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SHORT-TERM WIND SPEED ESTIMATION WITH ANN BASED HYBRID OPTIMIZATION METHODS IN ÇUKUROVA REGION

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Annotation. Short term wind speed estimation has a great importance in the renewable energy field. Because the continuous change of the wind energy depending on the wind speed causes the production/consumption imbalance in the networks. In order to prevent instability of the voltage and frequency changes, the balance between electricity production and consumption in the network must be provided continuously. Moreover, the installation costs of wind energy systems are relatively high so wind speed estimation studies are significant to minimize wind energy losses in the future. Nonlinear changes in the wind speed affect the modeling time and accuracy of the wind energy systems. Therefore, a short-term wind speed estimation method based on artificial neural network is proposed. In this study, a short-term wind speed estimation is performed by using the Artificial Neural Network (ANN) and ANN-based hybrid methods such as ANN-Harmony Search (ANN-HS) and ANN-Invasive Weed Optimization (ANN-IWO). Input parameters are obtained by using meteorological measurement stations. These parameters are the ambient temperature, wind speed and humidity in the Çukurova Region, Adana/Turkey. ANN-based hybrid estimation methods are preferred because of its success in modeling nonlinear sequences such as wind speeds. These powerful methods used in estimation problems are combined and presented as a new hybrid approach in order to reduce the errors. The errors in the estimations are determined by Root Mean Square Error values (RMSE) so the performance estimation results between the hybrid methods and ANN methods are presented in detail.

Keywords: wind speed, ANN, Harmony Search, IWO, hybrid method, estimation, short-term.

INTRODUCTION

Energy demands of countries are increasing day by day due to rapid population growth, industrialization, technological developments and economic races arising from the need to strengthen the economies of the country. Particularly in developed countries, the energy industry is widely used to generate electricity from fossil fuels. However, when greenhouse gases released from fossil fuels are harmful to the environment and fossil fuels are consumable energy sources, interest in alternative energy sources has increased all over the world. Renewable energy sources, which are alternative to fossil energy sources, are the new way of energy future for renewable energy countries by being a clean, economical, reliable and sustainable energy source.

Wind energy, which is one of the renewable energy sources, generates electricity from wind power, lack of raw material shortage and dependence on foreign sources, has no negative impact on nature and human health, and requires little space in its installation, increasing the importance of wind energy today. Although wind energy is an important renewable energy source in obtaining electricity and alternative to fossil sources, the fact that electricity production from wind energy is dependent on meteorological weather conditions, periodically changing wind speed and direction due to nature's discrete structure causes serious fluctuations in energy. In addition, it is important for user and operators in order to balance the system frequency and nodal voltage magnitudes in the electrical power systems by generating electrical energy from wind power. Hence, short-term wind speed estimation with a high degree of accuracy have a significant role in the power system.

In recent years, many scientists and researchers have conducted extensive research into short-term wind speed estimation methods to efficiently utilize wind energy. Table 1 presents the estimation methods used for the estimation of wind speed in the literature.

Shao (2016) proposed a new method to analyze the short-term wind velocity estimation and distribution characteristics of wind velocities and to promote model configuration by using wavelet transform (WT) and neural network optimization. In order to examine the wind speed property distribution based on the percentage of scalogram of energy distribution in different seasons, power spectrum and seasonal model analysis are performed. In this way, wind speed over time has contributed to perfecting the

examination of seasonal model characteristics and has been able to support sample division by calculating statistical measurement based on the estimated frequency range (Shao et al., 2016).

