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Abstract: This Deliverable of SafeWind project presents the need of wind power forecasting under the Indian climatic and grid conditions.

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1. Overview of wind power development in India

1.1 History of wind power development in India

The first systematic efforts to harness wind energy in India were made during the 1950s and the early 1960s by the Council of Scientific and Industrial Research (CSIR) and the National Aeronautical Laboratory (NAL), mainly for water-pumping applications. Work on water pumping windmills continued till the mid 1980s. A large number of these windmills were reported to have been installed in Orissa and Tamil Nadu. However, due to the lack of evolved institutional mechanisms to maintain these machines that were dispersed in the remote rural areas, the initiative could not be launched on a larger scale.

The original impetus to develop wind energy in India came in the early 1980s from the government, when the Commission for Additional Sources of Energy (CASE) had been set up in 1981 and upgraded to the Department of Non-conventional Energy Sources (DNES) in 1982. This was followed in 1992 by the establishment of a full-fledged Ministry of Non-Conventional Energy Sources (MNES), renamed as Ministry of New and Renewable Energy (MNRE) in 2006.The Indian Renewable Energy Development Agency (IREDA) was established in 1987 as a financial arm of the Ministry to promote renewable energy technologies in the country. It provides finances to manufacturers, consultancy services to entrepreneurs, and also assists in the development and upgradation of technologies. The original intent of these institutions was to encourage a diversification of fuel sources away from the growing demand for coal, oil, and gas required to meet the demand of the country's rapid economic growth. The wind energy programme of the MNRE was aimed at catalysing commercialization of wind power generation on a large scale in the country. A market-oriented strategy was adopted from the inception, which has led to the successful commercial development of the technology. The broad-based national programme included wind resource assessment; research and development support; implementation of demonstration projects to create awareness and opening up of new sites; involvement of utilities and industry; development of infrastructure capability and capacity for manufacture, installation, operation and maintenance of wind power plants; and policy support. The MNRE provides support for research and development, survey and assessment of wind resources, demonstration of wind energy technologies and has also taken fiscal and promotional measures for implementation of private sector projects.

The Government of India planned several demonstration wind farms in the coastal regions of the country and an aggregate demonstration wind power capacity of 71 megawatt (MW) under the demonstration programme of the Ministry has been established at 33 locations in nine states[3]. The first modern wind turbine was set up in 1985 in Veraval, Gujarat, in the form of a 40-kilowatt (kW) Dutch machine connected to the grid, which was an initiative of late Dr K S Rao, the then Director of Gujarat Energy Development Agency (GEDA), and this project was a joint venture between GEDA and J K Synthetics Ltd India[4]. The demonstration projects developed an impression of the technical as well as economic viability of the wind energy projects.

1.2 Current status of wind power development in India

With the government initiatives of the wind power demonstration programme, wind resource assessment programme, fiscal benefits to the wind farm owners and various policies like minimum electricity tariff for wind energy, renewable purchase obligations declared by various states, and soon the Indian wind power is being grown at a rate of approximately 1500 MW per year since the past four years. Now with the total wind power installed capacity of 10242 MW as on 31 March 2009, India became the fifth largest wind power market in the world after USA, Germany, Spain and China[5]. It ranked third in terms of the annual wind power capacity addition with the addition of about 1486 MW during the year 2008-09. Figure1 show the cumulative wind power installed capacity and annual wind power installation in India from 1996 till 2009.

[3] **Purohit I. and Purohit P.; Wind energy in India: status and future prospects; Journal of renewable and sustainable energy 1, (2009).**

[4] **VVN Kishore, Renewable Energy and Energy Technology, a knowledge compendium-2008**

[5] **Annual report, Ministry of New and Renewable Energy, Govt. of India, 2008-09.**

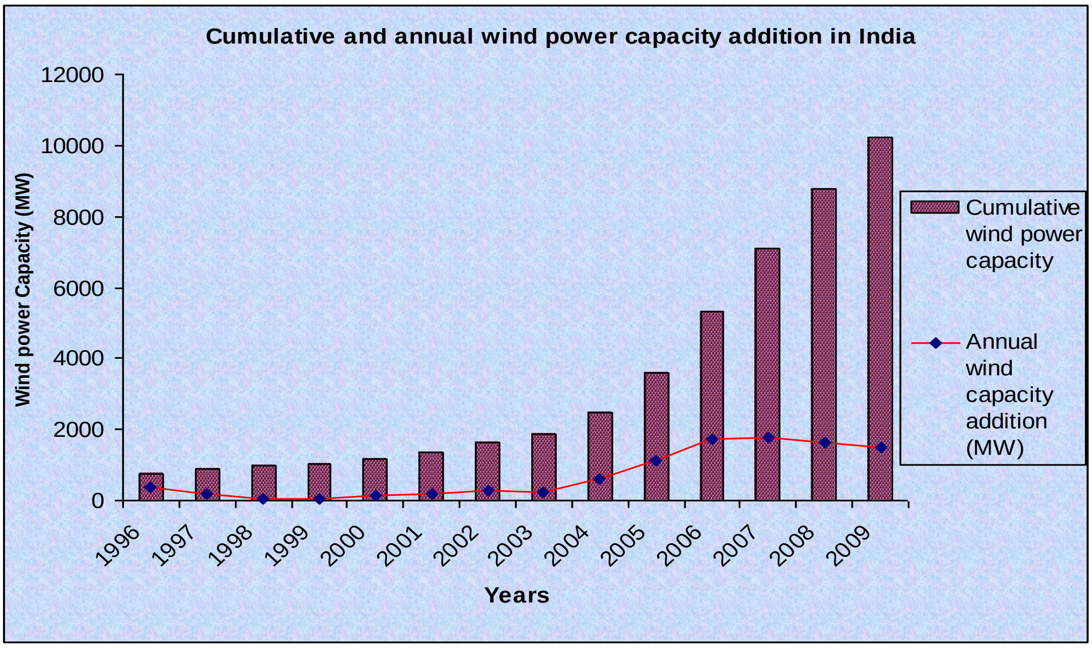


Figure 1: *Year wise and cumulative wind power installed capacity in India*

Source: Centre for Wind Energy Technology, Chennai (www.cwet.tn.nic.in)

