SARI / Energy

INDIA-SRILANKA WIND ENERGY KNOWLEDGE EXCHANGE PROGRAM

3-6 NOVEMBER, 2009

CHENNAI, INDIA

This publication was produced for India-Sri Lanka Wind Energy Knowledge Exchange Program. It was prepared by the Indian Wind Energy Association

Prepared for: **SARI/Energy**
USAID
New Delhi, India

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ACKNOWLEDGEMENTS

This Training Material was prepared by Indian Wind Energy Association with support from the Center for Wind Energy technology and others experts from India. The Training Material was co-funded by USAID SARI/Energy under Task Order 3.10 India-Sri Lanka Wind Energy Knowledge Exchange Program itself.

InWEA gratefully acknowledge the support provided by USAID, PA Consulting Group, the resources persons and speakers.

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INTRODUCTION OF THE INDIAN WIND ENERGY SECTOR

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GENERAL: Indian Energy Industries have an installed capacity of 150 GW of Electricity generation as on date of which 14 GW is from all Renewable Energy Sources in which about 10.3 GW is from Wind Energy. Wind is one of the fastest and most viable Renewable energy technologies. In India, the annual capacity addition per year is currently about 1700MW. India also has about 1MW of wind solar hybrid domestic system which are mostly used as standalone applications. So in what follows you will be seeing a brief introduction to the wind energy sector in India.

WIND ENERGY IN INDIA: India ranks 5th in Wind power generation as on date, with US having the highest installed capacity of over 25GW, with Germany, Spain, China following with 24, 17 and 12 GW respectively. In the Indian wind power development, the primary driving factor has been feed in tariffs (FIT) and accelerated depreciation and other tax incentives for domestic wind systems. Hence most of the investors in Wind Energy, apart from the demonstration projects of State and Central Governments are all from the

TABLE 1: STATE WISE WIND POWER INSTALLED CAPACITY *(Ref)*

State	(MW)	% (MW)
Tamil Nadu	4305	42.0
Maharastra	1939	18.9
Gujarat	1567	15.3
Karnataka	1327	13.0
Rajasthan	73.8	7.2
Madhya Pradesh	213	2.1
Andhra Pradesh	123	1.2
Kerala	27	0.3
West Bengal	1	0.0
Others	3	0.0
Total	10242	100.0

Private Sector. Today there are more than 3500 wind farm owners having capacities of WEG (Wind Electric Generator) from 225 kW to 2000 kW and most of the owners have bought either from Vendors (system integrators) or manufacturers having joint ventures or licensing agreement with Foreign collaborators mostly of European origin. State-wise installed capacity is given in Table-1

India has got an ambitious plan to exploit in full, the wind energy potential in the Country which is estimated to be 48 GW of which only 20% has been exploited as on date. However, this amounts to about 3 to 5% of net electricity generated in India.

POWER AND ENERGY IN THE WIND: It is well known that wind is certainly an inexhaustible abundant source of energy which is caused by the differential solar radiation on the Earth's geo-diverse surfaces, having different degrees of absorption/reflection/ refraction/convection/transmission. Wind power is not only a renewable green source of energy; but also results in significant saving of potable/drinking water, which is much needed for human survival. Electricity generation by wind consumes only $(1/200)^{th}$ to $(1/400)^{th}$ of water that is used by nuclear/oil/coal. We understand the wind as breeze (gentle/ comfortable), a force to reckon with at times of design of structures, a power to harness through wind machines and a brute force/power to be resisted during cyclones/hurricanes. We need to be clear that a Country with a long coast line need not necessarily be having economic/technical potential for wind power with its diurnal variations of land breeze/sea breeze. At the other extreme the mere occurrence of good monsoon or frequency of cyclones & hurricanes may not provide an economical viability, a technical feasibility of wind power. When wind (i.e. velocity 'U') is a resource, it has a force proportional to square of wind velocity (U^2), the power proportional to cube of wind velocity (U^3).

WIND TURBINE MANUFACTURERS IN INDIA: There are more than 12 manufacturers of Wind Turbines which are grid connected to State Electricity Boards. Most of the manufacturer's facilities are in Pune, Ahmedabad, Chennai and Puducherry. The technology has been steadily improving which has resulted in the cost reduction of more than 8 times in the last 3 decades i.e. from 40 cents (US $)in 1980s to about 3-4 cents (US $) in 2009. This has given rise to several new entrants in the MW Class wind turbines in India.

Some of the names along with the foreign collaborators are listed in Table -2

TABLE 2: WIND TURBINE MANUFACTURERS IN INDIA ***(REF)***

Company	Foreign Collaborator
Elecon Engineering Co Ltd	Turbowinds, Belgium
Enercon (India) Ltd	Enercon, Germany
GE Wind Energy India Ltd *	GE, USA
Ghodawat Energy Ltd	AMSC-Wintec, Austria
Hansen drives Ltd **	Hansen, Belgium
Kenersys India Pvt Ltd	Kenersys, Germany
Lietner Shriram Manufacturing Ltd	Leitner Technologies, Italy
LM Glasfiber India Pvt Ltd ***	LM Glasfiber, Denmark
Pioneer Windcon Pvt Ltd	...
Regen Powertech Pvt Ltd	Vensys, Germany
RRB Energy Pvt Ltd	...
Southern Windfarms Ltd	...
Suzlon Energy Ltd	...
Vestas Wind Technology Pvt Ltd	Vestas, Denmark
WinWind Power Energy (P) Ltd	WinWinD, Finland
*Yet to start operations, ** gearboxes *** only blades	
Note: Collaborator is financial or technical, list is indicative	

While Suzlon Energy is the largest manufacturer in India, it is World's 5^{th} leading player in WEGs. Apart from meeting the Indian WEG-market, for several manufactures it is also an export opportunity. It seems around 8000 crores worth WEGs made in India are exported abroad.

WIND ENERGY PROJECT DEVELOPMENT: Wind energy development in India has been initiated by the demonstration projects established by Government of India in highly windy areas. Steps to follow for a wind power project are as follows:

- Wind Resource Assessment through measurements, micro surveying and potential site identification
- Choice of the capacity and the number of the wind turbines for the identified sites for wind farming
- Micrositing of the wind turbines in a particular wind farm
- Erection and commissioning of wind turbines
- Establishment of continuous monitoring systems like SCADA
- Grid connection of wind turbines
- Power quality measurements and feed back
- Wind resource prediction/forecasting and load scheduling to load demand & Generation Management
- Power trading options across inter-state boundaries

TECHNOLOGY OPTIONS: Wind energy development has by nature, is a merger of several inter-disciplinary subjects starting with meteorology, environment, mechanical composites, electrical systems and electronic controls along with the civil engineering requirements for the foundation and the tower structure.

Here, the Rotor which converts the kinetic energy in wind to mechanical energy has a possible efficiency level of 45-55%. Theoretically, it can go up to 59% which is known as BETZ's limit and the rotatory energy is then converted to mechanical energy through a system of gears to make the low rotation into higher rotation to interface with the generator. Most of these gear systems have been designed with an efficiency of 92-97% in the highly matured industry, which is manufacturing the mechanical components. From the gear system it goes to the generator which converts the mechanical energy to electrical energy where the high level of efficiency has been established in the industry to the tune of 90-95%. So in a sense, technology option in the first phase of kinetic to mechanical energy has been shifting from constant speed rotor to variable speed rotor all over the world. The variable speed rotor is of capable capturing about 15 to 20% more energy from the turbulent wind. The mechanical system which has also been seeing several advancements in terms of geared, direct drive and gearless machines is still banking on proven technology for cost effectiveness. If there is gear system, it is interfacing the rotor with a low speed shaft and the generator with a high speed shaft. The latter is to generate power to match with the constant frequency and voltage of electric grids viz. Utilities.

Conversion of mechanical to electrical energy through the generators is also going through several advancements in technology in the recent years. From traditional squirrel cage induction generators which convert AC-AC as the wind varies has been shifting to synchronised AC-DC-AC type of generators for efficient power capture from the wind. In the aero dynamic controls, the shift is taking place from traditional stall control to pitch control and modern machines have active controls independently for stall as well as pitch mechanism. These sophisticated active controls require power electronics and hydraulics interfacing with various systems. Some of the latest WEGs use electro-magnetic/mechanical control systems instead of hydraulics. The modern machines manufactured in India with foreign collaboration have capacities more than 1 MW and they are highly suited for a tropical Country like India.

In general, India has more than 59 wind electric generator models manufactured by several manufacturers, some of whom have stopped business and some of them have newly entered into business with latest models. In effect there are only 11 to 12 manufacturers who are actively involved in Grid connected WEG development in India.

ROLE OF C-WET IN WIND POWER DEVELOPMENT IN INDIA: As earlier mentioned, C-WET is an Autonomous R&D Organisation, established under the Ministry of New and Renewable Energy and it has enabled orderly wind power development in India. It has been the only reliable source quite some time for the assessment of wind energy potential in India. It offers value added services in terms of identification of potential windy sites and project planning, Micrositing and due diligence studies in the area of wind resource assessment. Its services are utilised by Private, Public and Government agencies equally. C-WET has an International standard Test Station at Kayathar close to Kanyakumari which can test wind turbines from 225 kW to MW class machines. Wind turbine type testing is an accredited service under NABL certification and it is recognised in more than 52 Countries in the World today and C-WET is striving to get MEASNET (A high quality measurement network of institutions based in Europe/Germany who carry out wind turbine testing and measurement for technical excellence) membership which will give C-WET India the global recognition. C-WET also ensures the quality of the machines which are connected to Indian power utilities to protect the investors as well as manufacturers utilities equally. C-WET follows IEC:WT-01 standards and carries out the type certification of wind turbines under a scheme called TAPS 2000 which has been customised for Indian conditions with the help and guidance of experts from RISO/Denmark which follows several standards which are currently in vogue in the Indian Wind Industry.

C-WET also coordinates with several academic institutions, National Research Laboratories and private companies independently in Research and Development in the area of wind energy to facilitate cost reduction in wind electric generation. C-WET assists the regulatory body which is the Central Electricity Regulatory Authority (CERC) in technical matters on policy and regulatory issues. It does the design evaluation for the purpose of certification of assessing the various models which are being offered by several manufacturers in Indian market following International standards. C-WET releases a list of models of manufacturers which is called RLMM (Revised List of Models & Manufacturers) every quarterly which is referred by the Electricity Boards for enabling the grid connection to power utility services, of the WEG models.

C-WET also undertakes Human Resource development suitable to the Indian Wind Energy Industry by conducting National and International Training Programmes. Since this is an area of multi disciplinary nature, academicians & industry and Scientists of C-WET join hand together to complete the training programmes.

THE NATIONAL POLICY AND REGULATORY INTITIATIVES: The Government of India, in association with the manufacturers IWTMA (Indian Wind Turbine Manufactures Association) IWPA (Indian Wind Power Association) and InWEA (Indian Wind Energy Association) has discussed several aspects to promote wind energy in India. The recent initiative by the Government of India are more towards generation based incentive for the wind farm developers and energy by repowering of wind farms which are having old and low capacity machines and also it has a policy to give open access and power trading including inter state trading facilities for wind. In some states in India, even net metering concepts practiced in USA & Europe for small/domestic wind turbines, for wind solar hybrid systems are already in place. There are IPP (Independent Power Producers) enablers who manage establishment of Wind Power projects with CDM (Clean Development Mechanism) benefits of Carbon Credits.

FUTURE INDIAN SCENARIO:

Issues in Wind Power Developments: Availability of accurate wind potential data all over India is one of the issues. C-WET has assessed more than 620 Stations spread all over the Country by continuous monitoring of wind as a resource and identified more than 216 locations as economically viable and wind potential. As on date, in India a site which has more than 200 watts per square meter as Wind Power Density (WPD) is declared economically viable. With recently picked up micro wind generation i.e to exploit urban wind areas and low wind areas and to facilitate remote village electrification domestic wind mills of .3 kW to 30 kW are being adopted. This micro wind generation as on date has a low market demand since it has been mostly developed as a standalone system which is often not grid connected. The grid interface system which will have similar concepts such as net metering along with exporting to grid and importing from the grid in a house connection is likely to be possible soon. It has fast track implementation of wind power projects given by Government having fiscal and financial initiative. India is likely to penetrate the wind as a green power upto 10% of electricity generation of the Nation, with the highly supportive Governmental policies.

