A Detailed Literature Review on Wind Forecasting

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Abstract— **There are several forecasting methods available to estimate the uncertainty of the wind. Wind behavior is chaotic in nature. These forecasting methods are used to predict wind power generation capacity for the grid. With the introduction of smart grid has created enough space for integrating renewable (wind power) in to the grid. Several methods have been proposed by researchers to estimate the wind speed. In present days there is a lot of research is going on to estimate the wind speed by using mathematical, biologically inspired computing methods to minimize the prediction error. This paper presents a review of several forecasting techniques which are using presently. This paper will be helpful for the new researchers who are going to work in this area. This paper will also be helpful to the wind farm operators to know about the present wind estimation model capabilities and will give an idea to estimate the wind speed at their particular wind farms.**

Keywords- wind forecasting; Auto Regressive Moving Average (ARMA); Computational fluid dynamics; Numerical Weather prediction(NWP); neural networks; Adaptive Neuro-Fuzzy Inference System (ANFIS)

I. INTRODUCTION

In modern power systems integration of wind energy has become one of the key issue. Wind energy is the most promising energy in the present day world. In now a days wind energy is fast growing among all the renewable energy sources. The chaotic behavior of wind is a great challenge to the stability and reliability of power system. Wind power forecast is helpful for unit commitment, power system operations and economic dispatch [2]. Wind forecast depends on several factors like temperature, humidity, direction of wind etc. Increasing wind energy penetrations in power systems creating a great challenge to its operation. Nature of wind makes its prediction difficult and advanced forecasting methods like ANEMOS are giving platform for wind speed prediction [9]. Wind forecasting is important for power system reliability and it reduce the cost of power system if we deal with variable output generation [12].

To convert available wind power to actual power the curve varies non linearly as shown in power curve in figure1.

The fig1 shows the relationship between wind speed (m/s) and output power. This curve shows variation of output power for change in wind speed. The output power is zero for speeds below a minimum speed that is known as threshold speed (around 3m/s). A growth in power output can be observed till the machine attains its nominal power (around 15m/s), and a constant power output above that level till the cut off speed is reached (around 25m/s) [1],[23].

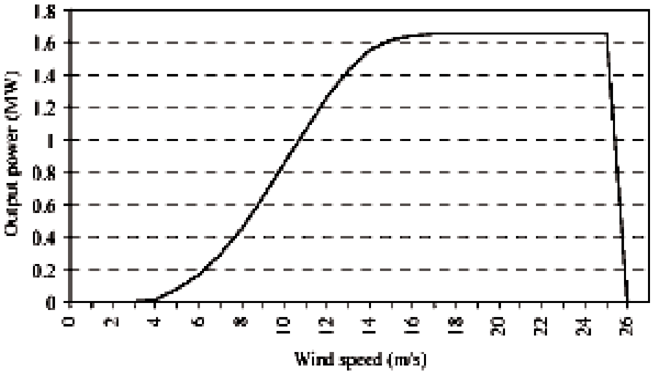

Figure1. Power Curve for 1.65 MW Wind Turbine

Theoretically wind energy delivered by the rotor of the wind turbine is given by

$$P_r = 0.5\rho\Pi R^2 C_p(\lambda,\beta)V^3 \quad (1)$$

Where P_r = wind power of the rotor
ρ = air density
R = The rotor radius
V= The wind speed
C_p = Rotor power coefficient
λ = Blade pitch angle
β = Tip speed ratio

The rest of the paper has been organized as follows: Section II deals with wind forecasting definition, types of wind forecasting based on time scales and their application and it give an over view of all wind forecasting methods such as persistence method, physical method, statistical method, heuristic method, hybrid method. And it also discuss about their performance and limitations. Section III gives a brief presentation on literature overview of wind forecasting and their application. Papers has reviewed up to 2011 for this literature. This paper is concluded in section IV.