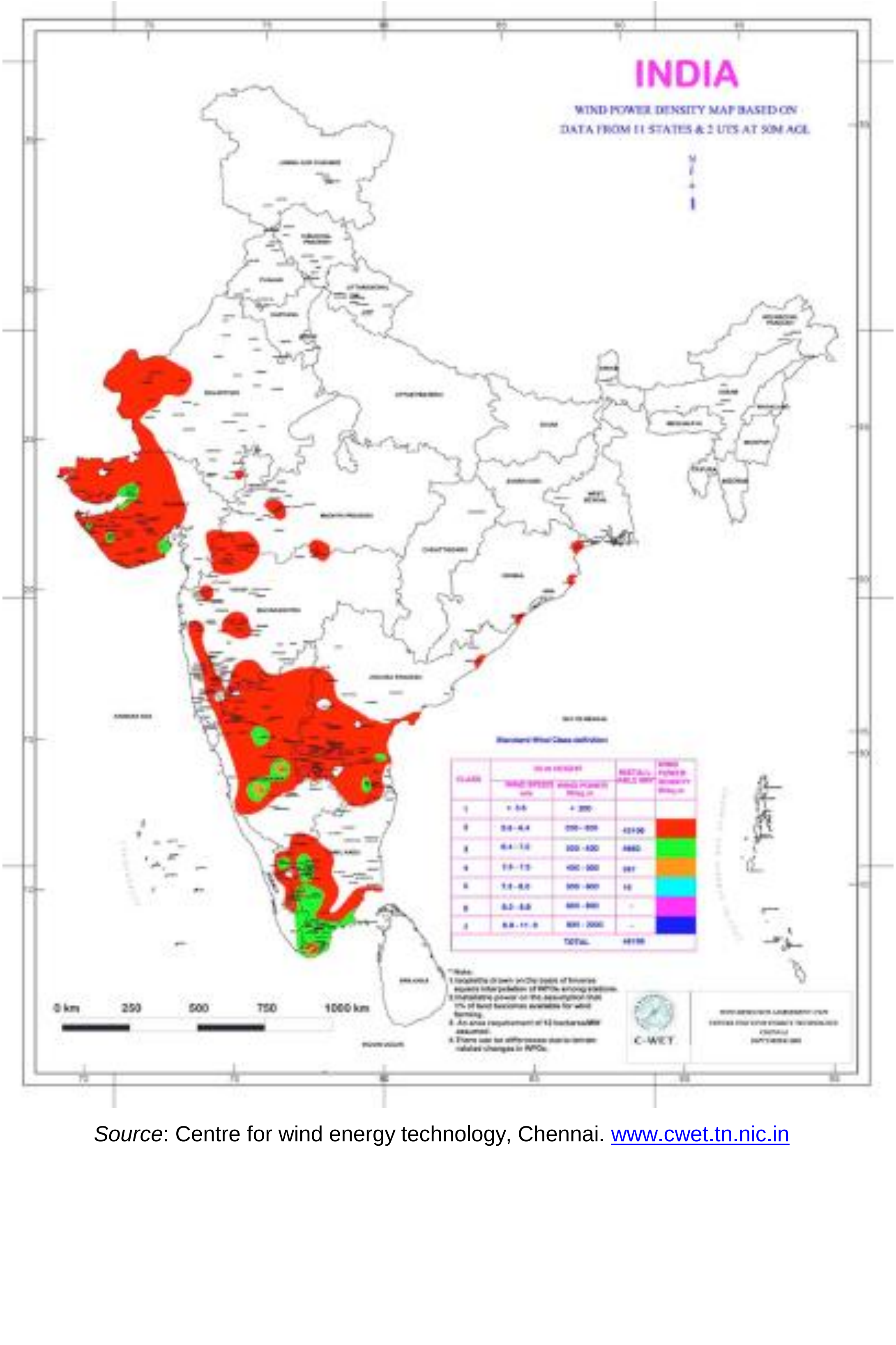
The above figure shows that the wind power addition has been taken at a higher rate during 2003-06 and is being developed now almost at a constant rate since 2006. It is expected that wind power installation will grow continuously and will meet the Government of India target of addition of 14500 MW wind power during the Eleventh Five-year Plan, which is from 2008-12. The average wind turbine size installed in India has been increased from about 250 kW in 1998 to about 1000 kW in 2008, with the wind turbine size of about 1.5 MW mostly being installed now a day. The amount of electricity fed to the grid from wind power project was about 12 billion units in the year 2008-09.

1.3 Wind resource in India

Wind resource assessment is an ongoing process. The wind resource assessment programme in India was started in 1985 and is being implemented by Centre for Wind Energy Technology (CWET), Chennai in association with state nodal agencies. Under this programme around 1,050 wind monitoring stations were setup in 25 states and union territories. Out of these 216 stations with annual wind power density greater than 200 W/m2 at a height of 50 m above ground level have been found suitable for wind power generation. Based on the wind resource assessment data, recently the potential of wind power generation in the country for grid integration has been estimated by the CWET, Chennai to about 48,500 MW taking sites having wind power density greater than 250 W/m^2 at 50 m hub height with 3% land availability in potential areas for setting up wind farms at land requirement of 12 ha/MW. The previous estimates for wind power potential was 45,000 MW assuming 1% of land availability for power generation in potential areas[6]. This potential is distributed in the states of Tamil Nadu, Andhra Pradesh, Karnataka, Gujarat, Maharashtra Rajasthan, Madhya Pradesh and Orissa. The technical potential, which is based on the availability of infrastructure, for example, availability of grid, land, and so on is estimated to be about 15,000 MW considering a maximum 20% penetration of existing capacities of grids through wind power in potential states.

In case of India the available wind resource is in the low wind regime, that is, wind power density is in the range of 250- 450 W/m^2 only. Figure 2 shows the wind power density map of India.

[6] **Purohit I. and Purohit P.; Wind energy in India: Status and future prospects; Journal of renewable and sustainable energy 1, 2009**



Source: Centre for wind energy technology, Chennai. www.cwet.tn.nic.in

Table 1 gives the gives the state wise distribution of wind potential and Table 2 shows the state wise wind power installations in the country.