The major issue of utilisation of wind power has been the infirmity of the wind. This can be overcome the current sophisticated technology to forecast wind enabling load scheduling to meet the load demand and generation gap.

Innovative approach to Operation and Maintenance "O&M", is now being implemented using Central Monitoring systems and SCADA type continuous monitoring with remote controls.

Another important issue in the Indian wind power development is development of infrastructure facility in wind farmable areas such as roads and logistics for larger machine components to reach windy Regions. Other infrastructural facilities for establishment of human habitation wind farm and establishment of electrical grid for evacuation of the power generated by the wind turbines. Most of the State and Central Government have been concentrating on these infrastructural developments and hence wind power in India has become more viable and the growth is sustained at the global rate of more than 20% every year. Table 3 gives a few keys for sustaining this 20% wind power growth in India.

Ref:
Key Reference to statistics :- Shri Venugopal Pillai,"Revolution in the Air", Electrical Monitor,October 2009,PP. 30-37

TABLE 3: WIND POWER INDUSTRY TRENDS

AREA	CURRENT STATUS	DESIRED CHANGE
Resource	Gross-potential	Microzonation for accuracy
Private investments	Tax/incentive driven	CDM/generation/green Energy/Quality
Manufacturing	From foreign IPRs/DWG	Indigenous Design capability
Competition	Cut-throat	Open-Consortium
Health-monitoring	minimal	Learn from failures
R&D & innovation	In closed doors	A consortium and industry supported
Small Wind Turbines & Hybrid (Wind+Solar)	Small alone battery charger type	Net metering with Grid interactive/interfaced
Grid Code	Not mandatory	May be practiced to ensure power quality/stability of Grids

THE REGULATORY FRAMEWORK FOR RENEWABLES IN INDIA

Mahesh Vipradas

Renewable energy technologies have been developed and deployed in India since mid-1980s with a range of policy initiatives by the government. These policies were directed towards development of different renewable energy technologies for diverse applications including power generation from renewable energy sources like wind, solar, small hydro etc. This article reviews the recent developments in wind power sector in India.

Policy support

In 1993, the Ministry of New and Renewable Energy (MNRE), earlier known as the Ministry of Non-Conventional Energy Sources (MNES), issued guidelines for purchase of power from renewable energy sources by state utilities. These guidelines marked the power purchase tariff of Rs. 2.25 per unit, with an annual escalation of 5%. The guidelines also prescribed other promotional measures like wheeling[1] and banking of power generated from different renewable energy sources. The guidelines were adopted by various state utilities, and provided the initial policy support for renewable-based power generation in India. Besides a fixed power procurement rate, the government provided other incentives like accelerated depreciation, and exemption in customs duty for imports of components /machinery for renewable energy systems/projects.

The regulatory framework

Subsequent to the enactment of the Electricity Regulatory Commissions Act in the year 1998, State Electricity Regulatory Commissions (SERCs) became key players in determining power tariffs. The SERCs were constituted to bring transparency and competition into the sector.

The Electricity Act 2003 repealed the earlier acts: The Indian Electricity Act, 1910; The Electricity (Supply) Act, 1948; and The Electricity Regulatory Commission Act, 1998. The Electricity Act 2003 further strengthened the role of regulatory bodies in pricing, and in the promotion of competition and transparency. The Act, have specific provisions for promotion of power generation from renewable energy sources:

Section 61 (h)

"The Appropriate Commission shall, subject to the provisions of this Act, specify the terms and conditions for the determination of tariff, and in doing so, shall be guided by the promotion of co-generation and generation of electricity from renewable sources of energy."

Section 86 (1) (e)

"to promote co–generation and generation of electricity through renewable sources of energy by providing suitable measures for connectivity with the grid and sale of electricity to any persons, and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee."

The National Electricity Policy, formulated by the Ministry of Power**,** in pursuance of the provisions of the Act, also stresses the need for the promotion of non-conventional energy sources:

[1] Wheeling refers to transportation of electric power over transmission lines.

5.12 Cogeneration and Non-Conventional Energy Sources

5.12.1 Non-conventional sources of energy being the most environment friendly there is an urgent need to promote generation of electricity based on such sources of energy. For this purpose, efforts need to be made to reduce the capital cost of projects based on non-conventional and renewable sources of energy. Cost of energy can also be reduced by promoting competition within such projects. At the same time, adequate promotional measures would also have to be taken for development of technologies and a sustained growth of these sources.

In terms of specifying a percentage of total consumption which should come from renewable energy sources, the policy specifies that,

5.12.2 … Progressively the share of electricity from non-conventional sources would need to be increased as prescribed by State Electricity Regulatory Commissions. Such purchase by distribution companies shall be through competitive bidding process. Considering the fact that it will take some time before non-conventional technologies compete, in terms of cost, with conventional sources, the Commission may determine an appropriate differential in prices to promote these technologies.

The National Tariff Policy, formulated by the Ministry of Power, has specific guidance on purchase tariff for power generated from renewables:

Section 6.4…. It will take some time before non-conventional technologies can compete with conventional sources in terms of cost of electricity. Therefore, procurement by distribution companies shall be done at preferential tariffs determined by the Appropriate Commission.

Such procurement by Distribution Licensees for future requirements shall be done, as far as possible, through competitive bidding process under Section 63 of the Act within suppliers offering energy from same type of non-conventional sources. In the long-term, these technologies would need to compete with other sources in terms of full costs.

The Electricity Act 2003, and subsequent policies, provide for three important promotional measures for renewables:

1. The Act provides a framework for tariff determination in Sec 61(h) and the tariff policy further elaborates it providing a long-term policy for pricing of power from renewable sources of energy, prescribing a gradual step by step introduction of competition.
2. In addition to provisions on tariff determination, which boosts investor confidence, the Sec 86 (1)e, of the Act creates demand for power generated from renewable energy sources by mandating SERCs to specify a percentage of consumption which should be procured from renewables.
3. Power evacuation infrastructure is a critical requirement for promotion of renewables-based generation, since sources like wind and small hydro are geographically unevenly distributed and often located in remote areas. The Electricity Act addresses this by mandating SERCs to take suitable measures to ensure connectivity with the grid. Providing the infrastructure for evacuation of power is the responsibility of the state transmission utility (STU), and it is expected that the STUs would prepare grid expansion/augmentation plans in the light of the renewable energy potential of the state.

The provisions regarding tariff determination and percentage specification have been implemented by many SERCs. Table 1 gives the percentages specified by different SERCs for procurement of power from renewable energy sources.

Table 1: State-wise renewable energy procurement percentage specified by respective SERCs

<table>
<tr><th>State</th><th>RPS % Speci-fied</th><th colspan="4">Tariff fixed by commissions in INR per kWh</th><th>Validity of Tariff (years)</th></tr>
<tr><td>Tamil Nadu</td><td>13%</td><td colspan="4">3.39 (fixed)</td><td>20</td></tr>
<tr><td>Maharashtra</td><td>3-6%</td><td colspan="4">3.50 + escalation</td><td>13</td></tr>
<tr><td></td><td></td><td colspan="4">of 0.15 on an annual basis</td><td></td></tr>
<tr><td>Karnataka</td><td>10%</td><td colspan="4">3.40 (fixed)</td><td>10</td></tr>
<tr><td>Andhra Pradesh</td><td>5%</td><td colspan="4">3.50 (fixed)</td><td>10</td></tr>
<tr><td>Gujarat</td><td>2%</td><td colspan="4">3.37 (fixed)</td><td>20</td></tr>
<tr><td rowspan="2">Rajasthan</td><td rowspan="2">7.5%</td><td>Jaisalmer, Barmer, Jodhpur Distts. (EHV evacuation)</td><td>Jaisalmer, Barmer, Jodhpur Distts. (evacuation at 11/33kV)</td><td>Other Distts. (EHV evacuation)</td><td>Other Distts. (evacu ation at 11/33k V)</td><td rowspan="2">20</td></tr>
<tr><td>3.59</td><td>3.48</td><td>3.67</td><td>3.56</td></tr>
<tr><td></td><td></td><td colspan="4">escalation of 0.02 /0.04Rs for the first 12 years + escalation of 0.01 for the balance 8 years</td><td></td></tr>
<tr><td>Madhya Pradesh</td><td>10%</td><td colspan="4">4.03 reducing at 0.17 subsequently fixed at 3.36 till the 20th year</td><td>20</td></tr>
<tr><td>Kerala</td><td>3%</td><td colspan="4">3.14 (fixed)</td><td>20</td></tr>
<tr><td>West Bengal</td><td>3.8%</td><td colspan="4">4.00 (fixed, to be used as a cap)</td><td>Flexible</td></tr>
<tr><td>Haryana</td><td>3-10 %</td><td colspan="4">4.08 (with 1.5 % escalation per year)</td><td>5</td></tr>
</table>

These SERCs have also issued tariff orders for purchase of power from different renewable energy sources, which is a technology-specific tariff. This implementation of the provisions of the Electricity Act has boosted power generation from renewable energy, with total installed capacity reaching to 13838 MW as on 31st January 2009.

Emerging issues

It is clear from Table 1 that despite the provisions of the Electricity Act and subsequent policies, some states have not yet specified percentage for procurement of power from renewables. Some of the states have not complied, with requirement of specifying percentage for power procurement from renewable energy sources, since there is minimal renewable energy potential available. (Currently, all regulations/orders by SERCs require renewables-based power to be purchased from plants located within the state.) Some states, in spite of good resource potential, have specified very modest percentages. In states with adequate renewable energy resources, the development of renewable power is limited to the capability of the state to purchase power from renewable projects, to the extent that it does not substantially affect consumer tariffs. Renewable energy resources therefore remain under-utilized in these states. On the other hand, states which do not have / or have a very limited renewable resource can not procure power form renewable energy sources. One possible solution, to optimally utilize the renewable energy resource, is to specify a national minimum Renewable Procurement Obligation (RPO). The National Action Plan on Climate Change published by the Government of India in 2008, indicates the necessity of such a national minimum percentage.

Given the energy security and climate imperatives, renewable sources of energy are slated to play an important role in meeting the country’s energy demand. Power generation, being one of the most important applications of renewable energy, needs to be governed by an informed regulatory framework that facilitates its growth and improvement.

WIND RESOURCE ASSESSMENT IN INDIA

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1.0 INTRODUCTION

Wind power technology has become one of the most promising renewable energy technologies for electricity generation in India and elsewhere. It is important to say that wind power is considered one of the most environmental friendly energy sources on a global scale because it produces no emissions. However, financial risk is very high in the wind farm development due to various reasons. It can be reduced if proper wind assessment is done. Wind data particularly, wind speed data are very critical because a small change in the wind speed at a site can have a significant impacts in determining whether the project is economically viable or not.

There are three basic steps to identify and characterise the wind resource in a given region. In general, they are prospecting, validation and optimisation. Under prospecting, the identification of potential windy sites within a fairly large region, in the range of several square kilometre (areas) would be considered. Generally this is carried out by meteorologists who depend on various sources of information such as topographical maps (in India, Survey of India map), climatological data from meteorological stations (e.g. India Meteorological Department), and satellite imageries, etc. A site visit also will be conducted at this stage and a representative location for wind measurement would be identified. Validation process involves a more detailed level of investigation like wind measurements and data analysis. The most imperative and final step is micro survey and micrositing. In this paper, the importance of wind resource assessment and methods for assessment are described briefly

2.0 WIND RESOURCES

The wind over a region can be considered a resource similar to the “fossil fuel” beneath the earth’s surface. But unlike fossil fuel, the wind resource varies with time of day, season of year, and even to some extent from year to year.