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II. WIND FORECASTING:

Forecasting of wind is an estimation from expected power production of the wind turbines in the future. This power production is expressed in kW or MW depending on the nominal capacity of the wind farm. Now a day's wind power forecasting tools are based on a combination of physics based and statistical methods [7]. The data which we require for wind forecasting is collected from several turbines at wind farms. The Supervisory Control And Data Acquisition (SCADA) systems installed at each wind turbine are used to obtain necessary data. Wind forecasting will differ from place to place, that is a unique forecasting technique is not developed for all the places. Forecasting is also depends on the geographical area.

Wind forecasting is divided into 4 types based on time scales [39].

TABLE I. WIND FORECASTING BASED ON TIME SCALE CLASSIFICATION

Time horizon	Range	Applications
Very short-term	Few seconds to 30minutes ahead	-Electricity market clearing -Regulations actions
Short-term	30 minutes to 6 hours ahead	- Economic Load Dispatch Planning -Load Increment/Decrement Decisions
Medium-term	6 hours to 1 day ahead	- Generator Online/Offline Decisions - Operational Security in Day-Ahead Electricity Market
Long-term	1 day to 1 week or more ahead	- Unit Commitment Decisions - Reserve Requirement Decisions - Maintenance Scheduling to Obtain Optimal Operating Cost

Statistical, Neural network methods and several advanced hybrid methods are more accurate for very short term forecast range. NWP method is most accurate for short term forecasting. Accurate wind power forecasting is needed to locate the wind power plant at optimal places, to determine the reserve power and to hold for balancing energy [37].

Wind power forecasting methods can be broadly classified in to five types

- Persistence method
- Physical method
- Heuristic methods
- Learning method
- Hybrid method

A. Persistence method:

Persistence method is very simple in nature. It assumes that the wind power at a certain time in future will be same as that is when forecast is made,

$$P_{t+k/t} = P_t \tag{2}$$

Where

$P_{t+k/t}$ = Wind power after certain instant of time

P_t = Wind power in present instant

At a functional level, the immediate available measurements of wind power should be used, that may provided by the SCADA system. It is simplest among all the forecasting methods. Any advanced forecasting is worth implementing, only if it out performs the persistence model [1].

B. Physical method:

The idea of physical method is to improve the NWP (Numerical weather prediction) by using the physical considerations about the terrain such as the roughness, orography and obstacles. This method includes a model that describes the physical relationship between atmospheric condition, wind speed, local topography and the output from the wind power plant. NWP (Numerical weather prediction) models are the essential inputs for all the wind power forecast models which depend on weather forecast. A model chain of various hierarchical levels with different NWP models are used. Meteorological observations carried out by meteorologists, weather monitoring stations, satellites etc. in the world; mark the starting point of the model chain. A global NWP model, which models the atmosphere of the planet earth, is computed using all the available data as input. By using physical laws and governing the weather, the developed NWP model predicts the future state of the atmosphere. Computational fluid dynamics (CFD) is used as an another substitute method in physical domain [13].

C. Statistical method:

Statistical methods can be modeled easily and it is economical compared to other methods. Statistical methods use the previous history of wind data to forecast the present over the next few hours. These are good for short time periods. The disadvantage with the statistical method is error increases with the prediction time. Statistical time series models are used to predict wind power output up to six hours in advance. The auto regressive moving average (ARMA) is a well known time series statistical model. It is based on time series analysis [6]. This model shows the good forecasting results within 1 to 2 hours. Auto regressive integrated moving average (ARIMA) models have three components as auto regressive, integrated, and moving average. When the second term that is integration term absent then the resulting model is known as ARMA mode and it is denoted as

$$X_t = \sum_{j=1}^{p} a_j X_{t-j} + \sum_{k=0}^{q} b_k e_{t-k} \tag{3}$$

The equation is a realization of the time series X at time t that depends on linear combination of past observations of X and a moving average of series e. In the above expression p is the order of the autoregressive process of X and q is the order of the moving average error term. In the ARMA model we have to identify the p and q which are tentative [28].

