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Time-series prediction of wind speed using machine learning algorithms: A case study Osorio wind farm, Brazil

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HIGHLIGHTS

- Machine learning algorithms are developed to predict the time-series wind speed data.
- The developed models are MLFFNN, SVR, FIS, ANFIS, ANFIS-PSO, ANFIS-GA and GMDH.
- The employed models were examined on 5-min, 10-min, 15-min and 30-min intervals.
- GMDH model for all time intervals can successfully predict the target.
- PSO and GA algorithms can increase the prediction accuracy of the ANFIS model.

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ABSTRACT

Machine learning algorithms (MLAs) are applied to predict wind speed data for Osorio wind farm that is located in the south of Brazil, near the Osorio city. Forecasting wind speed in wind farm regions is valuable in order to obtain an intelligent management of the generated power and to promote the utilization of wind energy in grid-connected and isolated power systems. In this study, multilayer feed-forward neural network (MLFFNN), support vector regression (SVR), fuzzy inference system (FIS), adaptive neuro-fuzzy inference system (ANFIS), group method of data handling (GMDH) type neural network, ANFIS optimized with particle swarm optimization algorithm (ANFIS-PSO) and ANFIS optimized with genetic algorithm (ANFIS-GA) are developed to predict the time-series wind speed data. The Time-series prediction describes a model that predicts the future values of the system only using the past values. Past data is entered as input and future data to be used for represents MLA output. The developed models are examined on 5-min, 10-min, 15-min and 30-min intervals of wind speed data. The results demonstrated that the GMDH model for all time intervals can successfully predict the time-series wind speed data with a high accuracy. Also, the combination of ANFIS models with PSO and GA algorithms can increase the prediction accuracy of the ANFIS model for all time intervals.

1. Introduction

The depletion of fossil fuel energy resources, increasing concern of air pollution, global warming and energy crisis have encouraged the research for clean and pollution-free sources of energy [1]. Wind energy is one of the most common of clean energies that has been developed significantly in the world [2]. This type of energy is more accessible, inexhaustible, fairly cheaper, renewable and sustainable, and environmentally friendly [3]. Wind energy is a free source of energy that has served the mankind for many countries for driving wind turbines, pumping water, ships, etc. Developing wind energy systems can improve the idea of electricity generation without pollution in the future [4]. However, the integration of wind farms into the power networks has become an important problem for commitment and control of power plants, connecting and disconnecting the power to the grid and management of the power [5]. The produced power by wind turbine is related to the wind speed. Wind is considered one of the weather variables which more difficult to be estimated [6]. Wind is intermittent in nature, so it is not possible to predict exact wind speed because of the continuously changing climate conditions.

Therefore, the advent of alternative energy sources, particularly wind power, and the need to manage energy resources necessitate the use of advanced tools for prediction of short-term wind speed (or other types of renewable energies) [7]. The contribution of wind speed prediction for a safe and economic operation of the network will organize by independent power producer, system operator distribution and

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electrical companies. In recent years many investigations have proposed machine learning algorithms (MLAs) (or Artificial Intelligence methods) to predict the variation of meteorological data such as wind speed, solar irradiance, relative humidity, and air temperature [8–15]. Artificial Intelligence methods are defined as an extensive scientific discipline which enable computer programs to solve the complex nonlinear problems. In this study, seven types of MLAs are implemented to predict the time-series wind speed data (a time series prediction describes a model that predict the future values of the system only using the past values). It is exposed the procedure to achieve the possible models which better explain the time-series wind speed behavior. These methods are described as follows:

The first method is multilayer feed forward neural network (MLFFNN) that is defined as a new method of programming computers. This method is employed to analyze the problems that are very difficult to solve using conventional techniques [16]. The second method is group method of data handling (GMDH) type neural network. This method for the first time has been introduced by Ivakhnenko [17] as a multivariate analysis approach for complicated systems modeling and recognition. GMDH with the algebraic approach of the progression avoids the complexity of obtaining former information [18]. Therefore, the complicated systems without having particular information of the systems will simulate by applying this method.

The third method is support vector regression (SVR) that optimize its structure based on the input data. This method has been introduced by Vapnik [19], which works based on the classification and regression technique [20]. In recent years, SVR was successfully employed on classification tasks in very different areas of application [21–24]. The fourth method is fuzzy inference system (FIS) that is defined as the process of mapping a set of input data into a set output data, using an approach based on fuzzy logic. For this model, membership functions (MFs), fuzzy logic operators and if-then rules are defined as the main parts of the fuzzy inference system [25]. The fifth method is adaptive neuro-fuzzy inference system (ANFIS). An ANFIS model is defined as a combination of an ANN (generally, radial basis function neural network) into a fuzzy inference system. This combination is carried out to obtain the knowledge of the human expert to adjust the fuzzy parameters [26]. The sixth method is the combination of particle swarm optimization (PSO) algorithm with ANFIS model (ANFIS-PSO). The PSO algorithm is employed to increase the performance of the ANFIS model, tuning the membership functions required to achieve a lower error. This optimization algorithm that was proposed by Kennedy and Eberhart in 1995 is a heuristic approach [27]. The seventh method is based on the interconnection of genetic algorithm (GA) and ANFIS model (ANFIS-GA). Many studies for prediction of wind speed have been published that a short summary of them is presented in the following.

