Deep Learning based Wind Speed Forecasting-A Review

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***Abstract*— Wind speed forecasting is the term used for predicting speed of wind to generate wind power. Deep learning, which is the subfield of machine learning and is used to implement on a large data sets and predictions made using deep learning with LSTM can increases the accuracy rate to the great extent. The combination of deep learning with LSTM can enhances the prediction rate as due to the property of LSTM of pattern remembrance for longer duration of time. This survey discusses the existing functionality measures of different approaches by partitioning them into various methodologies: models of very small time gap, small time gap, and longtime gap. All these approaches include certain models with various parameters, advantages and disadvantages are discussed. The focus of this survey is to present a better and efficient evaluation of various approaches to help the researcher to select best model out of all present models.**

Keywords—RNN, LSTM, Wind Speed Forecasting

I. INTRODUCTION

Prediction of wind speed is just the estimation of power of wind and this forecasting is helpful in power generation .And also it is done so as to maintain the gap between power consumption and power production. Wind speed forecasting based learning techniques which uses the concept of deep learning with long short term memory (LSTM) deals with the wind speed predictions, so that it can be utilized more efficiently by the power generation authorities .These predictions are made so as to match the variations produced by wind due to its volatile nature. If these variations can be traced or we can say predicted down earlier than it can help out in continuous power supply and generation. Deep learning is a subfield of machine learning and can be implemented on large data sets to provide good and accurate results. Learning algorithms can be easily used and implemented in deep learning and introduction of LSTM deals with the prediction problems. LSTM proves to be of great importance due to its property of remembering certain patterns for longer durations. Various approaches for wind speed forecasting were developed but they have certain issues regarding their performance and accuracy. Different approaches produces different results in changing of environment, conditions, wind parameters etc. and also utilization of individual model shows the confined nature. Different models with same parameters were providing the different results, and also the accuracy was not up to the mark. Also the result varies with the observations also i.e. whether it is very short, short, medium, long range forecasting. In order to solve these problem there is a need or to enhance the accuracy and performance the need of a more accurate model evolved and in this research work a new model is proposed using deep learning and LSTM (long short term memory). Deep learning models based on neural networks and it picks out the best feature to improve the performance and the property of pattern remembrance of LSTM for longer duration of time makes it a more reliable and efficient combined prediction models. Combination of deep learning methods and LSTM (long short term memory) can enhance the accuracy as well as can provide a better way of prediction. The survey paper is structured as follows: Description table for various wind speed approaches, wind speed horizons, comparison of wind speed forecasting models with various advantages and disadvantages.

II. RELATED WORK

The mentioned table includes the various research work in the field of wind speed prediction and there main objective is included with the approaches involved.

TABLE 1. REALATED WORK ON VARIOUS APPROACHES OF WIND SPEED FORECASTING

S.No	PAPER	PUBLISHER	YEAR	OBJECTIVE
1	Wind speed prediction using fuzzy	Ioannis G. Damousis, Minas C. Alexiadis, John	2004	This paper focuses on the fuzzy model for wind speed forecasting and