Table 1

Wind speed estimation methods used in the literature

Reference	Estimation Time Interval	Input Variables	Output Variables	Estimation Methods
Shao and others, 2016	Seasonal	Wind Speed	Wind Speed	Wavelet Transform – Neural Network
Karasu and others, 2017	Every Minute	Wind Direction Wind Speed	Wind Speed	Nonlinear Autoregressive Neural Network
Zhao and others, 2017	Hourly	Wind Speed	Wind Speed	Wavelet Transform Machine Model- Artificial Neural Network
Alberdi and others, 2017	6-12-24 Hourly	Ambient Temperature Solar Radiation Wind Speed	Wind Speed	Numerical Weather Forecasting
Khodayar and others, 2017	Seasonal	Wind Speed	Wind Speed	Deep Neural Network
Baby and others, 2017	Daily	Meteorological Data	Wind Speed	Nonlinear Autoregressive Network with External Inputs (NARX) Network
Yue and others, 2017	Seasonal	Wind Velocity	Wind Velocity	Support Vector Machine - Particle Swarm Optimization
Makhloufi and others, 2017	Every Minute	Wind Speed Wind Direction	Wind Speed	Wavelet Balancing - Data Processing Neural Network Group Method
Yadav, and others, 2017	Hourly	Amb Wind Speed Rüzgar yönü	Wind Speed	Artificial Neural Network
Yatiyana and others, 2017	6 Hourly	Wind Velocity Generated Wind Power Wind Position	Wind Velocity Generated Wind Power Wind Position	Autoregressive Integrated Moving Average (ARIMA)
Nair and others, 2017	Daily	Wind Speed	Wind Speed	Artificial Neural Network Method, Autoregressive Integrated Moving Average Method
Ahmed and others, 2017	Hourly	Meteorological Data	Wind Speed	Artificial Neural Network
Kumar and others, 2018	6 Monthly	Wind Speed	Wind Speed	Artificial Neural Network - Bayes Rearrangement
Alencar and others, 2017	6-12-24 Hourly	Wind Speed	Wind Speed	SARIMA- Artificial Neural Network

Karasu (2017) estimated the next minutes' wind speed with the Nonlinear Autoregressive Neural Networks Model using one-minute time data for one month. This estimation method has been found to have a high predictive performance for the wind speed data set of Zonguldak province compared to other methods (Karasu et al., 2017).

Zhao (2017) used the active learning methods to estimate the wind speed in a region. Active learning is a particular example of semi-supervised machine learning applied to selected samples for short-term wind speed prediction. The method initiated with starting network training set and then additional samples from large amounts of unlabeled learning sets were selected. Support Vector Machine (SVM) and Artificial Neural Network (ANN) models developed with an active learning approach for single-step.

Moreover, multi-step forward short-term wind velocity estimation were examined. The number of training samples was significantly reduced and the accuracy of the model was ensured (Zhao et al., 2017).

Alberdi (2017) presented his work in estimating wind speed for overhead line classification. The method used for estimation was applied in a pilot line and analyzed the results. According to the results, weather forecasts adapted with linear regression are not safe and temperature exceedances are high due to wind forecasts (Alberdi et al., 2017).

Khodayar (2017) proposed a deep neural network (DNN) architecture with stacked autoencoder (SAE) and stacked condensing autoencoder (SDAE) for short-term wind speed prediction. The error rate measurements of the results indicate that DNNs outperform Artificial Neural Networks shallow architectures and that the proposed rough extensions of SAE and SDAE improve wind speed estimates by addressing uncertainties in wind speed data (Khodayar et al., 2017).

Baby (2017) used the nonlinear automatic regressive neural network model for wind speed modeling. The model produced using meteorological variables as input data was trained and tested. Finally, the wind energy potential is also calculated using a nominal 2.1 MW wind turbine indicating the generation capacity of the area (Baby et al., 2017).

Yue (2017) proposed a combined estimation method to improve estimation accuracy. The proposed method compared with the Particle Swarm Optimization (PSO) and Least Squares Support Vector Machine (LSSVM) methods in terms of estimation errors. This method had an ability for decreasing the effect of wind speed nonstationary on the estimation results. Simulation results show that the proposed method can improve the accuracy of estimation and has practical engineering application value (Yue et al., 2017).

Makhloufi (2017) presented a Group Data Processing Method (GMDH) - Neural Network (NN) mechanism for estimating wind speed and produced wind energy in the short-term. The results showed that the Group Data Processing Method (GMDH) - Neural Network method performed well for wind speed predictions and that the wavelet use resulting in GMDH-NN resulted in superior accuracy and low errors, thereby enhancement estimation accuracy (Makhloufi et al., 2017).

Yadav (2017) realized one-hour forward wind speed estimation with the help of different ANN algorithm. Wind speed at Knock Airport varies in nature with various weather parameters. Therefore, the estimation of wind speed plays an important role for researchers. In order to estimate the short-term wind speed, the back-propagation algorithm based on the Levenberg-Marquardt algorithms was applied with the Artificial Neural Networks method and the desired results were obtained by estimating the low-wind speed error rate (Yadav et al., 2017).