Wind is movement of air in the atmosphere relative to surface of the earth. The air moves because of uneven heating of earth’s atmosphere. But the atmosphere is not heated directly by the incoming solar radiation. Radiation is first absorbed by the surface of the earth and is then transferred in various forms back to the overlying air. Since the surface of earth is not homogeneous, the amount of energy that is absorbed varies both in space and time. This creates temperature – density – pressure differences, which in turn create forces that move air from one place to another. Coriolis force is an additional factor, which controls the movements of air.

In terms of energy, wind is kinetic energy of air and power in the wind is the flux of kinetic energy passing through the vertical cross – sectional area (of the rotor of wind turbines).

Power in the wind is given by

$$P=1/2\ pAu * u^2 \qquad (1)$$

$$P=1/2\ pAu^3 \qquad (2)$$

Where pAu mass per unit volume of air
u=velocity of wind and
A=an area through which the wind passes normally.

The above expression gives the total power available in the wind, for extraction by a wind driven machine: only a fraction of which can be actually extracted. A. Betz of Gottingen showed in 1927 that the maximum fraction of power in the wind that could be extracted by an ideal aero motor was 16/27 or .593.

The power density is a flow of air through a unit vertical cross – sectional area and is given by

$P_d = ½ \rho u^3$ Watts/ m^2

2.1. WIND CHARACTERISTICS

2.2.1 Topographic Effects on Wind

Topography often plays a major role in modifying the wind speed in a given location. The natural behaviour of air when flowing over topography is to speed up considerably over the crests of hills. With favourable size, orientation and shape, topographic features can increase wind energy yield potential up to 100%. The terrains that are considered most suitable for potential wind energy sites are elevated ridges that are perpendicular (90 degrees) to the prevailing winds. Elevated terrain tends to cause accelerating forces that increase local wind speeds. The ridges intercept the winds and then compress and accelerate air as it moves upwards , increasing the wind speed at the ridge top. Therefore exposed ridges are known to be sources of higher localized winds. Other areas where the wind accelerates are steep divides or valleys that funnel the wind. For the purpose of wind power meteorology, which is primarily concerned with the wind flow from 10 to 200 m above the ground, the effects of the topography can be divided into three typical categories.

Roughness: The collective effect of the terrain surface and its roughness elements, leading to an overall retardation of the wind near the ground, is referred to as the roughness of the terrain.

Obstacle: Close to an object, such as a building or shelterbelt, the wind is strongly influenced by the presence of the obstacle, which may reduce the wind speed considerably.

Orography: The term orography refers to the description of the height variations of the terrain, referenced to a common datum such as the mean sea level. When the typical scale of the terrain features becomes much larger that the height of the points of interest they act as a orographic elements to the wind. , Near the summit or the crest of hills, cliffs, ridges and escarpments, the wind accelerate while near the foot and valley it will decelerate.

2.2.2 *Variation of Wind Speed with Height*

Wind speed is nominally zero at ground level and increases steadily with height. The change of wind speed with height is known as the wind shear or profile. The rate of increase with height strongly depends upon the roughness of the terrain and the changes in this roughness. The variation also depends on the atmospheric stability conditions. Even within the course of 24 hours, the wind profile will change between day and night, dawn and dusk. This can be described by the so called logarithmic wind profile with stability correction. This expression, which is well supported by theoretical considerations, is written

$$u(z) = \frac{u_*}{k}\left(\ln\frac{z}{z_0} - \psi\right) \quad (3)$$

Where u_* is the friction velocity, k the von Karman constant, Z_0 the roughness length, and ψ a stability dependent function, positive for unstable condition, zero for neutral and negative for stable conditions.

Another option is power law approximation. The expression is as follows.

$$\frac{u_{z1}}{u_{z2}} = \left(\frac{z_1}{z_2}\right)^{\alpha} \quad (4)$$

Where u_{Z1} and u_{Z2} are the wind speed at heights z1 and z2 respectively and α is the power law exponent, with a typical value of 0.14 for most of the homogenous site. A serious problem with this approach is that □□varies with height, surface roughness and stability, which means this equation is of quite limited applications

3.0 RESOURCE ASSESSMENT

In order to establish wind farms in a successful manner it is important to have a maximum possible accurate estimate of wind resources at a given site. The potential energy yield from the wind varies with the wind speed to the third power, i.e. a site with 10% higher wind speed has an approximately 30% increased wind energy potential yield. Generally wind resource assessment is done in number of phases and the details are as follows. The methodology of wind resource assessment on the basis of local wind measurements is indicated in Fig.1.

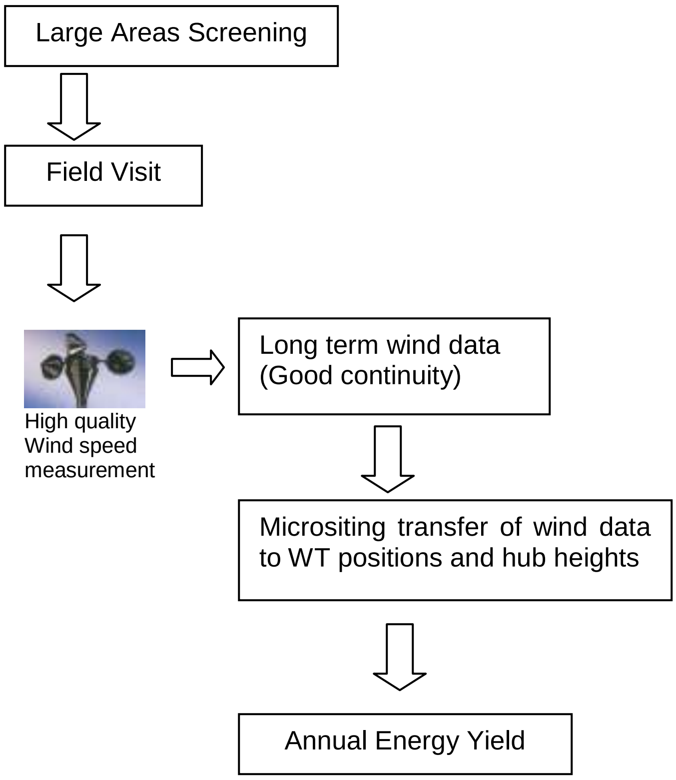

Fig.1. Wind Resource Assessment Methods

3.1 Large area screening & Field visit

This phase may be appropriate if the region is large, and no previous wind measurement programs have been conducted there. A large-area screening usually begins with a review of existing wind resource maps and other meteorological information, analysis of the meteorological characteristics of the state and their possible effect on wind speeds, and the development of screening criteria (such as terrain form, current use, vegetation cover and accessibility to roads and transmission), One recent approach to large-area screening is using geographical information systems (GIS), a computer mapping and analysis tool, to screen potential sites. Wind maps generated through meso scale modelling can also be used for large area screening.

Once a preliminary list of sites is prepared, the next step would be visit to the site. One purpose of such visits is to look for physical evidence to support the wind resource estimate developed in the large-area screening. Consistently bent trees and vegetation, for example, is a sure sign of strong winds. Another purpose is to check for potential sitting constraints. A third purpose of the site visit is to select a possible location for a wind monitoring station.

3.2 WIND MEASUREMENTS

Wind speed, wind direction, and air temperature measurements are required for useful wind resource assessment. Typically, each parameter is scanned every 1 to 2 seconds, and the data points are averaged by a data logger mounted on the tower. Data is normally collected at 10 or 60-minute average intervals. Historically, hourly averaged data have been used, but with the increased capabilities of wind models and computers, the 10-minute averaged data provide additional precision. The data logger calculates and stores the standard deviation of both wind speed and wind direction.

Wind speed is the most important measurement parameter. A 3-cup anemometer is the typical instrument. Several manufacturers offer low-cost, highly accurate, and resilient anemometers that have been used in wind resource monitoring for years. Collecting wind speed data at multiple heights is preferred to avoid errors in simulating turbine performance caused by wind shears. The multiple height data also provide a valuable backup if a sensor at one-height fails. The typical recommended scenario is to measure wind speed at three heights on a tower. For a 50-meter tower, measurements at 10, 25, and 50 meters are normal. For a 60-meter tower, measurements are at 10, 30 and 60 meters. Ten-meter data are the standard height for wind measurements. In areas that contain obstructions or vegetation, particularly within forest canopies, the lowest wind sensor is placed at a height that minimizes effects of surface roughness or obstructions. The 25- to 30-meter height is approximately the lowest level that turbine blades reach in their down position. Turbine performance can be estimated better with these data. The 50- to 60- meter height data represent wind turbine hub height. Turbine performance models require data at hub height. If turbines with hub heights exceeding 60 meters are proposed, the cost to erect and instrument a taller tower is significant. A Sodar provides an alternative for data collection in these cases. For accurate wind speed data it is important to minimize the effect of the tower on the instruments.

Wind direction data are collected at the same heights as wind speed data. A wind vane is used for determining the direction. Optimal layout of the wind farm depends on good wind direction information. Air temperature data are needed to determine the air density term in calculating wind power density and turbine performance. This measurement may be made at 2 to 3 meters above ground. Measuring at this height minimizes the effects of surface heating during daylight hours. Additional data parameters-barometric pressure, vertical wind speed, and precipitation-are recommended, but not mandatory.

The wind speed measurement period at the location must be long enough to cover all meteorological conditions in that region with a sufficient amount of data. Measuring over a period of one year can usually attain this. In order to account for seasonal or long-term variations of the wind potential the local short-term measurements must be correlated with instantaneous measurements of a nearby reference station that has collected long-term data. Once the relations between the local measurements and the measurements at the reference station have been established, the expected long term distribution of wind data at the predicted site is predicted by considering the local short term measurements according to the long term wind histogram. This procedure is often referred to as Measure, Correlate-Predict (MCP) method.

Wind speed measurements are among the most critical aspects for wind resource assessment. This is expressed by the fact the uncertainties in the wind speed are amplified by a factor between two and three to uncertainties in the predicted energy production because of the non linear relation between wind turbine power output and wind speed. Due to the lack of experience lot of wind speed measurements have unacceptable high uncertainties because best practice in selection of the anemometers, anemometer calibration, mounting of the anemometers, the selection of the measurement site as well as the measurement height and the duration of the measurements was not adopted. An international anemometer calibration round robin comparison showed that uncertainties up to more than +/- 3.5 % occurred in the calibrations in different wind tunnels. This translates into 10 % uncertainty in energy yield prediction. Preferably one anemometer should be top mounted (on a pole exceeding the mast) to avoid flow distortion. Booms should be mounted so that the flow field disturbance due to the booms at the mast is minimised. To avoid flow inclination effects the accuracy of the horizontal mounting of the anemometers is important as well. At the current state-of-the-art an uncertainty as low as 1-2 % in the wind speed determination and about 3 % in terms of energy production can be reached. Consequently it must be recommended to plan wind farms on the basis of high quality wind measurements within the wind farm area, especially in regions with complex terrain.

3.3 Micro scale Modelling & Micrositing

Wind farms vary considerably in size and scale depending on the physical limitations of the land, the wind resource available and the amount of energy sought. In a wind farm, turbines will typically be placed in rows perpendicular to the prevailing wind direction. Spacing within a row may be as little as two to four rotor diameters if the winds blow perpendicular to the row almost all the time. If the wind strikes a second turbine before the wind speed has been restored from striking an earlier turbine, the energy production from the second turbine will be decreased relative to the unshielded production. The amount of decrease is a function of the wind shear, the turbulence in the wind, the turbulence added by the turbines, and the terrain. This can easily be in the range of five to ten percent for downwind spacing of around ten rotor diameters. Spacing the turbines further apart will produce more power, but at the expense of more land, more roads, and more electrical wires.

In order to locate the turbines for optimum generation a careful exercise has to be carried out. Each turbine site must be selected based on topography and the optimum location where the highest wind power density are presumed to occur. This crucial step requires an experienced professional with a thorough knowledge of terrain effects on wind.