	model to generate power with spatial correlation [9]	B.Theocharis , and Petros S. Dokopoulos		genetic algorithm to train these models.
2	Recurrent Neural Network based wind speed prediction with large time gap for power generation. [13]	Ioannis G. Damousis, Minas C. Alexiadis, John B.Theocharis , and Petros S. Dokopoulos	2006	This method is used for problem of wind speed prediction based on weather information using recurrent neural networks.
3	Recursive Prediction Error algorithm for long term predictions of wind and speed. [15]	T.G. Barbounis, J.B. Theocharis	2006	To train the locally recurrent neural network using RPE algorithm by reducing the error into sub-problem in order to reduce the complexity.
4	Artificial Neural Networks based prediction of wind speed for small variations in time.[8]	Erasmo Cadenas, Wildfrido Rivera	2009	Different models were developed with different layers but simplest model was best and accurate.
5	Fraction ARIMA models based wind speed prediction for power [14]	Rajesh G. Kavasseri, Krithika Seetharaman	2009	To forecast wind speeds on the day-ahead (24 h) and two-day-ahead (48 h) horizons. This paper focuses on persistence model to analyze and compare the speed of wind.
6	ARIMA-ANN models for wind speed prediction method which is the hybrid of both the techniques [11]	Erasmo Cadenas, Wilfrido Rivera	2010	To train the error with the help of ANN which is generated by ARIMA model on hourly based time series data. To improve the accuracy of this hybrid model by reducing the mean square error, mean absolute error.
7	Markov chain model to predict the speed of wind in a very short time [1]	S.A. Pourmousavi Kani and M.M. Ardehali	2011	To develop ANN-MC wind speed forecasting model for few seconds prediction and pattern for very small time period are considered
8	Bayesian combination algorithm and NN models for the prediction of wind speed in short term [5]	Gong li, jing shi, Junyi Zhou	2011	The paper includes the two step methodology on Bayesian algorithms for wind speed forecasting and it also include neural network models
9	A new forecasting method which is based on Bayesian theory and structure break model to predict the speed of wind in a very short span of time series. Very short-term wind speed [2]	Yu Jiang ,Zhe Song, Andrew Kusiak "	2013	To use the prior information about wind to improve the results of the time series model which are predicted as a set of values different from other models.
10	k-nearest neighbour hood classification model for the prediction of wind speed having parameters in n – tupled input space [4]	Mehmet Yesilbudak, Seref Sagiroglu, Ilhami Colak	2013	The paper predicts the results on the basis of effect of various parameters on the wind speed and k-NN classification is used.
11	Hybrid model of seasonal adjustment method and the radial basis function neural networks which comprising wavelet transform technique to predict the wind speed in a short time gap[10]	Wenyu Zhang, Jujie Wang, Jianzhou Wang, Zengbao Zhao, Meng Tian	2013	To combine the wavelet transforms seasonal adjustment methods for the better and efficient result.
12	An	Da liu,	2014	The model

	optimized model of wind speed forecasting with the combination of wavelet transform and support vector machines [6]	Dongxiao Niu ,HuiWang, Leilei Fan		proposed include wavelet transform, genetic algorithm and support vector machines and use of these together overcome the other models ,also two evolutionary algorithms were considered.
13	Regression tress algorithms to predict the speed of wind for the very short time gap [3]	A. Tronsco, S. Salcedo-sanz, C. Casanova-Mateo, J.C. Riquelmw, L.Prieto	2015	This method includes the various types of regression tree in wind speed predictions. The objective is to check the performance of different regression tree models.
14	A Hybrid model comprising Support Vector Regression and Seasonal adjustment index using Elman recurrent neural network methods to predict the wind speed [12]	Jianzhou Wang, Shanshan Qin, Qingping ,China	2015	To develop a hybrid model PLERNN with SVR, SIA and ERNN to improve the accuracy results.
15	Optimized Least Squares Support Vector Machine are optimized by PSO algorithm to predict the speed of wind in a short time gap [18]	Youjun Yue ,Yan Zhao, Hui Zhao and Hongjun Wang	2017	In this paper the accuracy rate is tried to improve by combining approaches like Ensemble Empirical Mode Decomposition (EEMD) and Sample Entropy (SE) Also the optimisation is done by PSO.
16	Cross validation error method to minimize the number of training samples in order to improve the accuracy of wind speed prediction [19]	Xin Zhao, Haikun Wei, Chi Zhang, Kanjian Zhang	2017	The main objective is to reduce the training samples to reduce the training samples and thus enhancing accurate predictions.
17	Back propagation Neural Networks residual correction to reduce the error of the model of wind speed predictions . [20]	Zhang Chenhong, Wang Penghui, Zhao Yuanhang yagang	2017	In this approach the time series and Back propagation neural network is combined for correction and better wind speed prediction rate.
18	Convolution long short term memory network and WPC for wind speed prediction using deep learning approach [7]	Hui liu, Xiwie Mi, Yanfei Li	2018	To develop a combined model using WPD, CNN, and CNNLSTM ,all the techniques used have different task to achieve an produce a robust model
19	Lorenz disturbance based IPSO-BP Neural Network comprising PCA to pre-process the data and train the model using Error back propagation algorithm [18]	Yagang Zhang, Bing Chen, Yuan Zhao, and Guifang Pan	2018	The main objective is to increase the accuracy rate by correcting the prediction value by the introduction of Lorenz distribution

III. Wind Speed Horizons

Very short term forecasting: ranging from few n second to 30 minutes and useful in immediate and regulation actions. Short term forecasting: ranging from 30 minutes to 6 hours ahead and is useful in load dispatch planning and operational security. Medium term forecasting: ranging from a day ahead useful in reserve requirements. Long term forecasting ranging from 1 day to 1 week or more is useful in operational management and in optimizing the cost [21].The detailed description of all these models are given below in Table1, Table 2 and Table 3, Table 4 respectively.