Table 1: *State wise distribution of wind power potential in India*[7]

S. No.	State	Gross potential (MW)
1	Andhra Pradesh	8,968
2	Gujarat	10,645
3	Karnataka	11,531
4	Kerala	1,171
5	Madhya Pradesh	1,019
6	Maharashtra	4,584
7	Orissa	255
8	Rajasthan	4,858
9	Tamil Nadu	5,530
	Total	48,561

It may be noted that the above potential estimation is based on certain assumptions. With ongoing resource assessment efforts, extension of grid, improvement in the wind turbine technology, and sophisticated techniques for the wind farm designing the gross as well as the technical potential would increase in future.

Table 2: *State wise installation of wind power in India*[8]

State	Installation during 2008-09 (MW)	Total installed capacity (MW)
Andhra Pradesh	00	122.5
Gujarat	313.6	1566.5
Karnataka	316	1327.4
Kerala	16.5	27.0
Madhya Pradesh	25.1	212.8
Maharashtra	183	1938.9
Rajasthan	199.6	738.4
Tamil Nadu	431.1	4304.5
West Bengal	0.0	1.1
Others	0.0	3.2
Total	1484.9 MW	10242.3

2. Wind climate of India (Kishore VVN, REET: a knowledge compendium 2008)

India is a huge country with diverse climate. The huge mountain system of the Himalayan range not only has a great impact on the climate of India but also cuts off the Indian subcontinent from the rest of Asia. The weather in India is a complex phenomenon. Its diverse wind systems merit an independent treatment, which is taken up in this section. The main wind systems experienced in India are the sea and land systems, mountain wind systems, and the monsoons. While the sea and land systems and the monsoon systems are quite strong, the mountain systems are weak and erratic in comparison.

[7] **Centre for wind energy technology, Chennai. See http://www.cwet.tn.nic.in/html/departments_wra.html**

[8] **Indian wind energy Association. See http://www.inwea.org/aboutwindenergy.htm**

Monsoons are also caused by the fact that landmasses cool down and warm up faster than the sea. On a global scale, the differential cooling and heating of continents and oceans results in regional or global wind circulation systems which are the monsoons. The north-eastern or winter monsoons prevail from November to March and the south-western monsoon from June to September. As seen in Figure 3, India receives monsoon rains and winds in summer as the heating creates a low pressure area over the basin of the Indus River. Known as the South Asian (or Iranian) low, it appears in April and is fully developed from June to August. The onset of monsoons in India and South-East Asia is related to changes in the circulation pattern that occur by June. The monsoon air masses flow into the monsoonal low-pressure zone over northern India from a cell of high pressure, just off the eastern coast of southern Africa. Because of the Coriolis force, winds south of the equator change direction from southeast to south-west in the Arabian Sea and the Bay of Bengal. The south-west monsoon bursts on the Malabar Coast of India in early June and gradually moves northward over most of India. The monsoon period coincides with high wind speeds in most of southern and western India. In winter monsoons, the temperature over central Asia is lower, resulting in a zone of high pressure over the continent. This causes outward wind flow towards the sea.

Different altitudinal climatic zones are most clearly defined on the southern slopes of the Himalayas where they vary from the subequatorial and tropical climates of the foothills, at the lowest levels, to the snowy climate of the peaks, at the highest altitudes. The Foehn effect is seen when a strong wind traverses a mountain range and is deflected downward as a warm, dry, gusty, erratic wind. We have the valley mountain systems and the Foehn in many parts of the Himalayan region. One example is the wind-swept Leh valley.

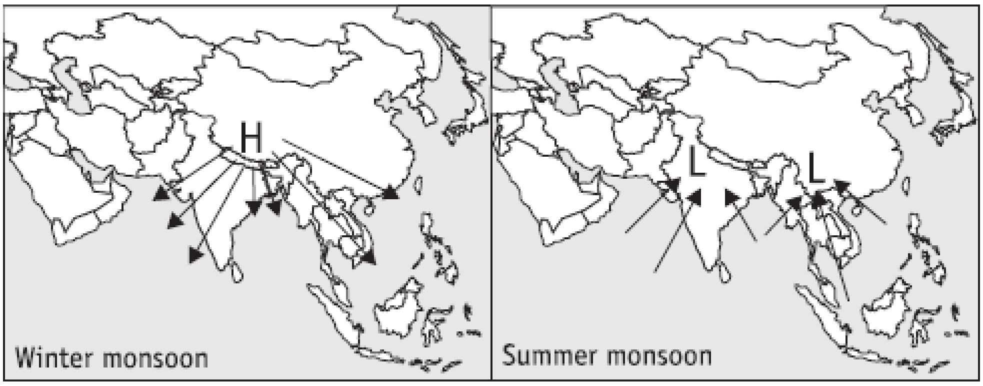


Figure 3: *Monsoon systems in India*

Larger-scale mountain–valley wind systems generally occur between the Himalayan massif and places to the south. When solar radiation is strong in summer, anabatic or valley winds continue into the night at the foothills of the Himalayas. Such winds are also witnessed in the outer periphery of valleys like the Kashmir valley or parts of the Terai and the Shivalik range (Himalayan foothills). In the neighbourhood of snow fields and glaciers, the katabatic winds, which flow with considerable force, are strengthened by the cooling of air through contact with ice and snow.

In addition to the above, the Deccan plateau and the western and eastern coastal ridges cause very high wind speeds in many parts of peninsular India. These winds coincide with the monsoon season. Local winds blowing through mountain gaps are sometimes observed in mountainous areas. These winds, at times, can be very strong and emerge as a jet on the downward side. Such winds are known to occur in mountain passes like Banihal and Tanmarg in Jammu and Kashmir.