Yatiyana (2017) presented ARIMA model to form the estimation model in Western Australia. In order to upgrade a statistical model-based estimation model, both wind speed and also wind direction were used for estimation analysis in this study. The results were shown that the proposed model enables to reliability and stability of the wind power plants (Yatiyana et al., 2017).

Nair (2017) found that the results obtained from the Artificial Neural Network - Autoregressive Integrated Moving Average Method hybrid model used in the wind speed estimation have much less error rate (Nair et al., 2017).

Ahmed (2017) provided a fast and less data-hungry estimation method based on nonlinear autoregressive neural networks for short-term wind velocity estimation. Artificial Intelligence (AI) method was selected. The developed method has been tested on two study areas and its effectiveness is demonstrated by comparison with a comparison of time series persistence. The effect of changing the size of the required input data was also analyzed and using the developed method, it was concluded that minimum historical wind speed data was required for one hour forecast (Ahmed et al., 2017).

Kumar (2018) presented a comparison of different wind speed estimation algorithms, namely the Regression Method and Neural Network (different neural network algorithms such as Levenberg-Marquardt, Bayesian Regularization, Scaled Conjugate Gradient). After evaluating the wind speed by each algorithm, respectively using the Artificial Neural Network method, Bayes Reorganization algorithm is one of the best algorithms for estimating the wind speed and concluded that it provides great help in controlling the economic and grid system (Kumar et al., 2018).

Alencar (2017) proposed a hybrid method to predict the wind speed daily. This method comprises of seasonal autoregressive integrated moving average (SARIMA) and Neural Networks. The methods have an ability for learning linear and nonlinear system behavior. The results presented that proposed method shows the superior performance for one-step ahead and multi-step ahead horizons compared with the wind speed forecasting approach (Alencar et al., 2017, p. 8).

WIND SPEED ESTIMATION METHODS

Wind speed depends on many physical and statistical parameters such as temperature, humidity, pressure. The instantaneous change in wind speed leads to the formation of nonlinear data over time. Therefore, researchers have used different methods and algorithms to predict wind velocity in order to reach highly accurate data estimates. The methods used in wind speed estimation are shown in Figure 1.

