Wind Power Forecasting

For Short Term Power Trading

A Project Report

Submitted by

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(EE08B080)

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THESIS CERTIFICATE

This is to certify that the thesis titled **WIND POWER FORECASTING FOR SHORT TERM POWER TRADING** submitted by Pritesh Patel, to the Indian Institute of Technology, Madras, for the award of the dual degree, **Bachelor of Technology in Electrical Engineering and Master of Technology in Power system and Power electronics**, is a bonafide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

KEYWORDS: Wind power forecasting, Power Trading, Numerical weather Prediction, Mean Absolute percentage error.

Energy crisis, global warming and depletion of ozone layer are the major factors looming the world today. India strives to identify and develop sustainable alternatives to fossil fuels, but a key obstacle to successful integration of wind power has been inability to accurately estimate the potential yield of sustainable energy sources like solar, wind energy etc.

The most unpredictable of all renewable resource is Wind, due to its dynamic nature. Many approaches exist to forecast wind power forecast. . Developing forecasting models is an overwhelming task, due to the random and stochastic nature of wind. In general wind power forecasting can be categorized into Physical approach and Statistical approach. In recent years lot of research going on wind power forecasting. But most of this work is being carried out from perspective of large scale utility (for developed nation like USA, DENMARK, SWEDEN).But same things does not hold true for developing nation like India. As Developing nation does not have sufficient expertise or budgetary ability to pursue projects like wind power forecasting for large wind farm.

So the focus of this project is to develop simple wind speed forecasting model with minimum number of parameters and minimum forecasting error (MAPE).This project presents methodologies for forecast generation and compares different statistical models for wind speed forecast like Auto regression, Auto regressive Moving Average and by curve fitting. And then wind power forecasting including consideration of wake effects and wind speed variation due terrain.

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ABBREVIATIONS

AR	Auto regression
MA	Moving Average
ARMA	Auto regressive moving Average
ACF	Auto correlation function
PACF	Partial Auto correlation function
NWP	Numerical Weather Prediction
MAPE	Mean Absolute percentage error
MW	Mega Watt

Chapter 1

Introduction

1.1 Project Motivation

Energy is vital input for social and economic development of any nation. With increase in agricultural and industrial activities in country. Demand of Energy is increasing day by day.

In 2012,despite a slowing global economy, Indian electricity demand continued to rise. Electricity shortages are common, and over 40% of population has no access to modern energy services. Indian electricity demand is projected to more than triple between 2005 to 2030.Despite major capacity additions over decade ,power supply struggles to keep up demand. .

Wind is an important source of non-conventional energy which is cheap, pollution-free, environment friendly and can be developed away from the sources of conventional energy .Wind Power is increasingly integrated into current power systems. As of 31 Jan 2013 the installed capacity of wind power in India was 18634.9 MW is installed in India[1]. Wind power accounts for 6% of India's total installed power capacity, and it generates 1.6% of the country's power. Due to unique geographical advantage india has huge capacity of 45000 MW ,adding more wind power into current electricity market.

1.2 Project contribution

Comparison of different statistical method is done for wind speed. Wind speed forecasting for different methods like Auto regression (AR),Auto regressive Moving Average (ARMA) and Curve fitting has been done under different dataset. Dataset used for wind speed forecasting are of Chennai(vyom airport). Wind speed forecasting for 8^{th} day with the help of historical weekly data by different method has been done.

Wind Power forecasting by basic method (which uses power curve) is compared with advanced method which takes care of Air density correction, terrain speed ups and Wake effects. Financial profit due to advanced method is also compared for a year. Different areas and industries where wind power forecasting can be used has been suggested in this project work

1.3 Thesis Objectives

The main objectives of this thesis are as follow:

1. Comparison of wind speed forecasting for short term by using statistical Models.
2. Site specific wind power forecasting, which takes care of terrain speed ups and wake effects .

1.4 Thesis Structure

Chapter 2: In this chapter several wind power or wind speed forecasting methods have been reported in the literature over the past few years. This paper provides insight on the foremost forecasting techniques, associated with wind power and speed, based on numeric weather prediction (NWP), statistical approaches, artificial neural network (ANN) different time-scales. Factors affecting wind speed forecasting are mentioned. Pros. and cons. of each method are also discussed.

Chapter 3 :In this chapter wind speed forecasting has been done with use of historical weekly data for 8^{th} day. Assumption taken for wind speed forecasting are discussed. wind speed forecasted is compared for different methods like Auto Regression, Autoregressive Moving Average and Curve fitting.

Chapter 4 :Wind Power is forecasted by basic method (which uses power curve) which uses forecasted wind speed .Air density is corrected for advanced method. With the help of software WINDFARMER which takes care of terrain speed ups and Wake effects, wind power is forecasted . Financial profit due to advanced method is also compared for a year.

Chapter 5: summarizes the projects main points and contributions and proposes direction and suggestion for scope of application of wind power forecasting.

Chapter 2

Background and Literature Review

2.1Wind Power in India:
The total installed capacity of wind energy in India is 18634.9 MW (as of Jan 2013)[1]; making India the 5th largest wind energy producer in the world. The annual capacity addition is growing at a rate of around 20%.

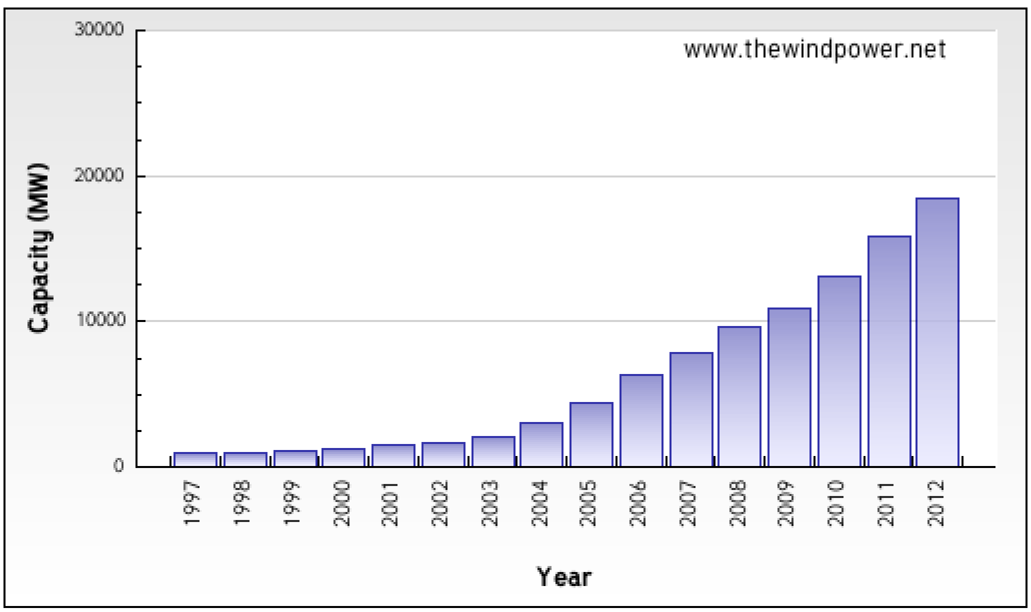

Fig- 2-1: Increase in production of wind power in India[2]

In India wind power production plants are mainly spread across Tamil Nadu (7134 MW), Gujarat (3,093 MW) ,Maharashtra (2310.70 MW), Karnataka (1730.10 MW), Rajasthan (1524.70 MW), MadhyaPradesh (275.50MW), AndhraPradesh (200.20MW), Kerala(32.8 MW),Orissa (2 MW) , West Bengal (1.1 MW) and other states (3.20 MW)

In 2012, according to the Central Electricity Authority, 8% of India's power capacity is supplied by wind energy. The growing wind power is brining prosperity to the country and serving towards energy security, but at a cost of technical challenges.

Indian electricity grid condition wasn't really good until Electricity Act 2003 was enacted for development and betterment of this sector. To continually serve the purpose of keeping the electricity grid stabilized, CERC then enacted Indian Electricity Grid Codes (IEGC, 2010) in which scheduling of wind power (and solar) is made compulsory with effect from January 1, 2012 for wind farms where the sum of generation capacity is more than 10 MW and all the wind turbines are connected to a common point of 33 kV. The wind turbine owners if not have signed the Power Purchase Agreement till this date will come under this regulation. According to this regulation the wind farm developers have to provide a day ahead forecast for next 24 hours in a block of 15 minutes. To safeguard the interest of wind farm developers, a relaxation ceiling of 70% accuracy was kept in such a way that if actual generation is under +/- 30% variation of the schedule, no Unscheduled Interchanges (UI) will be applicable. Over and above, Renewable Regulatory Fund (RRF) was also introduced for pooling UI accounts at the regional level for wind energy generators. This all has been done so as to manage the electricity well in advance before dispatching for distribution in such a way that the quality of electricity remains paramount.

2.2Wind Power forecasting Introduction

Wind power forecasting means predicting the amount of wind power that can be available at the next instant or in the next duration or horizon of days. Wind speed or Power forecasting is used in many industries like power exchanges, weather prediction, meteorology

In countries having a high penetration of wind energy in the electrical grid, in particular Denmark, Spain and Germany, India(growing wind power industry)wind power prediction tools turned out to be indispensable for the energy industry. The forecasts are mainly used for the day-ahead scheduling of conventional power plants and trading of electricity on the spot market. In addition, precise wind power predictions play an important role in the allocation of balancing power for the next few hours to come, reduce penalties, maintain reserve requirement, storage capacity and to make unit commitment , for dispatch decisions.

Wind power forecasting depends on various external factors like temperature, pressure at the site, humidity at the site, density of air, position of terrain. The relation between wind speed and wind power

$$P_{Wind}(t) = \frac{1}{2} * \rho * A * v^3(t) \qquad (2.1)$$

which is a non-linear equation ,where ‘ρ’ is density of air, A is the surface area of the wind turbine blade and v is velocity of wind.

Wind speed forecast errors are due to uncertainties of severe temperature, high precipitation etc. The error in wind speed forecast are mainly due to temperature and air density further error in wind power forecast are due to terrain roughness & wake effects. For most practical case in power systems, the wind power error should be less than or equal to 20%[3].

This report presents about the forecasting trough auto regression ,moving average & trough curve fitting ,which are sub-class of statistical approach. Statistical approach models will implement a relationship between input and the output of the model (here, number of the inputs to output can be more than one)by developing a statistical estimation of the parameters to predict the future events.

2.3 Overview of Wind Forecasting Methods

Several techniques have been identified for wind forecasting. These techniques can be broadly cataloged into Persistence method, Physical Approach (NWP), Statistical methods, and hybrid approaches [4].

2.3.1Persistence method

The simplest way to forecast the wind is to use persistence. This method uses the simple assumption that the wind speed at the time t + x is the same as it was at time t. In other words, the persistence technique is based on the assumption of a high correlation between the present and future wind values. This method was developed by meteorologists as a comparison tool to supplement the NWP models. In fact, the simplified method is even more effective than a NWP model in some very short-term predictions (several minutes to hours) . As expected, the accuracy of this model degrades rapidly with increasing prediction lead time.