In **very short term model** the approach ANN-MC (Artificial neural network-Markov chain) model [1] is used for the wind speed prediction, the model shows the reduction of MAPE, MPE and also certain uncertainties were reduced. The approach of Bayesian structural break model [2] shows certain set of values of wind speed and these set of values can be implemented in many applications but this model has low computing efficiency and small training samples. In the next approach local modes-based regression trees [3] the computation is done by comparing 8 regression tree algorithms, it shows small computational time but same function approximation is tough.
The model based on K-nearest neighbor classification [4] uses multi-tuple inputs and error rates were observed graphically ,model presented does not depend on data sets but the main drawback of this model was that if less number of parameters are used for prediction than it inappropriate results.

Kumar Ajay et al. (2017) [22] reviewed the different methodologies for document clustering using K-nearest neighbor classification and Artificial Neural Networks.

Kumar Ajay et al. (2017) [27] reviewed the different methodologies semantic similarity measures using semantic latent analysis.

In **short term model** the approach used Bayesian adaptive neural network model shows more accurate results as compared to the other models but sometimes is inconsistent too, the model comprising of wavelet transform , support vector machines provide stable model and removing fluctuations but uses only single parameter. Methods using smart deep learning model predicts better results for speed fluctuations but resource requirement is high. While in case of ANN (Artificial Neural Network) knowledge is gained from trained data but huge amount of data is required for this model. The fuzzy model is used in complex model but take longer time to train the data while on the other hand the hybrid model shows smaller error rate but requirement of previous knowledge is necessary.

Bali et al. (2018) [24] suggested the use of optimization technique for Rock Predication by using Artificial Neural Networks.

Kumar Ajay et al. (2018) [23] discussed the various methodologies for electricity load forecasting using Artificial Neural Networks and Machine Learning.

Bali et al. (2012) [25] suggested the use of optimization technique using goal programming approach.

Bali et al. (2014) [26] suggested the use of optimization technique for Optimal Component Selection.

In **Medium term model** the approach implemented such as ARIMA-ANN model in linear and non-linear time series but shows more accurate results if used separately. The Hybrid model shows quite significant and generalized result but it is quite complex also.

In **Long term model** the local recurrent neural network used shows stability and require smaller computational and storage but the structure is quite complex. In case of F-ARIMA model structure is simple but huge data requirement and non-linear problem handling is tough. The model based on local recurrence neural network shows higher adaptability but good training procedure is required.

IV. COMPARISON OF WIND SPEED FORECASTING MODELS

Table 2 describes the different models using different parameters, their advantages and disadvantages for very short term wind speed forecasting.

TABLE 2. COMPARISON OF VARIOUS APPROACHES FOR VERY SHORT TERM FORECASTING MODELS

AUTHORS	MODELS	PARAMETERS	ADVANTAGES	DISADVANTAGES
S.A. Pourmousavi kani,M.M. Ardehali(2011)	ANN-MC Model[1]	Speed	-Reduction of uncertainties and calculation time	-Overtraining and exploration a common problem
Yu jiang,Zhe song,Andrew Kusiak(2013)	Bayesian structural model[2]	Speed	-prediction is set of values -numerous results can be obtained	-ignorance of structural breaks can lead to more errors and unreliable results -low efficiency and small training samples
A. Tronsco,S. Salcedo-sanz, C.Casanova-Mateo,J.C. Riquelmw, L.Prieto(2015)	Regression tree model[3]	atmospheric pressure, temperature ,solar radiation, humidity	-small computation time - result can be interpreted easily in regression tree	-approximation of same functions cannot be done -global models have low computational cost than local models
Mehmet Yesilbudak,Seref Sagiroglu,IIhami Colak(2013)	K-Nearest model[4]	-direction, temperature, atmosphere, pressure, humidity	-model does not dependent on the data set type - multi tuppled input	-shows inappropriate results with less parameters

The following Table 3 describes the various approaches used by the researchers to predict the wind speed for short term forecasting

