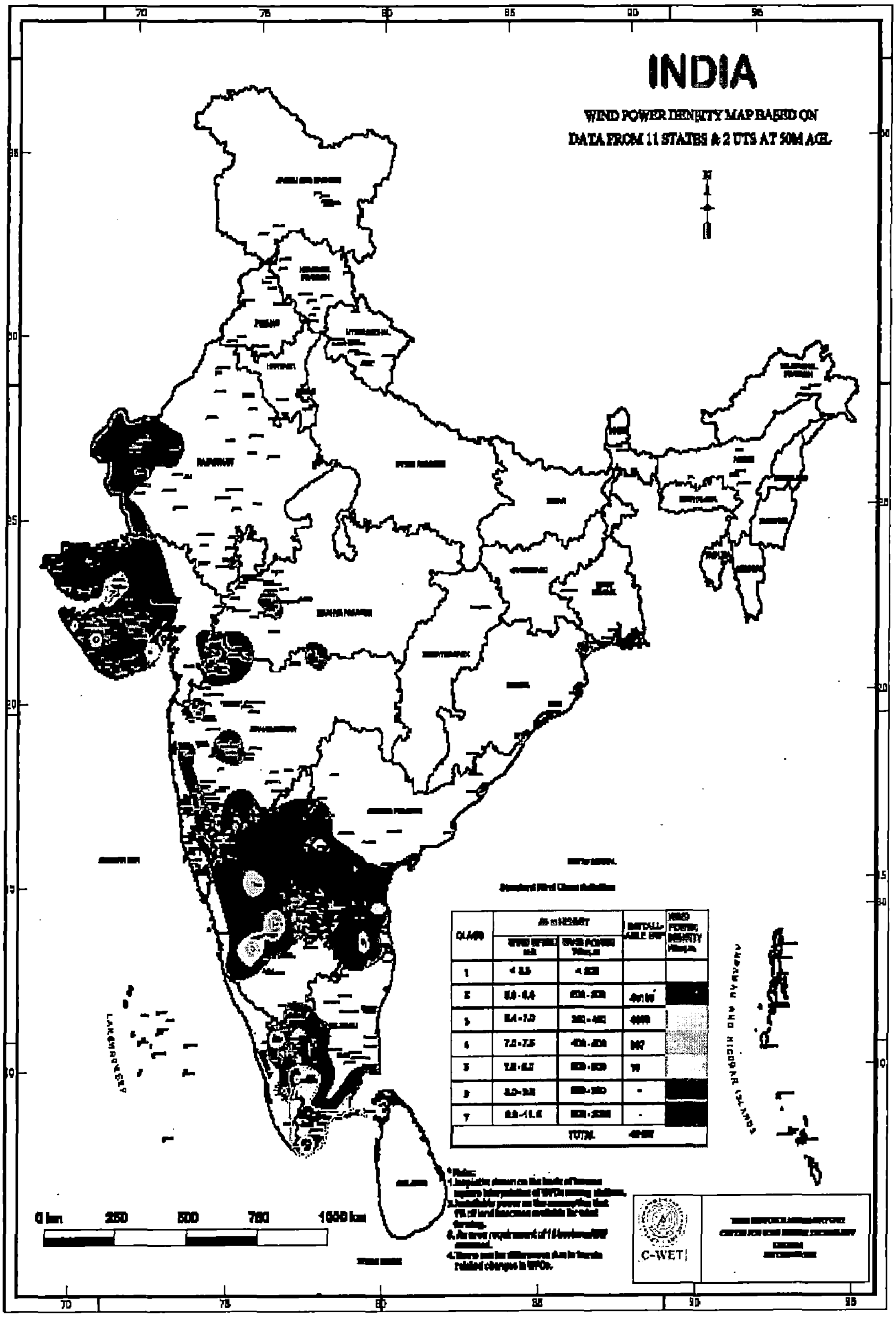


Fig. 2.5 Wind power density map of India [4]

- In aerodynamic modeling blade element moment theory is used for calculation of aerodynamic forces acting on the rotor blade.
- Control system modeling is used to keep the operating parameters of the wind turbine within the specified limit. These developments and growing trends towards wind energy signal is a promising future for the wind energy industry. With this improved technology wind turbine can be designed for its optimum power production at less cost.

2.4.4 Asaf Varol, Cumali 'Ilkılıc, Yasin Varol (2001) [8] said that, the research activities on wind energy seem to increase with time worldwide because wind energy is clean. It is important to increase the efficiency of the system. The idea of the surrounding aerofoils is similar to the steering blades of a water turbine like Francis or Kaplan turbine. The direction of the wind in nature is changeable. Therefore the correct position of the aerofoils is very important to increase the rotation speed. If this is not in the correct position the aerofoils will affect the system negatively.

2.4.5 Onder Ozgener (2005) [9] said that, the number of years for simple payback is a function of the wind speed, annual energy production from the turbine, the manufacturer's power curve and the installed costs of the Small Wind Turbine Systems. Changing just the blade design (airfoil) of the small wind turbine can increase the annual energy production from the turbine and greatly improve the manufacturer's power curve.

i. Blade:

- A steel mold can be used to produce a smooth surface.
- Along and narrow airfoil can be selected having larger aspect ratio than the classical (short and wide wing) blade.
- Blades can be made of epoxy–carbon fiber or GRP.
- Steel blades should not be used due to their weight and corrodibility.
- Lighting protection can be provided for GRP epoxy–carbon fiber blades.
- The rotor blades can be improved, but there are many profiles that might be used, and in addition, there is no requirement that the same

profile should be used throughout the blade length. The power factor value can be increased, but investment and producing cost of blades are quite high for a small windmill.

ii. Location:

- Picking the initial location can be done using empirical guidelines formulated for evaluating the effects of local topography and roughness elements affecting the wind, including the effects of tress and buildings, which can reduce system performance and affect experimental measurement. Therefore, the height of hub should be higher than that of the buildings and tress. Otherwise, vortex formation can affect system efficiency.

iii. Wind:

- Local values of wind velocity should be 3 m/s or higher, and the wind should be steady, to produce electricity effectively.

iv. Main gear system:

- This system should not be used in Small Wind Turbine Systems due to high friction.
- Direct fixed connection can be used between generator and blades rotors. This can increase C_p values due to lower friction.

WIND ENERGY CONVERSION SYSTEM

3.1 General:

This chapter presents the details of various components of WECS collected by visiting the three wind farms situated in Maharashtra State. Details of wind farms are given in Table 3.1.

Table 3.1: Details of wind farms visited in Maharashtra

Place	Manufacturers of WTGS	Capacity of one unit	Capacity	Number of units installed
Chalkewadi and Vankusawade	Suzlon, Enercon, Vestas RRB	250 kW to 2000 kW	> 200 MW	Approximately 1200
Nagaj	Suzlon	1250 kW	75 MW	60
Vijaydurg-Girye	BHEL-Nordex	250 kW	1.5 MW	6

3.2 Major components of wind turbine:

A Wind Turbine consists of the following major components:

3.2.1 Anemometer: Measures the wind speed and transmits wind speed data to the controller. Refer Fig. 3.1.

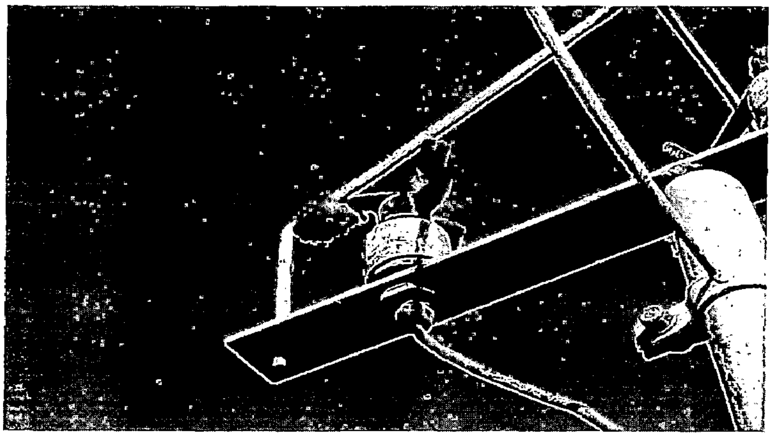


Fig. 3.1 An anemometer (at Vankusavde wind farm)

3.2.1 Blades: Most turbines have either two or three blades. Wind blowing over the blades causes the blades to "lift" and rotate. Refer Fig. 3.2.

Fig. 3.2 A turbine blade (at Vankusavde wind farm)

3.2.2 Brake: A disc brake, which can be applied mechanically, electrically, or hydraulically to stop the rotor in emergencies. Refer Fig. 3.3.

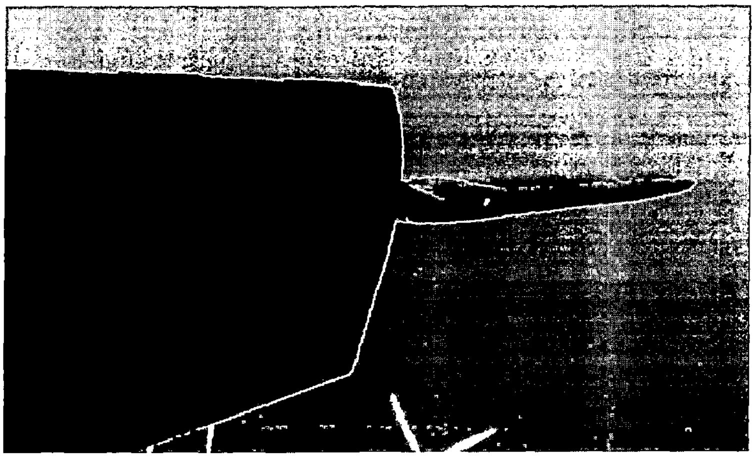


Fig. 3.3 A tip brake (at Vankusavde wind farm)

3.2.3 Controller: The controller starts up the machine at wind speeds of about 8 to 16 miles per hour and shuts off the machine at about 65 miles per hours. Turbines cannot operate at wind speeds above about 65 mph because their generators could overheat.

3.2.4 Gear box: Gears connect the low–speed shaft to the high–speed shaft and increase the rotational speeds from about 30 to 60 rotations per minute (rpm) to about 1200 to 1500 rpm, the rotational speed required by most generators to produce electricity. The gearbox is a costly (and heavy) part of the wind turbine. Engineers are exploring "direct–drive" generators that operate at lower rotational speeds and don't need gear boxes.

3.2.5 Generator: Usually an off–the–shelf induction generator that produces 50–cycle AC electricity. Refer Fig. 3.4.

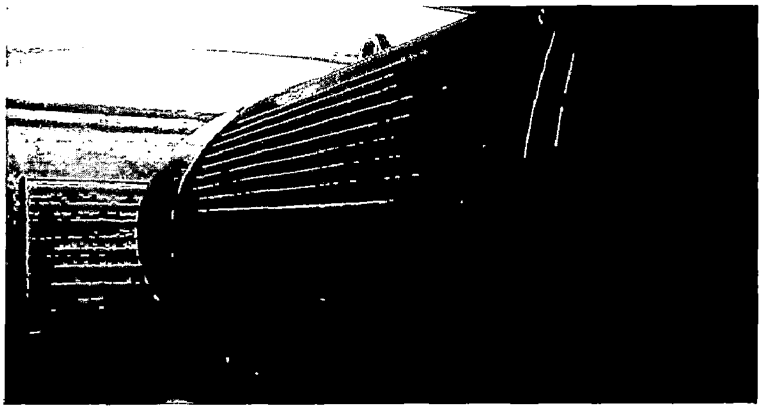


Fig. 3.4 Generator (at Vankusavde wind farm)

3.2.6 High–speed shaft: This is the shaft which connects the generator to the out put side of the Gear-box. The low rpm of rotor is stepped up to higher rpm up to the rotational speed of generator through gear-box that is connected to the generator. Drives the generator

3.2.7 Low–speed shaft: This shaft is directly coupled to the rotor through the hub. The rotor turns the low–speed shaft at about 30 to 60 rotations per minute.

3.2.8 Nacelle: The rotor attaches to the nacelle, which sits atop the tower. The nacelle includes the gearbox, low and high–speed shafts, generator, controller, and brake. A cover protects the components inside the nacelle. Some nacelles are large enough for a technician to stand inside while working. Refer Fig. 3.6.

3.2.10 Pitch: Blades are turned, or pitched, out of the wind to keep the rotor from turning in winds that are too high or too low to produce electricity.

3.2.11 Rotor: The blades and the hub together are called the rotor. There two types of rotors viz. horizontal and vertical. Horizontal rotors are preferred over vertical type arrangement. The horizontal rotors with two or three blade are used.

3.2.12 Tower: Towers are made from tubular steel or steel lattice. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.

3.2.13 Wind direction: This is an "upwind" turbine, so–called because it operates facing into the wind. Other turbines are designed to run "downwind", facing away from the wind.

3.2.14 Wind vane: Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind. Refer Fig. 3.7.

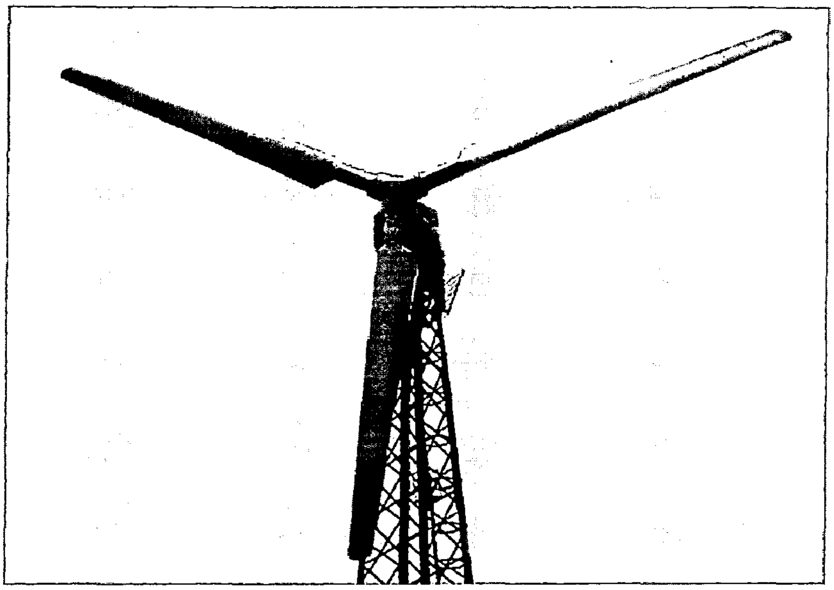


Fig. 3.5 A typical wind rotor (at Vijaydurg - Girye wind farm)

Fig. 3.6 A figure showing typical lattice type tower and nacelle (at Vijaydurg - Girye wind farm)

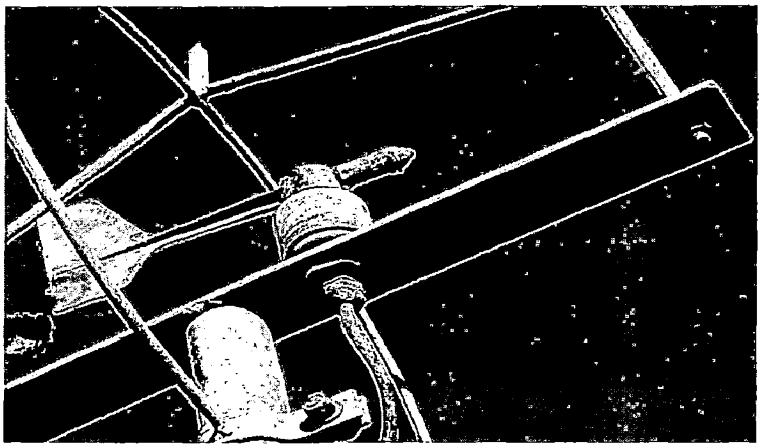


Fig. 3.7 A typical wind vane (at Vankusavde wind farm)

3.2.15 Yaw drive: Upwind turbines face into the wind; the yaw drive is used to keep the rotor facing into the wind as the wind direction changes. Downwind turbines don't require a yaw drive; the wind blows the rotor downwind. Refer Fig. 3.8.

Fig. 3.8 A typical Yaw drive system (at Vankusavde wind farm)

3.2.16 Yaw motor: When change in wind direction occurs yaw motor powers the yaw drive to rotate at wind direction.

3.3 Working of a wind turbine:

Wind turbines convert the kinetic energy in the wind into mechanical power. Simply stated, a wind turbine operates opposite to a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity.

The wind turns the blades, which spin a shaft, which is connected to a generator and makes electricity. Refer Fig. No 3.9 and 3.10.

3.4 Terms Related to wind energy:

3.4.1 **Power available in the wind (P):** The power available in the wind can be expressed by following equation:

Available Wind power, Pa= $0.5 \times \rho \times A \times V^3$ W/m^2 (3.1)

Where, ρ: The air density (kg/m^3), generally taken as 1.225 kg/m^3 [10]

A: Rotor area (m^2)

V: Velocity of wind (m/s)

3.4.2 **Power Coefficient (C_p):** Power coefficient of turbine is defined as ratio of power extracted by turbine to the power available in the wind.

$$C_p = \frac{Pe}{Pa} \quad (3.2)$$

Where, Pe: Power extracted by the system

Pa: Available power in the wind

Therefore Extractable wind power, P= $C_p \times 0.5 \times \rho \times A \times V^3$ W/m^2 (3.3)

Maximum theoretical value of C_p is 0.5963, which is known as Bentz Limit [10].

3.4.3 **Capacity Factor (C_p):** The capacity factor is also referred to as the Plant Load Factor, is the energy generated during a given period divided by the energy that would have been generated had the wind farm been running continually at maximum output.

3.4.4 **Tip Speed ratio (TSR):** Tip Speed ratio is the ratio of tip speed of rotor divided by the free speed of wind.

$$\text{There fore, TSR} = \frac{\pi DN / 60}{V} \quad (3.4)$$

Where, D- Diameter of rotor,

N- rpm,

V-Wind speed

3.4.5 **Solidity (γ):** Solidity is the ratio of effective area of the rotor to the frontal area of the rotor.

3.4.6 **Mean wind speed (V_m):** The wind velocity is not constant and changes from time to time. Hence mean velocity should be calculated over a large number of readings taken over a period of one year by average hourly, daily, weekly, monthly readings suitable.

$$V_m = \frac{\sum_{i=1}^{n} Vi}{n} \quad (3.5)$$

3.4.6 **Cut-in speed (V_{in}):** The minimum wind speed at which the machine will deliver useful power.