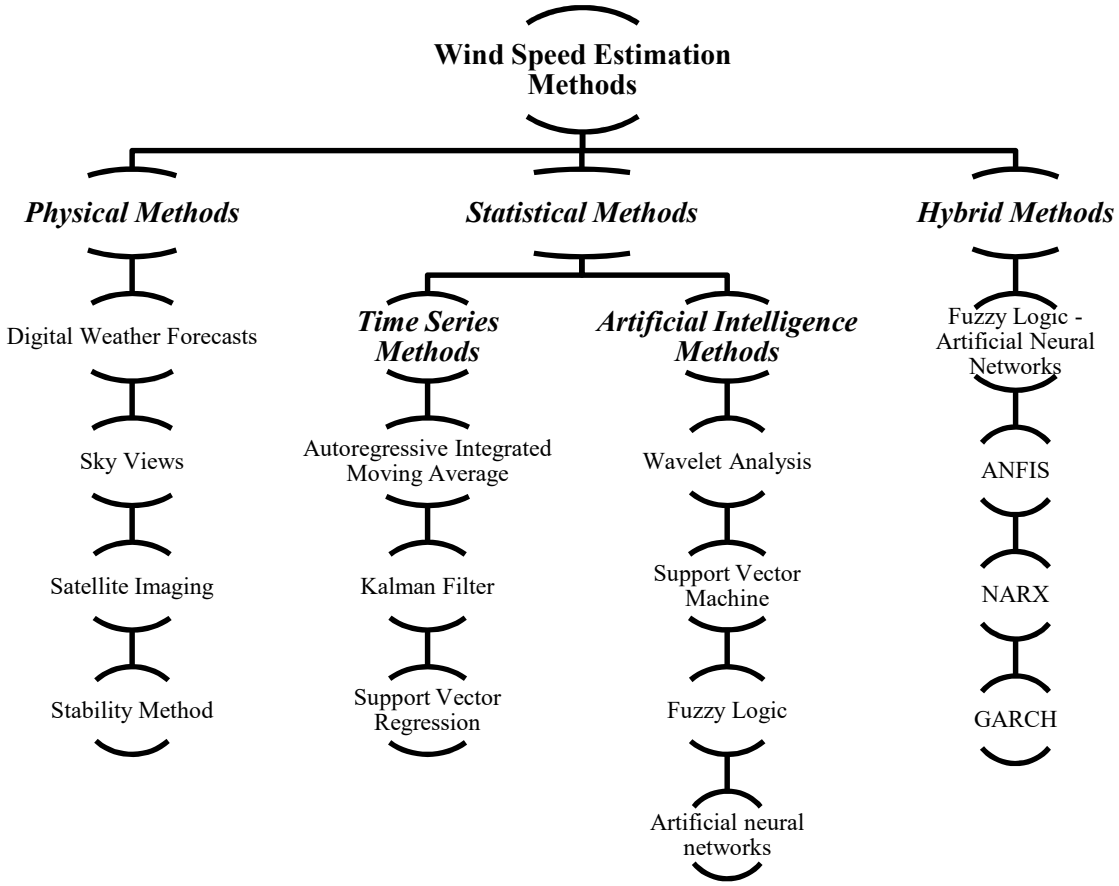

Figure 1. **Wind speed estimation methods generally used in the literature**

Physical Methods

Physical methods are based on parameterization using weather data such as temperature, pressure, solar radiation, fluctuations in airflow and weather conditions. It is a common method of estimating weather equations by using physics equations. These methods are presented as follows.

Numerical Weather Estimation Method is a great way of the identification an oncoming situation by using the statistical solutions of the equations expressing the change of parameters exhibition the status of the atmosphere.

Sky Imaging Estimation Method provides to detect clouds, predict the behavior and movement of the cloud. It creates image resolution from the horizon to the horizon of the sky and provides to obtain short-term estimation by using sky imagers with signal and image processing techniques. This method is often preferred for the generated power forecasting analysis of a renewable energy power plant.

Satellite Image Methods is most widely required in the field of satellite image processing that enable the monitoring of cloud movement to predict future cloud movements. This estimation method provides a great solution to estimate the very short-term radiation but it provides less efficient performance while clouds are formed or dispersed at the instant.

Stability Prediction Method has a simple assumption that the wind speed at a given future time is the same as the time at which the forecast was made. This method offers a stable for short-term forecasting.

Statistical Methods

These methods are time series and time series analyzes dealing with historical data. The time-series data is in specific time periods or in-entry series. These methods are a powerful data-driven mechanism that can predict the future action of a meteorological station or a power plant.

Time Series Methods

Time series is a series of observations on a parameter measured at consecutive points in time. Time Series Prediction Methods can focus on linear relationships, yet they are complex and perform well on a wide range of problems, assuming that your data is properly prepared and well structured.

Autoregressive Integrated Moving Average is an improved method of a conventional linear regression model. It is a generally used estimation model that uses historical data. The method is a basic prediction model that is relatively used as a basis for more complex models.

Kalman Filter is a technique for predict the status of different field systems. The method is generally used for the prediction of linear systems mathematically (linear equations - first-order equations in numerical equations). The method performs with a group of real-time statistical data and provides real-time wind speed prediction.

Support Vector Regression can also be used as a regression method that preserves all the main features (maximal margin) that characterize the algorithm. Support Vector Regression uses the same principles as the support vector machine for classification.

Artificial Intelligence Methods

Artificial Intelligence Methods are known as artificial intelligence algorithm system which reflects the human brain. This estimation method allows solving the complexity of nonlinear data, data editing, pattern recognition, simulation and optimization with high accuracy.

Wavelet Analysis provides effective solutions to compensate for noise or fluctuation in real-time input data sets before the estimation process is initiated. Therefore, it ensures improvements in order to increase the estimation reliability. This method is capable of analyzing the frequency and time-dependent data in order to eliminate noise and transient signals. Especially in recent years, wavelet analysis has been used in several applications on meteorological variables. This analysis is a method that is used to determine the periodic and characteristic structure of the data and is useful in revealing some properties of the physical structure of the data.

Support Vector Machine Method is a powerful way of controlled algorithms for both classification and regression. It is operated as data classification, regression and abnormality detection. It creates a statistical and mathematical theory to reach the correct estimates. In addition to these, this method is related with the nonlinear problems and solving complex computational problems. The method is preferable for estimation, regression and classification analysis.

Fuzzy Logic Method is used for an optimal clustering process using fuzzy logic functions to distinguish different sky conditions and temperatures. The method is capable for analyzing problem when there are many input variables.