2.3.2 Physical Approach

Numeric Weather Prediction (NWP)

Several physical models have been developed based on using weather data with sophisticated metrological for wind speed forecasting and wind power predictions. These models take into considerations several factors including shelter from obstacles, local surface roughness and its changes, effects of topography, speed up or down, scaling of the local wind speed within wind farms, wind farm layouts and wind turbines power curves.

Since NWP models are complex mathematical models, they are usually run on super computers, which limits the usefulness of NWP methods for very-short-term operation of power system. Disadvantage of NWP is the time it takes for processing & training model(days) and the implementation cost, Examples: Global Forecasting System ,Prediktor ,HIRLAM, etc.

2.3.3 Statistical methods

In this method relationship between wind speed prediction and measured power output from the wind farm is derived to predict the wind power. It generally does not use the power curve of the wind turbine and do not consider the local meteorology. These models are self-calibrate in nature and inherit any changes occurring in roughness or wind resource to provide an advance forecast

The statistical time series like AR,ARMA and neural network methods are mostly aimed at short-term predictions. Typical time series models are developed based on historical values. They are easy to model and capable to provide timely prediction.

The advantage of statistical methods is to provide relatively inexpensive statistical forecasting models that do not require any data beyond historical wind power generation data. However, the accuracy of the prediction for these models drops significantly when the time horizon is extended.Examples: ANN\ Feed-foreword ,Recurrent ,Multilayer Perceptron etc. Time series models\ AR, ARMA ,Exponential smoothing etc.

2.3.4 Hybrid Approaches

In general, combination of different approaches such as mixing physical and statistical approaches or combining short-term and medium-term models, etc., is referred to as a hybrid approach.

2.4 Historical Background and Literature Survey

It was dated in 320 BC at the time of Aristotle an inquisitive mathematician that he started observing atmospheric kinematics and wrote his first manuscript on this subject Meteorologica conferring to the phenomenon. The Odyssey continued with invention of instruments to measure state of atmosphere dated in 16th and 17th century, until late first half of the 20th century when computers were evolved and fast forwarded the development of weather forecasting, leading to a change in paradigm of knowledge.

Wind speed forecast isn't new; it was a part of weather forecasting for many decades where it was being used for ship navigation, ship traffic control, satellite launch etc. However, wind power forecasting recently have come into the picture with the arrival of large wind power producing farms.

Nowadays, wind forecasting is extremely important in the context of the electricity market liberalization. Wind forecast corresponds to an estimate of the expected wind speed to certain region. When it is intended to forecast weather conditions, in particular wind speed, it is crucial to know the historical weather conditions[5].

Basically, wind is created when air moves from areas of high pressure toward areas where the air pressure is lower. Seasonal temperature changes and the Earth's rotation also affect wind speed and direction. There are several aspects that may influence the wind speed, namely [6].

• Temperature: Air temperature varies along the day and from season to season due to changes in the Earth's atmosphere heating. Because of the sun's warming effect, there are more winds during the day than during the night.

• Atmospheric Pressure: Air pressure decreases with increasing altitude and fluctuates across

Earth's surface due to differences in land elevation. At the Earth's surface, wind blows horizontally from high to low pressure areas. The speed is determined by the rate of air pressure change, i.e. Pressure gradient, between the two areas. The greater the pressure difference, the faster the winds.

•Earth's Rotation: The rotation of Earth on its axis causes winds to shift direction, creating what are called the prevailing winds.

•Humidity: wind speed is also affected by the humidity over the region, Where the humidity is more wind speed is found to be less, and vice versa.

Important conclusion is that the best estimate accuracy has been obtained when the wind speed is the only input attribute.

Chapter 3

Wind Speed Forecasting

3.1 Introduction to Statistical Methods

Statistical prediction methods are based on one or several models that establish the relation between historical values of power, as well as historical and forecast values of meteorological variables, and wind power measurements. The physical phenomena are not decomposed and accounted for, even if expertise of the problem is crucial for choosing the right meteorological variables and designing suitable models. Model parameters are estimated from a set of past available data, and they are regularly updated during online operation by accounting for any newly available information (i.e. meteorological forecasts and power measurements).

Time series models is subclass of statistical methods .Important model includes AR,MA,ARMA etc

3.1.1 *AUTO REGRESSION (AR)*

$$x_t = a_1 x_{t-1} + a_1 x_{t-2} \dots\dots.. + a_m x_{t-m} + u_t \qquad (3.1)$$

In the above equation a_1 to a_m are auto regression parameters, u_t is white noise and 'm' is model order. This model is stable only for parameters α values within a certain range ($\Phi \leq 1$) .The validity of this time series is only when series is made stationary. Compact form of auto regression is given below.

$$\Phi(A) Z_t = a_t \qquad (3.2)$$

Where a_t is white noise with

$$\Phi(A) = 1 - \Phi_1 A - \Phi_2 A^2 - \cdots \dots \dots \dots \Phi_p A^p. \qquad (3.3)$$

3.1.2 *MOVING AVERAGE (MA)*

$$z_t = a_t - k_1 B_1 - k_2 B^2 \ldots\ldots\ldots\ldots\ldots - k_n B^n. \quad (3.4)$$

In the above equation a_t is white noise, k_1 to k_n are moving average parameters and 'n' is order of moving average.

Compact form of moving average model is

$$Z_t = \Theta(A) a_t. \quad (3.5)$$

Where

$$\Theta(A) = 1 - \Theta_1 A_1 - \Theta_2 A^2 - \cdots \ldots \ldots .. \Theta_q A^q \quad (3.6)$$

3.1.3 *AUTO REGRESSIVE MOVING AVERAGE (ARMA)*

ARMA model is combination of AR & ARMA model. Parameters required in ARMA model are fewer than AR model due to presence of AR and MA terms.

$$x_t = a_1 x_{t-1} + a_1 x_{t-2} \ldots\ldots\ldots + a_m x_{t-m} + u_t \quad (3.7)$$

$$z_t = a_t - k_1 B_1 - k_2 B_2 \ldots\ldots\ldots\ldots\ldots - k_n B_n. \quad (3.8)$$

The order of ARMA model is represented as(m, n).

Compact form of ARMA model is given by

$$(A) Z_t = \Theta(A) a_t \quad (3.9)$$

$$\Phi(A) = 1 - \Phi_1 A_1 - \Phi_2 A^2 - \cdots \ldots \ldots \ldots \Phi_P A^P \quad (3.10)$$

$$\Theta(A) = 1 - \Theta_1 A_1 - \Theta_2 A^2 - \cdots \ldots \ldots .. \Theta_q A^q \quad (3.11)$$

3.2 Time Scale Classification

Time scale classification of wind forecasting methods is vague. Majorly forecasting can be classified into four categories[8]

Time horizon	Range	Application
Very short term	Few seconds to 30 min ahead	-Electricity market clearing -Regulation Actions
Short term	30 minutes to 6 hour ahead	-Economic load dispatch -Load increment and decrement decisions
Medium term	6 hour to 1 day ahead	-Generator online/offline decisions -Operational security in day ahead security market
Long term	1 day to 1 week or more ahead	-Unit commitment decisions -Maintenance scheduling to obtain optimal operating cost

Table 3-1:Time scale classification of wind forecasting

Depending on the application of forecasting model some relaxation is allowed to time horizon limits. There doesn't exist any model which is applicable to all time horizons mentioned above, each model has their own restrictions and implications for each time horizon. Restriction can be complexity number of input variable, accuracy, cost time etc.In my report, short term forecasting implies 24 hours future values, which will be used for day ahead forecasting.

The temporal resolution of wind power predictions ranges between 10 minutes and a few hours (depending on the forecast length). Improvements of wind power forecasting has focused on using more data as input to the models involved, and on providing uncertainty estimates along with the traditionally provided predictions.

3.3. Case study-simulation of wind speed forecast with AR and ARMA

3.3.1Wind speed data set for a week

The data for analysis is from website www.wunderground.com with hub height of about 20 m above ground at Chennai.

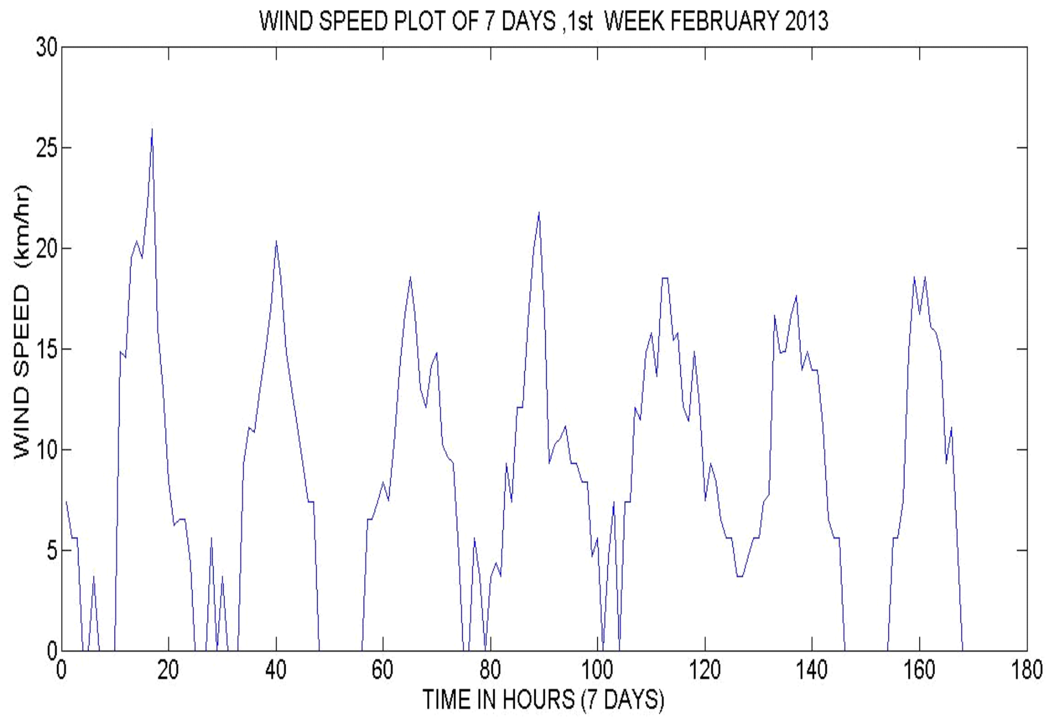

Fig. 3-1: Wind speed Plot for a week

From figure 3.1,we can see the volatile nature of wind speed, due to dynamic change in temperature and atmospheric pressure. We can see trend in above data set, may be due to seasonality effect.

Daily Pattern: The data taken for observation Vyom STATION(AIRPORT),CHENNAI[7]. There is random wind speed in morning hours from data, but the wind speed doesn't exceed of value 8.Then there is steep increase in wind speed at 10 in morning .it reaches highest at around 3-30 in afternoon.