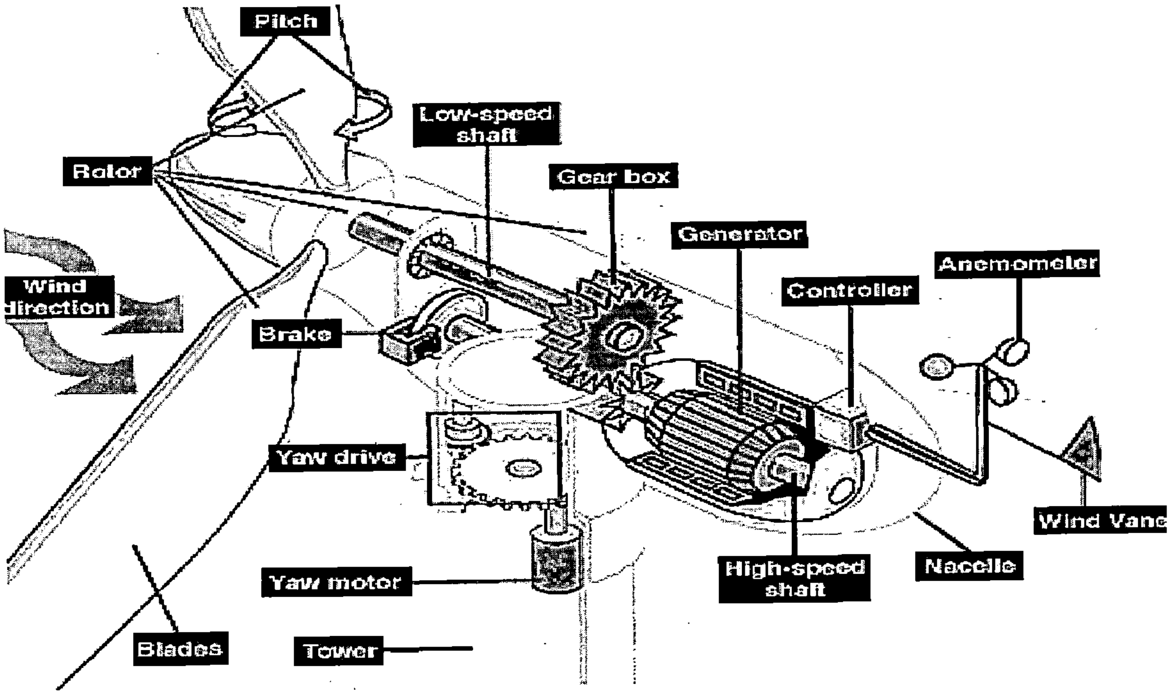


Fig. 3.9 Components of a wind turbine [11]

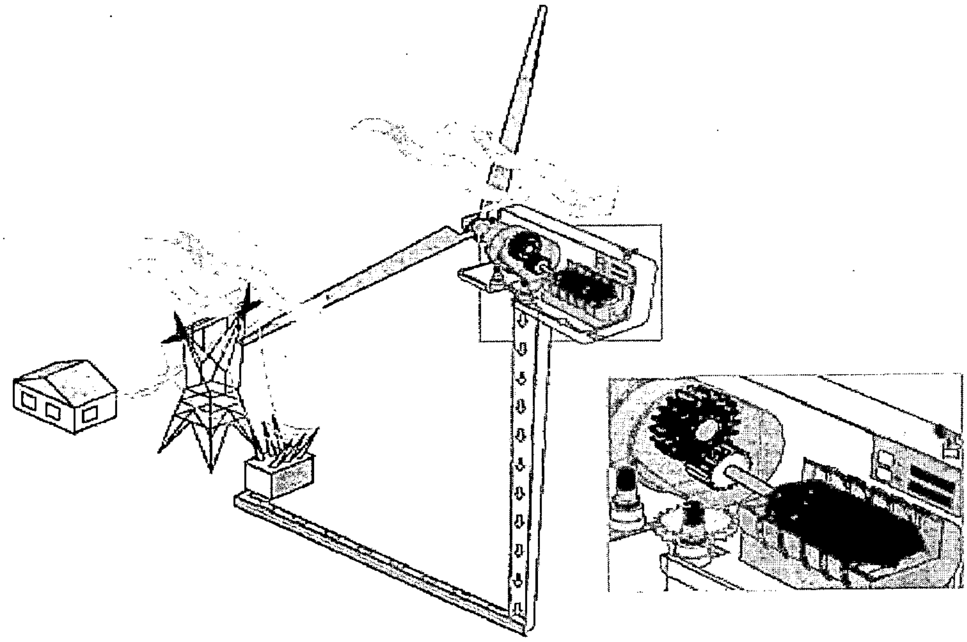


Fig. 3.10 Working of a wind turbine [11]

3.4.7 **Rated wind speed (V_r):** The wind speed at which the rated power (generally maximum power output of electrical generator) is reached.

3.4.8 **Cut- out speed (V_{out}):** The maximum wind speed at which the turbine is allowed to deliver power.

3.4.9 **Energy pattern factor (EPF):** Wind energy factor is defined as the ratio of actual energy in varying wind by calculated energy from mean velocity.

3.4.10 **Availability:** Availability is the proportion of the time that the turbine is available to produce power, including those periods when the turbine is on standby during calms and very high winds. For modem wind turbines, availability is typically 95-99%. Most new wind farms have availabilities of 97 -99% [12].

3.5 Power law equation:

The power law profile represents a simple model for the wind speed profile. Its basic form is [10]:

$$\frac{V_r}{V_d}=(\frac{Z_r}{Z_d})^{\alpha} \qquad (3.6)$$

Where, Z_r and V_r are reference height and velocity respectively and V_d is the velocity at desired height Z_d. And α is the power law exponent.

3.5.1 Correlation for the power law exponent as a function of velocity and height [10]:

$$\alpha=\frac{0.37-0.088\ In(V_r)}{1-0.088\ In(\frac{Z_r}{10})} \qquad (3.7)$$

Where, Z_r and V_r are in m and m/s respectively.

3.5.2 Correlation dependent on surface roughness [10]:

$\alpha= 0.096 \log_{10}(Z_0) + 0.016 [\log_{10}(Z_0)]^2 + 0.24$, (for $0.001\ m< Z_0<10\ m$) (3.8)

Where, Z_0 is the surface roughness in m. Surface roughness values may be selected from the following Table 3.2:

Table 3.2: Recommended values of surface roughness for different terrains [10]

Terrain Description	Z_0 (mm)
Very smooth, ice or mud	0.01
Calm open sea	0.20
Blown sea	0.50
Snow surface	3.00
Lawn grass	8.00
Rough pasture	10.00
Fallow field	30.00
Crops	50.00
Few trees	100.00
Many trees, few buildings	250.00
Forest and wood lands	500.00
Suburbs	1500.00
Centres of city with tall buildings	3000.00

3.6 Weibull Distribution [10]:

The Weibull distribution is used in fitting wind speed frequencies is an analytical representation of the probability distribution p (V) of speed. The mathematical form is expressed as:

$$p(V)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-\left(v/c\right)^{k}} \qquad (3.9)$$

Where, v: Hourly wind speed

c: Scale factor in m/s

k: Shape factor (dimensionless)

The Weibull's Probability Distribution for k=3 and c=8 is shown in Figure. 3.11.

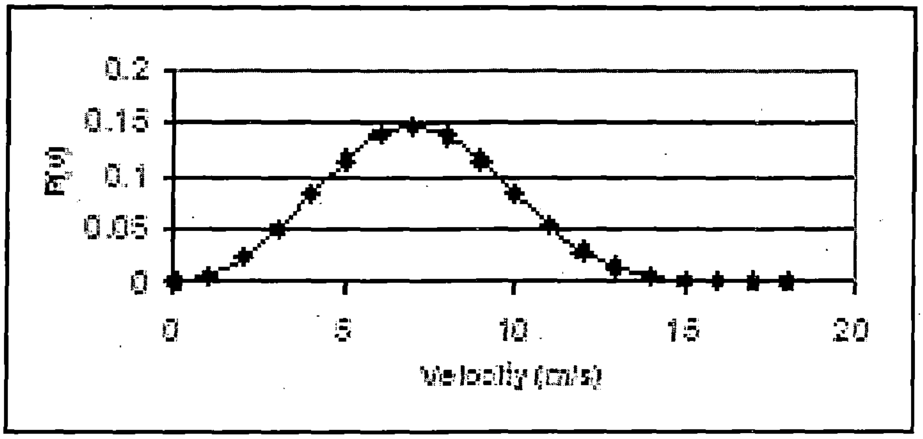


Fig. 3.11 Weibull's probability distribution for k=3 and c=8

3.7 Power Duration Curve:

The energy content in the wind can be visualized by plotting the power density-duration curve. Since (P/A) αv^3; this curve is obtained from the speed-duration curve by plotting v^3 instead of V on the y-axis. A typical annual power density-duration curve is shown in Fig. It is easy to visualize that the total area under the curve represents the energy content in the wind for a year.

The energy available for the rotor of a given wind machine is less than the total area under the curve in Fig. Referring again to Fig. 3.12 let the points a, *b* and c represents the power density values corresponding to the cut-in, design and cut-out speeds respectively. Draw horizontal lines from these points to intersect the power density-duration curve at points *d,* e and *f,* and drop perpendiculars *dg* and *fh* on the x-axis. From Fig. it is clear that the energy associated with the area under the curve to the right of *dg* is lost because of wind speeds less than the cut-in speed. Similarly the energy associated with the area to the left of *fh* is lost because of wind speeds greater than the cut-out speed. Also since the output of the machine is held constant at the rated value for wind speeds in excess of the design speed, the energy associated with the area above the line *be* is not used. Thus the actual energy available is given by the shaded area *kedgh.*

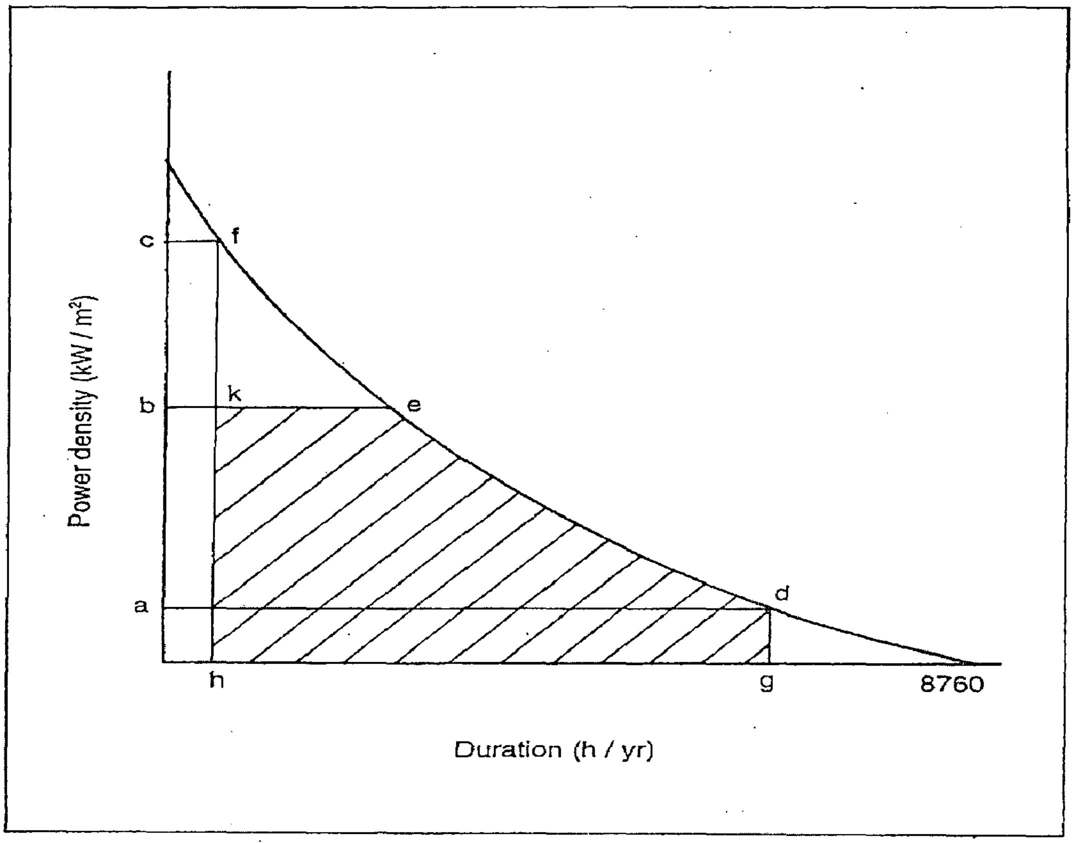
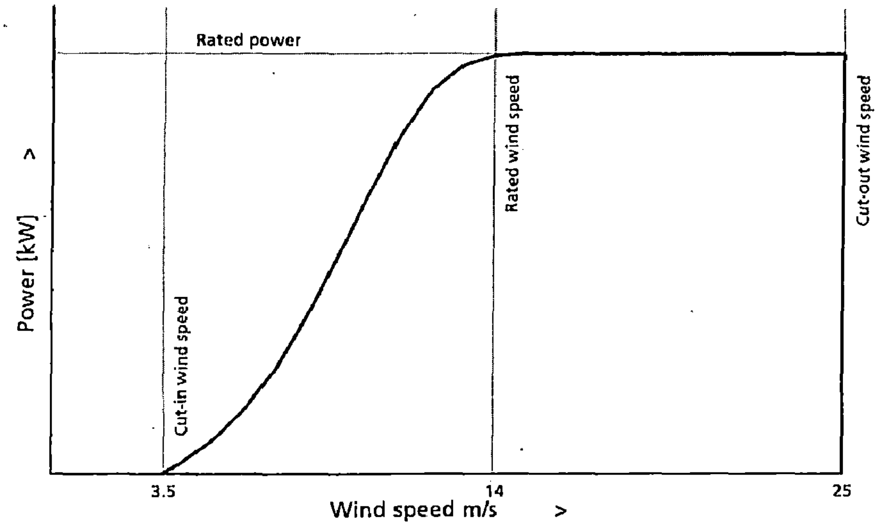


Fig. 3.12 Typical Power Duration Curve and Energy available for the wind machine [13]

3.8 Wind turbine Power curve:

The amount of power that a wind turbine generates depends on the wind speed at the time. The power curve describes the relationship between the wind speed and the power that the turbine generates. Typical power curve for a wind turbine is shown in the Fig. 3.13. At very low wind speed the turbine is unable to generate the electricity. As wind the wind speed increases to the cut-in speed the turbine begins to operates. Between the cut-in and rated wind speeds the turbine takes all the power it can from the wind. Above the rated wind speed which is capable of producing. The rated power level is chosen to give a high electricity production for low wind turbine cost. This is achieved by limiting the electrical and physical loads. The rated power is the same as the installed capacity.

When wind speeds are very high the turbine shuts down to protect itself from damage. This happens when the wind speed is higher than the turbine's cut-out wind speed. Also the variation of efficiency of wind turbine with respect to wind speed is shown in the Fig. 3.13 for Vestas 600 kW machine. When wind speed is below cut-in speed the wind turbine rotates but there is no power generation there fore efficiency is zero. Once wind speed crosses the cut-in speed the wind turbine starts to deliver the power. And efficiency of wind turbine gradually increases up to certain value of the wind speed. Then after efficiency decreases gradually up to cut-out speed.



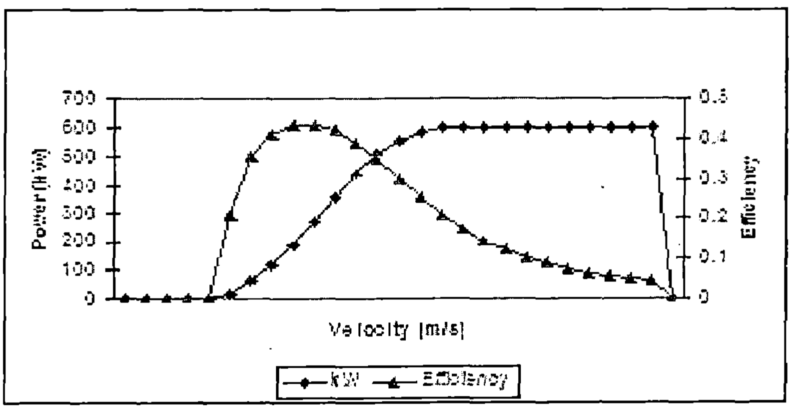


Fig. 3.13 Power curve for Vestas 600 kW machine, with cut-in velocity 5 m/s and cut-out speed 25 m/s [14]

3.9 Velocity Duration curve:

Velocity Duration curve is a graph with wind speed on the y-axis and no. of hours of the year for which speed equals or exceeds each particular value on the x-axis (Refer Fig. 3.14). This type of curve gives an approximate idea about nature of wind regime at each site. The flatter the curve more constant is the wind speed. The steeper the curve more irregular the wind regime.

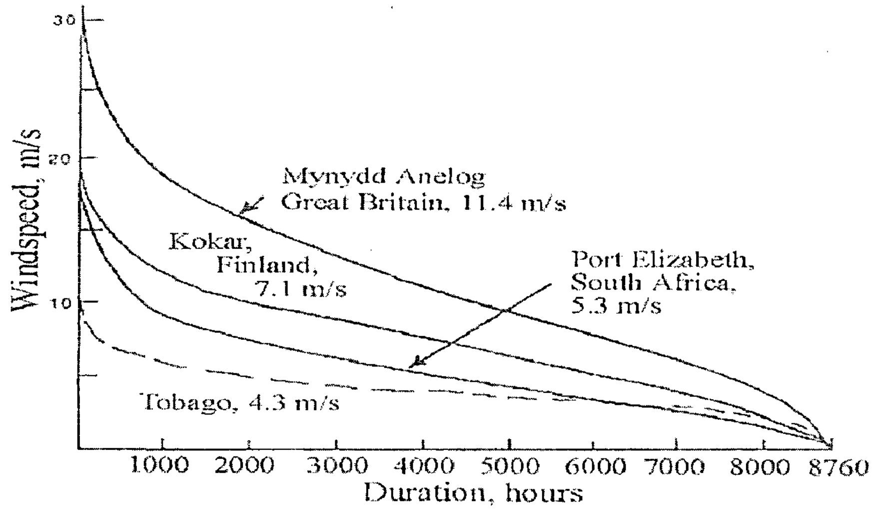


Fig. 3.14 A typical velocity duration curve [10]

PERFORMANCE EVALUATION OF A WIND FARM AT VIJAYDURG-GIRYE

4.1 General:

During the site visit performance of wind farm at Vijaydurg-Girye has been studied. The wind farm is situated in Sindhudurg district, Maharashtra state. The wind farm at Vijaydurg-Girye is owned by MEDA. The total installed capacity is 1.5 MW (six machines of 250 kW each) The layout of the site is given in Fig 4.1 and Fig. 4.2. The project started in the year 1994. The average PLF of the wind farm in the year 2005-06 is 10%. The study has been carried out in this chapter to find the expected increase in average PLF by raising the tower height.