D. Heuristic methods:

Artificial neural networks modeling inspiration was given by human brain. So there exists strong relation between biological neurons and artificial neural networks . Artificial neural networks(ANN) are the best for the forecast time series. ANN models are used to represent a complex non linear relationship [17], [19]. In neural networks radial basis function is superior with its performance for both linear and non linear and it is best suitable for wind power forecasting [26],[33].

Genetic algorithms (GA) are evolution based algorithms. The characteristics of individuals are therefore expressed using genotypes. A genetic algorithm based learning scheme can be used to train the input data which consists of wind speed and direction data [1] & [38].

Fuzzy sets and fuzzy logic allow approximate reasoning. With degree of certainty it allows modeling of common sense. Fuzzy logic is a research area based on the principles of approximate reasoning and computational intelligence. The fuzzy model could predict wind speed from 30 min to 2 hours ahead and it outperformed the persistent method [1] & [38].

Particle swarm optimization (PSO) is a global optimization approach, modeled on the social behavior of bunches of birds and schools of fish. PSO is a population based search procedure where the individuals, referred to as particles, are grouped in to a swarm. Each particle in the swarm represents a candidate solution to the optimization problem [38].

E. Hybrid methods:

Hybrid method is combination of both neuro fuzzy and ANN model. Hybrid methods are having better accuracy and good wind forecasting results compared to individual models. This hybrid method is used in such a manner that neuro fuzzy output is given to the ANN where we will get accurate wind power prediction [19].

III. LITERATURE REVIEW FOR WIND FORECASTING:

Reference [3] presented wind power density forecast for the duration of one to ten days ahead. It can be generated from wind speed predictions produced by an atmospheric model. Author compared the resultant density forecast with advanced time series models built using wind speed data and observations. In this paper we used the wind speed data at 10 meters height, recorded at the five wind turbines having different size and capacity for forecast evaluation. [4] Reveals that ANN models have a better accuracy compared to ARIMA model to forecast short term hourly wind speed. In this paper wind speed time series which consists of hourly mean values are measured in china Wind Park. This Wind speeds are collected by anemometers at 10 meters height and they collected for every 3s over a 10 min interval time. [5] Presented that wind speed is non stationary and time varying so it is difficult to forecast. But time series and ARCH model is well suitable. This model considers the hetero scedasticity which is based on “changing variance” so that it overcomes the traditional models and accuracy improves. A new genetic algorithm neural network model based on rough set is suggested in [8]. This model has quite satisfactory effect and forecasting precision is higher.

The importance of forecasting on power system operation and stability is discussed in [10]. And this also proposed a method for wind farm power forecasting based on JAVA technology. BP neural prediction model implemented by JAVA used for practical application in china. Reference [11],[14] focused on novel models such as Ensembe Empirical Mode Decomposition (EEMD) and Support vector machine (SVM). This model will decompose the wind data in to residue and some intrinsic mode function (IMF) components via EEMD which makes the corresponding time series more stationary. Finally all forecasting results gathered to give forecasting result. Reference [16] proposed a method for short term forecasting in Portugal. This method is a combination of wavelet transform (WT), PSO and ANFIS. The WT is used to decompose the wind power series into a set of better-behaved constitutive series. This method is effective and innovative. The average Mean Absolute Percentage Error (MAPE) and Normalized Mean absolute Error (NMAE) results are good. Reference [18] describes very short term wind power prediction for generator in Tasmania, Australia. The application of an ANFIS to forecast wind time series. The ANFIS model results are less than 4% MAPE. The results are compared with the persistence model. In [20] an advanced statistical method based on neural networks & fuzzy logic techniques which are used to forecast wind power output. A self organized map classifies data in to 3 different classes based on wind speed of the hour and for each class a different Radial Base Function (RBF) network is used for estimation.