Then there is decrease in wind speed in the evening, with small rise in very late hours on some days

The data plotted here is 1st week of February 2013.

The mean of above data set is 8.7 and variance 39.40.

3.3.2ACF of input dataset

Autocorrelation is the similarity between observations as a function of the time separation between them. It is a mathematical tool for finding repeating patterns, such as the presence of a periodic signal obscured by noise. Autocorrelation is the cross-correlation of a signal with itself.

$$ACF = \int g(t)g(t+k)dt. \qquad (3.12)$$

Where g(t) is a scalar function. Higher the value of ACF higher is the correlation.

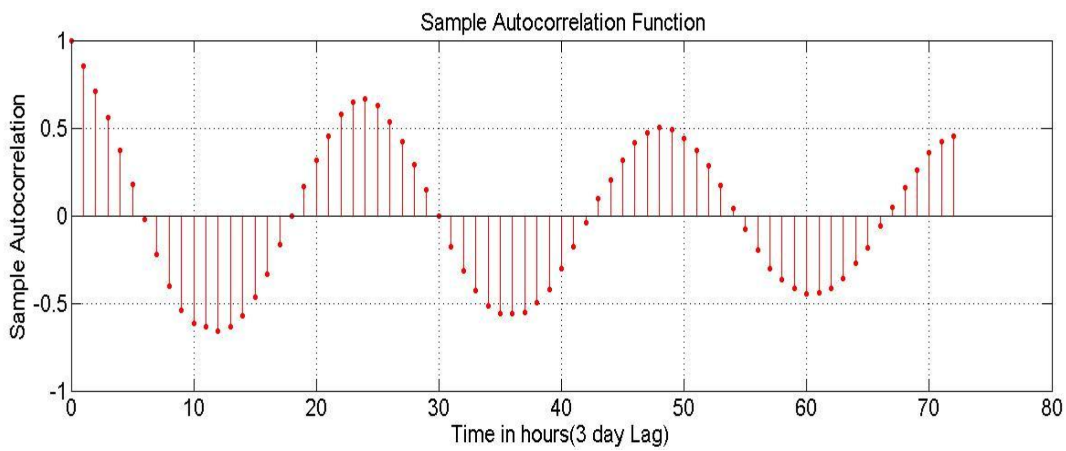

Fig. 3.2:ACF of input dataset

ACF is used to calculate order of AR model and its coefficient[8]. from the above graph ,it can be observed that along time length ACF is strictly decreasing. It can be observed from above graph that there is high correlation between lags of(1,2,3,4) and there is also significant amount in (22,23,24),(46,47,48) and (72,73).It is observed from the graph that there is trend in data.

3.3.3PACF of input dataset

The partial autocorrelation function (PACF) plays an important role in data analyses aimed at identifying the extent of the lag in an autoregressive model. .Partial correlation at lag k is auto correlation between Y_t and Y_{t-1} that is not accounted by lags 1 trough k-1.PACF is conditional correlation between same variables when the effects of one or more variable is removed.

Sample Partial Auto Correlation Function

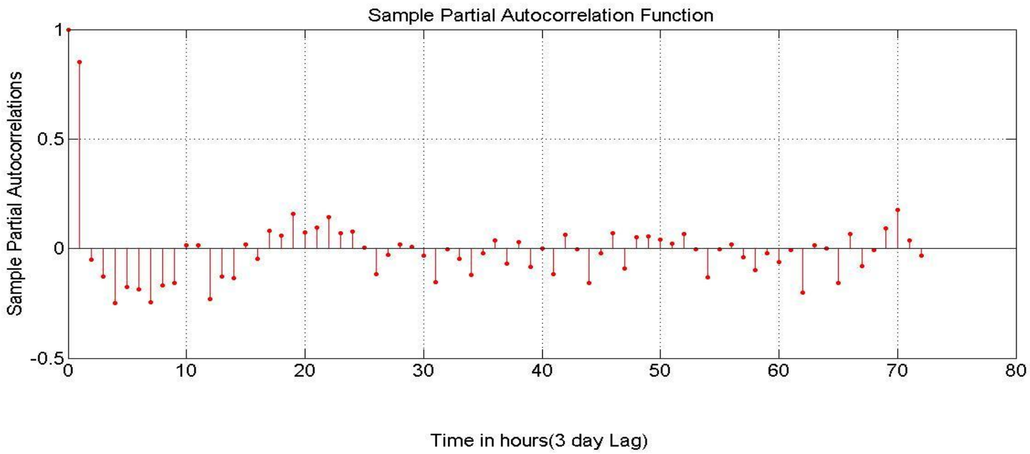

Fig. 3.3: PACF of input dataset

PACF is used to calculate order of MA model and its coefficient from the above graph it can be observed that there is high correlation at lag 1, and other lags from 2 to 72 are significantly low compared to 1 st one..So by using value of lag 1 all other lags can be explained. Above graph also shows that there is no trend in data set.

3.3.4 MEAN ABSOLUTE PERCENTAGE ERROR

MAPE is commonly used in quantitative forecasting methods because it produces a measure of relative overall fit. The absolute values of all the percentage errors are summed up and the average is computed.

It usually expresses accuracy as a percentage, and is defined by the formula:

$$M = \sum_{k=1}^{n} \left(\frac{\frac{|A_t - F_t|}{A_t}}{n} \right) \qquad (3.13)$$

where At is the actual value and Ft is the forecast value. The difference between At and Ft is divided by the Actual value At again. The absolute value in this calculation is summed for every fitted or forecasted point in time and divided again by the number of fitted points n. multiplying by 100 makes it a percentage error.

3.3.5 VARIANCE

The variance (σ^2) is a measure of how far each value in the data set is from the mean. The variance (σ2), is defined as the sum of the squared distances of each term in the distribution from the mean (μ), divided by the number of terms in the distribution (N).

Formula

$$\mathrm{Var}(n) = \sum_{k=1}^{n} ((x_i - x_{mean})^2/n) \qquad (3.14)$$

3.3.6 Simulation of Auto regressive model in System identification toolbox in matlab for finding order of AR and ARMA models.

System identification toolbox can be used for identifying minimum number of parameter required for AR and ARMA model. The Akaike information criterion is a measure of the relative goodness of fit of a statistical model. The AIC is grounded in the concept of information entropy, in effect offering a relative measure of the information lost when a given model is used to describe reality. It can be said to describe the tradeoff between bias and variance in model construction, or loosely speaking between accuracy and complexity of the model.

AIC values provide a means for model selection. AIC does not provide a test of a model in the sense of testing a null hypothesis; i.e. AIC can tell nothing about how well a model fits the data in an absolute sense. If all the candidate models fit poorly, AIC will not give any warning of that.

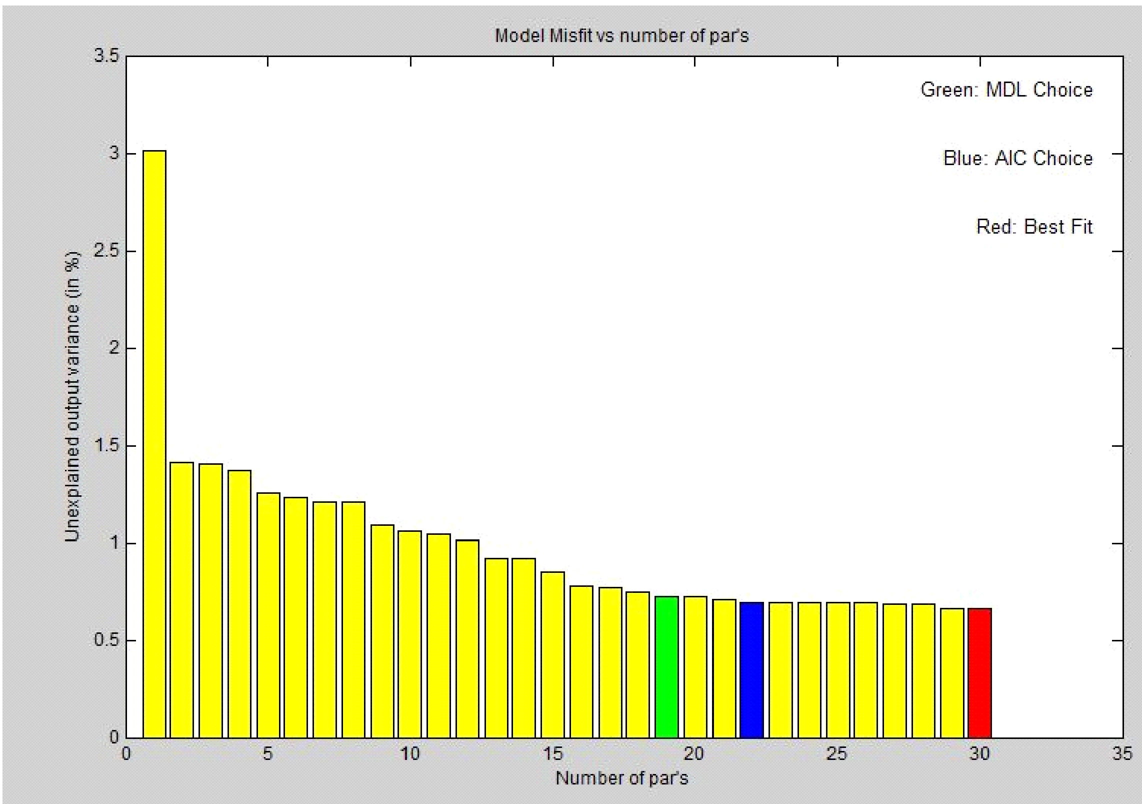

Fig. 3.4: Plot for determination of model order

from the Figure 3.4 it is observed as the number of parameter increases output variance decreases. But after number of parameter as 19 or 20 there is not much significant difference in variance. So the number of parameter taken for AR and ARMA model chosen or case study is 20.

3.3.7 Fitting best model

To estimate AR and ARMA models using the System Identification Tool GUI:In the System Identification Tool GUI, select Estimate > Polynomial models to open the Polynomial and State-Space Models dialog box. In the Structure list, select the polynomial model structure you want to estimate from the Auto regression.