Micrositing can provide high quality and spatially detailed yield estimates over the wind farm area such that each turbine can be sited for optimal energy yield. Considerations must also be given to turbine interference and design constraints (visual, noise etc.) within the “wind farm designs” stage. Finally energy estimates must be adjusted to reflect the likely long-term yield (typically 20 years) of the wind farm. The micrositing process involves conducting surveys, monitoring and flow modeling at individual sites to quantify the small-scale variations in the wind resource over the area. In complex terrain, micrositing may involve numerous wind speed measurements combined with computer modeling to predict speeds in areas where no measurements are taken.

There are several industry-standard techniques used in practice for modeling wind over a small region and later for micrositing. Some of the models available in the market are Resoft Windfarm, WinPRO, WAsP, GH WindFarmer etc. All these models have limitations due to linearisation of the model equations that restrict their applicability to low terrain slopes (e.g <-03). These models are also limited by the fact that they do not take into account thermal effects such as sea breezes or mountain-valley winds. Though these models have some limitations, they can give good results if ‘handled’ carefully.

4.0 CONCLUSION

An accurate wind resource assessment is a key element of the successful wind farm development. Generally wind resource assessment is done in number of phases. First phase is to identify and quantify wind areas in general. This activity is referred as ‘large area screening’. Second phase is referred to as the “feasibility study” phase with proper wind measurements. The third step is called micrositing’ which provides estimated energy over the wind farm such that each turbine can be sited for optimal energy yield.

5.0 REFERENCES

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TESTING OF WIND TURBINES

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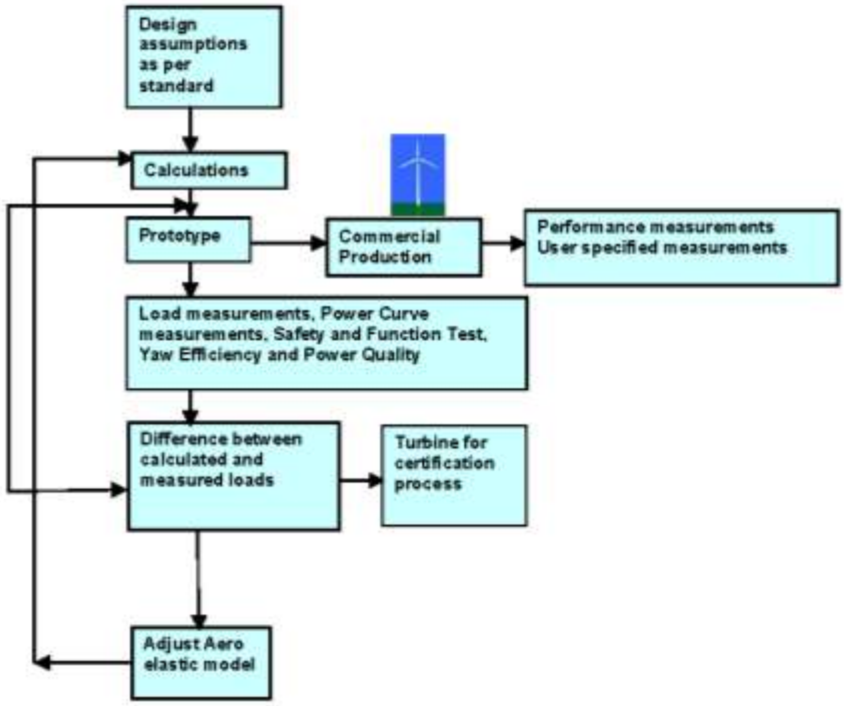
Wind turbine Testing is an important activity whereby calculations enabled by an aero elastic model are validated to improve the confidence in the design to ensure that the wind turbine can operate safety and optimally for a predicted lifetime. The design can also be improved subsequently for better performance by the evaluation of specific issues regarding terrain, environment and grid conditions vis-à-vis site specific measurements.

1. Requirement of Testing

The following flow chart gives the process from the design, design validation to commercial production of a wind turbine.

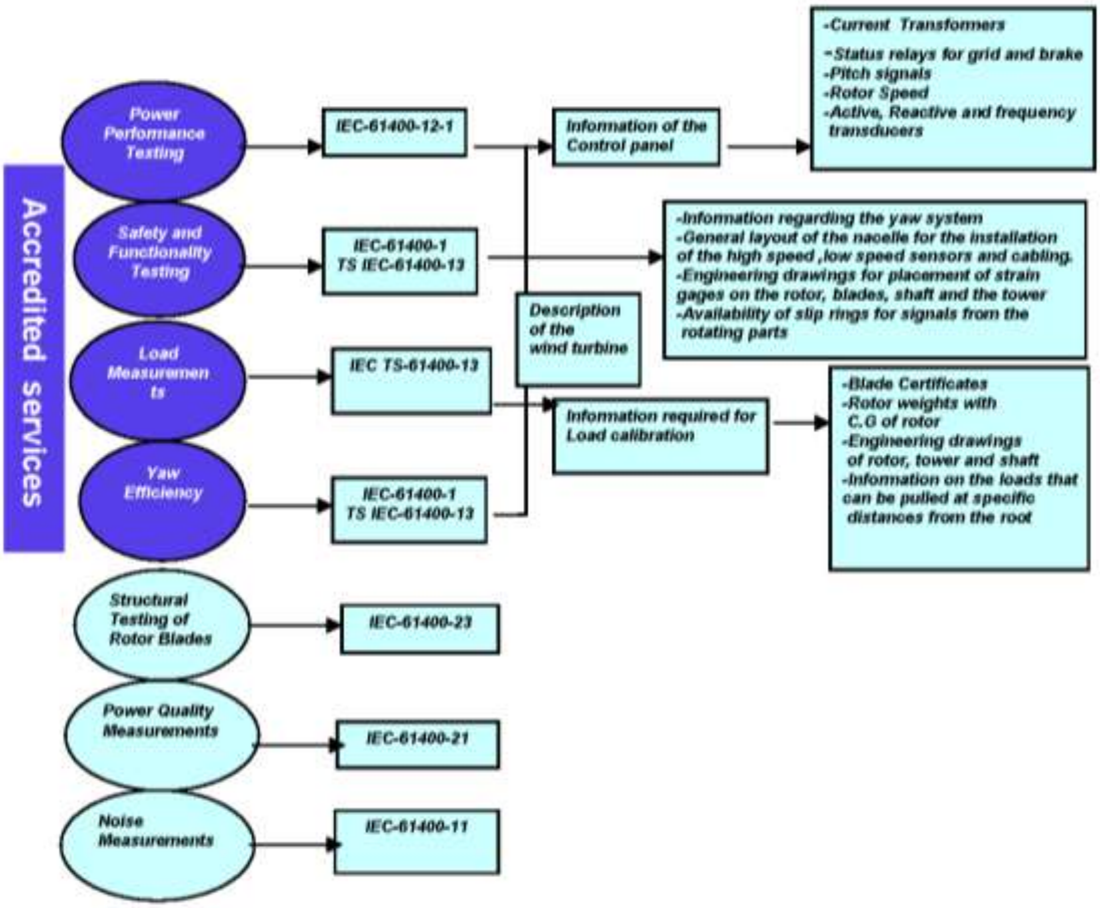


2. Benefits of Testing

Measurements are important inputs for the Designer, Manufacturer, Investor, Policy makers and for Research and development. These inputs are an integral part of the Type Certification process of a wind turbine wherein evaluation is made between the measured load vis-à-vis design loads.

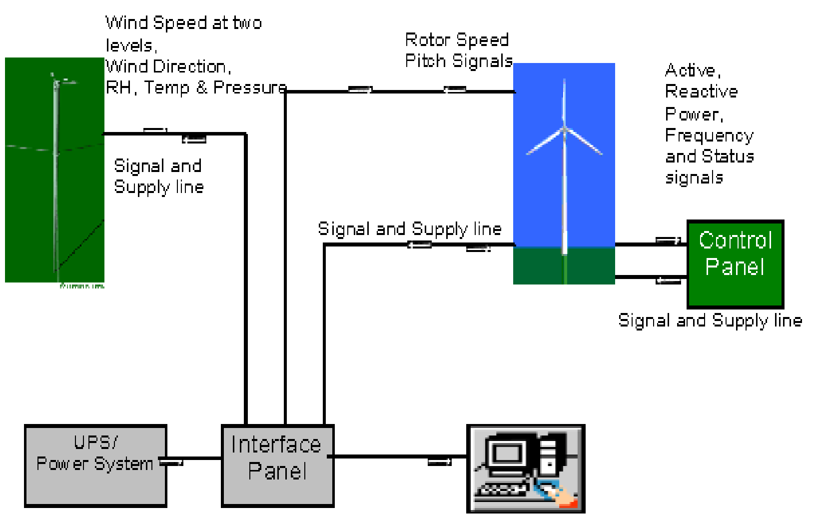
3. Overview of testing

The methodology of tests carried out on a wind turbine is as per the requirements of the specific International Standards issued by the International ElectroTechnical Commission (IEC). The reports issued by an accredited laboratory based on the IEC standards are accepted internationally. In order to carry out tests on a wind turbine the designer or the manufacturer has to draft a test plan which shall include information on technical details of site, wind turbine, instrumentation, data acquisition and details regarding scope of responsibilities and schedule of implementation. The overview of all tests and the corresponding International Standards is given below.



4. Power performance Testing

The power curve (or performance curve) is the most important characteristic of a Wind Turbine Generator (WTG). It describes the amount of electricity generated at different wind speeds. Experience has shown that measured power curves are much more reliable than calculated power curves that tend to be too optimistic. As a result measurements have the character of references, serving as sales arguments for the WTG manufacturers. Potential investors are therefore well advised to pay attention on the reliability of the power curve. It should be measured by an independent institute according to international standards and not calculated or estimated. A typical scheme is shown in the figure below. The measured power curve is often used by developers and manufacturers for a realistic estimate of the annual energy production at a particular terrain and environment condition.



The electrical power and coefficient of Power (Betz limit) are given by the equations 1 & 2

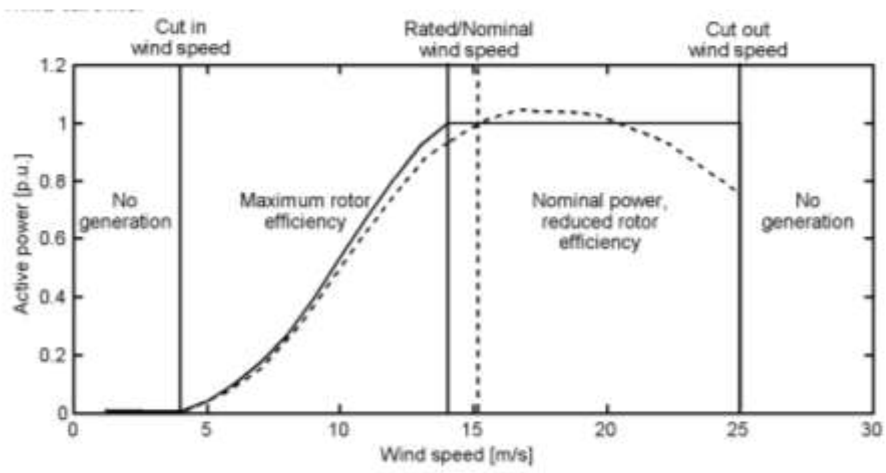
$$P = \frac{1}{2}\rho_{air} C_p A_r v_w^3 = \frac{1}{2}\rho_{air} C_p(\lambda,\theta)\pi r^2 v_w^3 \qquad - \qquad 1$$

$$Cp = \frac{1}{2}[1+[\frac{V2}{V1}]-[\frac{V2}{V1}]^2-[\frac{V2}{V1}]^3] \qquad - \qquad 2$$