4. 2 Technical Particulars of WTGS:

4.2.1 Turbine:

Cut-in wind speed	: 3-4 m/s
Cut-out wind speed	: 25 m/s
Wind speed at rated output	: 16 m/s
Wind speed at Maximum output	: 16 m/s
Energy output per machine as per site wind data assuming 95 % machine availability and 95 % machine availability	: 314857 kWh
Blade material	: Glass fiber
Length of blade	: 12.30 m
Swept area	: 530 m^2
Rotor speed	: 40 rpm
Tip speed ratio	: 6
Regulation (Stall / Pitch)	: stall
Weight of rotor	: 4.74 tons

4.2.2 Gear:

Gear ratio	: 1: 25.383
Gear type	: 2 stages helical
Indian oil equivalent	: Synthetic

4.2.3 Brake system:

Disk brake	: provided
Aerodynamic brake	: provided

4.2.4 Yaw system: : Active yaw

4.2.5 Generator:

Type	:Single Asynchronous with double winding
Nominal output (kW)	: 250 kW (45 / 250 kW), 6/8 poled
Tolerance in voltage	: + 13 %
Rated frequency	: 50 Hz
Tolerance in frequency	: + 2 Hz
Synchronous speed	: 1000 rpm/750 rpm
Power factor – No load	: Main winding 0.855, Second winding 0.82

4.2.6 Control system:

Type	: Micro processor based
Soft start	: Thyristor engagement
Capacitor rating	: 3 × 20 kVAr
Protection	: Provided
Safety function	: Provided
Error message	: 47 Error message
Display	: LCD
Remote control facility	: Provided
Sensors	: Provided

4.2.7 Tower:

Type	: Lattice type
Hub height	: 31.5 m
Weight	: 12 tons
Material	: Steel
Corrosion Protection	: Hot dip Galvanising

4.2.8 Nacelle:

Material	: Steel
Weight	: 2.0 tons
Approach	: Through center

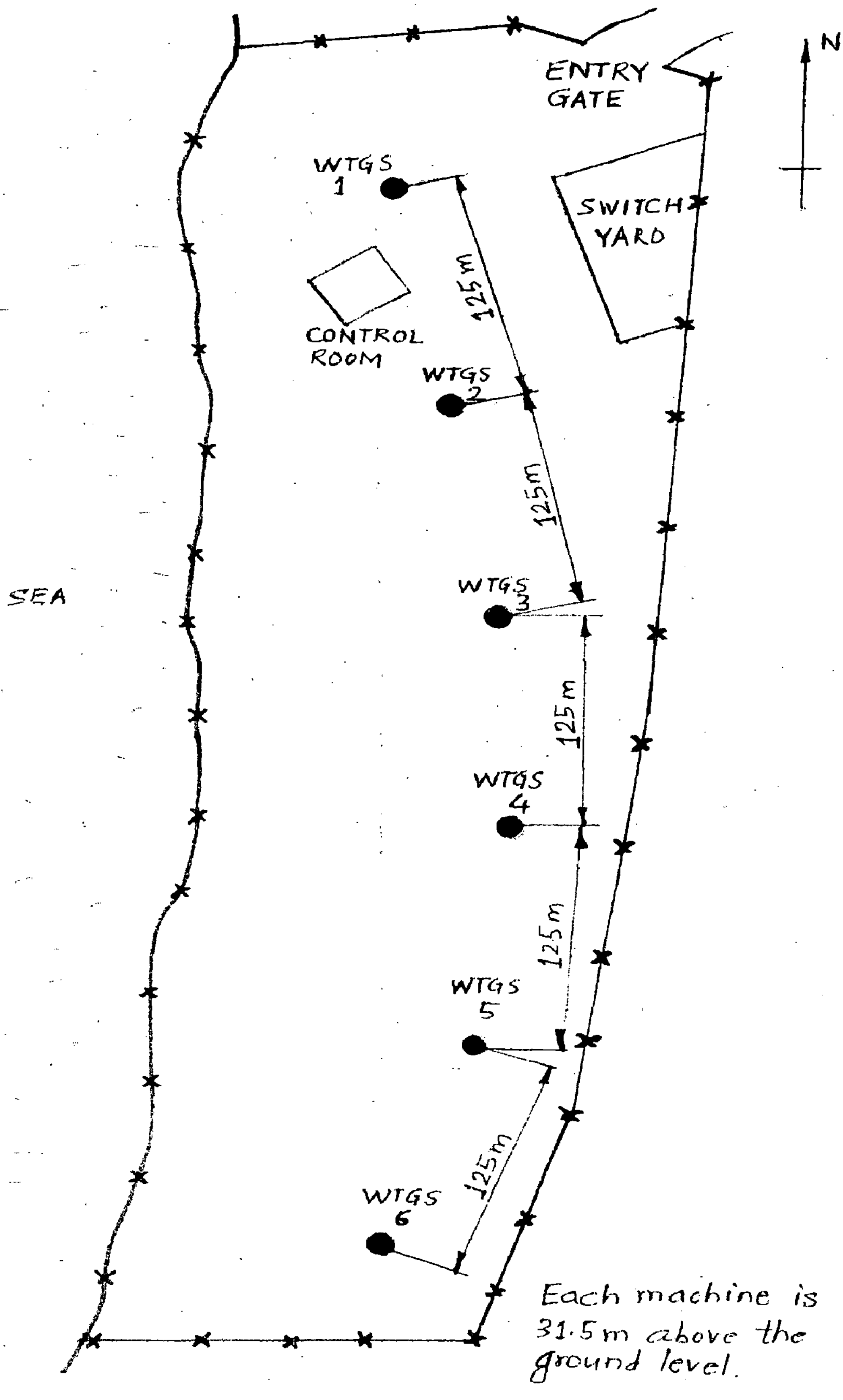


Fig. 4.1 Layout of Vijaydurg - Girye wind farm

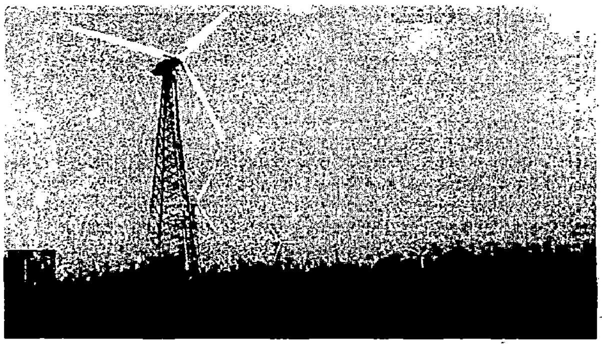


Fig. 4.2 (a)

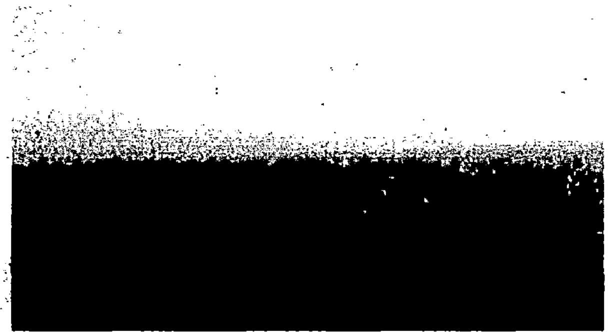


Fig. 4.2 (b)

Fig. 4.2 (c)

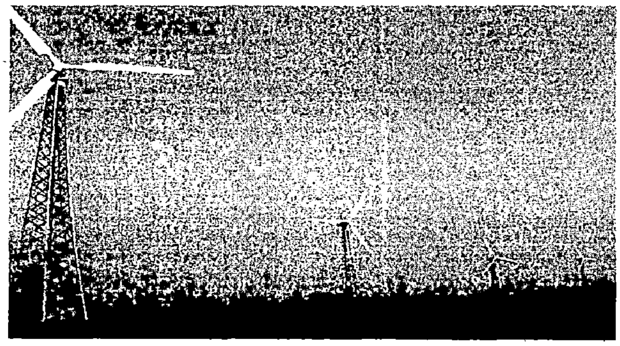


Fig. 4.2 (d)

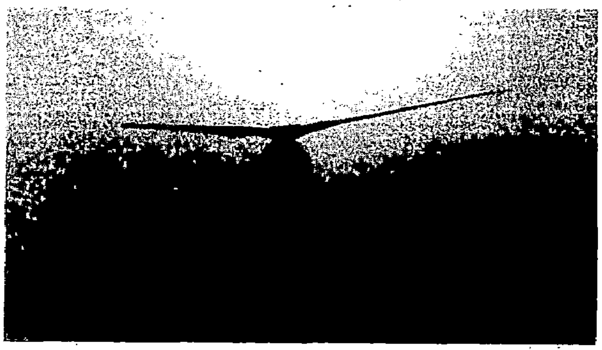


Fig. 4.2 (e)

Fig. 4.2 (f)

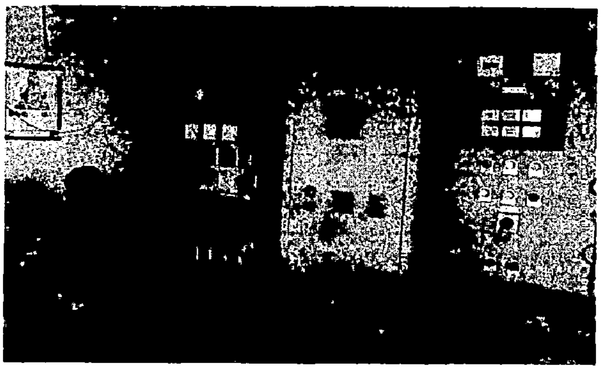


Fig. 4.2 (g)

Fig. 5.2 (a) to Fig. 5.2 (g) Different views at Vijaydurg - Girye Wind Farm showing WTGS, switch yard and control room

4.3 Performance evaluation of all WTGS:

For performance evaluation of all WTGS a site visit was conducted in April 2006. During the site visit one-year data of all six WTGS is collected as following:

i. Technical particulars of all WTGS (Given in article 4.2),

ii. Daily power generation data of each unit from April-2005 to March-2006,

iii. Wind speed data at the site,

iv. Unit wise maintenance sheet from April-2005 to March-2006.

For finding out the PLF, efficiency of each WTGS collected data is sorted unit wise.

4.3.1 Monthly average wind speed:

For calculation of monthly average wind speed data the data collected from site is used. Sample calculation for month of January is given below in the Table 5.

Table 4.1: Sample calculation for average wind speed in the month of January

Class interval (km/h)		Mean speed (Vm)			Jan	
From	To	km/h	m/s	V_m^3	F_i	$F_i \times V_m^3$
0.0	0.0	0.0	0.0	0.00	0.4	0.0
1.0	2.0	1.5	0.4	0.07	0.9	0.0
3.0	4.0	3.5	1.0	0.92	1.3	0.0
5.0	6.0	5.5	1.5	3.57	2.3	0.1
7.0	8.0	7.5	2.1	9.04	4.6	0.4
9.0	10.0	9.5	2.6	18.38	7.5	1.4
11.0	12.0	11.5	3.2	32.60	10.3	3.4
13.0	14.0	13.5	3.8	52.73	14.2	7.5
15.0	16.0	15.5	4.3	79.82	14.4	11.5
17.0	18.0	17.5	4.9	114.87	11.5	13.2
19.0	20.0	19.5	5.4	158.93	12.5	19.9
21.0	22.0	21.5	6.0	213.01	8.2	17.5
23.0	24.0	23.5	6.5	278.16	5.1	14.2
25.0	26.0	25.5	7.1	355.40	3.1	11.0
27.0	28.0	27.5	7.6	445.75	1.6	7.1
29.0	30.0	29.5	8.2	550.25	1.1	6.1
31.0	32.0	31.5	8.8	669.92	0.5	3.3
33.0	34.0	33.5	9.3	805.80	0.3	2.4
35.0	36.0	35.5	9.9	958.91	0.1	1.0
					Total	119.9

There fore Avg. V_m^3 for the month of January =119.9

V_m=4.9 m/s

However this wind speed is for 20 m height from ground level, therefore calculating the wind speed at the height of 31.5 m by using the eq. no. (3.6) and (3.7)

$$\alpha = \frac{0.37 - 0.088\ In(V_r)}{1 - 0.088\ In(\frac{Z_r}{10})}$$

$$\alpha = \frac{0.37 - 0.088\ In(4.9)}{1 - 0.088\ In(\frac{20}{10})}$$

$$\alpha = 0.25$$

$$\frac{V_r}{V_d} = (\frac{Z_r}{Z_d})^\alpha$$

$$\frac{V_{20}}{V_{315}} = (\frac{Z_{20}}{Z_{31.5}})^{0.25}$$

$$V_{31.5} = 5.7 \text{ m/s}$$

Similarly, for all other months,

Table 4.2: Average wind speed at 20 m and 31.5 m at Vijaydurg - Girye wind farm

Month	Avg. Wind Speed (m/s)	
	At 20 m	At 31.5 m
January	4.9	5.7
February	5.7	6.6
March	5.6	6.5
April	5.5	6.3
May	5.7	6.6
June	8.3	9.5
July	10.7	12.2
August	9.3	10.6
September	5.9	6.8
October	4.7	5.4
November	5.0	5.8
December	5.4	6.2

4.3.2 Average Efficiency of WTGS:

Low wind hours, machine down hours, grid down hours are calculated by using monthly maintenance sheet. By using generation data in each month and average wind speed calculated in article 5.3.1, the efficiency of all WTGS is calculated (for WTGS 1 in January-2006) shown below:

$P_a=0.5\times\rho\times A\times V^3=0.5\times1.153\times530\times(5.7)^3=56.58$ kW

By taking, $\rho=1.153$ kg/m^3, A=530 m^2, and V=5.7 m/s

Total generation hours for WTGS 1 in January-2006 are 673.05 hrs and number of units generated by WTGS 1 in January-2006 are 19930 (kWh).

Therefore, $C_p=\dfrac{29.61}{56.58}=0.5233$

4.3.3 PLF:

As given in Chapter-2, PLF or Capacity factor is the energy generated during a given period divided by the energy that would have been generated had the wind farm been running continually at maximum output.

Therefore, PLF for WTGS 1 in April-2005,

$$PLF=\frac{9550}{250\times24\times30}=0.0531$$

4.3.4 Machine availability:

The machine availability for WTGS 1 in April-2005 is,

$$\text{M/C availability}=\frac{\textit{Total time}-\textit{Machine Down Time}}{\textit{Total time}}=\frac{(30\times24)-1.45}{(30\times24)}=0.9890$$

Based on the calculations from article 4.3.2 to 4.3.4 for all WTGS the result are shown in Fig. 4.3. It can be seen that overall machine availability at Vijaydurg- Girye wind farm is 97%. But the generation hrs are only 68% and rest of the time the machine is un utilized due to low wind hrs in which machine rotor rotates but there is no generation as the wind speed is below cut in speed of the machine and unavailability of grid. Also the average efficiency of all WTGS is shown in Fig. 4.4. Also Tables 4.3 to 4.8 shows the unit wise performance of all WTGS. The graph follows the trend as in Fig. 3.13. Up to wind speed of 7.5 m/s efficiency tends to increase after that it decreases gradually. The maximum efficiency is about 52% at 7.5 m/s.

Table 4.3: Monthly performance of WTGS 1 in the year 2005-06

Month	Monthly Generation kWh	PLF (%)	V_m (m/s)	Low Wind Hrs	M/C Down Hrs.	Grid Down Hrs.	Total Down Hrs	Total Generation Hrs	M/C Availability	Efficiency
Apr-05	9550.00	5.31	6.3	206.67	1.45	44.92	253.03	466.96	0.9980	0.2677
May-05	9740.00	5.24	6.6	21.87	178.48	160.25	360.60	383.40	0.7601	0.2892
Jun-05	3800.00	2.11	9.5	0.00	440.05	247.67	637.72	32.28	0.3432	0.4494
Jul-05	42120.00	22.65	12.2	19.33	62.74	313.08	395.15	351.85	0.9160	0.2158
Aug-05	49790.00	26.77	10.6	37.97	20.68	101.55	160.20	583.80	0.9722	0.2344
Sep-05	24310.00	13.50	6.8	100.13	12.50	122.20	234.83	485.17	0.9826	0.5215
Oct-05	9050.00	4.87	5.4	180.30	0.00	112.17	292.47	451.53	1.0000	0.4166
Nov-05	10820.00	6.01	5.8	43.35	1.55	186.16	231.06	488.93	0.9978	0.3712
Dec-05	16710.00	8.98	6.2	75.10	4.34	7.58	87.02	656.98	0.9942	0.3493
Jan-06	19930.00	10.72	5.7	51.68	1.52	17.75	70.95	673.05	0.9980	0.5233
Feb-06	9010.00	5.36	6.6	136.18	4.30	22.00	162.48	509.52	0.9936	0.2013
Mar-06	17950.00	9.65	6.5	100.48	11.02	42.08	153.57	590.43	0.9852	0.3623
Total	222780.00	10.10		973.06	738.63	1377.41	3039.08	5673.90	0.9152	0.3502

Table 4.4: Monthly performance of WTGS 2 in the year 2005-06

Month	Monthly Generation kWh	PLF (%)	V_m (m/s)	Low Wind Hrs	M/C Down Hrs	Grid Down Hrs	Total Down Hrs	Total Generation Hrs	M/C Availability	Efficiency
Apr-05	8390.00	4.66	6.3	208.52	3.87	44.92	257.30	462.70	0.9946	0.2373
May-05	13120.00	7.05	6.6	34.85	36.95	160.25	352.05	511.95	0.9572	0.2917
Jun-05	17270.00	9.59	9.5	66.72	19.42	247.67	333.81	386.20	0.9730	0.1707
Jul-05	27630.00	14.85	12.2	5.95	210.70	313.08	529.73	214.27	0.7168	0.2324
Aug-05	50660.00	27.24	10.6	31.07	16.13	103.97	151.17	592.83	0.9783	0.2348
Sep-05	24480.00	13.60	6.8	92.27	12.03	124.82	229.12	490.88	0.9833	0.5191
Oct-05	7990.00	4.30	5.4	181.30	0.00	112.17	293.47	450.53	1.0000	0.3686
Nov-05	10110.00	5.62	5.8	51.48	18.54	186.16	256.18	463.82	0.9743	0.3656
Dec-05	13420.00	7.22	6.2	97.73	5.25	7.58	110.56	633.43	0.9929	0.2909
Jan-06	17560.00	9.44	5.7	80.77	2.68	17.75	101.20	642.80	0.9964	0.4828
Feb-06	8220.00	4.89	6.6	159.08	11.95	22.00	193.03	478.96	0.9822	0.1954
Mar-06	15380.00	8.27	6.5	112.75	18.68	42.08	183.51	570.48	0.9752	0.3213
Total	214230.00	9.73		1122.49	356.20	1382.45	2991.13	5898.85	0.9599	0.3092

Table 4.5: Monthly performance of WTGS 3 in the year 2005-06

Month	Monthly Generation kWh	PLF (%)	V_m (m/s)	Low Wind Hrs	M/C Down Hrs.	Grid Down Hrs	Total Down Hrs	Total Generation Hrs.	M/C Availability	Efficiency
Apr-05	8570.00	4.76	6.3	188.98	0.52	44.92	234.42	485.58	0.9993	0.2310
May-05	15120.00	8.13	6.6	16.82	0.00	160.25	177.07	566.95	1.0000	0.3036
Jun-05	19850.00	11.02	9.5	68.30	3.17	247.67	319.14	400.87	0.9956	0.1890
Jul-05	50310.00	27.05	12.2	12.50	2.53	313.08	328.11	415.88	0.9966	0.2180
Aug-05	51270.00	27.56	10.6	37.02	12.07	97.25	146.34	597.67	0.9838	0.2357
Sep-05	24170.00	13.43	6.8	95.93	0.00	116.83	212.76	507.23	1.0000	0.4960
Oct-05	7200.00	3.87	5.4	181.81	0.33	112.17	294.64	449.36	0.9996	0.3330
Nov-05	9870.00	5.48	5.8	59.27	0.46	186.16	245.90	474.10	0.9994	0.3492
Dec-05	12540.00	6.74	6.2	72.83	3.28	7.58	83.69	660.30	0.9956	0.2608
Jan-06	16470.00	8.85	5.7	62.05	1.42	17.75	81.22	662.78	0.9981	0.4392
Feb-06	7750.00	4.61	6.6	155.63	2.45	22.00	180.08	491.92	0.9964	0.1793
Mar-06	7750.00	4.61	6.5	155.63	2.45	22.00	180.08	491.92	0.9964	0.1878
Total	230870.00	10.51		1106.77	28.68	1347.66	2483.45	6204.56	0.9967	0.2852