TABLE 3. COMPARISON OF VARIOUS APPROACHES FOR SHORT TERM FORECASTING MODELS

AUTHORS	***MODELS***	***PARAMETERS***	***ADVANTAGES***	***DISADVANTAGES***
Gong li,jing shi,Junyi Zhou(2011)	Bayesian adaptive –NN model[5]	Speed	-provide reliable ,adaptive, and comparatively accurate result to NN	NN is not consistent in forecasting one hour ahead results
Da liu,Dongxiao Niu,HuiWang,Leilei Fan(2014)	WT+SVM+GA [6]	Temperature	-provide stable model -fluctuations in wind is eliminated by WT	-using only single parameter at a time -deep quantitative analysis is missed
Hui Liu,Xiwei Mi,Yanfei li(2018)	Smart deep learning model[7]	Speed	-Robust and effective model -predict better result for fluctuations	-more resources are required for computation
Erasmo Cadenas,Wilfrido Rivera(2009)	ANN model [8]	Speed	-gaining knowledge from training data-robustness-error tolerance is high	-requirement of large training data sets - careful analysis is required -great flexibility leads to inconsistent results
Ioannis G. Damousis, Minas C. Alexiadis,John B.Theocharis,Petros S. Dokopoulos(20004)	Fuzzy model [9]	Wind speed ,wind direction	-used where system are difficult to model -relatively less complex	-reduction in performance where terrain is complex -longer training time and cross correlation of data is low
Wenyu Zhang,Jujie Wang,Jianzhou Wang,Zengbao Zhao,Meng Tian(2013)	Hybrid model(WTT+SAM+RBFN) [10]	Speed	hybridizing results in smaller error rate - better forecasting performance	-previous Knowledge is required of various technologies

The Table 4 given below describes the various approaches used for wind speed prediction using medium term forecasting

TABLE 4. COMPARISON OF VARIOUS APPROACHES FOR SHORT TERM FORECASTING MODEL

AUTHORS	***MODELS***	***PARAMETERS***	***ADVANTAGES***	***DISADVANTAGES***
Erasmo Cadenas, Wilfrido Rivera(2010)	ARIMA-ANN model [11]	Speed	high accuracy in wind speed -can be implemented in linear and non-linear time series	model shows high accuracy rate separately
Jianzhou Wang, Shanshan Qin, Qingping ,China(2015)	Hybrid model[12]	Speed, direction	-high generalisation performance	optimization is quite complex - takes longer training time

The Table 5 given below describes the various approaches used for wind speed prediction using long term forecasting.

TABLE 5. COMPARISON OF VARIOUS APPROACHES FOR LONG TERM FORECASTING MODEL

AUTHORS	***MODELS***	***PARAMETERS***	***ADVANTAGES***	***DISADVANTAGES***
Thanasis G. Barbounis,John B.Theocharis,Minas C. Alexiadis,Petros S. Dokopoulos(2006)	Local recurrent NN model [13]	Speed ,direction, pressure, temperature	provide continuous stability during learning phase -smaller computational and storage requirement	-structure observed to be complex one
Rajesh G. Kavasseri, Krithika Seetharaman(2009)	f-ARIMA model [14]	Speed	-structure is quite basic -useful in time series model	-non-linear problem handling is tough -large amount of data requirement

T.G. Barbounis, J.B. Theocharis(2006)	Local recurrence NN model [15]	Temperature	-provide stable model -fluctuations in wind is eliminated by WT	-using only single parameter at a time -deep quantitative analysis is missed

V. DISCUSSION

In the above mentioned models and techniques the main focus is on increasing the accuracy rate to a certain extent. But basically the accuracy rate vary with change in parameters and other environmental conditions. In most of the cases utilization of various environmental factors are not clear for the better prediction of wind speed or the used factors does not provide a enhanced way of wind speed prediction for better power generation. The use of variety of parameters (atmospheric pressure, temperature, velocity, relative humidity) together with various deep learning techniques can certainly provide better prediction results in wind speed forecasting.

VII. CONCLUSION

After the detailed study of various researchers work the approaches for wind speed forecasting models has various limitations such as low efficiency, high computational cost, more resources requirement, high complexity and overtraining etc. so as to overcome certain problems which are not comprehensively achieved by the various prediction models the use of deep learning methods with LSTM (long short term memory) can result in the better prediction of wind speed for power generation. so it is necessary to develop a unique wind speed prediction model which have less error rate and produce better and more efficient result. Also these prediction can be of great use in various atmospheric activities predictions.

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