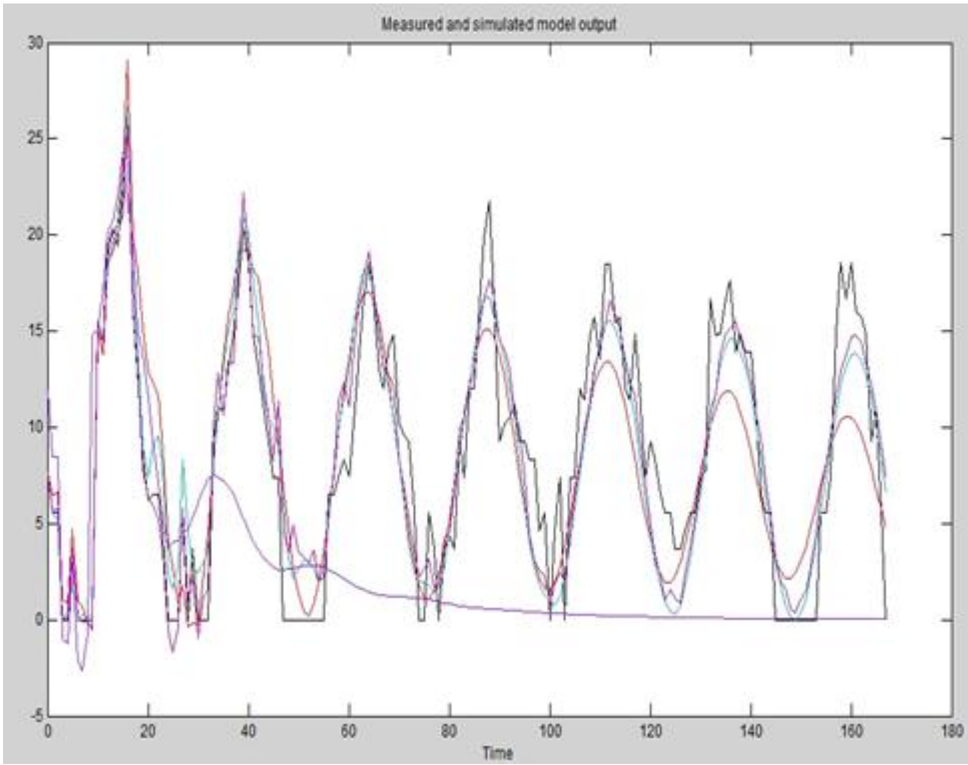

Fig. 3.5: Plot of best fit of AR models

From the above graph it can be observed that with increasing AR model parameter better and better fit is observed. But increasing the amount of goodness of fit is decreasing exponentially .So there has to good balance between number of parameters and goodness of fit. As we require lower number of parameter to avoid complexity & use of it for different data .There is should also be good amount of fit, so the model chosen in my case is AR(20).Table for best fits for Autoregressive models

Table 3-2: Best fit for AR models

Model	Color	Best fit
AR(10)	PURPLE	-43.49
AR(20)	RED	46.06
AR(30)	LIGHT BLUE	56.84
AR(50)	PINK	62.16

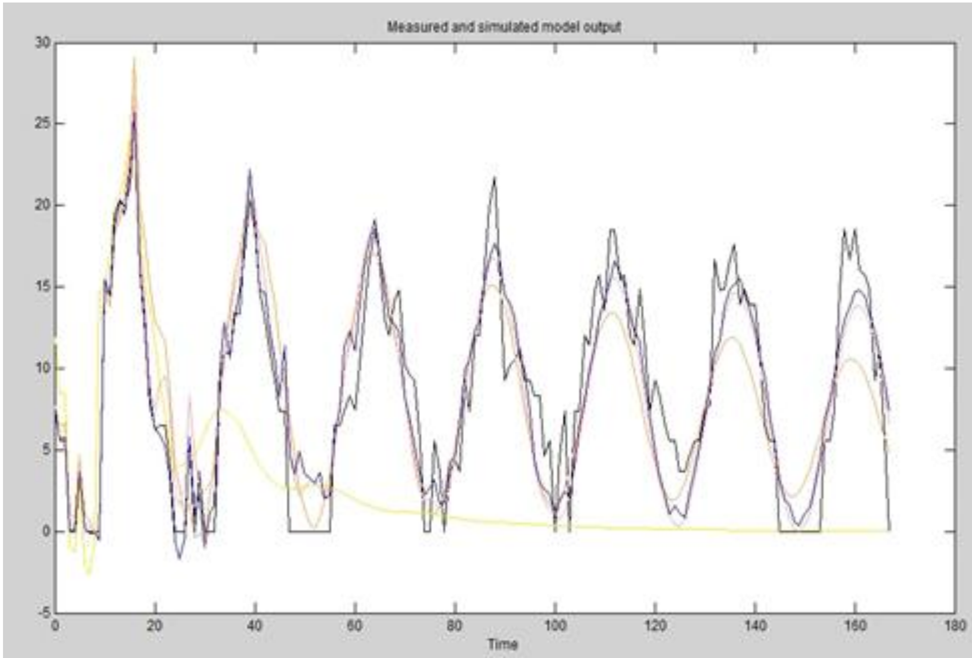

Fig. 3.6: Plot of best fit for ARMA models

From the above graph it can be observed that with increasing ARMA model parameter better and better fit is observed. But increasing the amount of goodness of fit is decreasing almost exponentially. So there has to good balance between number of parameters goodness of fit. As we require lower number of parameter to avoid complexity & use of it for different dataset . There is should also be good amount of fit ,so the model chosen in my case is ARMA(20,1).The Moving average order 1 is chosen because from PACF graph it has been observed that only 1st significantly high ,that can be used for forecasting. Table for best fit for ARMA models.

Table 3-2: Best fit for AR models

Model	Color	Best fit
ARMA(10)	YELLOW	-43.42
ARMA(20)	RED	45.06
ARMA(30)	PINK	56.54
ARMA(50)	DARK BLUE	62.10

3.3.8 FORECAST OF THE 8th day BY USING WEEKLY DATA

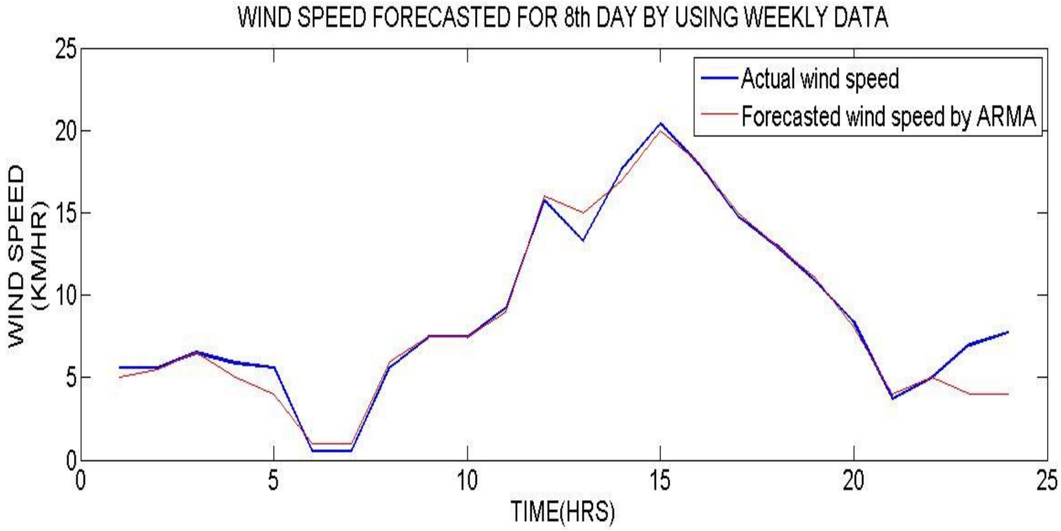

Fig. 3.7: Plot of wind speed forecasted for ARMA(20) model

In the Figure 3.6 blue line represents actual data of wind speed on 8th February 2013 ,red line represents ARMA(20,1), first it gradually goes down up to 5th hour of day and there is no wind for half an hour or so. then wind speed increases with time and there is peak wind speed at 15th hour of the day(original data) and for both model it is around 16-17th hour of the day. Then forecasted wind speed and original data decreases rapidly for original data and gradually for forecast data. There is lot of mismatch over there .All this is happening due to unpredictable behavior of wind speed..

The MAPE of forecasted wind speed ARMA(20,1) model is =18.8531.

The variance of forecasted wind speed due to ARMA(20,1) model =0.0230.

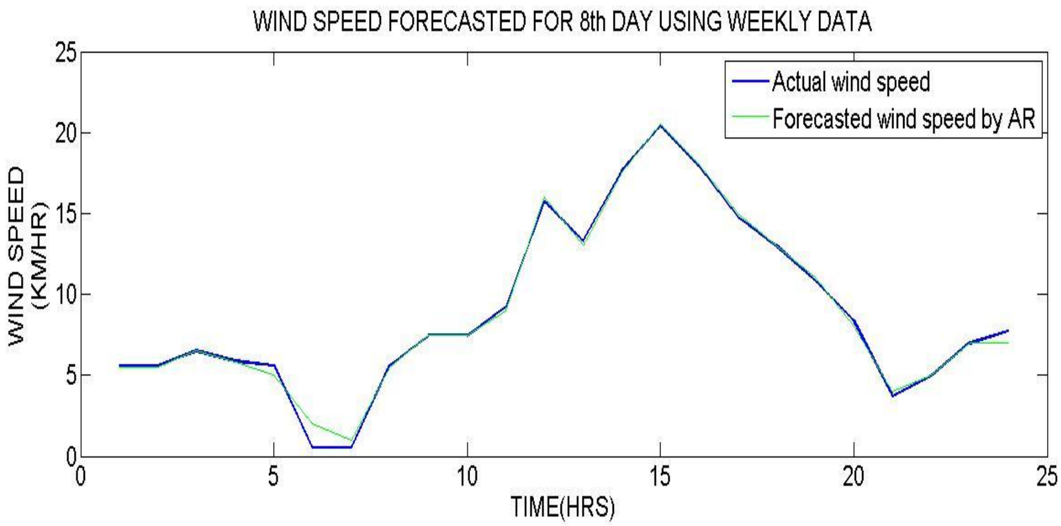

Fig. 3.8: Plot of wind speed forecasted for AR(20) model

In the Figure 3.7 blue line represents actual data of wind speed on 8th February 2013 and the green line represents AR(20) model forecasted wind speed for 24 hrs.

The MAPE of forecasted wind speed AR(20) model is =16.4460.

The variance of forecasted wind speed due to AR(20) model =0.0190.

It is found that AR(20)model is bit better than ARMA(20,1)

3.4 WIND SPEED FORECAST DUE TO CURVE FITTING

CURVE FITIING

Curve fitting is the process of constructing curve or mathematical function, that has the best fit to a series of data points, possibly subject to constraints. Curve fitting can involve either Interpola -tion, where an exact fit to the data is required, or smoothing in which a "smooth" function is constructed that approximately fits the data.