Reference [21] developed a new application based on wavelets for wind forecasting. The advantage of wavelet based forecasting is that it is not required to consider initial assumptions about the properties of time series and this approach can decompose the time series into different subseries which can be analyzed, separately predicted and later recombined to get aggregate forecast. And a coefficient predictor technique of wavelets which can predict wind speed up to 24hours has been developed. [24] Illustrates a technique for predicting wind speed power for several hours ahead, based on cross correlation at neighboring sites. Here in this paper two wind sites have been considered. Those wind sites are up wind and down wind, where wind velocity is from up wind to down wind. And This paper developed an ANN that improves forecasting accuracy compared to persistence model. Reference [25] deals with long-term wind speed forecasting based on meteorological information. In this paper 3 different neural networks are employed for forecasting models. These networks are having internal feedback paths with neurons that were implemented by infinite impulse response (IIR) filters. Reference [27] discuss about HHT-ANN forecasting model which improves forecasting accuracy. This Hilbert-Huang Transforms (HHT) is to analyze the signal local property scale, which is the time interval between two adjacent maximum and minimum values and it depends on wavelet transformation. Reference [29] proposed the two layered artificial neural networks for estimating the actual wind speed from the previous values of the same variable. In this paper we used ANN model for short term wind speed prediction, which uses Back Propagation Algorithm (BPA), whose function is to reduce error. And this model is applied to a practical case to forecast wind speed at a wind farm in Jeju Island. [30] Presented an overview of key issues in wind power prediction and challenges faced for wind power generation. It also discuss about wind power prediction techniques, electricity price forecasting and in wind power forecasting. And it focuses on data mining techniques which can applies to analyze and evaluate wind data. This data mining technique is helpful in dense data cases also.

A Taboo search method which is intelligent enough to achieve the global optimization is proposed in [31]. In this paper ANN based on Tabu search algorithm is used for wind speed prediction one hour in advance. This ANN based on Tabu search algorithm wind speed model improve its precision. Reference [32] focuses on one hour ahead wind speed estimation using a Bayesian approach. In this paper 2 years of wind data is modeled as an auto regressive process, and this results are compared with persistence method. Reference [34] presents a new technique for predicting both wind speed and wind direction. This technique is based on linear time series model and predicted interval is two years data. Reference [35] discussed very short term wind speed forecast based on historical data. In this paper, parameters which identify wind speed pattern are defined and wind pattern model is established. Inner Mongolia wind speed data is used to compare with the results. [36] is a new method for wind speed prediction based on wavelet and support vector machine (SVM). SVM is a supervised learning model and it is used for classification and regression analysis and it is associated with a complex mathematics. In Wavelet and support vector machine method first we decompose wind speed sequences in to coarse components and next each wavelet component is individually forecasted with corresponding SVM models. Finally forecasting results of wind speeds are obtained by wavelet reconstruction. [40] is using adaptive wavelet neural network (AWNN) approach to decompose the signal and predict the wind speed for next 30hours and thereafter feed-forward neural network (FFNN) is used for nonlinear mapping between wind speed and wind power output , which helps to transform wind speed to wind power forecast. A complete one year wind data of 10 min. average has been taken from NREL website and that was converted to 1hr. wind data of 8760 samples for the analysis.

IV. CONCLUSION:

Present day power system which has large share of wind power essentially requires wind speed forecasting. Accurate wind forecasting can judge the power system operation and maintenance. Forecasting of wind speed and power serves as a very important tool to improve the efficiency and reliability of power system. This planning and maintenance of power system can be done effectively with long term prediction methods. So from above it is clear that accurate wind forecasting methods are required to integrate wind power in to the power system.

This paper focused on several forecasting methods, their performance and application to study different wind farms. This paper carries several wind prediction techniques which can analyze wind data and they can estimate future wind speeds and thereby we can predict power. Forecasting techniques are differing from place to place and they also depend on the forecasting time. This paper has reviewed for forecasting techniques that were applied to the wind speed and power up to 2012.

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