Chang et al. [28] developed a radial basis function neural network (RBFNN) for short-term wind speed and power forecast. The proposed network was trained with 24 h of observation period with historical data. Also, their method was compared with other methods of neural networks. They obtained the mean absolute percentage error (MAPE) for backpropagation neural network (BPNN), RBFNN and ANFIS as 27%, 24% and 3.87%, respectively. Ramasamy et al. [29] proposed an artificial neural network (ANN) to estimate wind speed in the mountains region of India. Temperature, solar radiation, air pressure and altitude were selected as inputs of the model and mean daily wind speed was selected as the target. It was reported a MAPE and correlation coefficient around 4.55% and 0.98, respectively. Doucoure et al. [30] implemented wavelet neural network and multi-resolution analysis to forecast wind speed.

Liu et al. [31] developed a modified Taylor Kriging method in order to estimate wind speed time-series data. One-year wind speed data were divided into 10 samples and the proposed model was applied to each sample. The proposed method was compared with an autoregressive integrated moving average method (ARIMA) and the results illustrated that the proposed method outperformed the ARIMA method by 18.6% and 15.2% in term of mean absolute error (MAE) and root mean square error (RMSE), respectively. Noorollahi et al. [32] used ANNs for estimating temporal and spatial wind speed in Iran. They implemented BPNN, RBFNN and ANFIS models to predict the targets. The BPNN and ANFIS models yielded similar results. The RBFNN method illustrated larger errors in all cases. Schicker et al. [33] developed an interval-artificial neural network for short-term wind speed prediction.

Kumar et al. [34] proposed generalized regression neural network (GRNN) and multilayer perceptron neural network (MLPNN) in order to predict wind speed in Western Region of India. It was found that the GRNN model has given the better result than MLPNN in term of mean square error (MSE). Sheela et al. [35] proposed neural network based on hybrid computing model for wind speed prediction. The proposed model was compared with an MLPNN and the results demonstrated the hybrid computing model performed better in terms of minimization of errors. Petkovic [36] implemented an ANFIS method for estimation of wind speed distribution. It was achieved an improvement in predictive accuracy and capability of generalization with the ANFIS approach.

Bonfil et al. [37] developed a model based on SVR to predict wind speed for wind farms. Wavelet, extreme learning machine and outlier correction algorithm were developed in order to predict wind speed by Mi et al. [38]. Also, Liu et al. [14] applied secondary decomposition algorithm and Elman neural networks for forecasting wind speed data. It was achieved a satisfactory performance for the proposed method in multi-step wind speed prediction. Li et al. [39] developed a study based on three models of ANN to predict wind speed data. These methods were adaptive linear element, backpropagation and radial basis function neural network. It was observed that the three developed models were capable at wind speed prediction. Koo et al. [40] employed ANN to predict wind speed data based on geological and distance variables (a case study in South Korea).

Lodge and Yu [41] implemented an ANN to predict the short-term wind speed data. This model was constructed based on the current weather condition and historical wind speed data. The values of RMSE for training and testing datasets were determined as 0.5781 (m/s) and 0.8895 (m/s), respectively. Mohandes et al. [42] developed a support vector machine (SVM) for forecasting the wind speed data and compared to an MLP neural network. For testing datasets, the value of MSE for SVM and MLP models were obtained 0.0078 and 0.0090, respectively. Bilgili et al. [43] used MLP neural network in order to forecast wind speed data. To train the network, resilient propagation (RP) learning algorithm was employed. Also, *logsig* and *purelin* transfer functions were selected for the hidden and output layers, respectively. The MAPE for the developed model was obtained 14.13%.

Salcedo-Sanz et al. [44] developed evolutionary support vector regression algorithms to estimate short-term wind speed prediction. An Evolutionary Programming algorithm (EP) and particle swarm optimization algorithm (PSO) were applied to tackle the hyper-parameters estimation problem in regression SVM. Their results have shown that the new model based on SVM with EP algorithm outperformed the MLP neural network. Liu et al. [45] proposed two models of ANN to predict the wind speed data. The first model was SVM optimized with genetic algorithm (SVM-GA) and the second one was a combination of wavelet transform with SVM-GA model (W-SVM-GA). It was obtained that the W-SVM-GA performed better than the SVM-GA in terms of MAPE and RMSE.

1.1. The knowledge gap and novelty of this study

The wind speed forecast in the wind energy sector is valuable for wind power system planning, unit commitment decision, load balancing decision, maintenance arrangement and energy storage capacity optimization. Wind speed is period arrangement information measured at various interims of time. Wind speed data are always nonlinear and non-stationary therefore it is difficult to accurately estimate them. Hence, regarding the literature review, many investigations were