CURVE FITTING FOR 2 YEARS DATA YEAR 2011/2012

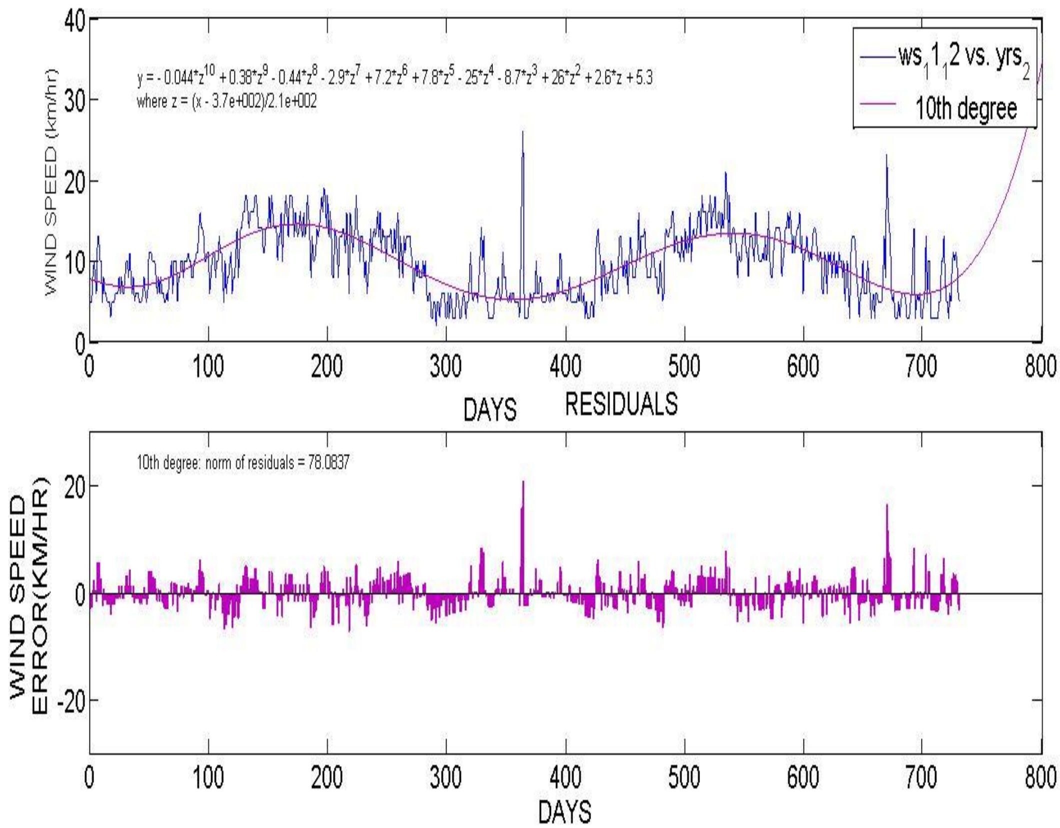

Fig. 3.9: Two yearly curve fitting plot

It can be observed from the above graph there is seasonality in wind speed data. In the above data set gradually increases day by day from January to may-June than wind speed starts decreasing in coming month. The above data set of wind speed is of Chennai was taken at height of of about 20 meters. There is spike observed due to with strong southwest winds, the North East monsoon (from October to December), with dominant northeast winds, and the Dry season (from January to

May).But in order to capture dynamic nature there should be some model to capture the unpredictable nature of wind.

FORECASTING USING CURVE FITTING WITH DATA AT 15 MINUTES INTERVAL

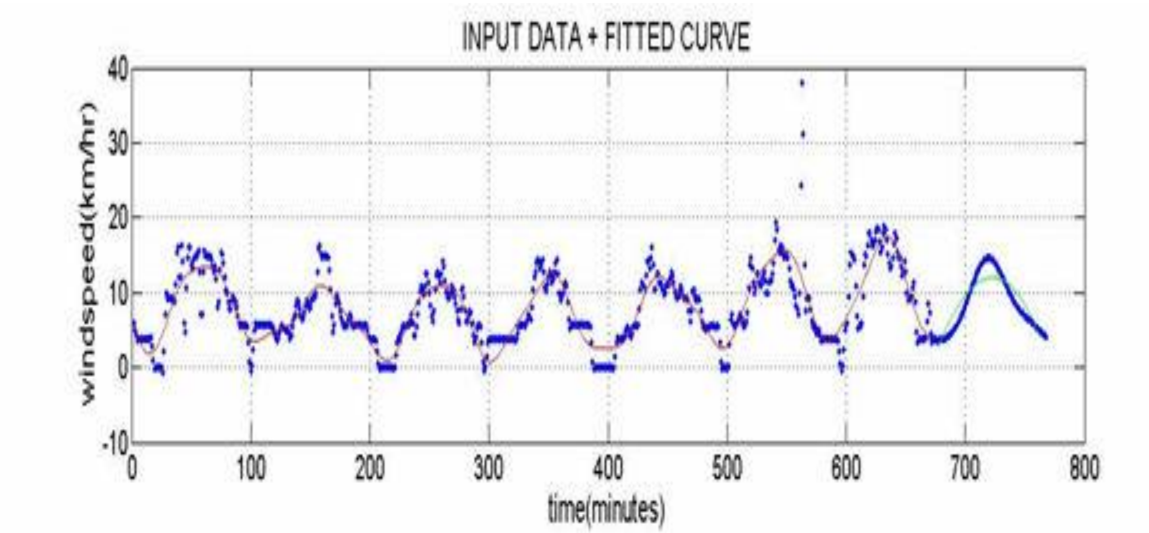

Fig. 3.10: Plot of wind speed forecasted by curve fitting

In the above graph the blue point represents wind speed datasets spaced at 15 min interval. Red curve represents fitted curve for old weekly data. Green curve is used for forecast for 24 hours forecast. The dark blue curve which is fitted above the green curve represents actual forecasted wind speed. In the above graph it is observed that there is lot of deviation in the fitted graph.

The MAPE of forecasted wind speed with help of curve fitting is =17.8470

The variance of forecasted wind speed due to curve fitting is=0.0430

3.5 ASSUMPTIONS TAKEN FOR WIND SPEED FORECASTING

The assumptions taken in the forecasting models are as follows:

1. Only wind speed is taken as input but in actual & practically other variables effecting wind speed should also be taken as input.
2. Only 1 week data is used to predict next 24 hours, that may not be enough.

2.6 Discussion on results and Conclusion

Auto regression(AR) has the least MAPE 16.4460 ,compared to ARMA and curve fitting method. So AR(20) model is preferred over the other models .It is also observed that variance in the AR(20) model is 0.0190 .Although curve fitting has better MAPE than ARMA but that variance is more than double. So in terms of least error and variance AR(20) Model is much better than other two in term wind speed forecasting accuracy. Even less number of parameter are required for calculation of AR(20) than ARMA(20,1),so AR(20) due to less complexity is preferred over ARMA(20,1).

From the above results :It can be observed that Statistical method (time series) models has MAPE around 16 to18.This due to rapid spikes in input in short duration. Auto regression is one of the basic method for forecasting. More advanced and complex method like ANN(artificial neural network),ensemble method can be used for reducing MAPE less than 16. Increase in industrialization and global warming changes climate ,which has huge impact on wind speed. So wind speed forecasting have more and more relevance in coming years.

Chapter 4

Wind Power Forecasting

4.1Introduction: Wind power forecasting

A **wind power forecast** equates to an estimate of the expected production of one or more wind turbines (referred to as a wind farm) in the near future. By production is often meant available power for wind farm considered (with units kW or MW depending on the wind farm nominal capacity). Forecasts can also be expressed in terms of energy, by integrating power production over each time interval.

4.2 DIFFERENCE BETWEEN WIND SPEED AND WIND POWER FORECASTS

The wind power of a wind turbine depends on the wind speed varies on a wide range of time, which depends on regional weather patterns, seasonal variations, and terrain types. The theoretical relationship between the energy (per unit time) of wind that flows at speed v (m/s) through an intercepting area A (m^2) is

$$P_{Wind}(t) = \frac{1}{2} * \rho * A * v^3(t) \tag{4.1}$$

Where ρ is the air density (kg/m^3), which depends on the air temperature and pressure. The easiest approach converting wind speed to wind power forecasting is to use the manufacturer power curves. However, the real relationship between the power generated by the whole wind farm and the velocity of the wind can, however, be more complex than above Eq. , which would results from the aging of the wind turbines and control factors. Furthermore, power curves can be classified into global, cluster, and turbine curves. The relationship between the wind velocity and the output power should be treated as a nonlinear and stochastic time-varying function of wind speed, which could not be described by a deterministic machine power curve. For example, we can use ANN structures or fuzzy logic as a specific area power curve. Moreover, the transformation of wind speed to power in a wind park is more difficult, which would use multiple wind direction and speed in order to achieve a wind farm matrix[10].

In Ireland, the study shows that using a power curve derived from measured wind and power can improve the forecast RMSE by nearly 20% in comparison to use the power curve only. In addition, due to the non-linearity of the power curve, wind speed forecasting errors are amplified in the high-slope region between the cut-in wind speed of the turbine and the plateau at rated wind speed, where errors are dampened. That is, the nonlinearity of the wind power curves leads to a further amplification of the error, and small deviations in the wind speed may result in large deviations in the power. As a result, a proper aggregate model of wind plants is needed to perform more accurate forecasting studies because a large amount of wind power can smooth power output curves.

4.3 Basic Method for Wind Power Forecasting

A reasonable starting point for modeling the power production of a wind farm under different weather conditions is the use of turbine manufacturer's power curve for wind power forecasting. Expected power production of a turbine is calculated over its range of operating wind speeds with help of power curve. It is therefore reasonable to say that for a particular wind speed, the power production of one turbine can be found by looking up the appropriate power value from the turbine power curve (interpolating between values if the wind speed is not an integer). Then the total power production of the whole wind farm to be simply this power value multiplied by the number of turbines. Raw meteorology forecasts Reference point meteorology forecast Wind farm power forecast combine and correct to conditions at on-site reference point convert to power values It is common practice to statistically refine raw meso-scale NWP forecasts to site-specific forecasts using historical NWP forecasts and concurrent measured on-site meteorology..In this basic method the NWP will be statistically corrected using measurements [11].

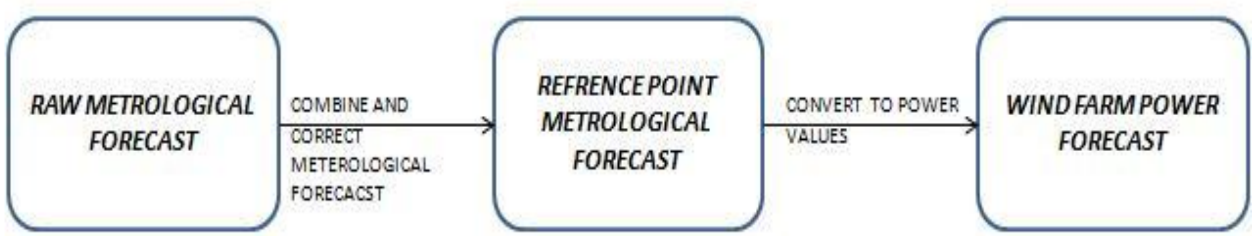

Fig. 4.1: Basic method for wind power forecast

4.3.1The Power Curve of a Wind Turbine

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds.