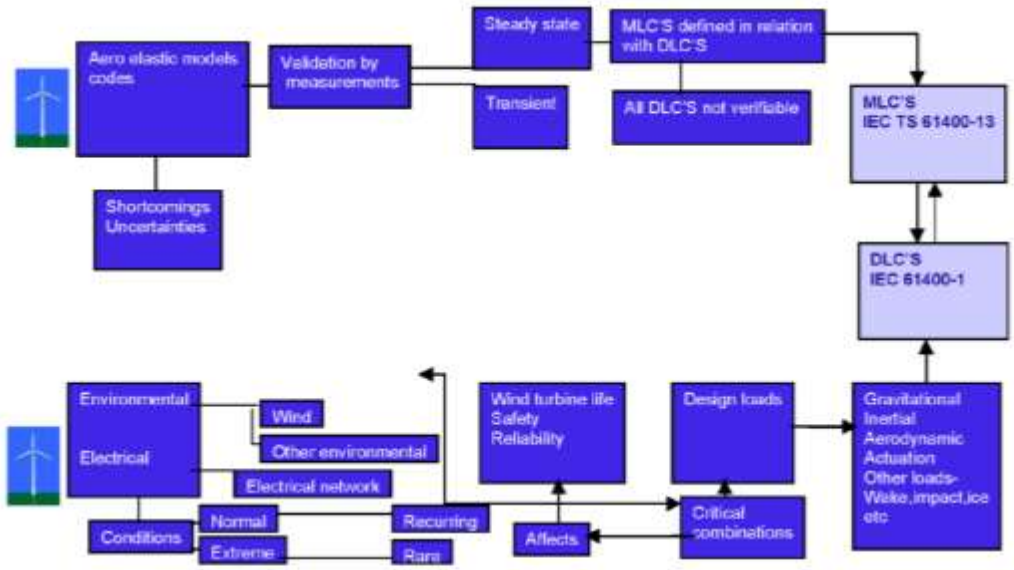
where

P is the electrical power in kW
P_{air} is the air density in kg/m^3
C, is the coefficient of power [ ]
A is the rotor swept area in m^2
V is the wind speed in rn/sec^2
V_1 is the upstream free flow wind speed in m/sec^2
V_2 is the downstream wake wind speed in m/sec^2

The power depends on the air density, swept area, wind speed and the rotor extraction efficiency and the performance can be improved if the design of the wind turbine is optimized for specific terrain, environmental and grid conditions.
A typical power curve is given below .The important issues of a power curve are cut-in and cut-out, cut-in and cutout hysteresis, power in the operating range and regulation. The power curve gives a very realistic indication of the performance and the safety of the wind turbine.



5. Load measurements



The mechanical loads which affect the wind turbine during its operational, transient and stand still conditions are required to be quantified. These loads are mainly from the rotor (the unit which constitutes three blades), nacelle (the unit which constitutes the main rotor shaft) and tower (the unit that holds the whole rotor and nacelle unit). The Measurement Load Cases (MLCs) are defined in relation to Design Load Cases (DLCs) described in 61400-1. All DLCs cannot be reasonably verified by measurements. The following are the mechanical loads in general which are related to specific DLCs and MLCs in the relevant IEC standards.

Blade loads
1. Edge-wise bending moment
2. Flap-wise bending moment

Rotor loads
1. Tilt moment
2. Yaw moment

Shaft loads
1. Shaft torque
2. Shaft bending moment in XX axis
3. Shaft bending moment in YY axis

Tower loads
1. Bending moments in XX axis at tower bottom
2. Bending moments in YY axis at tower bottom
3. Torsion at tower top

Measurement of Loads
The reference standard adopted for measurement of wind turbine loads is the “Technical Specification: IEC TS 61400-13, Wind turbine generator systems-Part 13: Measurement of mechanical loads”

Measurement Techniques

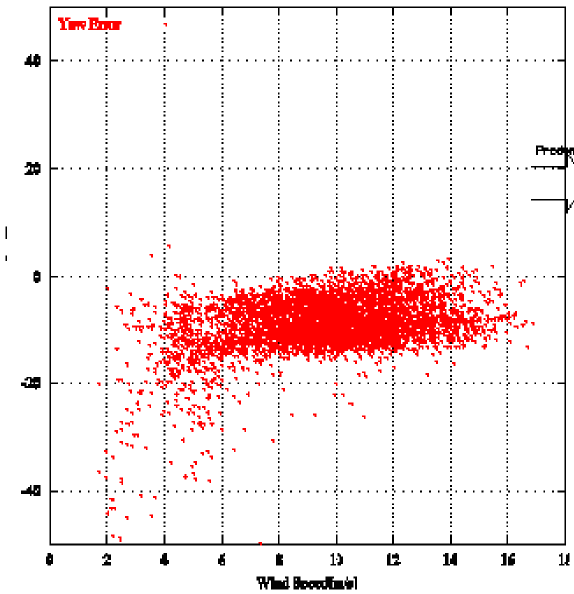
The measurement techniques for the various types of quantities in load measurements include

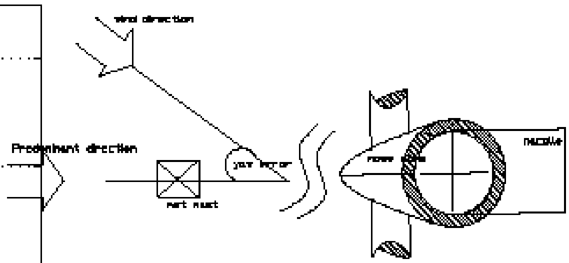
1. Instrumentation
2. Calibration
3. Signal Conditioning

Load measurements are used to determine the natural frequencies and equivalent loads on wind turbine components. The equivalent loads are evaluated using rain flow counting technique. The concept of the equivalent load is a convenient, short handed description of the fatigue impact of a given load measurement time history. The equivalent load is conceptually the single load equivalent that when applied with the total number of cycles in a given time history appearing at a given frequency does the same fatigue damage as the sum of all the different rain-flow counted load amplitudes in the measured load spectrum. The advantage of the equivalent load is that it provides a single descriptor of the fatigue damaging potential of a particular loading during a given time period. The equivalent loads are calculated for different wind speeds.

6. Yaw Efficiency

The yaw efficiency test indicates the capability of the wind turbine to follow the wind. It is the difference between the wind direction and the yaw position. The wind turbine is designed for the loads corresponding to the misalignment of specific values of yaw error. The measurement of the yaw error assists in the comparison of the measured values vis-â-vis the designed values. The rate at which the yaw system is enabled as defined in the controller during operating and fault conditions is also measured and compared. The yaw error at low winds are generally higher when compared to higher wind speeds as the winds are generally consistent at higher wind speeds.





7. Safety and Function Testing

The function and safety testing demonstrates the capability of the wind turbine to respond to the designed functions and to operate safely as per control and protection strategy of the wind turbine.

The following function and protection tests are carried out
Function
- Start up
- Normal stop Test
- Emergency stop Test
- Vibration Test
- Yawing
- Cable Twist

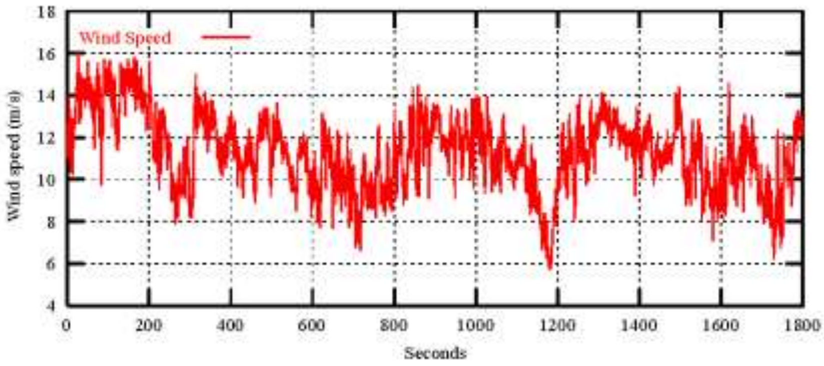
Protection
- Start up
- Normal stop Test
- Emergency stop Test
- Vibration Test
- Yawing

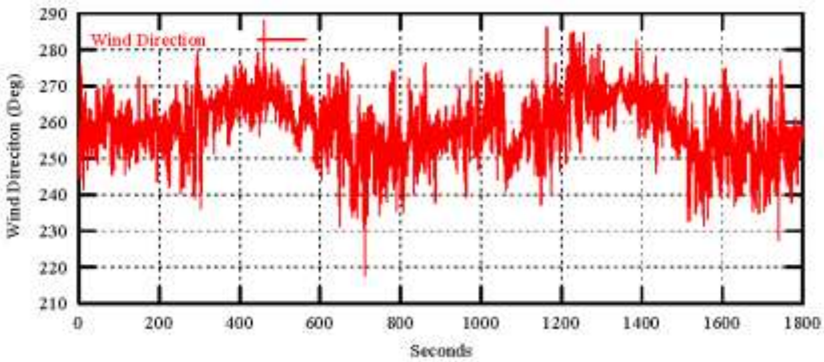
-Cable Twist

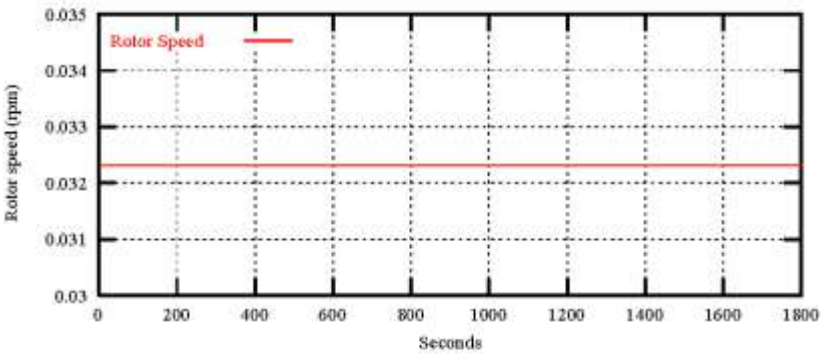
The parameters which are measured during the safety and function testing are given in the following table

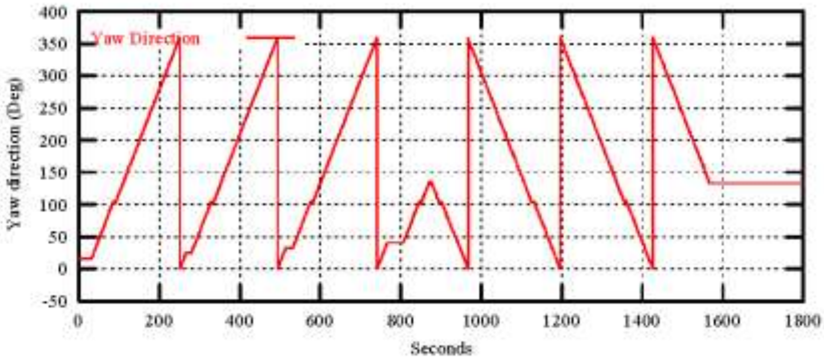
Safety & Function testing	Parameters *											
	WS	WD	RS	RP	YD	EBM	FBM	ST	AP	TC	GS	BS
Startup test	✓		✓			✓	✓	✓	✓		✓	✓
Normal stop test	✓		✓			✓	✓	✓	✓		✓	✓
Emergency stop test	✓		✓			✓	✓	✓	✓		✓	✓
Vibration test	✓		✓			✓	✓	✓	✓		✓	✓
Grid failure test	✓		✓			✓	✓	✓	✓		✓	✓
Overspeed test	✓		✓			✓	✓	✓	✓		✓	✓
Cutin to grid test	✓					✓	✓	✓	✓			
Yaw functionality	✓	✓	✓		✓			✓			✓	✓
Cable twist test	✓	✓	✓		✓			✓			✓	✓
Backwind operation	✓	✓	✓	✓	✓							
Cutin measurement								✓	✓	✓		

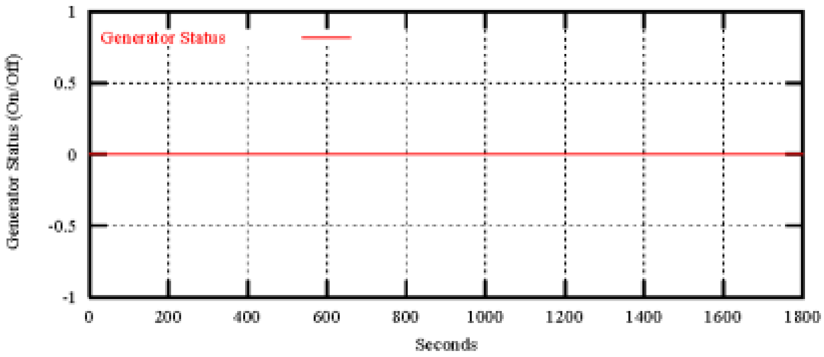
The following figures demonstrate the capability of function and the protection of the wind turbine during a cable twist test.