Artificial Neural Networks Method is an algorithm technology used to obtain solutions from data obtained by using mathematical and statistical methods. It is an artificial intelligence-based system based on a learning/education method. For weather analysis, the intermittent and discrete nature of nature can be effectively solved by the ANN method in the solution of nonlinear and complex data, without any prior assumption about the nature of these correlations.

Hybrid Methods

Hybrid methods provides to compensate for the weaknesses of individual methods. They are the synthesis of two or more estimation methods such as Fuzzy Logic - Artificial Intelligence, ANFIS, Self-relational Integrated Moving Average, GARCH and NARX. The main purpose of using hybrid methods is to upgrade the estimation accuracy and degrade estimation error by training the network's training or machine learning. These methods can be superior due to provide better prediction performance for both linear and nonlinear data analyzes compared to each prediction method.

Recommended Wind Speed Estimation Method

ANN based IWO and Harmony Search algorithm methods are proposed for the wind speed estimation in this study. Invasive Weed Optimization algorithm is a meta-heuristic optimization method proposed by Mehrabian and Lucas in 2006 (Mehrabian et al., 2006, p. 1.4). The algorithm has been proposed as a model for the strong colonization of weeds in nature and the continuation of the progeny in spite of all agricultural interventions. Weeds grow naturally in nature and then they continue to compete with other plants. Weeds continue to exist by adapting to the environment in all conditions and environments. This algorithm has been proposed based on the ability of the best in the weed community to survive in all circumstances. Firstly, the algorithm starts by creating a random set of weeds. Every individual expresses a

solution for its specific problem. Compatibility values for all solutions are computed and these compatibility values determine the amount of produced seed for each weed. Then all the weeds (solutions) produce seeds (new solutions). In the final state, solutions below a certain threshold are eliminated depending on colony capacity. The main characteristic feature of this method distinguished from other evolutionary methods is that the algorithm allows individuals with low suitability to produce seeds during the study. While other evolutionary methods do not give reproductive rights to individuals with low fitness values, this algorithm considers the possibility of saving useful data or knowledge and enables them the chance to reproduce. The pseudo-code for the algorithm is shown in the Figure 2.

Harmony Search (HS) algorithm, which has recently been used as a new optimization technique, was first proposed by Geem et al. (Geem et al., 2001). The algorithm is based on the principle of obtaining the best harmonic melody with the notes played by musicians in an orchestra. The HS algorithm is similar to the Genetic Algorithm (GA) in terms of computational logic. In addition, the most significant difference between these two methods emerges when proposing a new solution. Two individuals in the society are used to create a new decision variable with GA. In the HS method, the new individual created can carry the characteristics of all individuals in the society. The most significant advantage of the method over GA is that it is faster to complete an iteration in HS than GA. The pseudo-code for these algorithms are shown in the Figure 2.

a

```
Create a startup flock
Define parameters
Do
    Calculate the best fitness value
    Calculate standard deviation
    for every individual
    Calculate the number of seeds that the particle will produce
    according to its suitability value
    Let new breeding individuals breed in search space
    Add new individuals to the population
    if the population size has passed the value of P_max
    Eliminate individuals with low fitness value
end
while maximum iterations or minimum error criteria is not attained
```

b

```
Define harmony memory
Define harmony memory considering rate (HMCR)
Define Pitch adjusting rate (PAR) and other parameters
Do
    while (i<=number of variables)
    if (rnd_number<HMCR)
    Select a value from harmony memory
    if (rnd_number<PAR)
    Define the value by adding certain amount
    else_if
    Choose a random value
    end_if
end_while
Update the harmony memory
while maximum iterations or minimum error criteria is not attained
```

Figure 2. (a) **The pseudo-code for IWO algorithm**; (b) **The pseudo-code for Harmony Search algorithm**

RESULTS AND DISCUSSIONS

Short-term wind speed estimation is performed by ANN, ANN-HS and ANN-IWO methods in this study. Network structures of the methods have 3 inputs and 1 outputs. Input parameters are selected by using the meteorological data such as maximum ambient temperature, hourly ambient temperature and humidity. While the output parameter is the hourly average wind speed. The best results obtained from 20 trials are given for all three methods. In these methods, 400 iterations are run and 15 neurons are used in latent layers. For the training, data for October, November and December 2016 are used. As the test data, first 4-day wind speed estimation for January 2017 is performed shown in Figure 3.