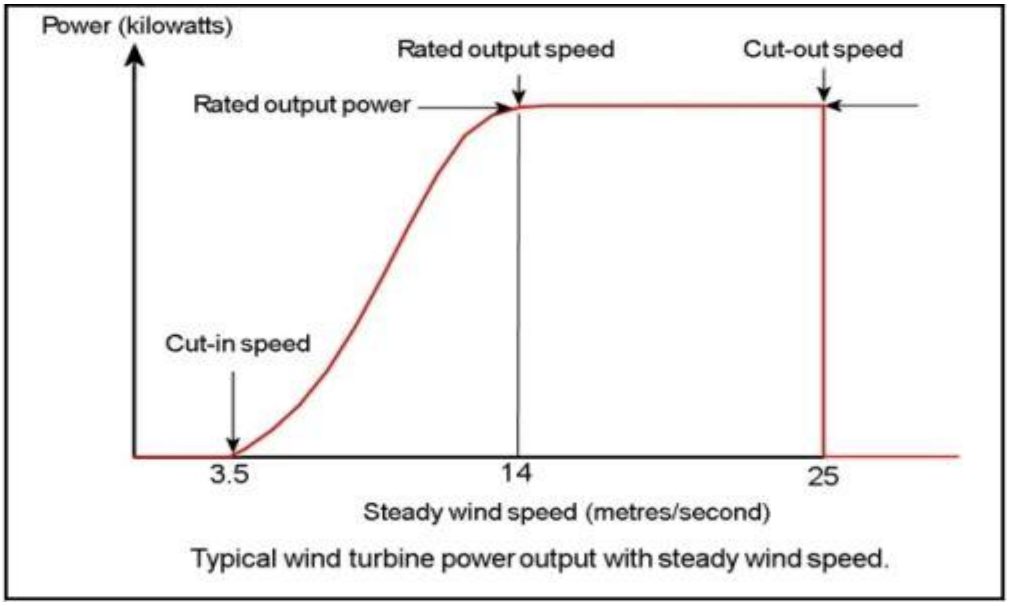

Fig. 4.2: Explanation of Power curve

4.3.1 Cut-in speed.

At very low wind speeds. There is insufficient torque exerted by turbine blades to make them rotate. However, as the speed increases, the wind turbine will begin rotate and generate electrical power. The speed at which turbine first starts to rotate and generate power is called the ***cut-in speed*** and is typically between 3 and 4 meters per second.

4.3.2 Rated output power and rate output wind speed.

As the wind speed rises above the cut-in speed, the level of electrical ouput power rises rapidly as shown in Figure 4.2. However, typically somewhere between 12 and 17 meters per second, the power output reaches the limit that the electrical generator is capable of. This limit to the generator output is called the ***rated power output*** and the wind speed at which it is reached is called the ***rated output wind speed.*** At higher wind speeds, the design of the turbine is arranged to limit the power to this maximum level and there is no further rise in the output power. How this is done varies from design to design but typically with large turbines, it is done by adjusting the blade angles so as to to keep the power at the constant level.

4.3.3 Cut-out speed.

As the speed increases above Figure 4.3 the rate output wind speed, the forces on the turbine structure continue to rise and, at some point, there is a risk of damage to the rotor. As a result, a braking system is employed to bring the rotor to a standstill. This is called the ***cut-out speed*** and is usually around 25 meters per second.

Wind speed at different altitude, wind speed is corrected as reference point metrological forecast

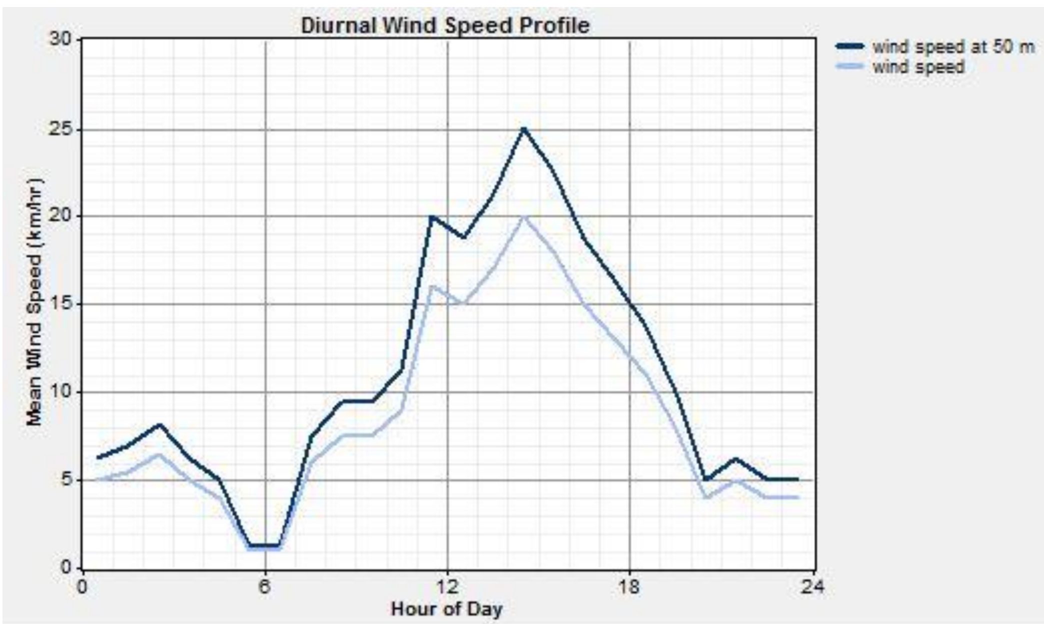

Fig. 4.3: Wind speed Plot at Altitude

In the above graph it can be observed that wind speed at height 50 m is more than ground level.

4.3.4 Case study

A part of muppandal wind farm, near Kanyakumari, Tamil Nadu is used for case study where Enercon E53 wind turbines are used 6 wind turbine as small windfarm is used for case study.

Power curve for ENERCONE53 800KW,ROTOR DIAMETER 50 M,POWER REGULATION PITCH CONTROL

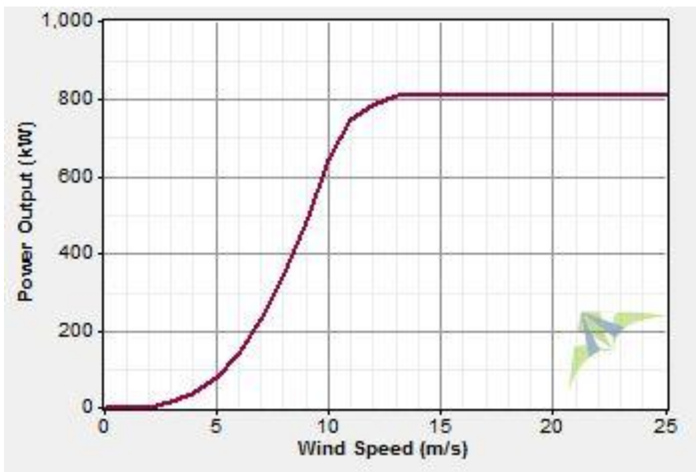

Fig. 4.4: Power curve for Enercon E53

Wind Power for a wind turbine is calculated as

$$P_{Wind}(t) = \frac{1}{2} * \rho * A * v^3(t) C_p \qquad (4.2)$$

Where ρ=1.225 kg/m^3,Cp=0.4.

Area swept by wind turbine(A) = 3.14*R^2 =3.14*25*25=1962.5 m^2

Wind speed(forecasted wind speed of AR(20) model) v(t) for 24 hrs.

So the Mean net Power P_{Wind}(t) =40.7 *6=244.2 KW ,for a day.

Mean net energy output=356308* 6=2137848(KWH/YR)

4.4 Wind Power Forecasting by Advanced Method

The advanced method for wind power forecasting ,first convert forecast of wind condition across site and then convert power value with help of Park model with help of windfarmer to wind power forecast.

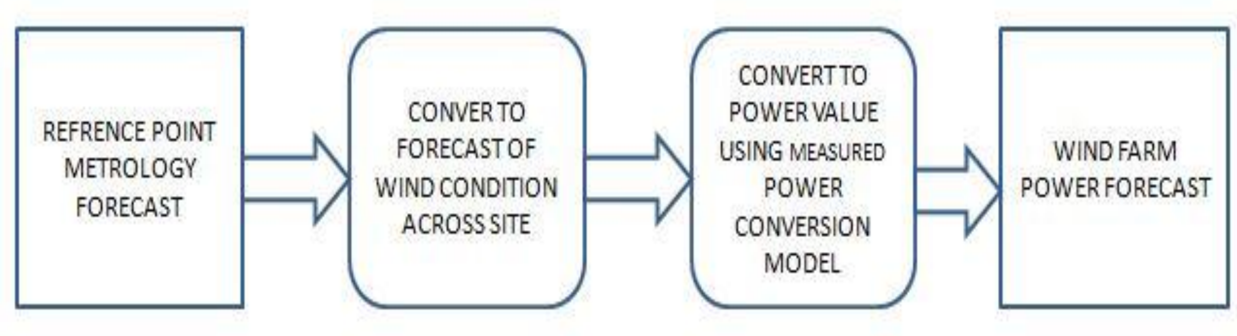

Fig. 4.5: Advanced Method for wind power forecasting

Site specific wake modeling

The basic method (scaling up the turbine power curve) takes no account of the layout of the wind farm and the specifics of the surrounding terrain. When there is no historical measured data available from the site, appropriate use of software such as GH Wind Farmer allows creation of a more complex power model that takes into account the directional dependence of wake effects from nearby turbines and wind speed variations across the site due to the terrain. If the NWP forecast has been refined to a specific reference point on the site (met-mast or central turbine) as in the basic model, the flow/wake modeling software can be used to create a model that predicts the conditions at each of the individual turbines based on the reference point wind conditions and so produce a power model that predicts the total power produced by all the turbines when particular weather conditions occur at the reference point.[11].

4.4.1AIR DENSITY CORRECTION

For example ,for a pitch regulated machine, the forecast wind speed can be corrected to the equivalent wind speed at the reference density using the formula

$$WS_{(corrected)} = WS_{(forecast)} * \left(\frac{forecast\ density}{Refrence\ density}\right)^{\frac{1}{3}} \quad (4.3)$$

Here reference density is taken as 1.225 kg/m^3 and forecast density is taken as 1.222 kg/m^3.

Glimpse of windfarmer(software).

The windfarmer software allows the user to design a windfarm to achieve maximum energy production within the geometrical and environmental constraints of site. Some of its core features include Wind data analysis ,Energy and wake loss calculation ,Sites condition assessment.