Table 3: *Average monthly wind speed data for some locations in India*

Location	State	Year of measurement	Average Monthly Wind Speed (M/s)												Annual avg. (M/s)
			Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Mylampatti	Tamil Nadu	Dec 2001- Nov 2002 at 25 m	3.16	3.53	3.12	2.74	5.92	7.12	8.84	8.41	5.88	2.80	2.70	2.78	4.75
Jasapar	Gujarat	Oct 2001-Sep 2002 at 20 m	3.59	4.00	4.45	5.31	7.03	6.57	7.09	5.86	4.84	3.64	2.67	2.58	4.80
Butavadar	Gujarat	May 2001-Apr 2002 at 20 m	4.87	4.82	4.67	4.72	6.67	6.33	6.50	4.69	3.62	3.26	3.73	4.06	4.83
Warshamedi	Gujarat	Jan 2002- Dec 2002 at 20 m	4.3	4.2	4.6	6.3	9.1	7.3	8.7	6.8	6.1	3.6	3.6	3.4	5.7
Kappattaguda	Karnataka	Jan 2001- Dec 2001 at 25 m	5.6	4.5	5.1	4.4	8.1	11.2	11.0	10.7	6.2	5.8	5.9	6.9	7.1
Aundhewadi	Maharashtra	Dec 2001- Nov 2001 at 25 m	5.0	4.1	4.6	4.8	9.5	8.8	11.1	9.6	6.8	5.2	5.5	3.9	6.6
Alangarapetta	Andhra Pradesh	Jan 2001- Dec 2001 at 25 m	4.5	3.6	4.3	4.4	7.9	10.5	10.1	8.8	4.3	3.4	3.6	4.0	5.8
Badvel	Andhra Pradesh	Jan 2001- Dec 2001 at 25 m	3.8	4.2	5.1	4.5	6.0	8.7	8.7	6.7	4.0	2.8	2.6	2.9	5.0
Haripar	Gujarat	Sep 1996- Aug 1998 at 20 m	4.72	4.76	4.72	5.61	6.68	6.76	6.72	6.13	4.89	4.75	4.53	5.16	5.45
Dongerwadi	Maharashtra	Mar 1998- Feb 2000 at 25 m	4.73	4.80	4.91	5.28	6.49	7.89	8.29	7.36	6.47	4.81	4.99	5.21	5.93

Source: Wind energy resource survey in India

Wind farms in India are mainly located in the coastal regions of Tamilnadu, Gujarat, Andhra Pradesh and the plateau of Maharashtra and Karnataka. The study of wind data from these areas shows that the wind speed is of higher strength between April to September. Table 3 gives the mean monthly wind speed data of some representative wind farm sites from different states in India.

From the above table it is clear that the strong wind flows mainly between the months of May to September except in some cases like Maharashtra and Karnataka where the wind flow is comparatively higher in the other months also. The peak wind speed noted at any moment in these sites are in the range of 20-25 m/s except for very few sites where peak wind speeds noted are quite high up to 35 m/s or even higher for a moment[9]. Apart from the wind resource assessment carried out by the government, the private wind farm developers also install wind masts either near the sites identified by CWET or in different locations to collect the wind resource data for longer periods and at greater heights. The wind resource data from these locations are analysed and based on this data, if find suitable, the site is approved by CWET for the development of wind farms.

3. Electricity market in India

In India the power sector is dominated by the thermal power plants. As on 30 June 2009, out of the total installed power capacity of 150,323 MW, 96,044 MW is from coal based and gas based thermal power plants, 36,916 MW is from large hydropower plants and only about 13,242 MW is from renewables[10]. For the well operations of the electricity market the robust transmission systems as well as the generation systems with good control equipments are necessary. Commercial autonomy to buy and sell power may not achieve the desired results if the transmission network do not have the desired capacity and the generation system does not feed the power at controlled frequency defined for the transmission lines. The electricity generation and transmission has been fully controlled by the state and central government agencies. Only a part of this is now shifted to the private sector to address the huge electricity demand. A brief sector overview of transmission and distribution infrastructure in India is given in following paragraphs.

3.1 Transmission system in India

The transmission infrastructure is mainly developed and owned by the government owned central transmission utilities (CTU) and the state transmission utilities (STU), and these are responsible for intrastate and interstate transmission network. Only recently the transmission sector has been opened for the private sectors. The national transmission system in India is presently under development, with non-adequate interconnections existing between regions. As the primary resources of power generation are unevenly dispersed in the country, the demand for regional interconnections are likely to increase and hence the power trading between the regions will increase too.

Power transmission has begun to be taken more seriously, particularly in the last year or so by the planners and investers, and it has been recognized that a strong and adequate transmission infrastructure is a prerequisite for ensuring free flow of power to the place of its requirement. The introduction of modern concepts like open access, trading and merchant power, and the growing importance of captive power, renewable energy sources and nuclear power in the power mix have led to new requirements in transmission investment, planning and operation[11].

The transmission network in the country is divided into five main regional networks which are significantly strong and are well functioning. The frequency integration of western, eastern, northern and north-eastern networks has been accomplished and the Southern Grid is likely to be integrated soon in future[12].

[9] **Wind energy resource survey in India-VII**

[10] **Power scenario at a glance, Central Electricity Authority, July-2009**

[11] **Powerline, Directory and Yearbook 2009**

[12] **Pandit A & Joshi B, Transmission Planning and grid integration of renewable energy sources; InWind Chronicle Volume 4 Jan-Mar2008**

3.2 Electricity Generation management in India

The electricity generation, transmission and distribution is managed by the State load dispatch centres (SLDCs) and regional load dispatch centres (RLDCs). These agencies manages the scheduling of power, which is undertaken on a day ahead basis with predefined time frame for each step at the regional and state level simultaneously. The process of scheduling starts at 9 a.m. with the central generating stations comunicating to RLDCs the availability of output (MW) for the next day broken down in time blocks of 15 minutes. The plant wise declared generation is broken up as per the share of different states for each individual central generating plant by the RLDCs and communicated to the SLDCs. The SLDCs do the exercise simultaneously at the state level and communicate to the RLDCs the drawal schedule for the next day. The RLDCs, based on the state demands, prepare a dispatch schedule, with a 15 minute time block, for the central generating plants and the final drawal schedule for the states by 5 p.m.

At the state level the generating plants, including the captive power plants willing to sell the power and the plants owned by the distribution licensee, communicate the availability of power (MW) to SLDCs. The day ahead dispatch schedule, within 15 minute time block, for the generating plants is prepared by the SLDCs depending upon the demand forecast, availability of power from central stations, preferences given by the distribution licensees and the comercial cost of power to the licensee, and the transmission system constraints.