Table 4.6: Monthly performance of WTGS 4 in the year 2005-06

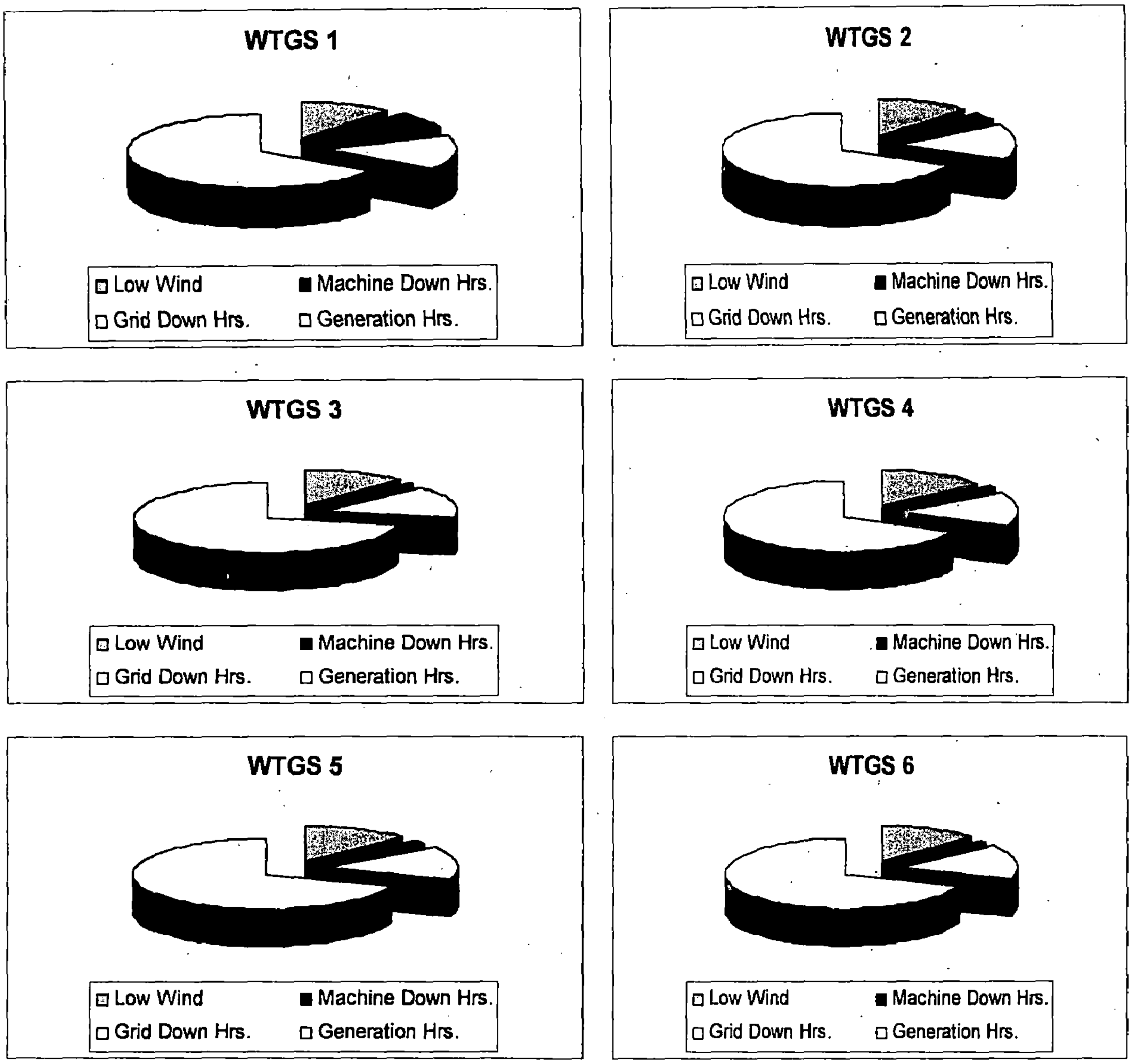
Month	Monthly Generation kWh	PLF (%)	Vm (m/s)	Low Wind Hrs	M/C Down Hrs	Grid Down Hrs	Total Down Hrs	Total Generation Hrs	M/C Availability	Efficiency
Apr-05	8370.00	4.65	6.3	203.28	39.53	44.92	287.73	432.26	0.9451	0.2534
May-05	15410.00	8.28	6.6	44.10	0.42	160.25	204.77	566.93	0.9995	0.3094
Jun-05	17780.00	9.87	9.5	73.17	7.83	247.67	328.61	391.33	0.9891	0.1734
Jul-05	44910.00	24.15	12.2	19.72	40.24	319.33	379.29	364.72	0.9459	0.2219
Aug-05	47510.00	25.54	10.6	42.93	26.83	102.35	172.11	571.88	0.9639	0.2283
Sep-05	21660.00	12.03	6.8	114.47	1.12	121.52	237.11	482.90	0.9984	0.4669
Oct-05	6050.00	3.25	5.4	208.23	2.35	112.17	325.10	418.90	0.9968	0.3002
Nov-05	8230.00	4.57	5.8	56.58	9.90	186.16	252.65	467.35	0.9863	0.2954
Dec-05	10650.00	5.73	6.2	98.12	25.73	7.58	131.43	612.57	0.9654	0.2388
Jan-06	13580.00	7.30	5.7	75.90	1.52	17.75	95.17	648.83	0.9980	0.3699
Feb-06	6680.00	3.98	6.6	203.53	3.10	22.00	228.63	443.37	0.9954	0.1715
Mar-06	14280.00	7.68	6.5	154.87	8.75	40.58	204.20	539.80	0.9882	0.3153
Total	215110.00	9.75		1294.90	167.32	1382.28	2846.80	5940.84	0.9810	0.2787

Table 4.7: Monthly performance of WTGS 5 in the year 2005-06

Month	Monthly Generation kWh	PLF (%)	Vm (m/s)	Low Wind Hrs	M/C Down Hrs	Grid Down Hrs	Total Down Hrs	Total Generation Hrs	M/C Availability	Efficiency
Apr-05	9160.00	5.09	6.3	189.58	1.17	44.92	235.67	484.33	0.9984	0.2475
May-05	16670.00	8.96	6.6	9.73	0.00	160.25	169.98	574.02	1.0000	0.3306
Jun-05	15420.00	8.56	9.5	78.20	19.60	247.67	345.47	374.53	0.9728	0.1572
Jul-05	34410.00	18.50	12.2	15.55	79.44	316.08	411.07	332.93	0.8932	0.1863
Aug-05	45840.00	24.64	10.6	28.50	34.31	101.95	164.76	579.23	0.9539	0.2175
Sep-05	22410.00	12.45	6.8	112.25	5.57	121.55	239.37	480.63	0.9923	0.4853
Oct-05	7610.00	4.09	5.4	201.50	0.33	112.17	314.33	429.67	0.9996	0.3681
Nov-05	9100.00	5.06	5.8	75.43	0.00	186.16	261.60	455.40	1.0000	0.3352
Dec-05	12150.00	6.53	6.2	72.68	12.29	7.58	92.55	651.45	0.9835	0.2561
Jan-06	16270.00	8.75	5.7	59.52	2.85	17.75	80.12	663.88	0.9962	0.4331
Feb-06	7620.00	4.55	6.6	172.58	1.73	22.00	196.31	475.68	0.9974	0.1824
Mar-06	16480.00	8.86	6.5	121.47	3.83	40.58	165.88	578.12	0.9949	0.3397
Total	213140.00	9.67		1136.99	161.12	1378.66	2677.11	6079.87	0.9816	0.2949

Table 4.8: Monthly performance of WTGS 6 in the year 2005-06

Month	Monthly Generation kWh	PLF (%)	Vm (m/s)	Low Wind Hrs	M/C Down Hrs	Grid Down Hrs	Total Down Hrs	Total Generation Hrs	M/C Availability	Efficiency
Apr-05	9330.00	5.18	6.3	207.82	16.55	44.92	269.28	450.71	0.9770	0.2709
May-05	17650.00	9.50	6.6	20.58	0.00	160.25	180.83	563.17	1.0000	0.3568
Jun-05	17710.00	9.83	9.5	67.28	6.69	247.67	321.64	398.37	0.9907	0.1697
Jul-05	42020.00	22.59	12.2	15.75	30.80	316.08	362.63	381.37	0.9586	0.1986
Aug-05	48240.00	25.93	10.6	30.63	0.00	98.75	129.38	614.62	1.0000	0.2157
Sep-05	22310.00	12.39	6.8	123.92	0.00	118.32	242.24	477.77	1.0000	0.4860
Oct-05	8100.00	4.35	5.4	190.77	0.00	112.17	302.94	441.06	1.0000	0.3817
Nov-05	8520.00	4.73	5.8	61.80	0.43	186.16	248.40	471.60	0.9994	0.3030
Dec-05	10590.00	5.69	6.2	104.33	35.47	7.58	147.38	596.62	0.9523	0.2438
Jan-06	15670.00	8.42	5.7	75.77	8.77	17.75	102.29	641.72	0.9882	0.4315
Feb-06	7800.00	4.64	6.6	148.53	2.97	22.00	173.50	498.50	0.9956	0.1781
Mar-06	18140.00	9.75	6.5	134.17	4.89	40.58	179.64	564.37	0.9934	0.3831
Total	226080.00	10.25		1181.35	106.57	1372.23	2660.15	6099.88	0.9878	0.3016



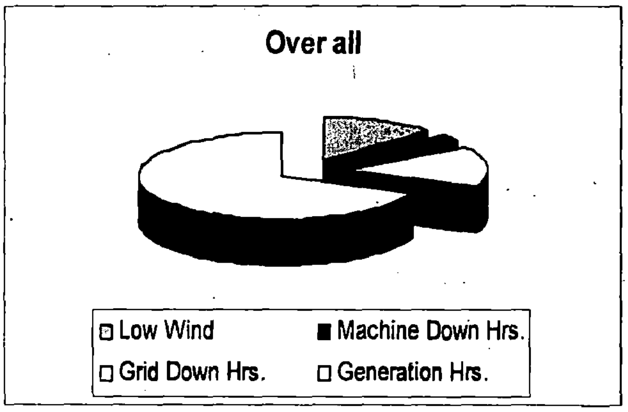


Fig. 4.3 Machine wise distribution of low wind hrs, machine down hrs, grid down hrs, and generation hrs at Vijaydurg - Girye wind farm in the year 2005-06

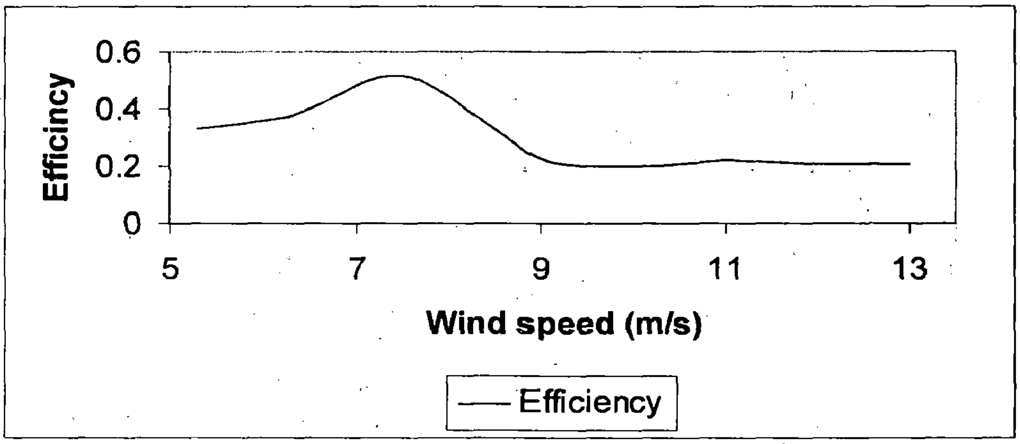


Fig.4.4 Average efficiency Vs Wind speed at Vijaydurg- Girye wind farm

4.4 PLF after increase in the Tower height:

The average PLF of all machines is found out to be 10%. However raising the tower height by some amount can increase this PLF. The present height of each tower at Vijaydurg- Girye wind farm is 31.5 m. The expected increase in generation can be find out by using the data supplied by MEDA and the using the equations (3.6), (3.7) and (3.9).

Following assumptions have been made:

i. Wind speed at the site remains constant,

ii. The machine availability and grid availability for respective month remains the same.

Taking scale factor and shape factor at 20 m height are as given in Table 4.9.

Table 4.9: Shape and scale factor on 20 m height at Vijaydurg - Girye wind farm [15]

Month	c (km/hr)	c (m/s)	k
January	16.4	4.6	2.6
February	19.4	5.4	2.9
March	19.0	5.3	2.7
April	19.2	5.3	3.2
May	19.0	5.3	2.3
June	27.1	7.5	2.5
July	36.7	10.2	2.3
August	31.3	8.7	2.8
September	17.7	4.9	1.8
October	14.3	4.0	1.9
November	17.0	4.7	2.9
December	18.6	5.2	3.0

By using Weibull's distribution the probability that speed in given month lies between 3.5 m/s to 25 m/s at given height by using Eq. No. (3.9) as follow:

$$p(V)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} e^{-(v/c)^{k}}$$

There fore for month of January at 40 m height, taking c=16.4 and k=2.6 and integrating within the limits 2.84m/s to 23.33 m/s

$$p(V)=\int_{2.84}^{23.33}\left(\frac{2.6}{4.6}\right)\left(\frac{v}{4.6}\right)^{(2.6-1)} e^{-\left(\frac{v}{4.6}\right)^{2.6}} dv$$

p (V)=0.7462

There fore expected generation hours in January= 0.7462×(31×24-Grid failure hrs)

= 0.7462×(31×24-17.75)

=730.75 Hrs.

The expected values for PLF up to 45 m are calculated. There is no significant improvement in PLF after 40 m refer Fig. 4.5; expected number of generation hrs for all machines at 40 m height is tabulated in Tables 4.10 to 4.15. The expected average PLF at 40 m height is 13%. The result is also shown in Fig. 4.6, as shown there is significant increase in PLF in month of April, May, June, February and March.

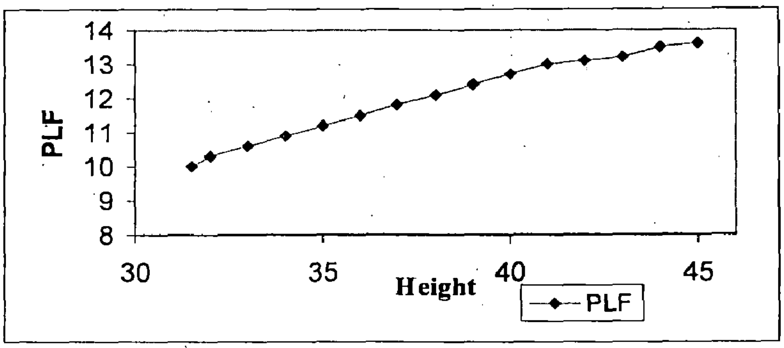


Fig. 4.5 Comparison of Height and PLF

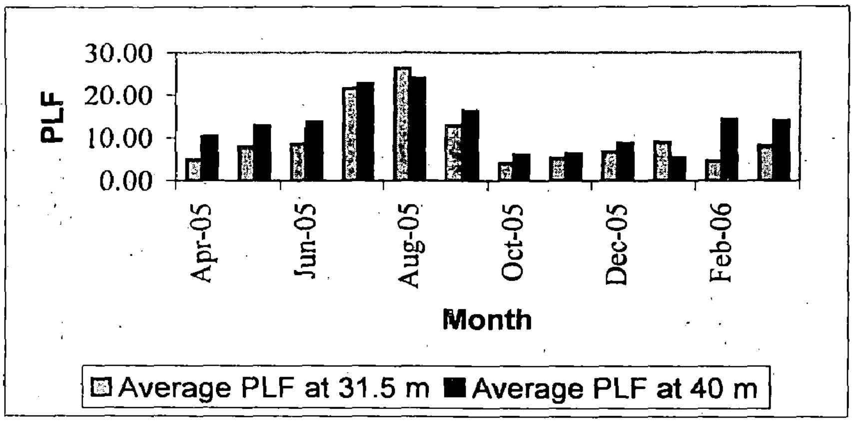


Fig. 4.6 Comparison of average PLF at 31.5 m and 40 m height

Table 4.10: Expected PLF of WTGS 1 at 40 m

Month	Monthly Generation kWh	PLF (%) Old	Total Generation (Hrs.) Old	Total Generation (Hrs.) at 40 m	V_m (m/s) at 40 m	M/C Availability	Efficiency	Expected Generation (kWh) at 40 m	Expected PLF at 40 m
Apr-05	9550.00	5.31	466.96	503.78	6.66	0.9980	0.42	19042.85	10.58
May-05	9740.00	5.24	383.40	499.41	6.97	0.7601	0.49	19223.75	10.34
Jun-05	3800.00	2.11	32.28	391.52	9.94	0.3432	0.24	9688.96	5.38
Jul-05	42120.00	22.65	351.85	377.21	12.70	0.9160	0.20	43207.60	23.23
Aug-05	49790.00	26.77	583.80	505.15	11.07	0.9722	0.22	44747.11	24.06
Sep-05	24310.00	13.50	485.17	547.76	7.17	0.9826	0.48	29142.22	16.19
Oct-05	9050.00	4.87	739.13	598.51	5.73	1.0000	0.33	11338.72	6.10
Nov-05	10820.00	6.01	488.93	511.07	6.14	0.9978	0.32	11550.36	6.42
Dec-05	16710.00	8.98	656.98	507.47	6.55	0.9942	0.38	16497.36	8.87
Jan-06	19930.00	10.72	673.05	428.06	6.04	0.9980	0.35	10056.86	5.41
Feb-06	9010.00	5.36	509.52	482.03	6.97	0.9936	0.49	24254.64	14.44
Mar-06	17950.00	9.65	590.43	594.51	6.86	0.9852	0.45	26048.19	14.00
Total	222780.00	10.10	5961.50	5946.47		0.9152		264798.62	12.08