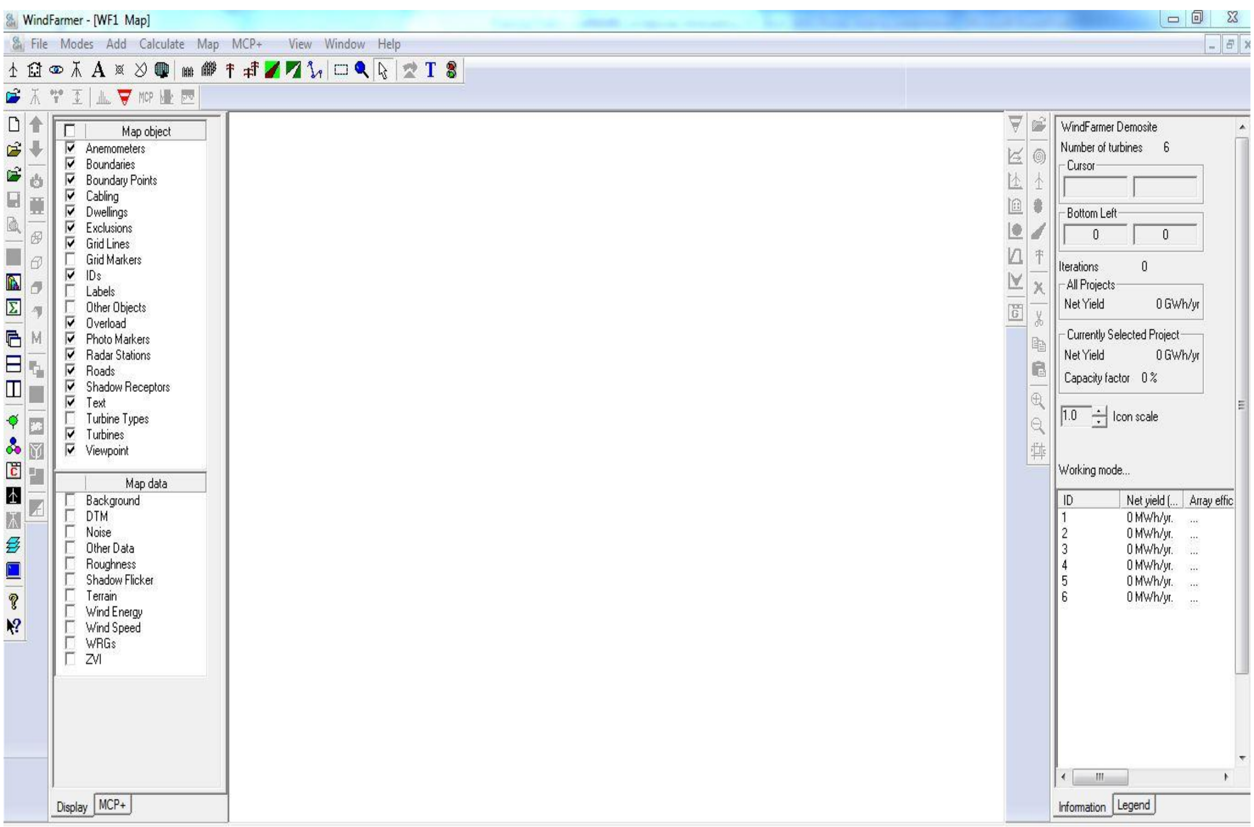

Fig.4.6: Glimpse of wind farmer

4.4.2 ENERGY CALCULATION

An energy calculation combines the incident wind speeds at each turbine with the power curve of the turbine to give the power output for the whole windfarm applying the frequency distribution results in the expected energy yield. The energy production of the wind farm is calculated using WndFarmer in conjunction a wind flow model with compatible output. The wind flow model is used to determine the ambient wind speeds at each turbine location Association Method, the measured data are scaled to the turbine locations using the predictions of the wind flow model.
A wake model is used to determine the changes to the incident wind speeds at each turbine within a wind farm due to the effects of other turbines. The accuracy of wake prediction has become increasingly important as larger wind farms are developed and turbines are placed closer together.

Program parameters used in energy yield calculation

1. **Site** reference air 1 **.225**

The air density for each turbine is calculated from the density (kg/m^3) site air density according to height above sea level (ASL) and the power curve used is adjusted according to lEO 61400-12-1.

2. Lapse rate -0.1 13

The lapse rate describes the variation of the air density ((kg/m^3)/km) with height.

3. Site roughness 0.03

This parameter can be used to calculate turbulence length (m) levels at hub height.

4. Maximum wind 70

Maximum wind speed for which energy is calculated. speed (m/s) The mean wind speed calculation from a Weibull distribution requires a high value.

4.4.3 WAKE MODEL

The calculation of wake effects employs a systematic approach where each turbine is considered in turn in order of increasing axial displacement downstream. By this method, the first turbine considered is not subjected to wake effects. The first turbine's incident wind speed, the thrust coefficient and the tip-speed ratio are calculated. Its wake is then modeled, as described below, and the parameters which describe its wake are stored. The effect of this wake on all turbines downstream can then be modeled. lf any of the downstream turbines fall within the wake of this turbine, the velocity and turbulence incident on these turbines can be determined, solely due to this upstream turbine being considered. The incident wind speed on the turbine is the sum of the wake and topographic effects .wake model considered in my case is

• Modified PARK model based on the method presented by Jensen and Katic

Due to the complexity of the wake directly behind the rotor. the model is initiated from two diameters (2D) downstream. This is assumed to be the distance where pressure gradients no longer dominate the flow.
The input parameters for model is listed below.

wake expansion 0.07

Describes the rate of the assumed linear expansion of the factor(k) wake. Increase this value for a high turbulence situation, decrease for offshore.

Surface roughness 0.03 m

4.4.4 MODIFIED PARK MODEL

This two-dimensional model uses the momentum theory to predict the initial profile from the thrust coefficient assuming a rectangular wind speed profile, and that the wake expands linearly behind the rotor. The figure below outlines the flow field used by the model.

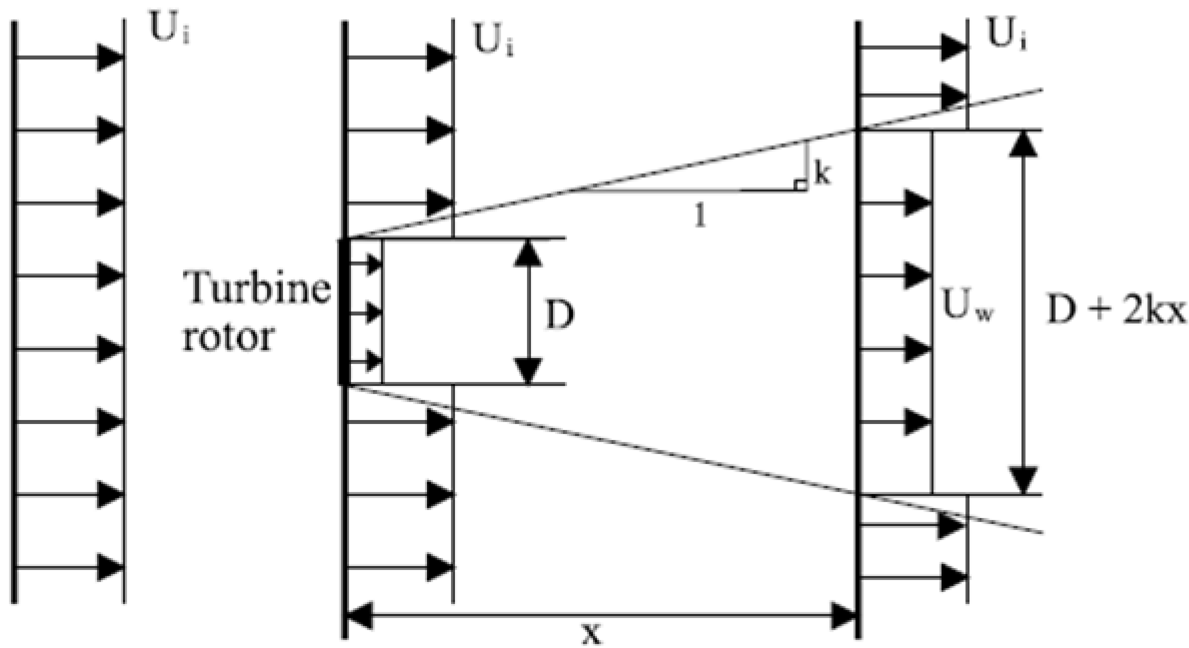

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Fig. 4.7: Park Model

Equation 4.4 is used to obtain the wake expansion factor length (zo) from a surface roughness length

WAKE DEVLOPMENT

The downstream wind speed is calculated using the following formula

$$U_W = U_i[1 - \left(1 - \sqrt{1} - C_t\right)\left(\frac{D}{D + 2kx}\right)^2 \quad (4.4)$$

Here U_i is the axial wind speed incident on the turbine, C_t is the thrust coefficient and' k 'is the wake decay constant that is defined by the following expression

$$\mathbf{k} = A/(\ \mathbf{\ln(h/z_0)}\ ) \quad (4.5)$$

where A is a constant equal to 0.5 and h is the turbine hub height.
The nature of the program means that k is set at the same value for all wind directions. This assumes that there is no significant variation in surface roughness length over the site and the surrounding area.

Wake Super Position

For each turbine downstream of the turbine under consideration, the program determines the axial displacement assuming rotational symmetry of the wake. The wake width and the wind speed at this displacement are then calculated. The turbines affected by the wake may not be totally in the wake so the percentage cover of the turbine's rotor in the wake is determined. If the whole rotor is within the wake, then the turbine wind speed is set as U_w. If some of the rotor is outside the wake, the wind speed at the turbine is the sum of U_w and the upstream velocity of the turbine creating the wake multiplied by the relative percentages of rotor cover.
If the turbine under consideration is in the wake of another turbine, the initial wake velocity deficit is corrected from the incident rotor wind speed to the free stream wind speed. This correction is necessary in order to ensure that at distances far downstream, the wake wind speed will recover to the free stream value rather than that incident on the rotor. Therefore, the initial centre line velocity U_{wi}, is scaled by the ratio of average influx velocity U_i and free upstream wind velocity according to the following formula:

$$U_w = \left(\frac{U_0}{U_i}\right) U_{wi} \quad (4.6)$$

To combine the wakes of two wind turbines onto a third turbine the overall wake effect is taken as the largest wind speed deficit and other smaller wake effects are neglected. This methodology is based on the results of the assessment of measured data from a number of wind farms.

Furthermore, where multiple turbine types are present, the model takes into account any variation in hub height and rotor diameter.