Presently the wind power generation is kept out of this scheduling exercise due to its variability. But the increasing penetration level of wind energy will make it mandatory to include the wind farm generation in this scheduling and hence, the importance of forecasting of wind power will become more important.

3.3 Power trading system

The resources of power generation are unevenly dispersed in the country, and by capitalizing on open access and expansion of interregional transmission capacity, the power trading between regions is likely to increase. Currently the trading constitutes only about 3% (27,713 MUs by end-February 2009) of the total power generation. However this share is expected to increase significantly. Since January 2004, the Central Electricity Regulatory Commission (CERC) has issued 43 trading licenses, which include major players like PTC India, Tata Power Trading Company, Adani Enterprises, Reliance Energy Trading, Lanco Electric Utility and NTPC Vidyut Vyapar Nigam.

The CERC issued guidelines in 2007 for setting up power exchanges and came up with the Indian Energy Exchange (IEX) in June 2008, which is the first ever power exchange in India. Later on the Power Exchange India Limited (PXIL) started in October 2008[13]. With these power exchanges, the power generation and trading will become free from the conventional regulations and is also expected to become competitive.

As per the existing regulations a day ahead market with hourly contract is being offered by IEX. In this the hourly electricity contracts in MW would be traded. It would also be possible to add certain conditions of block bids to additionally specify the continuous hours for which the bid should be accepted. IEX will collect the available transfer capability/available powers on all inter-regional links from RLDCs and the members may place their orders during the bid call period of 10 am to 12 noon of the auction day. In future the power exchange will charge suppliers a fee for uninstructed deviations between their predicted output and actual generation.

The above policy encourages wind energy suppliers to maintain a high level of reliability while also compensating the system for costs of having either excess or insufficient generation. This also motivates the development of wind forecasting systems in the Indian wind energy industry. These forecasting models should be capable of producing accurate forecasts of the wind power production in time horizons extending from few minutes to a day ahead. The priority is to minimize the deviation between predicted and actual output.

[13] **Powerline, Directory and Yearbook 2009**

4. Wind power forecasting scenario in India

At present no wind power forecasting is being undertaken in India at any time horizon and at any spatial level, that is, wind farm/regional level. Some of the forecasting models in practice today by different institutes and consultant companies/industries are basically designed for weather conditions in European countries and America. Meteorological data available for initial and boundary conditions for this region have good resolution and time scale. The major challenge is to test whether these models, with available global data, would accurately forecast tropical weather conditions that are mainly influenced by the monsoon[14].

4.1 Why is the wind power forecast necessary

In electricity grid, at any moment, balance must be maintained between electricity consumption and generation. While conventional power plants produce constant power output, the outputs of wind power plants fluctuate. To make the wind power competitive with conventional power plants in the Indian electricity market it is necessary to develop forecast models for power production from wind farms with high accuracy. Following points describe the need for wind power forecasting in India.

- The variability of wind generation can be regarded at various time scales. First, wind power production is subjected to seasonal variations. Winds in India are influenced by strong south-west summer monsoon, which starts in May-June and the weaker north-east winter monsoon, which starts in October. Winds are uniformly strong over the whole Indian peninsula, except the eastern peninsula from March to August. Wind speeds during the period November to March are relatively weak, though higher wind speeds are available during some part of the period on the Tamil Nadu coastline. Second, there are diurnal cycles mainly due to thermal stratifications and finally the fluctuations are observed at various temporal levels, that is, at the very short-term (minutes to intra minutes scale), medium-term (daily or weekly) and long term scale. Managing the variability of wind energy is a key aspect of greater utilization of wind energy. The forecasting methods/tools will help in predicting the wind variability and hence, making the wind power industry compatible to the growing electricity market.

- At present the scheduling of electricity generation in India is on a day ahead basis and is managed by the RLDCs and SLDCs. Currently the wind power plants are exempted from these scheduling, but looking ahead the market scenario and to boost the growth of wind energy sector it is necessary to develop the advance forecasting models to get accurate wind generation forecast.

- One of the most critical issues for the development of wind energy in India has been the transmission capacity of the grid in the areas where the wind farms were built. Like other countries the wind farms in India are located in the rural areas of coastal or hilly locations where the grids available are weak and with lesser evacuation capacity[15]. These weak grids are subjected to the voltage variations due to the variable demand of electricity as well as due to different power mix. Wind energy too includes the voltage variations, that is, increase in voltage due to active power generation and decrease in voltage due to reactive power consumption.

  The state transmission utilities (STUs) which are the agency responsible for the development of transmission infrastructure in their respective areas were averse to investing in transmission assets and evacuation infrastructure dedicated to wind farm of these remote areas due to its inherent nature and uncertainty of power generation. The Electricity Act 2003 (EA 2003) mandated the State Electricity Regulatory Commissions (SERCs) to promote harnessing of renewable energy sources by specifying minimum percentage for procurement from renewable energy sources and also by providing suitable measures for connectivity to grid for such sources. In this regard many states have released their renewable purchase specifications but still the issue of grid connectivity and evacuation infrastructure for renewable sources had not been taken seriously. There was a case in Tamil Nadu when the existing wind energy generation capacity was underutilized due to evacuation constraint.

[14] **Bhandare S, Chirayat T & Pillai S; Wind Power forecasting in India, IREDA News, volume5, April-December 2008.**

[15] **Pandit A & Joshi B, Transmission planning and grid integration of renewable energy sources; InWind Chronicle Volume 4 Jan-Mar2008**

The development of wind power forecasting tool with certain accuracy will give a sense of security to wind farm investors as well as transmission utilities to develop the infrastructure for harnessing the maximum power from this natural source in the area where its potential is plenty. These forecasting tools will also help the regulatory bodies to formulate the rules and grid code for wind power integration.

4.2 Available weather data and the possibility of development of models for wind forecasting in India

4.2.1 Available resolution of input data for wind forecasting

In India the National Centre for Medium Range Weather Forecasting (NCMRWF) is the agency which undertakes the numerical weather prediction (NWP) and diagnostic studies. The centre uses different weather forecasting models with different temporal, spatial, and vertical resolution. The NWP models used for weather forecasting by the centre are T80, T170, T254, MM, ETA, and WRF. The resolution level and forecast horizon of these models are given in Table 4[16].