Table 4.11: Expected PLF of WTGS 2 at 40 m

Month	Monthly Generation kWh	PLF (%)	Total Generation (Hrs.)	Total Generation (Hrs.) at 40 m	V_m (m/s) at 40 m	M/C Availability	Efficiency	Expected Generation (kWh)	Expected PLF at 40 m
Apr-05	8390.00	4.66	462.70	503.78	6.66	0.9946	0.42	18978.72	10.54
May-05	13120.00	7.05	511.95	499.41	6.97	0.9572	0.49	24209.23	13.02
Jun-05	17270.00	9.59	386.20	391.52	9.94	0.9730	0.24	27469.06	15.26
Jul-05	27630.00	14.85	214.27	377.21	12.70	0.7168	0.20	33811.02	18.18
Aug-05	50660.00	27.24	592.83	503.25	11.07	0.9783	0.22	44858.98	24.12
Sep-05	24480.00	13.60	490.88	545.36	7.17	0.9833	0.48	29033.77	16.13
Oct-05	7990.00	4.30	739.70	598.51	5.73	1.0000	0.33	11338.72	6.10
Nov-05	10110.00	5.62	463.82	511.07	6.14	0.9743	0.32	11277.22	6.27
Dec-05	13420.00	7.22	633.43	507.47	6.55	0.9929	0.38	16477.06	8.86
Jan-06	17560.00	9.44	642.80	428.06	6.04	0.9964	0.35	10041.15	5.40
Feb-06	8220.00	4.89	478.96	482.03	6.97	0.9822	0.49	23976.75	14.27
Mar-06	15380.00	8.27	570.48	594.51	6.86	0.9752	0.45	25784.77	13.86
Total	214230.00	9.73	6188.02	5942.16		0.9599		277256.44	12.67

Table 4.12: Expected PLF of WTGS 3 at 40 m

Month	Monthly Generation kWh	PLF (%)	Total Generation (Hrs.)	Total Generation (Hrs.) at 40 m	V_m (m/s) at 40 m	M/C Availability	Efficiency	Expected Generation (kWh)	Expected PLF at 40 m
Apr-05	8570.00	4.76	485.58	503.78	6.66	0.9993	0.42	19067.50	10.59
May-05	15120.00	8.13	566.95	499.41	6.97	1.0000	0.49	25290.83	13.60
Jun-05	19850.00	11.02	400.87	391.52	9.94	0.9956	0.24	28106.20	15.61
Jul-05	50310.00	27.05	415.88	377.21	12.70	0.9966	0.20	47008.91	25.27
Aug-05	51270.00	27.56	597.67	508.53	11.07	0.9838	0.22	45582.83	24.51
Sep-05	24170.00	13.43	507.23	552.68	7.17	1.0000	0.48	29923.50	16.62
Oct-05	7200.00	3.87	740.13	598.51	5.73	0.9996	0.33	11333.69	6.09
Nov-05	9870.00	5.48	474.10	511.07	6.14	0.9994	0.32	11567.89	6.43
Dec-05	12540.00	6.74	660.30	507.47	6.55	0.9956	0.38	16521.00	8.88
Jan-06	16470.00	8.85	662.78	428.06	6.04	0.9981	0.35	10058.21	5.41
Feb-06	7750.00	4.61	491.92	482.03	6.97	0.9964	0.49	24321.85	14.48
Mar-06	7750.00	4.61	491.92	611.52	6.86	0.9964	0.45	27097.03	14.57
Total	230870.00	10.51	6495.33	5971.78		0.9967		295879.44	13.51

Table 4.13: Expected PLF of WTGS 4 at 40 m

Month	Monthly Generation kWh	PLF (%)	Total Generation (Hrs.)	Total Generation (Hrs.) at 40 m	V_m (m/s) at 40 m	M/C Availability	Efficiency	Expected Generation (kWh)	Expected PLF at 40 m
Apr-05	8370.00	4.65	432.26	503.78	6.66	0.9451	0.42	18033.65	10.02
May-05	15410.00	8.28	566.93	499.41	6.97	0.9995	0.49	25277.06	13.59
Jun-05	17780.00	9.87	391.33	391.52	9.94	0.9891	0.24	27923.46	15.51
Jul-05	44910.00	24.15	364.72	371.74	12.70	0.9459	0.20	43971.01	23.64
Aug-05	47510.00	25.54	571.88	504.52	11.07	0.9639	0.22	44311.38	23.82
Sep-05	21660.00	12.03	482.90	548.38	7.17	0.9984	0.48	29644.65	16.47
Oct-05	6050.00	3.25	740.75	598.51	5.73	0.9968	0.33	11302.90	6.08
Nov-05	8230.00	4.57	467.35	511.07	6.14	0.9863	0.32	11416.12	6.34
Dec-05	10650.00	5.73	612.57	507.47	6.55	0.9654	0.38	16020.28	8.61
Jan-06	13580.00	7.30	648.83	428.06	6.04	0.9980	0.35	10056.86	5.41
Feb-06	6680.00	3.98	443.37	482.03	6.97	0.9954	0.49	24298.23	14.46
Mar-06	14280.00	7.68	539.80	595.78	6.86	0.9882	0.45	26184.70	14.08
Total	215110.00	9.75	6262.69	5942.26		0.9810			13.17

Table 4.14: Expected PLF of WTGS 5 at 40 m

Month	Monthly Generation kWh	PLF (%)	Total Generation (Hrs.)	Total Generation (Hrs.) at 40 m	V_m (m/s) at 40 m	M/C Availability	Efficiency	Expected Generation (kWh)	Expected PLF at 40 m
Apr-05	9160.00	5.09	484.33	503.78	6.66	0.9984	0.42	19050.27	10.58
May-05	16670.00	8.96	574.02	499.41	6.97	1.0000	0.49	25290.83	13.60
Jun-05	15420.00	8.56	374.53	391.52	9.94	0.9728	0.24	27462.00	15.26
Jul-05	34410.00	18.50	332.93	374.59	12.70	0.8932	0.20	41839.53	22.49
Aug-05	45840.00	24.64	579.23	504.83	11.07	0.9539	0.22	43876.55	23.59
Sep-05	22410.00	12.45	480.63	548.35	7.17	0.9923	0.48	29459.66	16.37
Oct-05	7610.00	4.09	739.91	598.51	5.73	0.9996	0.33	11333.69	6.09
Nov-05	9100.00	5.06	455.40	511.07	6.14	1.0000	0.32	11575.28	6.43
Dec-05	12150.00	6.53	651.45	507.47	6.55	0.9835	0.38	16320.04	8.77
Jan-06	16270.00	8.75	663.88	428.06	6.04	0.9962	0.35	10038.84	5.40
Feb-06	7620.00	4.55	475.68	482.03	6.97	0.9974	0.49	24348.00	14.49
Mar-06	16480.00	8.86	578.12	595.78	6.86	0.9949	0.45	26359.91	14.17
Total	213140.00	9.67	6390.11	5945.39		0.9816		286954.61	13.10

Table 4.15: Expected PLF of WTGS 6 at 40 m

Month	Monthly Generation kWh	PLF (%)	Total Generation (Hrs.)	Total Generation (Hrs.) at 40 m	V_m (m/s) at 40 m	M/C Availability	Efficiency	Expected Generation (kWh)	Expected PLF at 40 m
Apr-05	9330.00	5.18	450.71	503.78	6.66	0.9770	0.42	18642.67	10.36
May-05	17650.00	9.50	563.17	499.41	6.97	1.0000	0.49	25290.83	13.60
Jun-05	17710.00	9.83	398.37	391.52	9.94	0.9907	0.24	27968.19	15.54
Jul-05	42020.00	22.59	381.37	374.59	12.70	0.9586	0.20	44901.82	24.14
Aug-05	48240.00	25.93	614.62	507.35	11.07	1.0000	0.22	46227.05	24.85
Sep-05	22310.00	12.39	477.77	551.31	7.17	1.0000	0.48	29849.58	16.58
Oct-05	8100.00	4.35	739.65	598.51	5.73	1.0000	0.33	11338.72	6.10
Nov-05	8520.00	4.73	471.60	511.07	6.14	0.9994	0.32	11568.37	6.43
Dec-05	10590.00	5.69	596.62	507.47	6.55	0.9523	0.38	15803.04	8.50
Jan-06	15670.00	8.42	641.72	428.06	6.04	0.9882	0.35	9958.66	5.35
Feb-06	7800.00	4.64	498.50	482.03	6.97	0.9956	0.49	24302.96	14.47
Mar-06	18140.00	9.75	564.37	595.78	6.86	0.9934	0.45	26322.17	14.15
Total	226080.00	10.25	6398.47	5950.87		0.9878		292174.04	13.34

QUALITY STANDRADS

5.1 General:

In order to prepare a quality standrad, data from from wind farm have been collected, performance evaluation of a wind farm is coducted and presented in previous chapter. Based on the data collected from the wind farms an atempt has been made to prepare a quality standard which is presented in this chapter.

5.2 Wind turbine:

A **wind turbine** is a machine for converting the kinetic energy in wind into mechanical energy. If the mechanical energy is used directly by machinery, such as a pump or grinding stones, the machine is usually called a **windmill**. If the mechanical energy is then converted to electricity, the machine is called a **wind generator**. Wind generators are typically placed in large numbers, creating a wind farm. A **wind farm** is a collection of wind turbines all in the same location and used for the generation of electricity. Supply intended to provide a village, hamlet etc. with electricity for various appliances such as the following:

- Electricity for lighting and appliances fan, radio, TV, computer etc.) in home and public buildings such as schools and clinics.
- Electrical power for local service and industries.
- Electricity for lighting and general uses in public places and for collective use.

The electricity provided shall be in the form of 415/240 V AC line connections to users.
Main elements of Wind turbine system are:

i. Support structures: Tower, Fixtures and attachments.

ii. Power Generation System

- The Transmission system: The Hub, Main Shaft, Main Bearing, The Gear Box, The Coupling.
- The Generator

iii. The Control and Safety Systems: The Controller, Tip breaks, Hydraulic Brakes.

5.2.1 Scope:

The scope of the quality standards includes planning, designing, execution of civil works, installation of power generation equipment including turbine, drive system coupling between turbine and generator and/or mechanical device, generator, spares for operation of the plant; operation & maintenance etc.

5.2.2 Overall requirement:

The purpose of the present technical standards and specifications is to optimise the quantity, quality and safety of the electricity services provided by wind farm installations so as to meet the societal needs effectively and efficiently. The aim is to achieve the following objectives:

(i) **Guaranteed Output:** Plant owners and end-users place orders for various items that will satisfy their needs and, in turn, receive what they had ordered from suppliers in terms of available power at guaranteed efficiency.

(ii) **Reliable Operation:** During a specified service life, the Wind Turbine should not suffer from frequent outages and need for unanticipated repairs but should provide a high-quality continuous electricity service.

(iii) **Safety:** Electricity can be dangerous for people, equipment and property even when generated in small plants and quantities. Adequate protection shall be provided at the generating equipment, but also at the consumer end and throughout the electrical transmission (including transformers, surge arrestors etc.).

(iv) **Cost- effectiveness:** The Wind farm shall be planned and designed to achieve cost effectiveness.

5.3 Selection of Site:

On-site wind measurements should be taken prior to deciding to purchase a wind turbine. The data collected will determine the wind resource and help with wind turbine selection and economic value. The Wind speed should be measured for at least for one year. If possible Wind speed data of neighboring site should be referred for the analysis purpose. Power density and Velocity duration curve shall be drawn on the basis of wind speed data. These curves are useful for design and selection of wind turbine, tower height and type of tower.

a. In India Wind Farm planning considerations as per directed by MNES are as follows [16]:

- Average wind power density > 200 W/m^2 at 50 m height above the ground level
- Energy content > 2000 kWh/ m^2/year
- Land (10 Ha/MW); conjunctive use
- Accessibility – Transportation and erection
- Reliable grid/power dispatch network (33 kV and above preferred)
- Frequency : 47-52 Hz
- Voltage : + / - 15%
- Asymmetry : Within 15%
- Capacitors for compensation of reactive power consumption
- Wind penetration-20% of grid capacity

b. If the selected site comes under the forest area then Guidelines of forest land for non-forest purpose under the forest conservation act, 1980 shall be referred.

c. Anemometers, Indicators, Recorders, wind vane should be used while measuring the wind Speed and direction of wind

d. Wind mast should be at least 10 m high from the ground level to avoid the turbulence effects.

e. Measurements should be taken at the intended wind turbine location, the distance above the ground at which the turbine rotor hub will be located. If the instruments cannot be placed there, they should be placed near the intended location in a similar environment.

f. Measurements should be taken in an open area and not above the roof of a building where the wind flow is likely to be disturbed.

g. Requisites of the site as per IEC 60721-2-1:

- Grid availability.
- Accessibility for commissioning.
- Strong terrain / soil for proper foundation / civil work
- Favorable environmental condition to prevent corrosion & not prone to cyclone.
- Normal system operation ambient temperature range of -10^0 C to $+40^0$ C,
- Relative humidity up to 95 %,
- Atmospheric content equivalent to that of a non-polluted inland atmosphere
- Solar radiation intensity of 1000 W/m^2

h. Access to a site shall be safe and the following shall be taken into account:

- Barriers and routes of travel
- Traffic
- Road surface (Refer Fig. 5.1)
- Road width
- Clearance
- Access weight bearing capacity; movement of equipment at the site

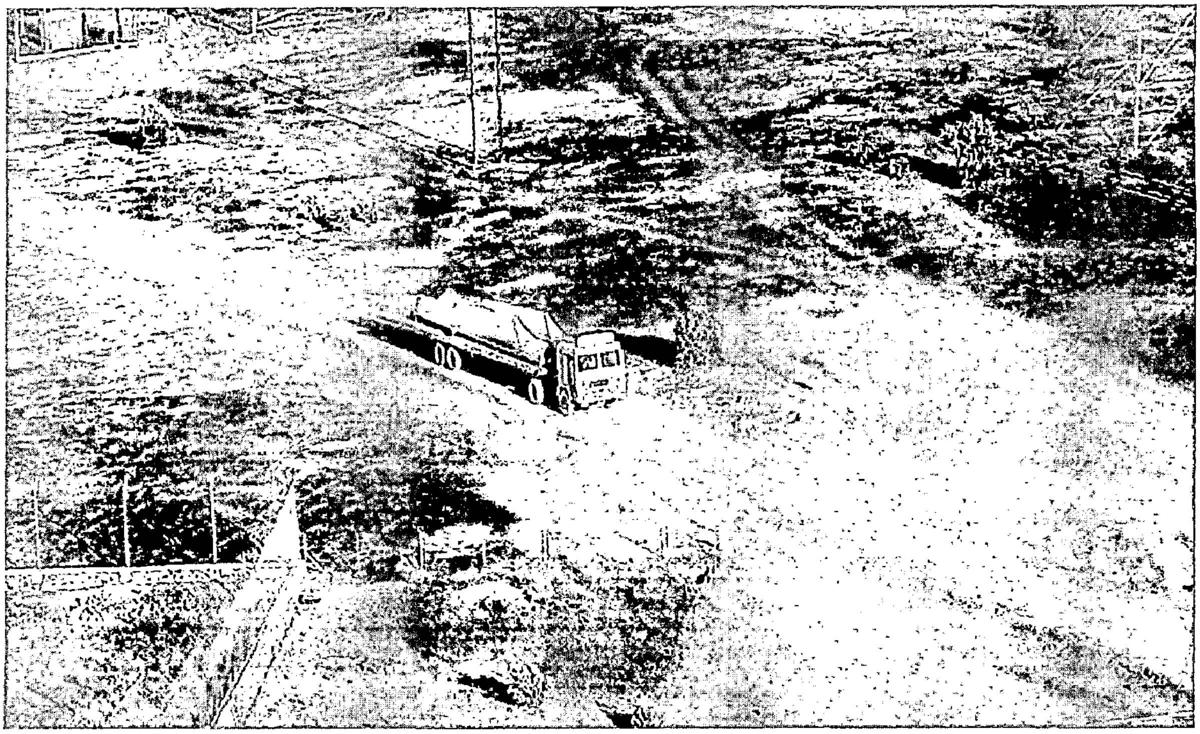


Fig. 5.1 (a)

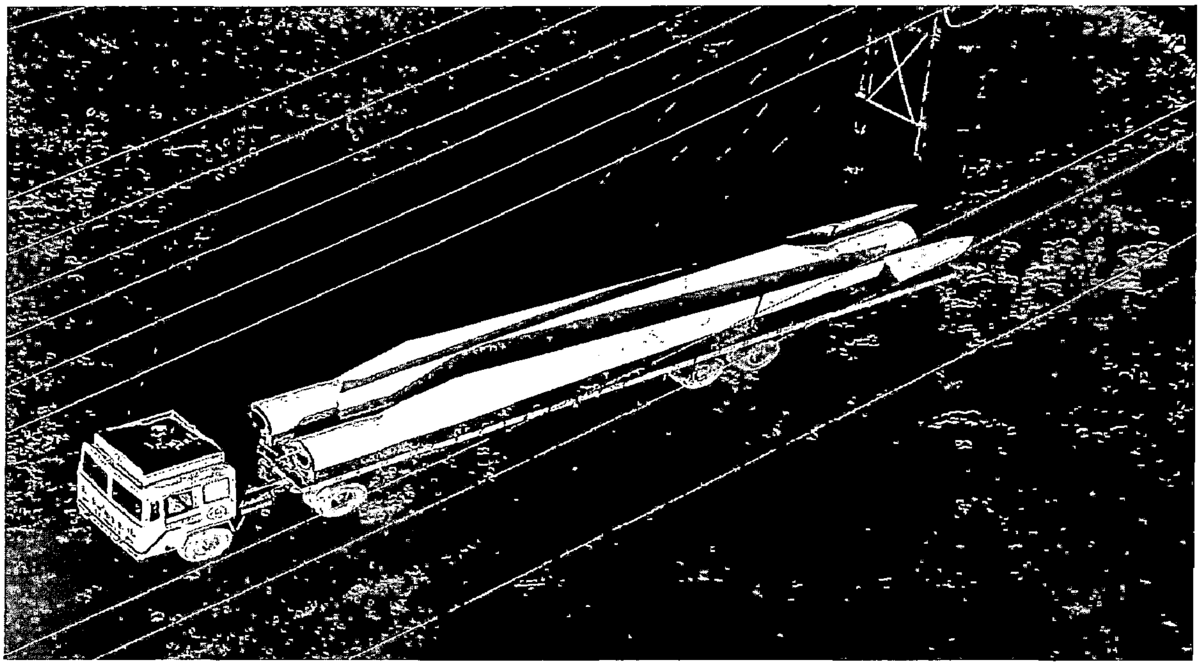


Fig. 5.1 (b)

Fig. 5.1 Appropriate road surface, road width and clearance shall be provided for easy access at wind farm (at Vankusavde wind farm)

5.4 Mechanical Equipments:

5.4.1 Instruction Manuals:

Instruction manuals complete in all respects shall be submitted before the shipment of the equipment by the manufacturers the instruction manuals shall contain full details and drawings of all equipments furnished, testing, operations and maintenance procedures etc. separately for each equipment.

5.4.2 Spare Parts and Site Consumables:

5.4.2.1 Spare Parts:

The recommended spare parts required for 5-year operation are to be procured along with the original equipment. All spare parts to be supplied shall be interchangeable with the corresponding parts of the Works and shall be of the same material and workmanship. They shall be replaceable without cutting or destruction of adjacent components. All spare parts shall be protected against corrosion and shall be marked with clear identification labels.