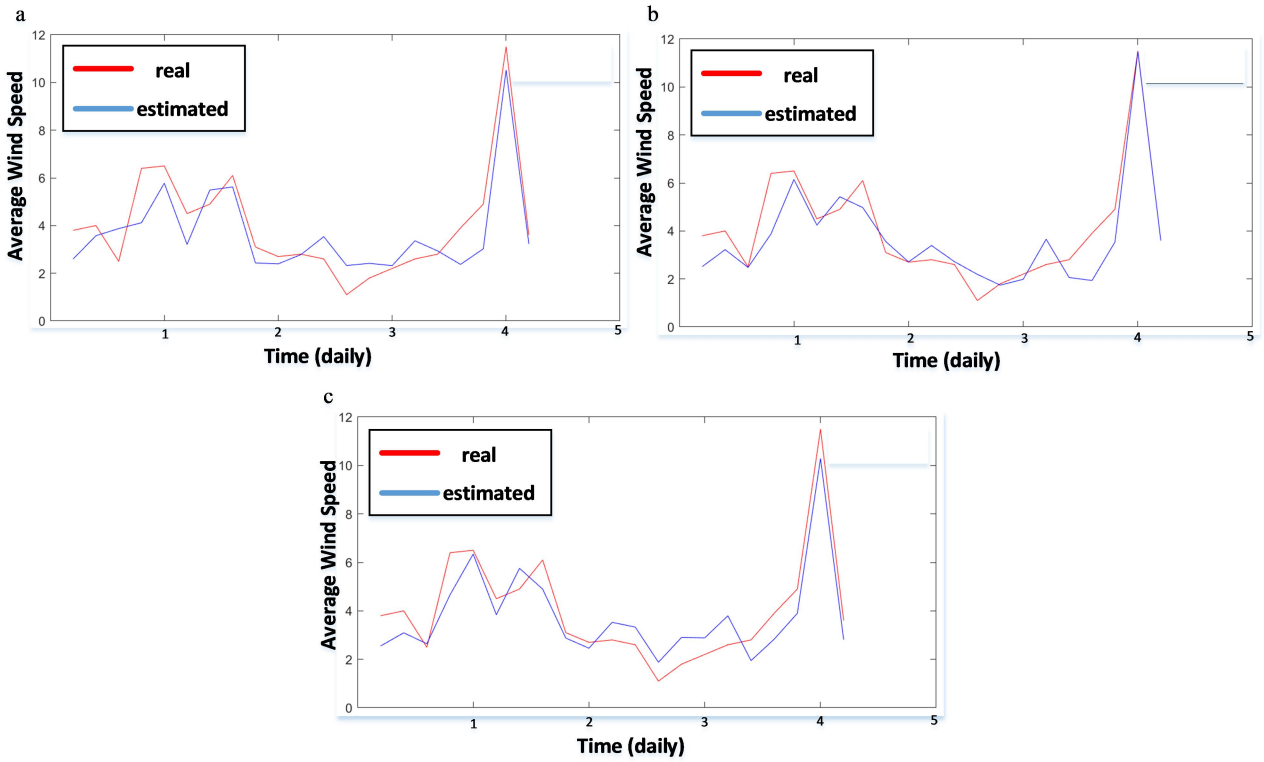

Figure 3. **Performance analysis of the proposed methods** (a) **ANN**; (b) **ANN-HS**; (c) **ANN-IWO**

The RMSE values of the methods used to evaluate the performance of artificial neural network models are given in Table 2.

Table 2

Performance analysis results of the proposed methods

	RMSE criteria	**Regression value**
ANN	1,0316	0,75115
ANN_HS	0,9658	0,76742
ANN_IWO	0,9239	0,76402

Estimation results shows that the best results are obtained by ANN-IWO method as a result of regression values and error analysis.

CONCLUSIONS

Short-term wind speed estimation is a significant issue for integrity and stability of the electric grids. In this study, ANN-based wind speed estimation is performed by using hourly time series consisted of temperature and humidity data in Çukurova Region. Estimation results obtained by ANN, ANN-HS and ANN-IWO are compared with each other. These hybrid methods play an important role in modeling and optimization of nonlinear sequences. The results show that ANN-HS and ANN-IWO methods are better than ANNs with shallow architectures, and enhance the wind speed estimation by handling the instabilities in the wind speed data. Estimation results present that the best results are obtained by ANN-IWO method as a result of regression and error analysis. It is hoped that these hybrid methods show high performance and shed light on future studies.

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