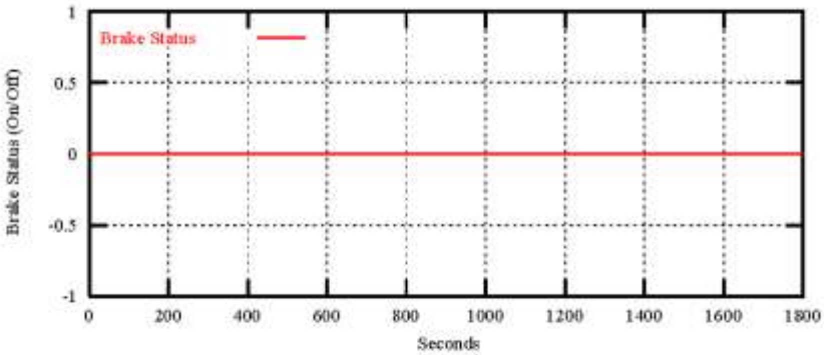

Wind Speed
Wind speed (m/s)
Seconds


Wind Direction
Wind Direciton (Deg)
Seconds


Rotor Speed
Rotor speed (rpm)
Seconds


Yaw Direction
Yaw direction (Deg)
Seconds





8. Conclusion

Measurements assists in understanding performance and safety issues at specific environment, terrain and grid conditions which enables design improvements. The awareness to the requirements of testing and its importance is the need of the hour to understand the operation of the wind turbine, improve the design and performance and to realize the benefits of wind turbine technology as envisaged by the entire stake holders in the wind energy sector.

TYPE CERTIFICATION OF WIND TURBINES AS PER TAPS-2000

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1.0 INTRODUCTION

Type Certification is obtained by wind turbine manufacturers for their wind turbine (WT) models, to demonstrate that wind turbine models are meeting the specified standards. Certification of wind turbines has a history of almost thirty years. Most of the countries with the active wind energy programmes have their National type certification / approval schemes along with testing facilities for Type certification / Approval of wind turbines. The scope for the certification is well defined in type certification schemes. The present trend is moving towards harmonization of certification requirements and International Standards (IEC) have been released on certification requirements. IEC standards are widely accepted.

2.0. Facility for Type Testing and Type Certification

Though, India has witnessed a rapid development in wind power generation during the last two decades, testing and certification facilities were not available in the country. Presently, the Indian WT manufacturers, with a few exceptions, are supplying the wind turbines of the types provided by their principals, which are certified by the type certification bodies in abroad. However, these type certificates are issued based on the European site conditions and approval schemes/technical criteria of the country in which they are carried out. In addition, the wind turbines installed in India undergo major/minor changes to suit the Indian conditions. All the major stakeholders expressed the need for establishing the testing facilities and certification system in the country. Based on the above, Ministry of New and Renewable Energy (MNRE) has established Testing and Standards and Certification (S&C) units as a part of Centre for Wind Energy Technology(C-WET). S&C unit has prepared a Type Certification scheme viz., “Type Approval - Provisional Scheme (TAPS-2000)”, the Indian Certification Scheme for wind turbines, which has been approved and issued by MNRE.

3.0 Type Certification

The purpose of the type certification is to confirm that the wind turbine type is designed, documented and manufactured in conformity with design assumptions, specific standards and other technical requirements. Type Certification applies to a series of WTs manufactured under the same design.

3.1 The Type Certification process can be broadly described as given below:

- Evaluation of
  - Design documentation
  - Type Test reports
  - Manufacturing system documentation
  - Type characteristic measurements (optional)
  - Foundation design (optional)
- Preparation of Final Evaluation Report
- Issue of Type Certificate, valid for a specified period
- Renewal of Type Certificate

4.0. Type Approval – Provisional Scheme (TAPS-2000)

S&C unit of C-WET, the Type Certification body, is the implementation agency of TAPS-2000. TAPS – 2000 aims to promote procedures and requirements for the establishment of uniform codes, standards and technical criteria for design, manufacturing and operation of wind turbines. TAPS – 2000 comprises of principles, procedures, requirements and the technical criteria for certification of wind turbines in India, addressed to applicants and others involved in the scheme. TAPS – 2000 was formulated in line with IEC standards. However the requirements of Indian standards are included wherever necessary to take into account of the Indian conditions. National and International rules, codes and standards relevant for certification of WTs. TAPS – 2000 is applicable only to the grid connected, horizontal axis WT.

Based on the implementation experience, TAPS-2000 was already amended in the year 2003.

4.1 As per TAPS-2000, Provisional Type Certification (PTC) is carried out according to three categories viz., Category-I, Category-II and Category-III. The outline of these three categories is mentioned below:

Category- I: PTC for wind turbine already possessing type certificate or approval.

Category- II: PTC for wind turbine already possessing type certificate or approval, with minor modifications/changes, including provisional type testing/measurements at the test site of C-WET / field.

Category- III: PTC for new or significantly modified wind turbine including provisional type testing/measurements at the test site of C-WET / field.

The documentation requirements for each category are detailed in TAPS-2000.

4.2 External Conditions

Wind turbines are subjected to environmental and electrical conditions, which may affect their loading, durability and operation. In order to ensure the appropriate level of safety and reliability, the conditions of environmental, electrical, operational and soil parameters must be considered in the design and also explicitly stated in the design documentation. The design documentation must be submitted by the manufacturer/supplier to the Type Certification body.

The wind turbine, subjected to PTC for installation in India, should be designed using representative environmental and other design conditions. Especially, the grid conditions and extreme wind climate in India are different compared to European conditions. As per TAPS-2000, the design shall comply with the requirements specified in IEC 61400 – 1 standard and modifications to IEC 61400 – 1, as given in TAPS-2000 to incorporate the Indian conditions. It is also included that the evaluation of extreme wind conditions of any wind farm site shall be carried out as per the Indian Standard IS : 875 (Part 3). The requirements on external conditions mentioned in TAPS-2000 are applicable for all the three categories of Provisional Type Certification.

4.3 Provisional Type Certificate

The Type Certification Body, Standards and Certification (S&C) unit of C-WET, will issue a Provisional Type certificate for a wind turbine model, based on satisfactory evaluation for completeness and correctness of the evaluation reports. The specifications of the certified wind turbine model are issued as a part of the Type Certificate. The make and model of components including allowable alternative suppliers are also mentioned in the Type Certificate.

5.0 Renewal process

The type certificate is valid for a specified period, as mentioned in the certificate, which is normally 1 year from the date of issue. Within the validity period of the certificate, a spot inspection of the installed wind turbine(s) of the model certified can be conducted. The renewal process includes the evaluation of quality system documentation and evaluation of any other minor modifications/ documentation, provided by the wind turbine manufacturers. The renewed certificate is issued after the successful completion of renewal process.

6.0 Conclusion

Type certification of wind turbines provides confidence to various stakeholders on the product. In order to ensure the quality of the wind turbines used in a wind farm project, availability of a type certificate is often included as a part of evaluation criterion by the developers, financial institutions and insurance companies in India. The type certification of wind turbines facilitates the industry to develop reliable wind turbines and also to ensure safety aspects.

POWER EVACUATION FACILITY AND TRANSMISSION FROM SEB

By A. Velayutham,
Ex-Member, MERC.

Introduction

Electrical load demands power for its action. Generators supply the requisite power. For techno commercial reasons the demand of consumers is met by Generators through Transmission & Distribution System. Wind Power Generators, like any other Electrical Generators have to supply power to the consumers**.** Wind Generators have to be integrated in to the Grid System. Grid connectivity does not mean only the physical linking with the state transmission system, but has to fulfill the operational and commercial needs of a power system. Wind power integration has to satisfy cost sharing related to optimisation of resources and the technical need of grid reliability, security and quality.

1. WIND POWER GRID INEGRATION

There are technical and commercial aspects concerning grid integration. Technical aspects include transmission and evacuation related issues and operation related issues.

2.1 <u>Transmission Requirements</u>

This is another very important issue on which no SERC has taken any holistic view. At best one or two SERCs have ordered that connectivity should be provided to renewable energy generators on priority.

In India, eight states have commercially feasible wind potential namely Tamilnadu, Karnataka, Maharashtra, Andhra Pradesh, Madhya Pradesh, Gujarat, Kerala and West Bengal. Mapped Potential at 50 mtrs Hub height is 45,000 MW. The estimation may go up based on future advancement in technology as well as considering offshore potential. With new wind power plants coming up at a rapid pace some planning and policy related issues need to be addressed upfront in order to facilitate harnessing of wind potential. Special attention is needed as wind plants are typically located in hilly or coastal areas; far away from the load centres.

Power system planning from broader perspective needs to be adopted to facilitate expeditious harnessing of available wind energy resource. According to EA 2003, it is the responsibility of the State Transmission Utilities to provide necessary transmission infrastructure. Transmission planning criteria may be relaxed taking into consideration seasonal wind power availability, after analysing techno-commercial aspects. As envisaged in the Act, various arrangements for off-take of wind power including open access should be enabled expeditiously. In many instances, wind power plants were asked to shut down for want of transmission corridor. Also, it was noted that while some States in the country suffered acute load shedding, available wind power plants were forced to shut down elsewhere in other parts of the country.

2.2 <u>Operational Issues</u>

By its nature, wind energy in-feed is stochastic and difficult to foretell. Wind generation has no capacity value, therefore it is difficult to maintain system frequency. There may be a need for maintaining positive and negative margins in the control area. Induction generator-based wind farms act as variable reactive power load on the grid and affect voltage profile of the system. A wind farm is a source of harmonics to the power system network.

In view of the above, it has been claimed in the past that the power system performance may be affected. System stability may be hampered during system dynamics. Frequency control could become difficult. In addition, it may lead to voltage degradation and possible grid disturbance. With advancement in technology as well as availability of control electronics, all these concerns can be easily addressed as elaborated below.

Dynamic system stability:

As regards the stability of the grid, there is a relation between individual generation size and the overall grid capacity of the system. In Indian power grid, the maximum size of the wind unit connected is of 2 MW. Even if 10 MW size units are added, still for all practical purposes, the rest of the grid may be considered infinite. Impact on grid stability is very minimal. Even if we consider wind clusters of 500 MW there are controls available to minimise the impact on the dynamic system stability. Even with higher wind energy penetration, the issue of dynamic grid stability could be easily and effectively addressed. Adopting Fault Ride through (FRT) capability for wind farms would strengthen the reliability of the system during disturbance. FRT control capability is the capability of WTG installations that enables the wind turbine to stay connected during and after grid faults in the power system.

Frequency control:

In the Indian power system, with the present quality of operation being between 49 Hz and 50.5 Hz, frequency control may not pose problems as the variation is permitted. When the Indian power system moves close to 50 Hz operation, inherent system response would improve. However, for frequency control, extra cost, if any, could be addressed in a regulatory regime. Further, the Indian power system can take the status of Infinitegrid with reference to wind power linking. Wind farm main controllers are capable of integration with the area frequency control system along with conventional power plants. The concern expressed that, with the increase in RPS obligation and increasing wind generation coming into system, frequency control could become difficult, is misplaced. An increase in RPS obligation may not impact frequency control. Modern wind energy plants have been equipped with features supporting grid integration. Geographical spread and size of the grid aids to tackle frequency problem.

Voltage control

Modern wind energy plants have taken steps to address reactive power requirement of their units for maintaining required voltage profile. Even if there are voltage control issues, the same could be handled effectively with available tools.

As regards harmonics generation, state-of-the-art control system is available to suppress. Improved forecast techniques help to minimise estimate errors.