5.4.2.2 Tools:

The required tools for normal operation and maintenance shall be procured.

5.4.3 Manufacturing Requirements:

5.4.3.1 Materials:

All materials used, shall be new and of first class quality free from rust, defects and imperfections. Materials of limited shelf life shall not be used after their expiry date.

Casting shall not be warped or otherwise distorted. The structure of the casting shall be homogeneous and free from excessive non-metallic inclusions. An excessive segregation of impurities or alloys at critical points in a casting will be cause for its rejection.

5.4.3.2 Welding:

All welding shall be performed by electric-arc method and where practical, with process controlled automatic machines. Particular care shall be taken in aligning and separating the edges of the members to be joined by butt-welding so that complete penetration and fusion at the bottom of the joint will be ensured. Where fillet welds are used, the members shall fit closely and shall be held together during welding. After being deposited, welds shall be cleaned of slag and shall show uniform sections, smoothness of weld metal, featheredges without overlap, and no porosity and clinker. Where weld metal is deposited in successive layers, each layer shall be thoroughly penned before the next layer is applied. Visual inspection of the ends of welds shall indicate good fusion with the base metal. Welds shall be ground flush on both the inside and the outside wherever dynamic stress occurs.

5.4.3.3 Protection of Machined Parts at Manufacturing Works:

a. Protection of machined surfaces against damages:

Finish machined surfaces of large parts shall be applied with anti-corrosive paints and protected with rubber sheet and wooden pads or other suitable means against damages during handling and transportation. Un-assembled pins or bolts shall be oiled or greased and wrapped with moisture-resistant paper. Large size bolts and studs shall be wrapped by polythene tapes.

b. Protection of surfaces against corrosion:

All steel and structures parts including steel poles shall be galvanised.

c. Bolts, Screws and Nuts etc.:

All bolts, studs, screws, nuts, and washers shall be as per ISO metric system. Mild steel bolts and nuts shall be of the precision cold forged or hot forged type with machined faces parallel to one another.

5.4.4 Equipment installation:

a. General Requirements:

i. All construction materials, tools and equipment required for complete installation including control and instrument equipment shall be supplied.

ii. Erection procedures not specified herein shall be in accordance with the recommendations of the equipment manufacture.

b. Installation Materials:

All materials required for installation, testing and commissioning of the equipment including the embedment, inserts, outdoor bolts, grouting of foundation etc. required for the foundations shall be furnished along with the drawings.

c. Cleaning:

All equipment shall be cleaned of all sand, dirt and other foreign materials immediately after removal from storage.

d. Equipment Assembly:

Equipment installed under these specifications shall be assembled if transported unassembled. The equipment shall be dismantled and reassembled as required to perform the installation and commissioning work described in these specifications.

e. Protective Guards:

Suitable guards shall be provided for protection of personal on all exposed rotating or moving machine parts. All such guards with necessary spares and accessories shall be designed for easy removal and maintenance.

5.4.5 Power Generation Equipments:

5.4.5.1 Rotor:

a. Balancing:

The rotor shall be dynamically balanced at manufacturer's works before dispatch.

b. Design features:

The rotor must be of a design, which performs efficiently and reliably in site conditions at minimum cost.

c. Bolts securing the turbine/generator base-frame to the floor must be removable and not subject to corrosion seizure. The rotor mounting bolts shall be of stainless steel.

d. The installation must allow access to all sides of the rotor and space to dismantle it, and access for greasing and maintenance tasks should be provided.

e. Paintwork must be provided where ever necessary and kept in good condition to avoid corrosion.

f. Retaining bolts and runner inspection bolts shall be protected by grease from corrosion. These bolts shall be of stainless steel (Corrosion Resistant).

5.4.5.2 The Hub:

a. The hub of the Wind Turbine connects to the main shaft.

b. The hub must be able to withstand all the loads generated by the blade.

c. The hub should be made by casting by SG Iron. Casting should be preferred over welding as the hub material must be highly resistant to the metal fatigue.

d. The hub must be attached to the main shaft in such a way that it will not slip or spin the shaft.

e. For smaller turbines use of key and key way can be employed, with key ways on the shaft and the hub. The shaft can be threaded and mating surfaces should be machined for tight surface.

f. For bigger wind turbines use of a permanent flange is recommended.

F. Main Shaft/Low speed shaft/ Rotor shaft:

a. It is principal rotating element, which transfers torque from the rotor to the rest of drive.

b. It should be forged from hardened and tempered steel.

5.4.5.3 Bearings:

a. Spherical roller bearings should be preferred

b. The bearing must turn freely. (it should be possible to check with a feeler gauge that the rolling element clearance is within the manufacturer's tolerances). The bearings will not rattle.

b. The maximum allowable angle is 0.5^0 to compensate small errors in alignments between Wind Turbine shaft and the bearing housing.

c. Bearings should be always lubricated by greasing.

d. Sealing of bearing housing is ensured by labyrinth packing. No rubber sealing should be used.

5.4.5.4 Drive systems:

a. Drive systems are the most important component of the Wind Turbine. It is placed between the main shaft and the generator, its task is to increase the slow rotational speed of the rotor blades to the generator speed 1000 to 1500 rpm.

b. Many Wind Turbines offered in India are direct coupled (refer Annexure) in such cases where direct drive couplings are used, the alignment shall be checked.

c. Gear ratio of 1:6 in every step is acceptable.

d. Roughly 1 % of power loss in each step is acceptable.

e. Teeth of gears should be made of special low carbon chrome-nickel steel. The teeth should be case hardened and polished to minimize the erosion and smooth operation.

f. The coupling should be placed between gear-box and generator.

g. The flexible coupling should be preferred.

h. Flexible couplings shall be inspected for any degradation such as cracking or stretching, and for alignment.

5.4.5.5 Mainframe:

a. Gearbox, generator and brakes shall be mounted on the main frame. It provides a rigid structure to maintain the proper alignment among those components.

b. The turbine and generator shall be fixed securely to the base frame before installation to achieve correct positioning.

c. When mainframe is a separate component, it should be a rigid steel casting or weldment. Threaded holes or other attachment should be provided in appropriate locations for bolting of other components. When mainframe is integrated gearbox, the case should be thick enough to carry requisite loads.

5.4.5.6 Nacelle:

a. The whole assembly except rotor shall be placed inside the Nacelle. It gives the protection to the electrical and Mechanical components from Sunlight, rain, ice or snow.

b. It shall be made of a lightweight material, such as fiberglass.

c. For larger machines nacelle cover shall be of sufficient size that it can be entered by personnel for inspecting or maintaining the internal components. Refer Fig. 5.2

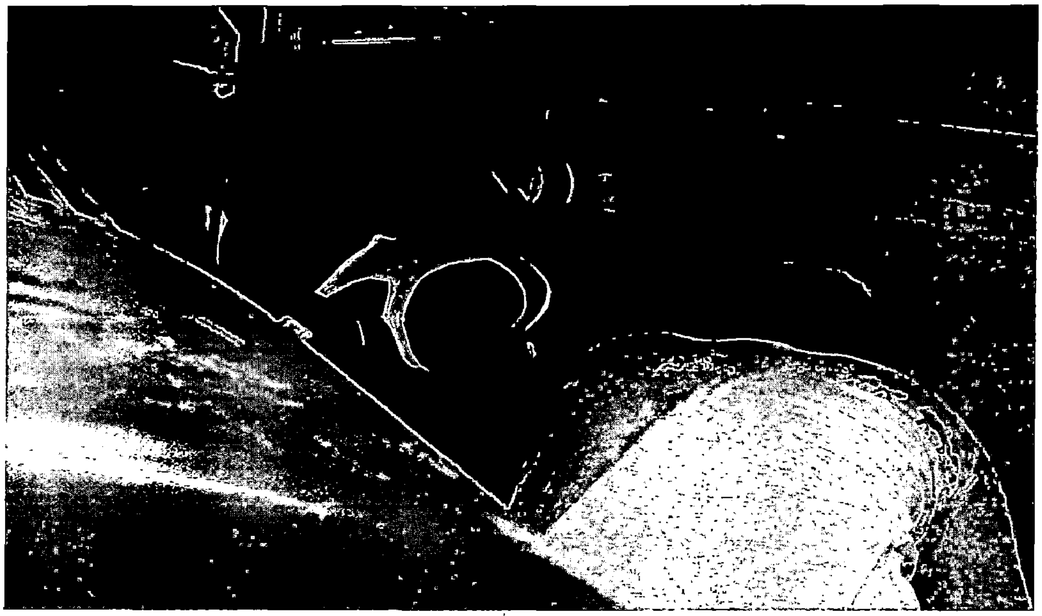


Fig. 5.2 Inside nacelle view (at Vankusawade wind farm)

5.4.7 Operations:

Personnel suitably trained or instructed in Wind turbine operations shall perform the operations.

a. Operations manual:

An operator's manual shall be supplied by the Wind Turbine manufacturer and augmented with information on special local conditions at the time of commissioning, as appropriate. The manual shall include:

- System safe operating limits and descriptions,
- Start and shutdown procedures,
- Emergency procedures plan.

The manual shall be available to the operation and maintenance personnel and shall be written in a language that can be read and understood by the operator.

b. The powerhouse shall be equipped with a logbook to a format that is in accordance with the maintenance / training manual and supplied accordingly. The logbook shall be supplied and used regularly and accurately during operation stage. Refer annexure 4.

d. A maintenance manual appropriate to the installation shall be supplied. Operations and maintenance records shall be kept and should include following:

- Wind Turbine identification
- Energy Produced
- Operating hours
- Shutdown hours
- Date and time of fault reported
- Date and time of service repair
- Nature of fault or service
- Action taken
- Parts replaced

5.4.8 Tools:

a. The wind farm shall be with a set of tools, which shall be detailed in the operator's manual.

b. The tool locations shall be silhouetted on a tool display board such that it is immediately apparent if a tool is missing or in use.

c. A rechargeable battery-powered lantern shall be provided, and this should be always charged or charging.

d. To test for correct alignments and runner and case tolerances, the basic tools such as a steel rule, a tape measure, some string, a square, feeler gauges, a dial gauge, and a spirit level shall be supplied.

Refer Annexure 2 for selection procedure of a wind turbine. Annexure 3 and 4 gives major technical particulars and power curves of certified WTGS by C-WET, offered by leading manufactures in India. Which can be used while selection of WTGS.

5.5 Electrical components:

5.5.1 General:

All electrical components shall meet the requirements of IEC-60204-1. The design of WTGS electrical system shall ensure minimum hazards to people and livestock as well as minimal potential damage to WTGS and external electrical system during operation and maintenance of WTGS. The design of electrical system shall take into account the fluctuating nature of the power generation from wind turbine.

5.5.2 Labels and Notices:

a. All electrical components shall carry labels describing their function. This applies particularly to switches and protection trips, circuit breakers, and fuses.

b. A block diagram showing the overall electrical layout shall be provided and shall be available in the wind farm, accessible, and durable. It should correspond to the labeling provided.

c. Individual units such as the controller shall have major internal connections and components labeled and should carry inside a circuit diagram corresponding to labels.

d. An illustrated notice in local language warning people of danger of electrocution shall be provided within easy view, and it shall be durable. It shall contain practical information on preventing and coping with electrocution and electric shock.

e. High voltage warning labels shall be placed on all cabinet doors and terminal covers enclosing equipment operating at above 50 volts.

5.5.3 Shielding:

All **live surfaces and points** shall be fully and reliably **shielded** from human contact. Cables and their connections to units shall be shielded both by conduit and by their insulation, and connections shall be within closed casings. **Door interlock isolators,** to isolate supply when the door is open, shall be provided on control gear with voltages above 50 Volts in order to ensure safe working.

5.5.4 Maintenance:

A maintenance manual shall be provided in place and used during operation stage.

5.5.5 Earthing:

a. The design of a WTGS system shall include a local earth electrode system to meet the requirements of IEC 60364 (For the correct operation of the electrical installations).

b. The range of soil conditions for which the earth electrode system shall be stated in design documentation together with recommendations should other soils conditions be encountered.

c. The choice and installations of the equipment of the earthy arrangement shall be made in accordance with IEC 60364-5-54.

5.5.6 Lightning protection:

To disperse lightning currents flows a earthing shall be provided. IEC 61024-1 shall be referred for design of earthing system.

5.5.7 Cables:

a. Strong conduit must be used to protect all cable in the wind farm from vermin attack to the insulation. Knockouts shall also be suitable protected. The end-of cable terminals shall be protected yanks or pulling. It should be ensured that the conduit is strong and physically secured to all enclosures by means of threaded connectors secured to the enclosure, so that any yank to the conduit is not transferred to the cable connections. The conduit shall also be sealed to the enclosure entrances in order to prevent insect and dust ingress.

b. Cable sizing. Current handling capacities of the cables should be 40%-50% greater than the rating of the over current protection device(s), after taking account of de-rating required for use in conduit and multiple cables.

c. Cables should not feel over-warm to the touch. If so, cables are undersized and should be replaced or doubled-up.

d. Power cables must be transferred from the generator down the tower to electrical switchgear at the base.

e. Copper conductors shall be preferred for minimum losses.

f. Power Cables should be continuous, and provided with substantial slack to avoid damages from yawing.

g. When the power cable wraps up too far, they must be unwrapped manually by disconnecting them or by using yaw drive.

h. Underground cables shall be buried at suitable depth so that service equipments or wind farm equipment does not damage them. Underground cables shall, if not protected by a conduit or duct, be marked by cable covers or suitable marking tape.

5.5.8 Sockets:

One or more electric sockets (outlet) shall be provided to allow use of electrical appliances and tools in the wind farm.

5.5.9 Lighting:

a. The control room must have safe illumination (minimum 10 watts/m^2 of floor area incandescent).

b. A battery-charging type lantern ("emergency lamp") on the tool display board, in charged or charging state, shall be provided.

c. An installation-powered light in wind farm area shall be provided.

4.4.10 Isolation switch:

a. A switch allowing the distribution system to be isolated from the generator and controller shall be provided. This should be located near the transformer and clearly labeled.

b. The switch must have a current rating equal to or higher than the rating of the OC trip.

5.5.11 Generator:

a. The following information shall be as a minimum, prominently and legibly displayed on the WTGS:
    - WTGS manufacturer and country
    - Model and serial number

- Production year
- Rated power
- Hub-height operating wind speed range
- Operating ambient temperature range
- WTGS class
- Rated voltage at the WTGS terminals
- Frequency at the WTGS terminals

b. Over-rating. The power rating given on the original nameplate must be at least 10% more than rated power.

c. Generator voltage. This must be between the nominal national voltage ±10%.

5.5.12 Instrumentation:

a. All instrumentation may be included on the control panel. Instrumentation should be at eye level or 1.5 meters from floor level.

b. Voltage. A voltmeter with voltmeter switches shall be provided.

c. Current. On a 3-phase system an ammeter shall be provided.

d. Frequency. On induction generator systems, a frequency meter shall be provided, to facilitate adjustment of the excitation capacitance and to indicate whether capacitors have failed.

5.6 Civil works:

Major component in civil works is a tower. Towers are support to raise main parts of the turbine in the air.

a. There are three types of tower in common use for horizontal axis turbines:

- Free-standing lattice (truss),
- Cantilevered pipe (tubular),
- Guyed lattice pole

b. Tubular towers have advantage unlike lattice tower, they rely on many bolted connections, which need to be torque and checked periodically. Also provided protected area for climbing to access the machine. Aesthetically they provide a shape, which is considered by some to be visually more pleasing them over struss.

c. Steel is preferred material for manufacture of wind turbine towers. Reinforced concrete is anther choice.

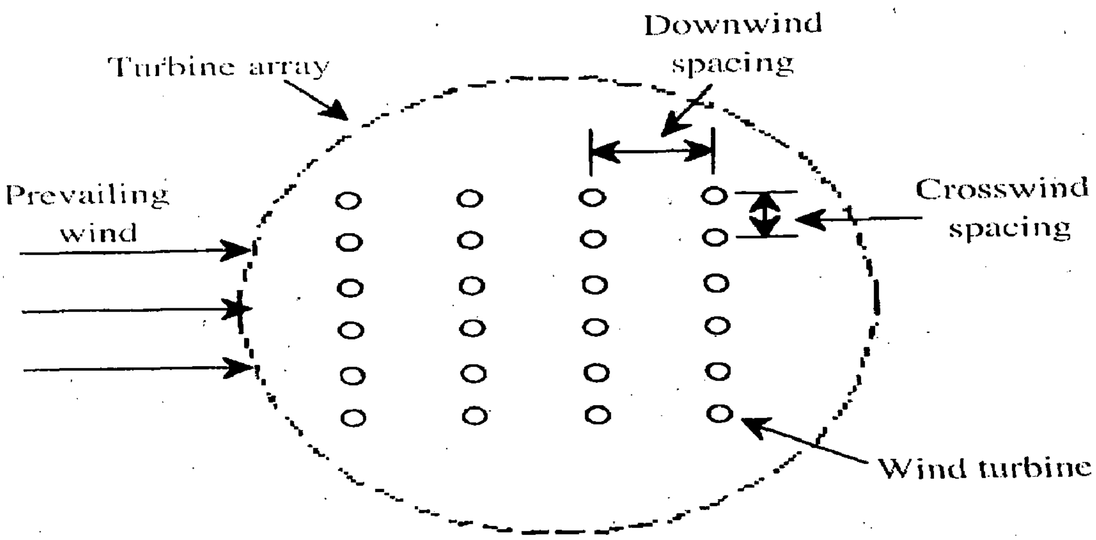
d. Wind turbine structural design shall be based on verification of the structural integrity of the load-carrying components. The ultimate and fatigue strength of the members shall be verified by calculations and or test. The structural analysis shall be based on ISO 2394. Loads to be considered in design calculations:

- Inertial and gravitational load: Inertial and gravitational loads are static and dynamic loads acting on WTGS resulting from vibration, rotation, gravity.
- Aerodynamic loads: These are caused by the airflow and its interaction with the stationary and moving parts of WTGS.
- Operational loads: These are the result of the operation and control of WTGS. They include drive train mechanical braking and transient loads, caused by rotor stopping and starting, yawing loads etc.
- Other loads: Such as wake load, impact loads, ice loads etc.

e. Steel should be galvanized or painted to protect it from corrosion.

f. The height of a tower is normally at least as high as the diameter of the rotor. Generally, tower height should not be less than 24 m because the wind speed is lower and more turbulent so close to ground.

g. Turbines shall be spaced eight to ten times diameter of the rotor apart in prevailing wind direction and five times rotor diameter in cross wind direction. In such cases array losses can be less than 10%. Refer figure 5.3.