Wind farm (A part of Muppandal windfarm,Tamilnadu)

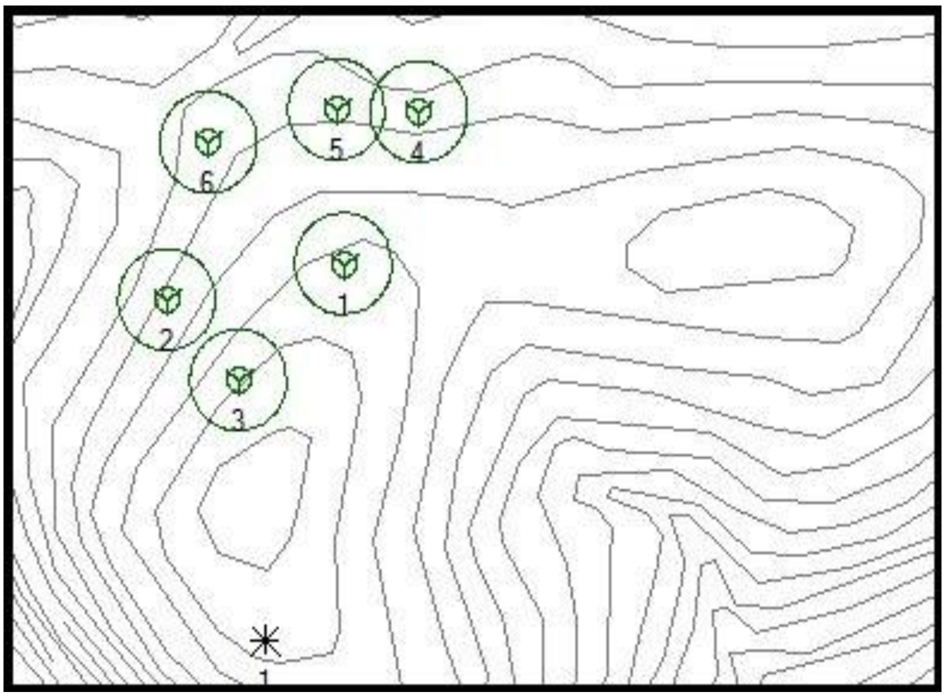

Fig. 4.8: Part of Muppandal wind farm

The above figure is modelled in software windfarmer.In theabove figure grey line represents terrain .Closer the line flater is the surface.The bigger eleptical polygon shape in the above figure represents Hill area .Total surface area under consideration for wind turbine is 770 m*460m.There are 6 turbines in the figure represented as number 1 to 6.'*'symbol represents anemoatry mast used for measuring wind speed.wind turbine used here are Enercon E53.It can also be observed that turbine 5 and 4 are in wake of eachother.Total windfarm is about 6*.8 MW = 4.8 MW.

4.4.5 Wind Power for a wind turbine is calculated as

$$P_{Wind}(t) = \frac{1}{2} * \rho * A * v^3(t) C_p \qquad (4.8)$$

Where ρ=1.225 kg/m^3,Cp =0.4.

Area swept by wind turbine(A) = 3.14*R^2 =3.14*25*25=1962.5 m^2

Wind speed(forecasted wind speed of AR(20) model) v(t) for 24 hrs.

With Overall loss factor around 17%

So the Mean net Power P_{Wind}(t) =33.5*6 KW ,for a day.

Mean net energy output=29374*6(KWH/YR)

4.5 Financial Calculation

Wind Power forecasting can be used for wind power trading.

In Tamil Nadu, Tariffs fixed by commissions in INR per kWh=3.39 INR

1) Wind Power Forecasted by basic method

So Average selling Price of power =3.39*24*40.7*6=19868.112 INR

For the Year it will be =19868.112*365=7251860.88 INR

2) Wind Power Forecasted by advanced method

So Average selling Price of power = 3.39*24*33.5*6 = 16353.36 INR

For the Year it will be =16353.36*365=5968976.4 INR

There is difference of 1282884.48 INR, this amount is huge for a small wind farm. If the owner of the wind farm informs the grid about the power to be delivered for day ahead power trading based on basic method ,ie much more than real power produced (calculated in advanced method),can cause him penalty.

4.6 Discussion and conclusion for wind power forecasting

From the above discussion its clear that wind speed forecasting error can contribute large source of error in wind power forecasting. This chapter also two different method of wind power forecasting. Basic Method uses wind power curve for Wind power forecasting .Chapter also Points out how wind speed varies with Altitude.

Advanced method is also used for wind power forecasting ,It takes into account of wind terrain speedups and Wake effects. Chapter also gives brief on how wakes are Model, With model Like Park Model, can help in wind power forecasting accurately. At last it is calculated that wind farm with basic with 6 turbine can produce around 2.13MWH/YR and advanced method forecast about 1.76 MWH/YR .So the financial difference of about it calculated 12lakhs 82 thousand is calculated on yearly basis. So Advanced Method can help to save lot of money created by forecasting error, if Advanced method is used

Chapter 5

Summary & Conclusions and Applications of Wind Power Forecasting

5.1 Summary & Conclusions

In this project wind speed forecasted for AR, ARMA and curve fitting ,and best forecasted model Auto regression AR(20) chosen as best model as it has least variance and MAPE. In the second part of project wind power is forecasted with basic method and by advanced method by the help of previously forecasted wind speed. Advanced method takes care of wake effect, terrain speed ups.

Chapter 2 mainly focuses on background and literature survey. This chapter introduces the current sate of wind energy resources in India .It also throws light on different methods available for wind forecasting .chapter also discusses different variable like temperature ,atm pressure etc affecting wind speed. But Studies show that for short term power trading only wind historical speed data is important for wind speed forecasting.

Chapter3 gives brief intro to different statistical methods available for wind speed forecasting. The chapter also focuses on different time scale classification for wind speed and power forecasting. It also shows short or long term wind speed forecasting can help in making different decision in electricity market.

8^{th} day wind speed forecasted with help of AR(20),ARMA(20,1) and curve fitting.AR(20) model is chosen the best model for wind speed forecasting because it has least MAPE and least variance available among other forecasted methods. It is also preferred over the other because it requires less number of parameter for forecasting.

Chapter4 deals with wind power forecasting, it points out the difference between wind speed and wind power forecasting. It also deals with comparison wind power forecasting for Basic method and Advanced method which takes care of Wake effect and Terrain speed ups, Chapter also discusses how wakes are developed by turbine. Windfarm is modeled in software Windfarmer .At last there is comparison made between two methods based on wind power trading and it is found that advanced solution can help to save lot of money on yearly basis.

5.2 Scope of Applications of Wind Power Forecasting

1.Different agents in the electricity market may have conflicting interests as they interact in the market environment. Wind power producers typically aim at minimizing their forecasting error over a longer period of time, in order to better schedule their generation. However, their main concern is in maximizing income. System operators, on the other hand, are concerned with guaranteeing the security of the system. System operators are interested in minimizing operational costs while maintaining a high level of reliability[13].

2.Wind power forecasting can be used to integrate wind energy into day ahead congestion forecast

3.In Intraday and Day Ahead Trading, amount of wind power that can be offered can be only offered ,can be only known with reliable prediction[14].

4.Unforecasted Large ramp events can affect electricity system reliability. So it is essential for wind power producer to forecast wind power[15].

5. Wind power forecasting can help forecast users in their decision-making processes (e.g., enabling derivation of advanced strategies for market participation).

6. Highly localized wind power forecasts allows us to predict possible bottlenecks in Local grids[15].

7.Wind power forecasting can help in decision of reserve requirement, unforecasted wind fluctuations raises electricity production cost.

Role of WPF in electricity market operations

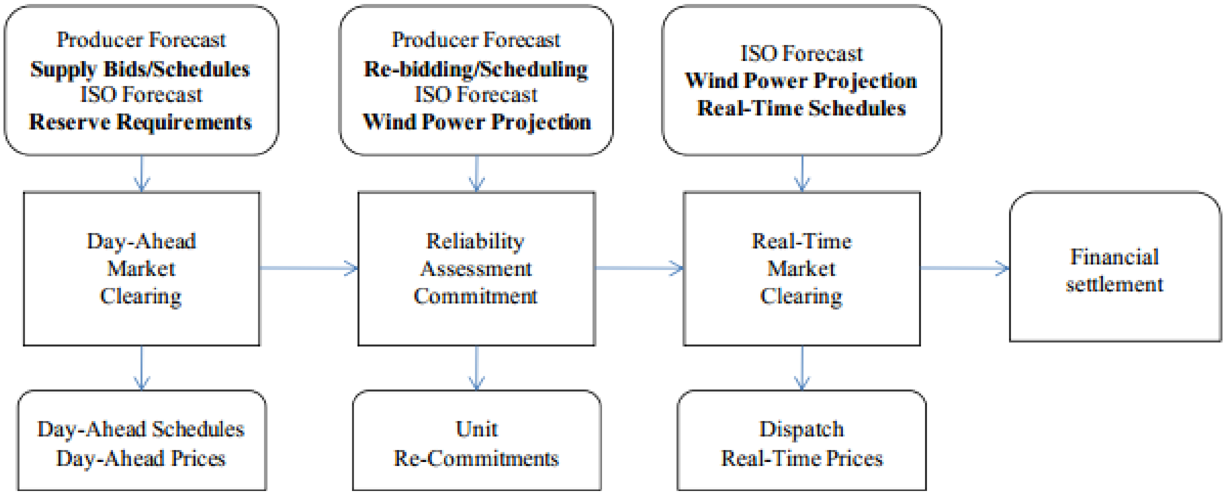

Fig. 5.1Role of wind power forecast in electricity market.

5.3 REFRENCES

1. Wikipidea.org/wiki/wind_power_in_india.

2. www.windpower.net.

3. Rajagopalan.S, Santoso S.,"Wind power forecasting and error analysis using the Auto-regressive moving average modeling," Power & Energy Society General Meeting, 2009. pp.1-6, 26-30.

4. Soman,Saurabh S,Zareipour , Hamidreza ; Malik, O. P.; Mandal , Paras A review of wind power and wind speed forecasting methods at different time horizons,North American Power Symposium (NAPS), 2010, 2010,pp. 1 - 8 .

5. Sergio Ramos, Joao Soares, Zita Vale, Hugo Morais, A Data-Mining Based Methodology for Wind Forecasting.

6. David Barber, "The Four Forces That Influence Wind Speed & Wind Direction", eHow.com Contributor, updated: December 16,2010.

7. www.wunderground.com (Wind speed Data source).

8. ww.kea.metsite.com ,(Wind speed data source).

9. For Identifying the number of AR or MA terms used in AR and ARMA method,

   https://onlinecourses.science.psu.edu/stat510/.

10. Collins,J;parks; J;Tindal, A; Forecasting for utility wind farm-The power model challenge, Integration of Wide-Scale Renewable Resources Into the Power Delivery System, 2009 CIGRE/IEEE PES Joint Symposium,2009,pp-1-10.

11. Lange. M, Focken. U., "New developments in wind energy forecasting," Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008, pp.1-8, 20-24.

12. P.R.J Campbell, Short term wind energy forecasting,. Electrical Power Conference, 2007.,pp- 342 – 346.

13. www.nrel.gov ,national renewable energy laboratory(NREL) , over view and introduction to wind energy.

14. The State-Of-The-Art in Short-Term Prediction of Wind Power by project Anemos http://anemos.cma.fr/download/ANEMOS_D1.1_StateOfArt_v1.1.pdf,2003

15. Wu, Yuan-Kang K. ,Nat. Penghu Univ., Taipei Hong, Jing-Shan,A literature review of wind forecasting technology in the world . Power Tech, 2007 IEEE Lausanne,2007,pp. 504 - 509