Sub- LDC (Sub Load Dispatch Centres)

So as to improve system operation with proposed high wind penetration, it is suggested to establish exclusively for RE sources, sub-load dispatch centres under SLDC to take care of commercial and operational needs of power system. Real time data of RE sources could be made available to sub-LDC. TheGrid Code needs to have provisions concerning RE source.

Wind energy is a freely available natural resource that needs to be harnessed to the maximum extent, as available. Accordingly, wind farm power generation projects need to be treated as MUST RUN stations and wind power needs to be dispatched at all times, as and when wind is available, in order to gainfully utilise the investments in the wind power assets and maximise generation from such wind farm assets.

2.3 Commercial aspects

When evolving a Balancing Code the following may be considered in respect of wind power, without compromising market-based needs.

- Green power
- Variable energy output
- Saving in fossil fuel
- Minimising carbon emission
- Energy has to be absorbed, as and when available

As envisaged in the Act, various arrangements for off-take of wind power including open access should be enabled expeditiously. Reactive power pricing specified by various SERCs may be continued for the time being. Metering arrangement needs to be strengthened for smooth implementation of SERC orders. However, in future, reactive power pricing has to take care of both reactive power supply and absorption with voltage threshold specified.

INDIAN WIND GRID CODE

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1. Introduction

India today stands fifth in the world with an installed capacity of 10242.5 MW of wind power (as on March 2009) which constitutes 7% of the total 1,52,000 MW connected to the grid. This has grown from 3.5% in 2004 to the present capacity it is today.

Wind turbines are installed in areas with sufficient wind power density (> 200 W/ sq.m at 50 m hub height level) with provision to connect to the grid. Areas with good wind power density are not necessarily places with a strong grid, as they are mainly concentrated in rural areas away from locations with major generating stations. However, in the initial days due to the low penetration of wind energy in the grid, impacts on the overall power system were limited to local effects. Local impacts like voltage fluctuations, flicker, reactive power absorption were observed at the point of connection to the grid. With the exception of penalties by state electricity boards for VAR drawl from the grid, there were no technical regulations to govern the connection of the wind turbines to the grid. However, with the increasing penetration of wind turbines, as high as 42 % in terms of installed capacity in states like Tamil Nadu, the need was felt to establish a standard operating practice for the wind turbines. This has lead to the draft Grid code for wind turbines to establish the guidelines specific to wind turbines.

2. Grid behaviour of wind turbines

Important aspects which determine the grid behaviour of wind turbines are that majority of these are fixed speed turbines consisting of induction generators. This is unlike the conventional generators which are synchronous generators / alternators and have characteristics different from the induction generators. Machines with induction generators need capacitor banks for VAR support, otherwise reactive power will be drawn from the grid. The drawl of reactive power affects the voltage profile at the point of connection to the grid. However, wind turbines of variable type, which use wound rotor or permanent magnet synchronous generators, do not need a reactive power support. They may have to deal with issues like harmonics generated by the power converters, which has to be kept under control.

Another major characteristic is the behaviour of the wind turbine during system faults/ disturbances. The wind turbines are designed to disconnect from the grid during system faults, when the voltage at the point of connection drops beyond a certain percentage of the nominal value If wind turbines are to remain connected to the grid during system fault, a source of reactive power must be able to sustain the wind turbine in the generation mode during such fault conditions.

The variable nature of wind, which is talked of as one of the drawbacks of wind energy is also an important grid aspect. Wind generation cannot be scheduled due to its unpredictability.

Moreover, different manufacturers follow different operating standards and the system behaviour in the absence of any grid code will be unpredictable.

3. World scenario

Internationally the countries who are leaders in terms of installations have framed grid codes for wind. USA, Germany, Spain, Denmark, China, Nordic Countries Canada, Ireland have enforced their grid codes. Each of these grid codes have a common framework dealing with issues specific to wind, however the regulations take into the nature of the grid, installed capacity, penetration of wind, high wind potential zones etc. For instance, the Danish grid code has been formulated keeping in mind the high penetration of wind power in the country.

The grid codes for wind, in general deal with the following issues:

- Active power control
- Frequency
- Voltage and reactive power issues
- Fault ride through capability
- Protection
- Power quality issues like flicker, harmonics etc.

4. Grid code requirements

4.1 ***Active power control***

This is the ability of the wind turbine generators to regulate the active power output of the wind turbine according to system requirements. Active power control of wind turbines is to ensure a stable frequency in the system, to prevent overloading of transmission lines, to avoid large voltage steps and in-rush currents during start up and shut down of wind turbines. In a wind turbine, the power output is a function of the wind speed and the power fed into the grid by the turbine is irrespective of the frequency of the grid. However, with this feature the active power controller will take into account not only the wind speed, but also the requirements of the grid. The wind turbines will also have to regulate the in rush currents during start up.

During a fault, if the turbine were to stay on line, the active power output has to be reduced in a controlled manner to prevent tripping of the generator. All the same, the active power output should be brought back to the pre fault value after the fault is cleared.

The rate at which the power is ramped up after a system fault or during start up should not cause significant power surges.

4.2 ***Frequency requirements***

System frequency is a major indicator of the power balance in the system. A decrease in generation vis-a-vis the demand causes the frequency to drop below the nominal frequency and vice versa. In India, the frequency varies from 48.5- 51.5 Hz due to the power imbalance. This imbalance can be mitigated by primary control and secondary control of conventional synchronous generators. During an increase of load, the energy stored in these synchronous generators can balance the power for 1- 30 s, this is the primary control. The secondary control, employed with in a time span of 10 – 15 min. is by governor action which increases the input to the generator and stabilizes the system frequency.

Low penetration of wind turbines does not affect the system frequency. High penetration of wind turbines can have a significant impact on the grid. Even so, the wind turbines may not be able to contribute to primary control. The power output of the wind turbine can be regulated during high frequency, if need be. However, during low frequencies the output of the wind turbine cannot be controlled to contribute more power to the grid.

4.3 ***Voltage and reactive power issues***

Wind turbines with induction generators need reactive power support. Capacitor banks are the preferred method of reactive power compensation in wind farms, though dynamic VAR support devices like the STATCOM are available. If not properly compensated reactive power drawl from the system can cause increased losses, overheating and de- rating of the lines. Doubly fed induction generators and synchronous generator based wind turbines do not have any constraints with respect to reactive power. Thus, the behavior of different types of wind turbines can be standardized by means of the grid code.

4.4 ***Fault / low voltage ride through***

This refers to the ability of the wind turbine to remain connected to the grid without tripping from the grid for a specified period of time during a voltage drop at the point of connection. The period of fault ride through depends on the magnitude of voltage drop at the Point of Common Coupling (PCC) during the fault and the time taken by the grid system to recover to the normal state.

During system disturbances, if generators of large generating capacity connected to the grid continue their operation, this aids the system in returning to normal operation. On the other hand, disconnection of such a generator would further aggravate the disturbance and may lead to a system collapse. If the fault causes loss of a conventional generating unit, the system would need sufficient spinning reserve to cover the loss of the generator. Hence the need for fault ride through capability.

During a fault that causes a voltage drop at the wind turbine terminals, the reactive power demand of induction generators increases. Unless a reactive power support is available at the generator terminals, the reactive power will be drawn from the grid. This will reduce the thermal capacity of the conductors connecting the turbine to the grid, to transfer active power and cause further drop in voltage at the point of common coupling.

4.5 ***Wind farm protection***

In case of large wind farms connected to the grid, wind turbines are required to remain connected to the grid within specified voltage and frequency limits. High short circuit currents, under voltages and over voltages during and after the fault can damage the wind turbine. The relay protection system of the wind turbine should take in to account:

- Normal operation of the system and support to network during and after the fault.
- Secure wind farms from damage originating from faults in the network.

Wind turbines are required to be equipped with under frequency and over frequency protection, differential protection of the generator transformer, and back up protection. The protection system requirements have been mentioned in some of the grid codes, while others have not exclusively mentioned about wind farm and system protection.

Grid codes require that wherever low voltage ride through schemes and frequency protection schemes are applied on the wind turbines, the settings should be done in proper coordination with the transmission system protection relaying.

4.6 Data requirements

Monitoring of large wind farms to obtain up-to-date information on the real time status of the wind farm is essential. This will help in tracking the dynamic changes that the wind farms will undergo. The system operator can change the set point according to the operating conditions.

4.7 Power quality issues like flicker, harmonics etc

Flicker is defined as the visual fluctuations in the light intensity as a result of voltage fluctuations and is caused by wind turbines, both during continuous operations and switching operations. Human eye is most sensitive to frequencies in the range 1- 10 Hz. The flicker from wind turbines is mainly caused by the effect of tower shadow, which lies in the range of 1-2 Hz. Power fluctuations due to wind speed fluctuations lie in the frequency range of < 0.1 Hz and hence are less critical to flicker. Flicker in variable speed turbines is found to be lower than that of fixed speed wind turbines due to smoothening of the power fluctuations.

During switching operation, the generator cuts in and the large in-rush current of the generator is limited by the soft starter. A few seconds after the generator is connected, capacitors are switched in for reactive power compensation. These power fluctuations, both active and reactive power, during switching operation cause flicker. However, for variable speed turbines such in rush currents do not arise.

Harmonics are generated by variable speed turbines with power converters, like doubly fed generator and full variable speed wind turbine. Induction generator based wind turbines which are directly connected to the grid, do not have harmonic issues.

The grid codes specify limits for flicker and harmonics due to their impact on the grid. Flicker is a main concern for fixed speed wind turbines connected to weak grids. As regards, harmonics, many grid codes do not speak of limits for harmonics in their grid codes. IEC 61400-21 recommends measurement of harmonic emissions only for variable speed turbines. IEEE STD-519-1992 is followed by many countries for grid integration of turbines.

Voltage imbalance is another power quality issue which can affect the performance of induction generators. The effect is severe during fault conditions. Most of the grid codes impose the same voltage requirements for unbalance as for conventional generators.

5. Indian Wind Grid Code

The draft Indian Wind grid code addresses issues related to the wind energy plant as an addendum to the existing Indian Electricity Grid Code (IEGC).

The IEGC lays down the rules, guidelines and the standards to be followed by the various agencies and participants in the system to plan, develop and operate the power system in an efficient, reliable, economic and secure manner. The IEGC broadly covers the planning code for inter state transmission, the connection conditions (minimum technical and design criteria which are complied with by the transmission utility), operating code for the regional grid and scheduling and dispatch code for conventional generators. The IEGC would be suitably amended to incorporate the criteria to be complied with for wind turbine generators and any additional features would be a part of a supplement to the IEGC.

The following are proposed in the draft Indian Wind Grid Code:

5.1 Planning Code for transmission systems evacuating wind power

Wind power evacuation shall feature as a part and parcel of the overall grid planning.

The transmission utility / transmission system operator shall consider both short term and long term expected wind generation in the region. The planning criterion should consider the following scenarios:

i. System peak load with high wind generation
ii. System light load with high wind generation
iii. Local light load with high wind generation

The high wind generation shall be classified as a percentage of the overall wind farm capacity, based on the voltage level to which it is connected. For instance, wind farms connected below 66 kV levels may reach their peak capacity during the windy months as wind turbines see the same wind over a smaller geographical spread; this must be taken care of during the transmission planning.

The N-1 contingency criteria may be adapted for planning of transmission lines wind farms connected above 220 kV or of capacity 100 MW and above at 220 kV levels. The underlying idea is that N-1 contingency planning does not make economic sense for smaller wind farms and loss of generation of small wind farms does not have a significant impact on the grid.

The Wind power addition plan for every five years issued by the Ministry of New and Renewable Energy shall be considered for planning of transmission lines. Wind farm owner shall also give the requisite planning data to the transmission utility.