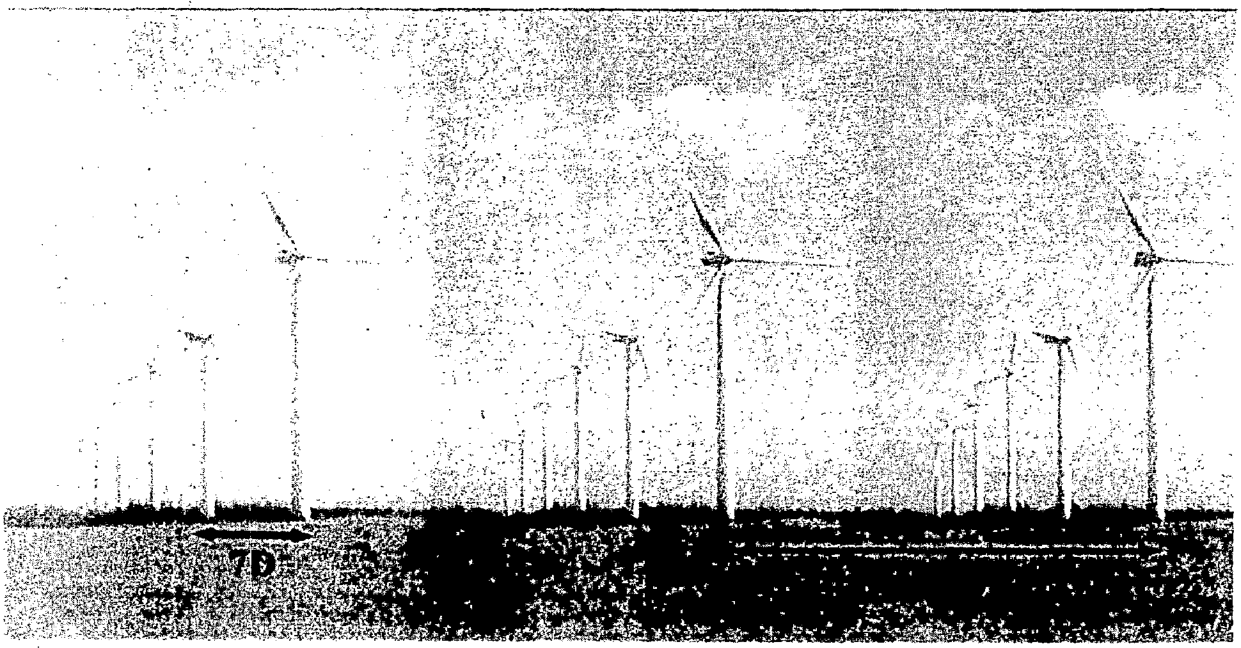


Fig. 5.3 Figure showing crosswind spacing and down wind spacing at wind farm [17]

h. Commonly found heights of tower in India are 30 m, 40 m, and 50 m.

i. Tower top provides interface for attaching the main frame of the wind turbine to the tower. Stationary part of bearing should be attached to the tower top.

j. The foundation of tower must be sufficient to keep the turbine upright and stable under the most extreme design conditions. The weight of the concrete is chosen to provide resistance to overturning to under all conditions. In case of rocks foundation may consists of rods grouted into holes drilled into the rock. A concrete pad may be used to provide a level surface. Refer Annexure 6 for typical lattice tower foundation.

5.7 Installations, Operation and Maintenance:

5.7.1 Installations:

a. Foundation/anchor systems: Where specified by the manufacturer for safe installation or assembly, special tools, jigs and fixtures and other apparatus shall be used.

b. Assembly of Wind Turbine Generator Systems: A WTGS shall be assembled according to the manufacturer's instructions. Inspection shall be carried out to confirm proper lubrication and pre-service conditioning of all components.

c. Erection of Wind Turbine Generator Systems: A WTGS shall be erected by personnel trained and instructed in proper and safe erection practices. No part of a WTGS electrical system shall be energized during erection unless it is necessary for the erection process. In this case, the energization of such equipment shall be carried out in accordance with a written procedure to be provided by the WTGS supplier. All elements where motion (rotation or translation) may result in a potential hazard shall be secured from unintentional motion throughout the erection process.

d. Fasteners and attachments: Threaded fasteners and other attachment devices shall be installed according to the WTGS manufacturer's recommended torque and/or other instructions. Fasteners identified as critical shall be checked and procedures for confirming installation torque and other requirements shall be obtained and used.

In particular, inspection shall be carried out to confirm the following:

- proper assembly and connection of guys, cables, turn buckles, gin poles and other apparatus and devices;
- proper attachment of lifting devices required for safe erection.

d. Cranes, hoists and lifting equipment: Cranes, hoists and lifting equipment, including all hoisting slings, hooks and other apparatus required for safe erection, shall be adequate for safe lifting and final placement of the loads. Manufacturer's instructions and documentation with respect to erection and handling should provide information on expected loads and safe lifting points for components and/or assemblies. All hoisting equipment, slings and hooks shall be tested and certified for safe load.

e. Commissioning tests: Wind Turbine Generator systems shall be tested, after installation to confirm proper, safe and functional operation of all devices, controls and apparatus and be tested in accordance with the manufacturer's recommended procedures. Testing shall include, but not limited to:

- safe start-up
- safe shutdown
- safe emergency shutdown
- safe shutdown for over speed
- function test for protection system

5.7.2 Operation and Maintenance:

a. A manual comprising a detailed description of the operating procedures and maintenance tasks as well as detailed drawings of all components in local language (or English) must be compiled by the design engineer. The following specifications must be included.

b. Address and phone number of suppliers and sub-suppliers for spare part ordering and guarantee claims.

c. Technical description and specifications relevant for operation & maintenance.

d. Lubrication table and required lubricants for all bearings, gearbox etc.

e. Operation instructions for start-up, shut down, emergency.

f. Checklist for normal operation (bearings, instruments, coupling rubbers, noise, vibrations etc.)

g. Check list for fault detection and communication with manufacturer

h. Sample (master copy) for operation sheet for the operator (data, instrument readings, observations, reading interval, remarks and signature) Refer Annexure 5.

i. Sample (master copy) for maintenance sheet for the operator (lubrication intervals, check interval, signature)

j. Wiring diagram of power-station with description of all fuses (type, size)

k. A wind turbine system must be stopped at least once in a six month for cleaning and to check for erosion damage around structures, cracks, corrosion damage etc.

l. Movable parts shall be greased regularly and test-operated at least once a month.

m. Faulty civil structures and damages must be regularly (min. 6 months) repaired.

n. The bearings should be manually checked for vibration and excess temperature at least twice a week unless the control system provides automatic temperature monitoring. The temperature of the bearing housing should not exceed the limit prescribed by the manufacturer. Manufacturer's maintenance manual takes precedence over the following rules.

o. All fastener connections of the foundation; turbine, generator and other vibrating parts should be checked 1 week and 4 weeks after commissioning or any assembly work. Regular checks shall be made every 6 months.

p. Abnormal leakages are an indication for changing the seals or other worn out parts. Leakages may also indicate loose fasteners.

5.7.3 Safety:

a. The emergency procedure plan shall take following into account:

- Over speeding
- Icing conditions
- Lightning storms
- Earthquakes
- Broken or loose guy-wires
- Brake failure
- Rotor imbalance
- Loose fasteners
- Lubrication defects
- Sand storms
- Fire, flooding
- Other component failure

b. Guards shall be provided to the personnel for climbing on the tower

c. Safe access paths and working places for inspection and routine maintenance

d. Warning signs for live conductors

e. Suitable fire protection

f. An alternative escape route from the nacelle Refer fig. 5.4.

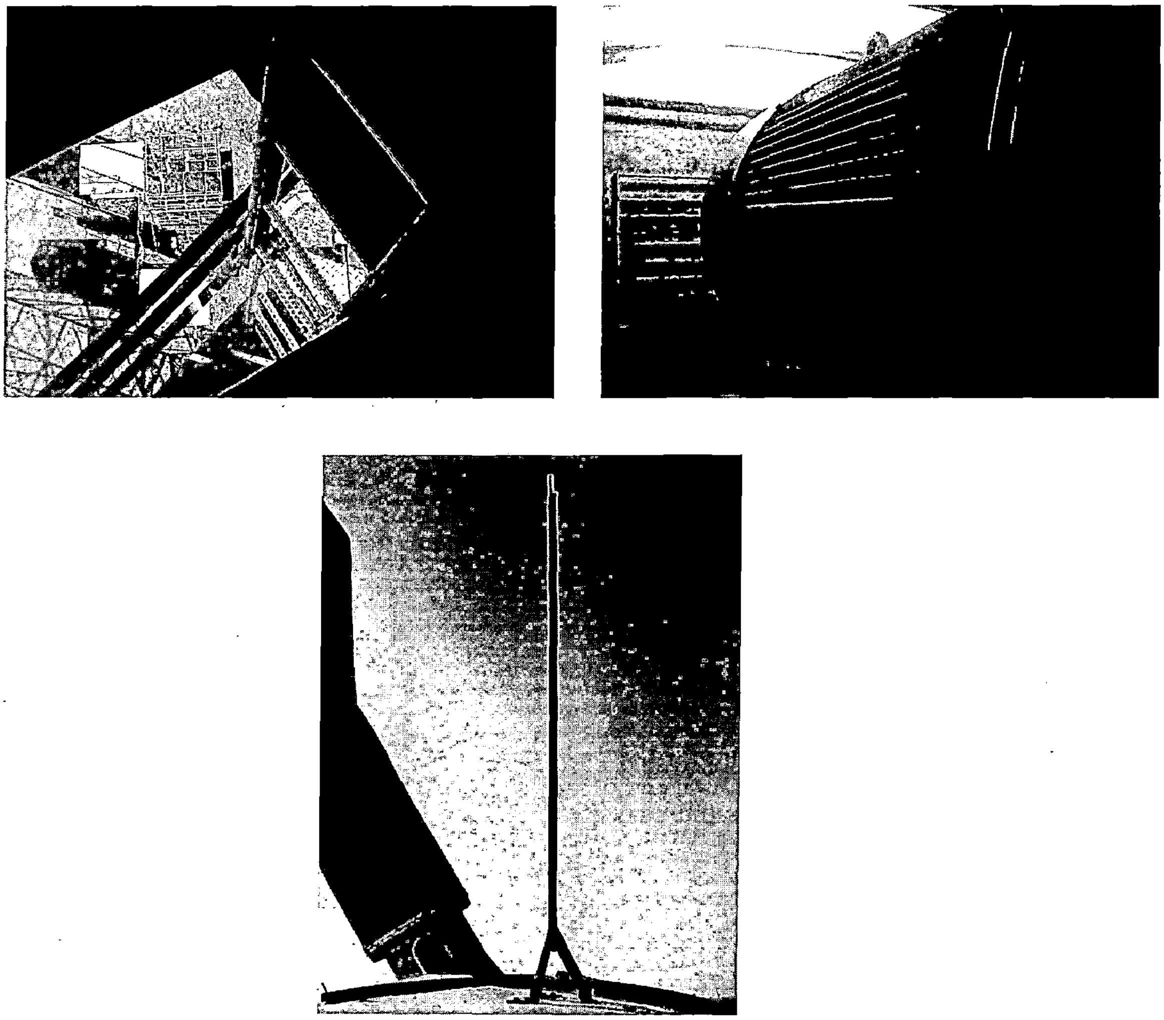


Fig. 5.4 Figures showing entry route, alternate escape route of a nacelle and a lightening protection (at Vankusavde wind farm)

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions:

On shore wind potential of India is 48,199 MW however technical potential is limited to 14,775 MW of which 4, 228 MW has been exploited so far. Today wind energy in India is contributing 3% of total installed capacity through conventional type of sources. Hence there is lot of scope for wind energy development in India. However, the main problem is technology, which is being imported. Some other barriers are need of strong financial base; need to bring down the cost/kWh, long term PPAs, and lack of awareness on positive aspects of wind farms.

In order to make a quality standard studying various components during site visits and conducting performance evaluation of Vijaydurg-Girye wind farm have under taken present study. An attempt has been made for preparation of a quality standard keeping in mind the problems associated with wind farm installations and operations observed in site visits as following:

- Transportation and installation in hilly area
- Problems associated with rotor blade i.e. failure due to fatigue
- Mechanical brakes/hydralic brake failure due to wearing or leakage of brake oil
- Leakage of gear oils etc.
- Yawing problems: related to twisting of power cables
- Lightning problems
- Grid problems
- Environmental issues like Noise level
- Civil structure maintenance

Based on performance evaluation of Vijaydurg-Girye wind farm, following are conclusions

- Average PLF at Vijaydurg – Girye wind farm is 10% at 97% machine availability and 84% grid availability

- Efficiency Vs Wind speed follows the general trend i.e. gradual increase in efficiency of 52% up to 7.5 m/s and the gradual decline in efficiency.
- The maximum generation occurs in the monsoon period i.e. in month of July-2005 to September-2005. The generation in this period is about 67% of total generation.
- PLF of wind farm can be increased to 13% by raising the tower height to 40 m with 97% machine availability and 84% grid availability.

6.2 Recommendations:

An attempt has been made for preparation of a quality standard but it is unconcluded. However there is further scope for improvement in this quality standard to bring this in final stage.

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17. Indian Wind Turbine Manufacturers Association, www.indianwindpower.com

ANNEXURE-1

WIND TURBINE STANDARDS

IEC 61400-1-Safty of WTGS:

Deals with safety philosophy, quality assurance and engineering integrity, and specifies requirements for the safety of WTGS, including design, installation, maintenance and operation under specified environmental conditions. Its purpose is to provide the appropriate level of protection against damage from all hazards from these systems during their planned lifetime. This standard is concerned with all subsystems of WTGS such as control and protection mechanisms, internal electrical systems, mechanical systems, support structures, foundations and the electrical interconnection equipment.

IEC 61400-2-Small Wind Turbine Safety Systems:

Deals with safety philosophy, quality assurance, engineering integrity and specifies requirements for the safety of Small Wind Turbine systems, including design, installation, maintenance, and operation under specified external conditions. This standard is concerned with all subsystems of Small Wind Turbine systems such as protection mechanisms, internal electrical systems, mechanical systems, support structure, foundations and electrical interconnection with the load.

IEC 61400-12- Power Performance Measurement Techniques:

Specifies a procedure for measuring the power performance characteristics of WTGS of all types and sizes connected to the electrical power network. It is applicable for both the determination of the absolute power performance characteristics of a Wind Turbine Generator system and relative differences among the Power Performance characteristics of various Wind Turbine Generator configurations.

IEC 61400-13-Acoustical Measurement Techniques:

Presents sound a measurement procedure that enables noise emissions of a Wind Turbine to be characterised. This involves using measurement methods appropriate to noise emission assessment at locations close to the machine, in order to avoid errors due to sound propagation, but far enough away to allow for the finite source size.

IEC 61400-13-Load Measurements for WTGS:

Develop guidelines for measuring loads on Wind Turbine structures (Scope of work under development).

IEC 61400-22-Certification Standard:

Develop guidelines for certification and type approval of turbines using test data and analysis structures (Scope of work under development).

IEC 61400-23-Full Scale Structural Testing Of Rotor Blades for WTGS:

This standard is intended to be used as a guideline for full scale testing of rotor blades of a possible part of a final design verification of the structural integrity of the blade. The tests included are fatigue tests, static tests and model tests. The standard describes recommended practices to perform various tests on full-scale blades and gives guidance on interpretation or evaluation of results. It describes the blade and load data with the appropriate format necessary to evaluate the test results. Guidance is given on which (partial) safety factors should be incorporated during testing and evaluation.

IEC 61400-21-Power Quality Requirements for Grid Connected Wind Turbine:

To prepare a standard for determining the characteristics of Wind Turbine output, with respect to the impact on the power quality in the public supply system, while securing proper operation of the Wind Turbine.

IEEE Standard:

IEEE 1094-1991 standards recommended practice for the Electrical Design and Operation of Wind farm Generation Station.

Authorized Organization For Certification Of Wind Turbines in India:

C-WET (Center for wind energy Technology), Chennai, is the authorized body who issues certificates to wind turbines for their exclusive use in India. The activities of C-WET are as follow:

i. Research and Development,
ii. Wind resource assessment,
iii. Testing,
iv. Standards and certifications,
v. Information, training and commercial services.

Taking into consideration of the Indian conditions especially wing and grid conditions, the certification system for India has been prepared, viz., Type approval-provisional scheme (TAPS-2000). As per TAPS-2000, the Provisional Type Certification (PTC) is being carried out under three categories, as detailed below:

- Category–I: PTC for wind turbine generators already possessing valid type certificate or approval.
- Category–II: PTC for wind turbine generators already possessing valid type certificate or approval with minor modifications/changes.
- Category–III: PTC for new or significantly modified wind turbine generators.

ANNEXURE-2

WIND TURBINE SELECTION

- Select initial tower height to clear obstacles and reduce surface roughness effects.
- Calculate Wind Turbine diameter (Rotor diameter)

i. $$D=\sqrt{\frac{0.145 \times E_{wind}}{Cp \times Vm^{3}}}$$

ii. C_p=0.25 (Typical value)

iii. $V_{in} \leq 0.6 \times V_m$

iv. $V_r = 3 \times V_m$

v. $V_{out} \geq 5 \times V_m$

vi. $P_r = 0.5 \times \rho \times C_p \times A \times V_r^3$

- Select a Wind Turbine from a commercial manufacturer
- Obtain Power Vs Wind Speed characteristics of the Wind Turbine. The Wind Turbine should be matched to the wind speed frequency distribution at the site.
- Analyse the chosen wind turbine performance at the initial tower height using wind speed frequency distribution data and the power curve.
- Optimise the performance by changing the tower height as necessary.
- Select a more suitable wind turbine if necessary and repeat analysis to optimise the performance.