Table 4: NWP models used by NCMRWF

Model Name	Resolution (Horizontal)	Forecast Horizon
T80	1.4°x1.4°	24-120 hour
T170	0.7°x0.7°	1-7 days
T254	0.5°x0.5°	24-168 hours
MM	10-30 km	1-3 days
ETA	32 km	1-3 days
WRF	27 km	1-3 days (6 hourly)

Source: www.ncmrwf.gov.in (last accessed September-2009)

The global high-resolution assimilation forecast system T254L64 (T254 spectral waves in horizontal and 64 layers in vertical) was implemented at NCMRWF in January 2007.[17] The above prediction model makes the use of direct assimilation of radiances from satellites. As the wind farms are concentrated on rural areas of hilly or coastal regions it is important to understand the performance of forecasting models at regional levels. Parvinder M and Ashok Kumar, of NCMRWF carried out a study for the evaluation of location specific weather forecast (mainly monsoon forecast) using T80/T254 models for following parameters

1) Rainfall (mm)
2) Cloud cover
3) Wind speed
4) Predominant wind direction
5) Maximum and minimum temperature trend for the year 2008.

The correlation and root mean square error (RMSE) values were calculated for the evaluation of the skills of the forecast for the maximum and minimum temperature, cloud amount, wind speed and direction. They observed that the correlation and the RMSE for cloud amount and wind speed were quite good (RMSE in the range of 3.5 -5.5, and correlation between 0.1-0.3) but for wind direction the correlation were not very good and RMSE values were high. They were of the view that the performance of T254 model was satisfactory.[18]

One of the issues is that the numerical weather prediction output is available in India with good spatial resolution but the temporal resolution is six hourly only. In the absence of higher resolution wind

[16] **Vipradas M, Wind power generation forecasting: need and possibility in India; Inwind ChronicleVol4, Jan-Mar 2008.**

[17] **Rajagopal et al., Monsoon- 2008**

[18] **Parvinder M and Ashok Kumar, "Location specific weather forecast including statistical interpretation forecast and its evaluation" Monsoon-2008; NCMRWF.**

forecasting models have to be adopted for lower resolution and also for the Indian climatology, mainly affected by monsoon.

In case of India as stated above the forecasting tool have to be adopted for the available lower resolution. The physical models would be easier as they can be run with limited data but would have to be adopted with the local parameters like contour and landscapes. Statistical models would require historical data to start working, but the adaptation in terms of establishing the empirical equations would be necessary. The validation and fine tuning of models would take time before these are ready for testing. The wind plant models, which would use the output from the wind forecast models, are well understood and are being used in India for wind resource assessment/micrositing and estimation of expected energy generation.

4.3 The Immediate need for wind power forecasting

As explained in previous paragraphs the wind power potential in India is high and the industry is growing at good pace. The problems which industry in the country is facing are the lack of evacuation capacity availability in wind power potential areas, difficulty in planning of transmission system due to its intermittency, competition in electricity market and so on. All these make for the strong need of wind power forecasting. Currently the wind farm developers in India are using some wind analysis models which give the estimation of yearly energy generation based on the climatic data (that is wind speed, direction and air density), local inputs like contour, turbine locations, roughness parameters and wind turbine characteristics, that is, power curve. But these models do not give the forecasting of energy generation on daily or monthly basis. The development of forecasting tools can be taken at the following steps.

The immediate step would be the development of tools to use the climatology forecasts, that is, long term annual and diurnal wind resource availability for planning. The climatology forecast would provide the daily and monthly generation from a wind farm connected to the grid. These forecasts would help in long-term planning of the generation sources as well as grid planning.

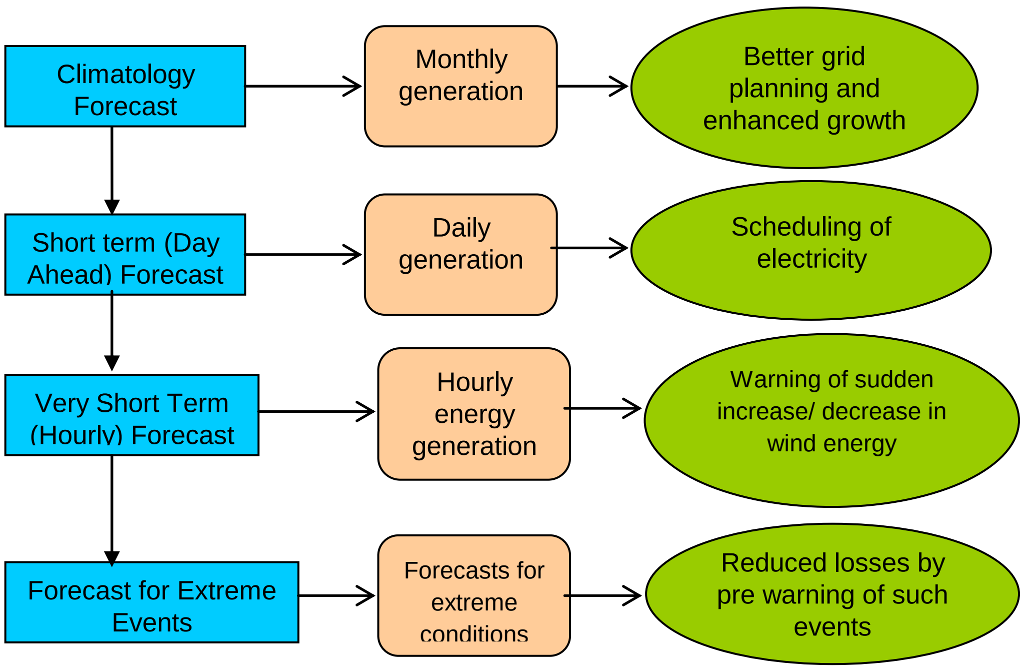


Figure 4: *Need for development of forecasting models*

The next step would be for development of models for short term, that is, day ahead forecasting after having the climatology forecasts models. The very short-term (hourly) predictions can be taken at a later stage (when power infrastructure will be so developed that the grids will have no demand supply

gap) will help in warning regarding the sharp increase or decrease in wind energy generation and will ultimately help in the management of grid frequency. Figure 4 is a representation of the steps needed and benefits of development of forecasting systems.