5.2 Connection code for wind farms

Wind farms shall maintain certain minimum technical standards for grid connection with respect to the following:

5.2.1 Transmission voltage range

The wind farms must be capable of normal operation for the following voltage ranges. The limits are taken from the standards set for conventional generators in the IEGC / state grid codes:

Table 1: Voltage withstand limits for wind farms

Voltage (kV)			
Nominal	% Limit of variation	Maximum	Minimum
400	+5% to -10%	420	360
220	+11% to -9%	245	200
132	+10% to -9%	145	120
110	+10% to -12.5%	121	96.25

66	+10% to -9%	72.5	60
33	+5% to -10%	34.65	29.7

5.2.2 *Voltage unbalance*

Voltage unbalance, defined as the ratio of the deviation between the highest and lowest line voltage to the average of the three line voltages, can cause negative sequence current to flow in the rotor of the wind turbine. As per the Grid Standard (CEA) followed, the following limits have been specified:

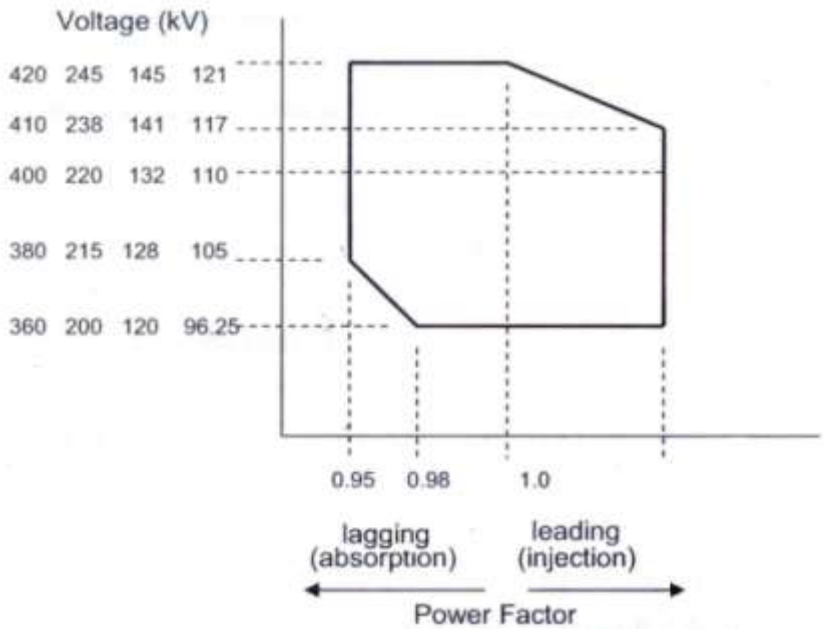
Table 2: Voltage unbalance limits for wind farms

Voltage level (kV)	Unbalance (%)
400	1.5
220	2
<220	3

5.2.3 *Reactive power capability*

The wind farms shall be able to maintain a power factor of 0.95 lagging to 0.95 leading at the grid connection point. Wind farms at higher voltage levels (66 kV) shall maintain the following characteristics (refer figure 1):

Figure 1: Voltage vs. power factor characteristics of wind farms connected above 66 kV



At system voltages higher than nominal, the requirement is a lagging power factor, whereas at lower voltages, the wind farm can operate at leading power factor injecting reactive power to the grid.

5.2.4 Frequency tolerance range

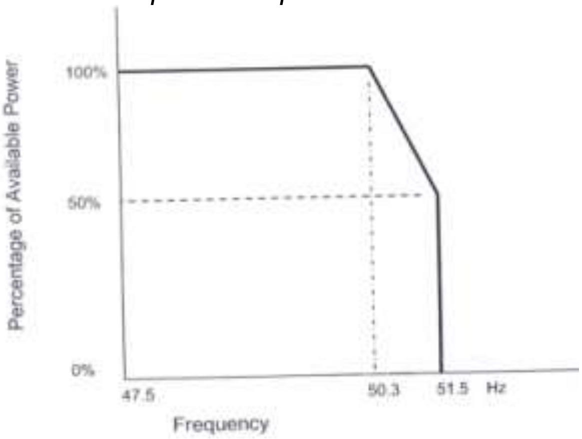
The frequency tolerance range for wind farms is 47.5 – 51.5 Hz. Beyond this, the frequency tolerance shall be manufacturer specific. Wind farms shall be able to withstand change in frequency up to 0.5 Hz/sec.

5.2.5 Active power control

For wind farms at high voltage levels (66 kV), active power control of the wind farm output shall be possible on system operator's request.

The active power response of wind farms to frequency should be such that the power injection into the grid is limited at frequencies above nominal.

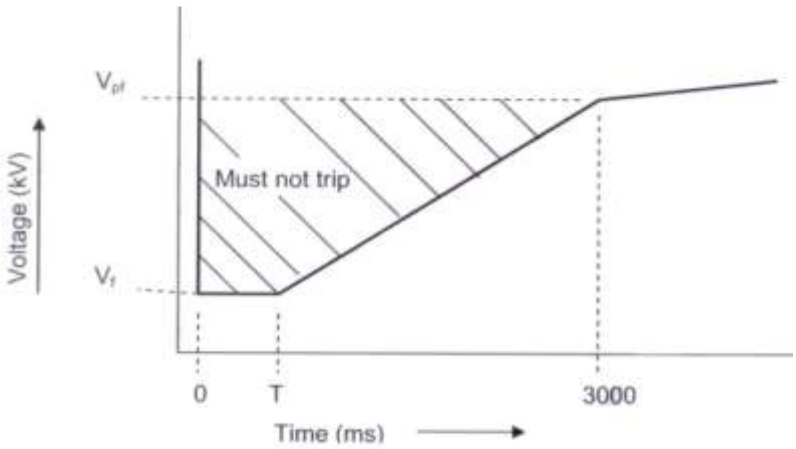
Figure 2: Variation of active power output of wind farms with respect to frequency



5.2.6 Low voltage ride through

Wind farms connected at 66 kV and above shall have low voltage ride through capabilities. The operating characteristics are depicted below (refer figure 3):

Figure 3: Fault ride through characteristics



V_f : 15% of nominal system voltage

V_{pf} : Minimum Voltage for normal operation of the wind turbine

Table 3: Fault clearing time and voltage limits

Nominal system voltage (kV)	Fault clearing time, T(ms)	Vpf (kV)	Vf (kV)
400	100	360	60.0
220	160	200	33.0
132	160	120	19.8
110	160	96.25	16.5
66	300	60	9.9

The fault ride through requirement brings the wind farms at par with the conventional generators, which have this feature. The fault clearing times are as specified in the IEGC / state grid codes. However, the timeline for implementing the same shall be based on the penetration levels of wind farms, the additional cost involved and usefulness in terms of grid management strategies.

5.2.7 Protection schemes for wind farm protection:

The minimum requirement with respect to wind farm protection are:

i) under/over voltage protection
ii) under/over frequency protection
iii) over current and earth fault protection
iv) load unbalance (negative sequence) protection
v) differential protection for the grid connecting transformer
vi) capacitor bank protection
vii) tele-protection channels (for use with distance protection) between the grid connection point circuit breaker and user connection point circuit breaker.

5.3 Operating code for wind farms

The wind farm shall adhere to the operating code for safety and reliable operation of the grid.

5.3.1 Voltage at the grid connection point

Table 4: Operating voltage limits for wind farms

Voltage (kV)			
Nominal	% Limit of variation	Maximum	Minimum
400	+5% to -10%	420	360
220	+11% to -9%	245	200
132	+10% to -9%	145	120
110	+10% to -12.5%	121	96.25
66	+10% to -9%	72.5	60
33	+5% to -10%	34.65	29.7

5.3.2 Frequency of operation for wind farms

The operation of the wind turbine shall be as shown in figure 2. Wind turbine shall not be started above 51.5 Hz.

5.3.3 *Reactive power and voltage control*

The requirement with respect to reactive power and voltage control will be as mentioned in the IEGC.

i) VAR drawl from the grid at voltages below 97 % of nominal will be penalized.
ii) VAR injection into the grid at voltages below 97 % of nominal will be given incentive.
iii) VAR drawl from the grid at voltages above 103 % of nominal will be given incentives.
iv) VAR injection into the grid at voltages above 103 % of nominal will be penalized.

As such VAR drawal from the grid when voltage is below 95 % of nominal and injection into the grid when voltage is 105 % above nominal shall be minimize by the wind farm operator. The charges for VAR exchange shall be specified by the Central / State Electricity regulatory Commissions.

5.3.4 *Ramp rate limits*

Ramp rate limits aims at regulating the active power generated from the WTG and minimizing the sudden variations in generated power due to variations in the wind.

The ramp rate limits specified for wind farms of 50 MW and above are:

Table 5: Ramp rate limits for wind farms

Wind Farm Installed Capacity (MW)	10 min Maximum Ramp(MW)	1 min Maximum Ramp(MW)
50-150	Installed Capacity/1.5	Installed Capacity/5
>150	100	30

The ramping down of wind generators would be as per the request of the system operator.

5.3.5 *Power Quality*

The assessment of power quality of wind farms is done as per the requirement of IEC 61400-21: Wind Turbine Generator Systems, Part 21: Measurement and Assessment of Power Quality Characteristics of Grid Connected Wind Turbines"

As regards voltage flicker limits, the IEC 61000-3-7 shall be followed. IEC 61000-4-15 gives the guidelines on measurement of flicker.

The harmonic content will be governed by Total harmonic distortion of voltage, V_{THD}

$$V_{THD} = \sqrt{\sum_{n=2}^{n=50} \frac{V_n^2}{V_1^2}} \times 100$$

Where Vn: n^{th} harmonic of voltage
V1: fundamental frequency (50 Hz) voltage

The harmonic content of the supply current is given by:

$$I_{THD} = \sqrt{\sum \frac{I_n^2}{I_1^2}} \times 100$$

Where In: nth harmonic of current

I1: fundamental frequency (50 Hz) current

The limits for the harmonic contents are as follows:

Table 6: Voltage harmonic limits

System Voltage (kV)	Total Harmonic Distortion (%)	Individual Harmonic of any Particular frequency (%)
765	1.5	1.0
400	2.0	1.5
220	2.5	2.0
132	3.0	2.0

Table 7: Current harmonic limits

Voltage level	<69 kV	>69 kV
ITHD	5.0	2.5

5.3.6 Operation during transmission congestion

During network congestion, wind farms shall operate as per instructions of system operator. Wind shall be backed down as a last resort and shall be considered like overflowing reservoir in Merit Order Dispatch

5.3.7 The demand estimation for operational purposes and demand management shall be as described in the IEGC / state grid codes. Wind energy forecasting shall be considered for demand estimation. The demand management shall take into account variable nature of wind.

5.3.8 Forecasting

Wind energy forecasting will become a necessity with increase in penetration of wind power. Scheduling of other generating plants can be carried out based on the forecast data for wind.

Centralised forecasting facility will be a requisite in an area with aggregated capacity of 200 MW and above. The forecast will be for the following time intervals:

i) Day ahead forecast**:** Wind power forecast with an interval of one hour for the next 24 hours for the aggregate wind farms. This will help in assessing the probable wind energy that can be scheduled for the next day.

ii) Hourly forecast: Wind power forecast with a frequency of one hour and interval of 30 minutes for the next 3 hours for the aggregate wind farms. This helps in minimizing the forecasting error that can occur in the day ahead forecasting.

Scheduling of other generators shall consider available wind generation for the duration. The spinning reserve shall be necessary to account for sudden loss of wind generation, based on the wind power forecast information.

As mentioned earlier, the forecasting will be implemented after considering factors like the penetration level of wind farms, cost and tariff.

6. Summary

The Indian Wind Grid Code has been designed keeping in mind the growth of wind energy in the power sector scenario over the past years. Today, wind constitutes the largest share of the 12 % capacity of renewable energy sources in the country. As such, the framing of the grid code has been timely, as it will bring 'Wind' at par with the conventional generators. The technical requirements for small wind farms have been kept minimal and have been limited to operating voltage limits, frequency tolerance limits, reactive power drawal and protection schemes. Conditions like fault ride through capability and forecasting that are stringent in the present context have been specified for larger wind farms and will be implemented in due course of time taking into account the penetration levels of wind energy, cost of implementation, tariff structure and usefulness in terms of grid management strategies.

References:

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[4] Grid integration of wind energy conversion system – Siegfried Heier – Second Edition