ANNEXURE-3

Table A: Major technical particulars of wind turbine generator systems in India

(In the ascending order of rating from 225 kW to 2000 kW)

Sr.		225 kW			230 kW	250 kW	
No.	Item	1	2	3	4	5	6
1	Make	JMP Ecotecnia	NEPC India	Vestas RRB	Enercon	AMTL-Windworld	BHEL-Nordex
2	Model No.	Ecotecnia28/225	NEPC	V 27	E-30	W-2500-250	N29/250
3	Rating kW	225/40	225 / 40	225 / 50	230	250	250/45
4	Rotor Diameter (m)	28	29.8	27	30	25	29.7
5	Highest Hub Height (m)	41	45	50	50	31	30/40
6	Type of tower	Lattice	Tubular	Lattice	Tubular	Tubular	Lattice
7	No. of blades	3	3	3	3	3	3
8	Power regulation	Stall	Stall	Pitch	Pitch	Stall	Stall
9	Type of generator	Asyn.	Asyn.	Asyn.	Syn.	Asyn.	Asyn.
10	Single speed / Double speed / Variable speed (Generator)	Dual	Dual	Dual	Variable	Dual	Single
11	AC/ DC /AC system	No	No	No	Yes	No	No
12	Rated Voltage (V)	400	400	400	415	415	415
13	Geared / Gearless	Geared	Geared	Geared	Gearless	Geared	Geared
14	Cut-in speed (m/s)	4.5	4	3.5	2.5	3.5	4
15	Cut-out speed (m/s)	25	25	25	25	25	25
16	Rated speed (m/s)	14.5	15	13.56	12.5		15
17	Survival wind speed (m/s)	70	60	70	60		70
18	Weight						
	a. Tower (kg)	13000		24000	31000	14000	
	b. Nacelle (kg)	7170		8500	11000	6700	
	c. Rotor (kg)	3115		2900	4500	4500	
	d. Total (kg)	23285		35400	46500	25200	33500

(Continued Table A)

Sr. No.	Item	250 kW					
		7	**8**	**9**	**10**	**11**	**12**
1	**Make**	CWEL	Das Lagerway	India Wind Power	NEPC India	Pioneer Wincon	Shri Ram EPC (TIG)
2	**Model No.**	C2920/250	LW30/250	Iwind-29/250	NEPC	W250/29	250T
3	**Rating kW**	250	250	250/45	250/50	250	250/80
4	**Rotor Diameter (m)**	29.2	30	29.7	27.6	29	28.5
5	**Highest Hub Height (m)**	41.5	36.5	50	45	50	40
6	**Type of tower**	Tubular	Lattice	Lattice	Tubular	Lattice	Lattice
7	**No. of blades**	3	2	3	3	3	3
8	**Power regulation**	Stall	Pitch	Stall	Stall	Stall	Stall
9	**Type of generator**	Asyn.	Asyn.	Asyn.	Asyn.	Asyn.	Asyn.
10	**Single speed / Double speed / Variable speed (Generator)**	Dual	Variable	Dual	Dual	Single	Dual
11	**AC/ DC /AC system**	No	Yes	No	No	No	No
12	**Rated Voltage**	415	400	415	400	415	400
13	**Geared / Gearless**	Geared	Geared	Geared	Geared	Geared	Geared
14	**Cut-in speed (m/s)**	4	3	3 to 4	4	4	4
15	**Cut-out speed (m/s)**	25	25	25	25	25	23
16	**Rated speed (m/s)**	15	13	15.5	17	18	14
17	**Survival wind speed (m/s)**	70	60	55	60	>52	58
18	**Weight**						
	a. Tower (kg)		17000	23000		26000	20000
	b. Nacelle (kg)		7500	12500		12500	11500
	c. Rotor (kg)		2500	4350		3700	2100
	d. Total (kg)	33500	27000	39850	6000	42200	33600

(Continued Table A)

Sr. No.	Item	250 kW		300 kW	315 kW	320 kW
		13	14	15	16	17
1	**Make**	Windia-Nedwind	Tacke	Elecon-HMZ	Royalaseema-Mitsubishi	REPL-Bonus
2	**Model No.**	Nedwind 30	TW250	300kW/30m	MWT315	Bonus 320
3	**Rating kW**	250	250/80	300	315	320
4	**Rotor Diameter (m)**	31	26	30	29	33
5	**Highest Hub Height (m)**	45.5	55	40	40	40
6	**Type of tower**	Tubular/Lattice	Tubular	Lattice	Lattice	Lattice
7	**No. of blades**	3	3	3	3	3
8	**Power regulation**	Stall	Stall	Pitch	Pitch	Stall
9	**Type of generator**	Asyn.	Asyn.	Asyn.	Asyn.	Asyn.
10	**Single speed / Double speed / Variable speed (Generator)**	Single Speed	Dual	Single	Single	Single
11	**AC/ DC /AC system**	No	No	No	No	No
12	**Rated Voltage**	400	400	400	400	400
13	**Geared / Gearless**	Geared	Geared	Geared	Geared	Geared
14	**Cut-in speed (m/s)**	4	3	4	4.5	4
15	**Cut-out speed (m/s)**	25	25	25	24	25
16	**Rated speed (m/s)**	13	14	13	14.4	15
17	**Survival wind speed (m/s)**	60	60	55	60	
18	**Weight**	for Lattice				
	a. Tower (kg)	18000	68000	8000		20000
	b. Nacelle (kg)	10000	14000	15000		10000
	c. Rotor (kg)	4800				6500
	d. Total (kg)	32800				36500

(Continued Table A)

Sr. No.	Item	330 kW	350 kW	400 kW			410 kW
		18	**19**	**20**	**21**	**22**	**23**
1	**Make**	Enercon	Suzlon	Elecon-Turbowind	Kirloskar-WEG	NEPC India	Aban-Kenetech
2	**Model No.**	E-33	S.33/350	T400-34	MS3-400L	NEPC	33M-VS
3	**Rating kW**	330	350/100	400/100	400	400/100	410
4	**Rotor Diameter (m)**	33.4	33.4	34	39.3	31	33
5	**Highest Hub Height (m)**	50	70	34	50	36	
6	**Type of tower**	Tubular	Lattice	Tubular	Tubular	Tubular	Lattice
7	**No. of blades**	3	3	3	2	3	3
8	**Power regulation**	Pitch	Stall	Active Stall	Pitch	Stall	Pitch
9	**Type of generator**	Syn.	Asyn.	Asyn.	Asyn.	Asyn.	
10	**Single speed / Double speed / Variable speed (Generator)**	Variable	Dual	Dual	Single	Dual	Variable
11	**AC/ DC /AC system**	Yes	No	No	No	No	Yes
12	**Rated Voltage**		415	660	660	690	440-480
13	**Geared / Gearless**	Gearless	Geared	Geared	Geared	Geared	Geared
14	**Cut-in speed (m/s)**	3	3.5	4	4.5	4	4
15	**Cut-out speed (m/s)**		25	25	20	25	29
16	**Rated speed (m/s)**	12	14	14	11.5	15	Variable
17	**Survival wind speed (m/s)**		67	60	60	60	
18	**Weight**						
	a. Tower (kg)			18000	21000		
	b. Nacelle (kg)		13500	13600	12200		
	c. Rotor (kg)		9600	4400	3400		
	d. Total (kg)			54000	36600	50000	

(Continued Table A)

Sr. No.	Item	500 kW				550 kW	600 kW
		24	25	26	27	28	29
1	**Make**	AMTL-Windworld	Windia-Nedwind	Vestas RRB	Vestas RRB	Windia-Nedwind	BHEL-Nordex
2	**Model No.**	W-3700/500	Nedwind 40	V39	V39	Nedwind 44	N 43/600
3	**Rating kW**	500	500	500	500	550	600/125
4	**Rotor Diameter (m)**	37	40.77	42	47	43.77	43
5	**Highest Hub Height (m)**	41.5	39	41.5	50	39	60/50
6	**Type of tower**	Tubular	Tubular	Lattice	Lattice	Tubular	Tubular/Lattice
7	**No. of blades**	3	2	3	3		
8	**Power regulation**	Stall	Stall	Pitch	Pitch	Pitch	Stall
9	**Type of generator**	Asyn.	Asyn.	Asyn.	Asyn.	Asyn.	Asyn.
10	**Single speed / Double speed / Variable speed (Generator)**	Single	Single	Single	Single	Single speed	Dual speed
11	**AC/ DC /AC system**	No	No	No	No	No	No
12	**Rated Voltage**	690		690	690	400	690
13	**Geared / Gearless**	Geared	Geared	Geared	Geared	Geared	Geared
14	**Cut-in speed (m/s)**	4.5	4	4	4	4.5	3 to 4
15	**Cut-out speed (m/s)**	25	25	25	25	25	25
16	**Rated speed (m/s)**		15	14	15	13	13
17	**Survival wind speed (m/s)**			56	70	76	70
18	**Weight**						
	a. Tower (kg)	27000	30500	19000	32000	30500	67000/34000
	b. Nacelle (kg)	21400	22000	18000	20400	24600	22000
	c. Rotor (kg)	9800	12000	8200	7200	10400	14000
	d. Total (kg)	58200	64500	45200	59600	65500	103000/70000

(Continued Table A)

Sr. No.	Item	600 kW						
		30	31	32	33	34	35	36
1	**Make**	CWEL-Dewind	Elecon-Turbowind	Enercon	NEG Micon	Tacke	Tacke	Vestas RRB
2	**Model No.**	Dewind 46	T-600-48	E-40	NM600/48	TW600e	TW600a	Pawan Shakti 600
3	**Rating kW**	600	600/120	600	600/150	600	600	600
4	**Rotor Diameter (m)**	46	48	44	48	46	46	47
5	**Highest Hub Height (m)**	70	60	58	70	60	60	
6	**Type of tower**	Tubular	Tubular	Tubular	Tubular	Tubular	Tubular	Lattice
7	**No. of blades**	3	3	3	3	3	3	3
8	**Power regulation**	Pitch	Active Stall	Pitch	Stall	Stall	Active Stall/ Semi Pitch	Pitch
9	**Type of generator**	Asyn.	Asyn.	Syn.	Asyn.	Asyn.	Asyn.	Asyn.
10	**Single speed / Double speed / Variable speed (Generator)**	Variable	Dual	Variable	Dual		Dual	Single
11	**AC/ DC /AC system**	Yes	No	Yes	No	No	No	No
12	**Rated Voltage**	690	690	415	690		690	690
13	**Geared / Gearless**	Geared	Geared	Gearless	Geared	Geared	Geared	Geared
14	**Cut-in speed (m/s)**	2.5	3.5	2.5	3	3	3	4
15	**Cut-out speed (m/s)**	22	25	25	20	20	20	25
16	**Rated speed (m/s)**	11.5	12.5	12.5	15	13.5	12.5	
17	**Survival wind speed (m/s)**	55.3/55.8	60	56		55.8	57	70
18	**Weight**							
	a. Tower (kg)		58000	64200		71000	52000	
	b. Nacelle (kg)		23000	8000			20000	
	c. Rotor (kg)		12000	30500		38700	9000	
	d. Total (kg)		93000	102700		109700	81000	

(Continued Table A)

Sr. No.	Item	750 kW					800 kW	
		37	38	39	40	41	42	43
1	**Make**	Jeumont	CWEL Emergya	NEG Micon	NEPC Norwin	Pioneer Wincon	BHEL-Nordex	Enercon
2	**Model No.**	750	LW52/750	NM-48/750	47-ASR-750	W755/48	N50/800	E-48
3	**Rating kW**	750	750	750/200	750/180	755	800/200	800
4	**Rotor Diameter (m)**	48	51.5	48.2	47	48	50	48
5	**Highest Hub Height (m)**	46	50	55		50	50	74.85
6	**Type of tower**	Tubular	Tubular	Tubular	Tubular	Tubular	Tubular	Tubular/Concrete
7	**No. of blades**	3	3	3	3	3	3	3
8	**Power regulation**	Active Stall	Pitch	Stall	Active Stall	Semi-Pitch	Stall	Pitch
9	**Type of generator**	Syn.	Syn.	Asyn.	Asyn.	Asyn.	Asyn.	Syn.
10	**Single speed / Double speed / Variable speed (Generator)**	Variable	Variable	Dual	Dual	Dual	Dual	Variable
11	**AC/ DC /AC system**	Yes	Yes	No	No	No	No	Yes
12	**Rated Voltage**	870	690	690	690	690	690	690
13	**Geared / Gearless**	Gearless	Gearless	Geared	Geared	Geared	Geared	Gearless
14	**Cut-in speed (m/s)**	3	3	<3.5	3 to 4	4	3 to 4	2
15	**Cut-out speed (m/s)**	25	25	25	25	25	25	
16	**Rated speed (m/s)**	13.5	12	17			14	12
17	**Survival wind speed (m/s)**	59.5	60	60	60		65	
18	**Weight**							
	a. Tower (kg)			46000				
	b. Nacelle (kg)			22000				
	c. Rotor (kg)			13500			16000	
	d. Total (kg)		100500	81500				

(Continued Table A)

Sr. No.	Item	850 kW	950 kW	1000 kW	1250 kW	1500 kW	1650 kW	2000 kW
		44	**45**	**46**	**47**	**48**	**49**	**50**
1	**Make**	Pioneer Gamesa	NEG Micon	Suzlon	Suzlon	GE Wind Energy	NEG Micon	Suzlon
2	**Model No.**	G52-850/G58-850	NM-54/950	S.64/1000	S.64/1250 and S.66/1250	1.5s	NM-82/1650	S88/2000
3	**Rating kW**	850	950/200	1000/250	1250/250	1500	1650	2000/250
4	**Rotor Diameter (m)**	52/58	54.5	64	64/66	70.5	82	88
5	**Highest Hub Height (m)**	65	55/72.3	65	65	64.7/85	80	80/100
6	**Type of tower**	Tubular	Tubular	Lattice/Tubular	Lattice/Tubular	Tubular	Tubular	Tubular
7	**No. of blades**	3	3	3	3	3	3	3
8	**Power regulation**	Pitch	Stall	Pitch	Pitch	Active Pitch	Active Stall	Pitch
9	**Type of generator**	DFM	Asyn.	Asyn.	Asyn.	Asyn.	Asyn.	Asyn.
10	**Single speed / Double speed / Variable speed (Generator)**	Variable	Dual	Dual	Dual	Variable	Single	Dual
11	**AC/ DC /AC system**	Yes	No	No	No	Yes		
12	**Rated Voltage**	690	690	690	690		690	690/600
13	**Geared / Gearless**	Geared	Geared	Geared	Geared	Geared	Geared	Geared
14	**Cut-in speed (m/s)**	3	<3.5	3	3	4		4
15	**Cut-out speed (m/s)**	21	25	25	25/22	25	20	25
16	**Rated speed (m/s)**	17		11	12	12	14	14
17	**Survival wind speed (m/s)**		59.5	67	67		52.5	67
18	**Weight**							
	a. Tower (kg)		68000		98000			
	b. Nacelle (kg)		24500		44000			
	c. Rotor (kg)		15500		19800			
	d. Total (kg)		108000		161800			265300

ANNEXURE 4

Table B: Power curves of wind turbine generator systems of manufactures in India

(250 kW to 2000 kW)

Make	Vestas RRB	CWEL	India Wind Power	Pioneer Wincon	TTG	Suzlon	Vestas RRI
Model	V27-225	C2920/250	Iwind 29/250	W250/29	TT250	S.33	V39-500
Rating (kW)	225	250	250	250	250	350	500
Rotor Dia. (m)	27	29.2	29.7	29	28.5	33.4	47
Wind Speed (m/s)	Power in kW						
0	0	0	0	0	0	0	
1	0	0	0	0	0	0	
2	0	0	0	0	0	0	
3	0	0	0	0	0	1	
4	5	0	12	0	0	4	3
5	17.2	12.05	24	8.7	15.5	20	43
6	33.4	32.91	35	29.1	35	42	96.
7	55.1	59.87	58	54.9	46	73.4	16
8	82.9	91.95	95	83.6	84	114.1	24
9	115	123.94	128	112.7	115	157.6	32
10	149	152.81	161	137.8	154	203.8	40
11	181	180.41	190	159.1	181	246.9	45
12	206	204.9	213	180.8	212	291.3	48
13	219	224.24	225	199.2	236	331.5	49
14	224	238.04	234	210.9	250	348.3	49
15	225	247.11	245	221.6	260	339.7	50
16	225	253.41	254	238.9	264.5	321.5	50
17	225	258.18	261	249.2	262.5	303.6	50
18	225	260.29	265	250.9	260.5	290	50
19	225	259.37	271	250.5	260	278.9	50
20	225	255.58	267	251.4	260	268.3	50
21	225	249.71	263	246.6	262	257.9	50
22	225	243.02	259	238.9		249.4	50
23	225	236.27	253	239.3		242.3	500
24	225	230.09	248	233.8		236.6	500
25	225	224.41	245	233.8		232.5	500

(Continued Table B)

Make	CWEL Emergya	NEG Micon	BHEL Nordex	Pioneer Gamesa	Pioneer Gamesa	NEG Micon
Model	LW52/750	NM750/48	N50/800	G52-850	G58-850	NM950/548
Rating (kW)	750	750	800	850	850	950
Rotor Dia. (m)	51.5	48	50	52	58	54
Wind Speed (m/s)	Power in kW					
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	1.5	0	0	0	9.7	0
4	30.3	19.5	23	27.9	33.5	24
5	69.1	53.1	57	65.2	78.5	70
6	121	97.4	90	123.1	145.3	126
7	192	155.3	165	203	236.6	207
8	285	244.6	257	307	358.8	320
9	405	349.2	359	435.3	513.1	448
10	556	462.2	470	564.5	669.7	579
11	733	564.5	572	684.6	778.3	701
12	750	640.5	668	779.9	828.1	785
13	750	696.3	747	840.6	844.4	856
14	750	729.8	805	848	848.7	903
15	750	745.5	838	849	849.7	930
16	750	750	842	850	849.9	945
17	750	744.6	840	850	850	950
18	750	734.8	827	850	850	942
19	750	723	808	850	850	933
20	750	711.9	785	850	850	923
21	750	701.4	757	850	850	916
22	750	694.3	728	850		910
23	750	692.8	743	850		907
24	750	695.2	742	850		906
25	750	700.6	745	850		907

(Continued Table B)

Make	Suzlon	Suzlon	Suzlon	GE Wind Energy	NEG Micon	Suzlon
Model	S.60	S.64	S.66/1250	1.5s	NM82/1650	S.88/2000
Rating (kW)	1000	1250	1250	1500	1650	2000
Rotor Dia. (m)	60	64	66	70.5	82	88
Wind Speed (m/s)	Power in kW					
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	0	0	0	0	0	0
3	10	0	5	0	0	0
4	26.1	35	35	28	28	40
5	78	89	93	93	144	167
6	145	148	151	197	309	337
7	230.5	275	285	326	511	568
8	349.3	446	454	521	758	849
9	530.1	621	639	753	1017	1161
10	711	811	832	1021	1285	1575
11	837	990	1008	1308	1504	1825
12	950	1127	1152	1473	1637	1927
13	1000	1198	1241	1500	1648	1970
14	1000	1250	1250	1500	1650	2000
15	1000	1250	1250	1500	1650	2000
16	1000	1250	1250	1500	1650	2000
17	1000	1250	1250	1500	1650	2000
18	1000	1250	1250	1500	1650	2000
19	1000	1250	1250	1500	1650	2000
20	1000	1250	1250	1500	1650	2000
21	1000	1250	1250	1500	1650	2000
22	1000	1250	1250	1500	1650	2000
23	1000	1250		1500	1650	2000
24	1000	1250		1500	1650	2000
25	1000	1250		1500	1650	2000

ANNEXURE 5

MONTHLY PERFORMANCE REPORT

Name of the Wind Power Project:

Location: State:

Month: Year:

1. Unit Size :
2. Nos. :
3. Model :
4. Date commissioning :
5. Installed capacity :
6. Total machine hrs.

Date	Daily Generation (kWh)	Generator Hours	Down Time hours						Remark
			Inadequate Wind speed	Machine		Grid		Total	
				Fault	Shutdown /Maintenance	Fault	Shutdown /Maintenance		
1	2	3	4	5	6	7	8	9	10
Total									

Total Monthly Generation :

Capacity Factor for the month :

Availability Factor for the month :

Cumulative Generation in the financial year (kWh) :

Generation in the same month in the previous year (kWh) :

Percentage of previous year's generation in the same month :

INDIVIDUAL MACHINE PERFORMANCE REPORT

Machine No.	Monthly Generation	Generation Hrs.	Inadequate Wind speed Hrs.	Monthly Machine down time Hrs.	Monthly Grid down time Hrs.

MONTHLY MAINTENANCE SHEET

Name of the Wind Power Project:

Location: State:

Month: Year:

Unit Number :

Installed capacity :

Date	Fault (Hrs)		Difference in Hrs	Type of fault	Action taken	Maintenance Hrs		Type of maintenance	Total down Hrs
	From	To				From	To		
Total									