After developing the forecasting conditions for normal climatic conditions of India, the focus could be on improving the accuracy of models and to tuning them for the extreme conditions of climatology (high wind speed, thunder storms, wind gusts[19], wind shear and so on), which are difficult to predict and the events like power system errors (Load variations, frequency imbalance etc.), and losses due to cyclones[20], earth quakes and so on. Based on the definitions of extreme events discussed in various SafeWind meetings and the questionnaire developed for project partners, TERI identified the extreme events for Indian conditions and prepared the list of seven extreme events, which can be considered while tuning the forecasting models for local conditions. The detailed filled up questionnaire for extreme events is given in Annexure I.

India would have an advantage of European experience of some of these extreme events which are common, and care may be taken in the initial stages in the development of the forecasting tool, and to modify them for the probable troubles which may arise due to these extremes.

5. Conclusion

The development of wind power forecasting models for Indian condition is very much needed as the wind power is growing at a faster rate and the higher penetration of wind power into the grid will make it necessary to develop the grid code for better grid management and scheduling of power. The tools with higher accuracy of forecasting will help in developing grid codes and better planning of the transmission system. For the investor in wind energy project it will be useful for competing in the electricity market in India where the day ahead hourly trading has been started by the IEX and PXIL. The wind power forecasting tools will help all the transmission and distribution utilities, wind turbine manufacturers, developers and operators of wind farm, wind power investors, and regulatory bodies. Based on their requirement it has been concluded that at the first stage the climatology forecast models could be used for improvement in the transmission planning and then the short-term forecasting models have to be developed and tested for the wind farms, which will help in scheduling of the power and make wind power industry competitive to conventional power system up to certain extent in the electricity market. There is a need for joint effort to be taken by wind industry, utilities, research organisations, wind data and forecast providers i.e. Indian Meteorological Department, and NCMRWF to go ahead on high resolution data collection and development of wind forecasting models for the tropical weather conditions of India. The experience of European wind industry will help in developing the accurate wind power forecasting tool for Indian climate.

[19] **Mani A. and Mooley D. A., Wind energy data for India-1983**

[20] **Sorensen P et al. Power quality and integration of wind farms in weak grids in India; April-2000**

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Annexure I Definition of extreme events in Indian climatic and grid conditions

India has currently the wind power installed capacity of about 10500 MW, which is very small compared to the conventional power systems, that is, only 7% of total installed power capacity is from wind power and the rest is from thermal power plant and large hydropower plants. In coming years, penetration level of wind power will increase, and it will play a crucial role in the country's electricity supply. To optimize the grid utilization, and to control the use of limited natural resources used for the conventional power plants, it is important to understand the criticality of the wind power generation, and to develop the better forecasting tools for wind power prediction. This is required to meet the scheduling of the power supply. Apart from meeting the requirement of normal scheduling it is necessary to identify the extreme conditions, which will affect the normal operation of the wind turbines in an abrupt manner and may cause huge losses or adverse impact on the power systems. In this document the extreme events for the Indian climatic and grid conditions have been defined and summarized based on the previous experiences of the wind power actors.

The most common problem for the wind farms in India are the weak grids with high fluctuation in the voltages. The deviation from climatology, that is, the wind gusts and wind shear too are the events which are considered as extreme events. The situations like cyclones are extremes which are difficult to predict and cause massive loss to the systems.

The questionnaire prepared for the SafeWind partners have been filled up for the Indian conditions and the list of extreme events is given here.

Answers to the questionnaire prepared for SafeWind partners are as follows.

- The *first question* aims at defining *what an extreme event is*, for the various wind energy actors represented in the project, being forecasters or forecast users, meteorologists or involved with power system aspects.

The text for the first question has been formulated as:

"There may be different views of what an extreme event may be. A meteorological definition can be formulated as "an event that significantly deviates from climatology" (1). In contrast, a definition more focused on risk analysis would be "an event that potentially has dramatic consequences" (2).

Question 1: From your experience and your activity, which of the definitions (1) or (2) fit best to your view of extreme events? If possible, please explain why…"

Answer: Both the definitions fit the definition of extreme events, for example, the events like extreme gusts and wind turbulence, thunderstorms, cyclones and so on, are the events which affect the operation of the wind turbines and the generation, and ultimately cause difficulty in grid management. On the other hand, the unbalancing voltage and frequency of the weak grids directly affect the performance of the wind machines and reduces the total electricity generation from wind farms.

- The *second question* focuses on the idea of *categorizing extreme events*, ie. on defining broad categories of events which are seen as different extremes, either due to their origin, or to their potential consequences.

"During the SafeWind kick-off meeting, a first sorting of extreme events has been proposed, with the aim of reaching a first proposal definition. The 3 categories have been identified as:

- *Extreme (large-scale) meteorological events, including eg.*
    - *High wind speeds*
    - *Thunderstorms, tornadoes*
    - *Severe variability*
    - *Ramps*

- *Extreme (local) meteorological events, including eg.*
    - *Gusts*
    - *Wind shear*
    - *Turbulence*

- *Extreme power system events, including eg.*
    - *Phase errors (error in the timing of a ramp up or down)*
    - *Amplitude Errors (error in the magnitude of power production)*
    - *forecasting errors with extremely high costs*

Question 2: Do you agree with these categories, or would you consider some other categories of extreme events?"

Answer: All the categories defined above could be considered as extreme events. Also the case of the inadequate evacuation capacity and variations in the grid frequency can be included in extreme power system events and the effect of cyclones can be included in extreme large scale meteorological events.

- The *third question* concentrates on the *potential consequences of extreme events*. This is due to the fact that extremes should be associated to their 'cost' in order to define their importance in a risk-aversion point of view.

The text for the third question has been formulated as following. A Table was also provided for the various partners to perform the classification of the various extreme events in terms of their potential consequences

"Question 3: Please try to rank these 3 categories (and possibly newly proposed categories of extreme events) in terms of their potential impact on your activity, as well as the events included in each category. Ranking is from 1 to 5, with

- *1: 'Highly significant impact',*
- *2: 'Significant impact'*
- *3: 'Average impact',*
- *4: 'Low impact'*
- *5: 'Very low impact'"*

Events	Impact level
Extreme meteorological events	
High wind speeds	2.0
Thunderstorms	2.0
Cyclones	1.0
Extreme small/local scale events	
Gusts (threatening turbine structure)	3.0
Wind shear	3.0
Turbulence	3.0
Extreme power system events	
Grid imbalance (variable frequency)	2.0
Phase errors (error in the timing of a ramp up or down)	1.0
Amplitude Errors (error in the magnitude of power production)	2.0
forecasting errors with extremely high costs	2.0

- The f*ourth question* aims at *listing all extreme events* that may be encountered (or feared to happen) by the various wind energy actors. The events collected from this question will permit to thoroughly describe and illustrate the various extreme events in the catalogue to be produced.

"Question 4: Please fill in the table below with a descriptive list of the type of events that are considered as extremes in your group/institute/company. The event listed may cover different time scales, and may be related to a meteorological event, or alternatively to power system or economical issues. This question obviously concerns more forecast users that forecasters. However, forecasters may fill this table from their operational experience with various forecast users.

An example is given in the Table below:

- *The column 'Type of event' gives a short description of the extreme event considered*
- *The column 'Time/spatial scale' tells on the time and spatial scale of the event considered. While gusts or extreme shear events relate more to a very-short time and local scale, forecast errors may have an importance in a time scale between few minutes to few days ahead and for entire region owing to their spatio-temporal propagation*
- *The column 'Frequency' informs on the known (or felt) frequency of such events. As an example, extreme wind speeds may be a rare extreme event in central Germany, while extreme wind shears may be frequent extreme events in complex terrain with windy climates*
- *The column 'Consequences' tells on the potential consequences of the extreme event considered, which can be structural, related to wind farm or power system management, or finally economical*
- *The column 'Format of expected solution' gathers views on how future tools should evolve for better handling these extremes, and how those solutions should be presented. For some*

extremes, it may be felt that warnings are the best option, while for some others, it is new types of forecasts that should be provided

- *The column 'Reasonable warning horizon/potential action' tells about how much in advance forecast users would like to be warned of potential extremes events, and the kind of action that would taken if those warnings were to be issued. "*

Answer: TERI based on its knowledge bank and the information from various wind farm developers and operators listed the extreme events encountered or feared to be encountered. These are as given below

Type of event	Time/spatial scale	Frequency	Consequences	Format of expected solution	Reasonable warning horizon/potential action
Extreme (large scale) meteorological events					
Extreme high wind speeds	For few minutes to hours at regional level	Less frequent	Frequent cut off of the wind turbines	Warning of such situations, so the precaution can be taken for reducing the loss to grids	Short term warning at regional level for these extreme wind conditions
Thunder-storms	Hours to days at regional level	Frequent during monsoon season	Short term loss of power generation, as well as failure of grids	Warning that such situations may occur	Short term warning i.e a day ahead forecasting at regional level will help
Cyclones	Few hours at regional level	Once or twice in many years	Damage to the wind turbines and the grid infrastructure	Development of infrastructure resistant to certain level of cyclonic conditions.	Prediction of the event may help in making advance arrangement for tackling the impacts
Extreme (local) meteorological events					
Wind Gusts	Few minutes, at local scale	Frequent mainly during the summer and the winter	Large imbalance in the power generation	Use climate forecast models for estimating the occurrence of wind gusts	Short time. i.e 1 to 6 hourly forecast may help.
Wind shear	Few minutes at local scale	Frequent	Decrease in performance of wind turbines	Development of the structure of turbines resilient to these effects	Warning from few hours to a day.
Extreme wind turbulence	Few minutes at local scale	Less frequent	Decrease in performance of wind turbines, may decrease the strength of the components.	Development of the structure of turbines resilient to these effects	Warning from few hours to a day.
Extreme power system events					
Variation in	Few hours	Moderately	Large imbalance	Better	Warning from

Type of event	Time/spatial scale	Frequency	Consequences	Format of expected solution	Reasonable warning horizon/potential action
the demand of power (supply demand gap)		frequent	to the grid and causing the risk of wind turbine operations	forecasting and scheduling of power exchange through the grid	few hours to a day will help in better management of the grid
Excessive reactive power consumption by wind turbines	Few minutes to hours at local level	High (in older wind farms)	Imbalance to the grid, ultimately reducing the net energy generation	Better wind forecasting and the system for reactive power compensation for wind turbines	Daily and monthly forecasting of the wind generation will help in designing the capacity of converter /capacitor banks

- The *fifth question* relates to the *possibility of studying (or not) those extreme events* from the data owned by the various project participants. Obviously, if no data is available for a given type of extreme event, it will be particularly difficult to define some test case in the future for dealing with this particular type of events.

"Question 5: For each of the extreme events listed above, please inform about the possibility of identifying them in some of your available datasets. Such datasets could then be used as a basis for the developments to be performed in the project. If possible, please insert plots that would permit to illustrate such events."

The extreme events listed above are based on the information collected from various news related to the occurrence of the events. The detailed information about the event is available with the individual wind farm owners or the operators where the events happened. The best effort can be made to collect the datasets describing the events in detail.

- The sixth *question* relates to the *possibility of identifying (or not) the costs of these extreme events* from the data owned by the various project participants. Identifying the cost function of the various forecast users will permit to study how the developments carried out within the project will lead reduction of the costs of extreme events for forecast users.

"Question 6: For each of the extreme events listed above, please inform about the possibility of identifying their costs or not. If not, please about which type of information would be necessary to define such costs in the future. "

The identification of cost is possible up to certain extent for few cases like the impact of cyclone which caused the damage to about 18 MW wind turbines in the Gujarat state of India. For other events the extent of the failure of power systems, the period of failure and the amount of expected wind energy loss during that period etc. are the required information to estimate the cost of the these extreme events that could be collected from the operators of the wind farms.