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New Hybrid Method Proposal for Wind Speed Prediction: a Case Study of Lüleburgaz

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This study proposes a hybrid prediction method where Back Propagation Artificial Neural Network (BP-ANN) and Adaptive-Network Based Fuzzy Inference System (ANFIS) Cascade model are used together to predict the wind speed. At the initial stage, to increase the accuracy of prediction, an additional ANFIS layer is used which is driven with outputs acquired from BP-ANN. Thus, a Sugeno type ANFIS model is used for future prediction and prediction capability of a conventional BP-ANN algorithm is increased. At the second stage, BP-ANN outputs and cascade model outputs are compared to the measured value and a selection criteria algorithm is developed that accepts the output very close to the real value. The proposed model generates a prediction output based on a hybrid operation of the two systems unlike the other study in literature. The proposed model is tested with the data taken from the sample station and the results are compared to real calculation values with regard to various statistical error parameters. Results of the study have shown that the hybrid model generates the closest prediction results to the real values compared to the other models. This flexible algorithm developed to predict the wind speed can be also used in other fields in future research.

Key words: *Back Propagation ANN, ANFIS, wind speed prediction.*

1. Introduction

Renewable energy policy and the study of a renewable energy potential in general and in various regions of the country have been the subject matter of comprehensive research in national and international literature. Environmentally friendly renewable energies are divided into six main categories according to their sources: geothermal energy, hydraulic energy, wind energy, wave energy, biomass solar energy and they all can be converted into electrical energy. Electrical energy can be obtained from these renewable energies by using different application (Ozdamar et al. 2005, Belfkira et al. 2008). Carbon-dioxide free technologies for energy production are effective methods for reduction of air pollution. Among the renewable energy sources utilization of hydropower, solar and wind energies provide the best opportunities. Especially from the beginning of the year 2000, the number of studies in this field has strongly increased. In some parts of this research, environmental pollution and energy policies economy and its social maintenance (Demirbaş 2001), the situation of stock fossil resources (Kaygusuz 2002), the suggestions for using these resources effectively (like cogeneration systems) (Akdeniz et al. 2002) and the dangers of foreign dependency of Turkey in terms of fossil fuel supply are emphasized as well as the importance of renewable energy resources and their usage (Kaygusuz & Kaygusuz 2002).

Total wind energy potential of Turkey was studied in a joint research carried out by the Electrical Power Resources Survey and Development Administration (EIE) and the Turkish State Meteorological Service (TSMS). This study predicts that the total technical potential is at a level between 40-85 GW for land only. In rural areas annual average of the wind speed over 10 meters height is 4.5-5.6 m/s in the Aegean region and other shore areas, and 3.4-4.6 m/s - in inland areas (EUAŞ 2008). The research intended for determining the wind-power potential in various regions of Turkey is the other part of this study. The regions having the wind power potential like Elazığ-Maden (Akpınar & Akpınar 2004) Uğurlu and Aydıncık (Eskin et al. 2008) districts of Gökçeada and Alaçatı (Mutlu et al. 2009) have been analyzed by applying various methods. It has been proved by the study that Weibull dispersion is more suitable for the dispersion of data taken from the factual measurements (Akpınar & Akpınar 2004, Eskin et al. 2008, Süzek 2007). Results of the above mentioned studies are based on prediction of wind speed data. As known, electrical wind power varies in a direct ratio to the cube of the wind speed. Therefore, small errors in speed prediction might lead to significant variations from the real value in determination of the potential. Economical and marketing problems caused by unstable behavior of the wind energy conversion system increase even more because of wrong speed prediction (Varkani et al. 2009). In recent years the Back Propagation Artificial Neural Network (BP-ANN) and the Adaptive-Network Based Fuzzy Inference System (ANFIS) based study is used more often than the other models in wind speed prediction (Kusiak & Zhang 2010, De Giorgi et al. 2011, Jafarian &Ranjbar 2010, Oğuz & Güney 2010, Singh & Chandra 2011). This is because these algorithms using artificial intelligence techniques can generate more accurate prediction values with less calculation load. BP-ANN is also addressed as a tool for the power system security assessment (AL-Masri et al. 2010).

In this study, a prediction model is presented based on hybrid operation of BP-ANN/ANFIS which can generate closer prediction results to the measured values compared to the classical BP-ANN model. It includes an implementation different from the above mentioned studies developed for Turkey. Lüleburgaz district of Marmara region is selected as a prediction field. Daily average data for wind speed, pressure, temperature and humidity by TSMS between 1989 and 2004 for Lüleburgaz district are used to train BP-ANN and then the values for 2005 are predicted. A proposed hybrid method is described in the following section. The forecasting results and conclusions are presented in Sections 3 and 4, respectively.

2. Proposed Method

This study, aiming to predict the wind speed, has developed a method which improves prediction results by using the output data of BP-ANN as input data for ANFIS model. Initially, daily average data for wind speed, pressure, temperature and humidity in Turkey are used to train BP-ANN and the values for 2005 are predicted. Levenberg –Marquardt is chosen as a training algorithm. BP-ANN has provided required accuracy after 29 iterations (Epoch). Structure of the used BP-ANN is shown in Figure 1.

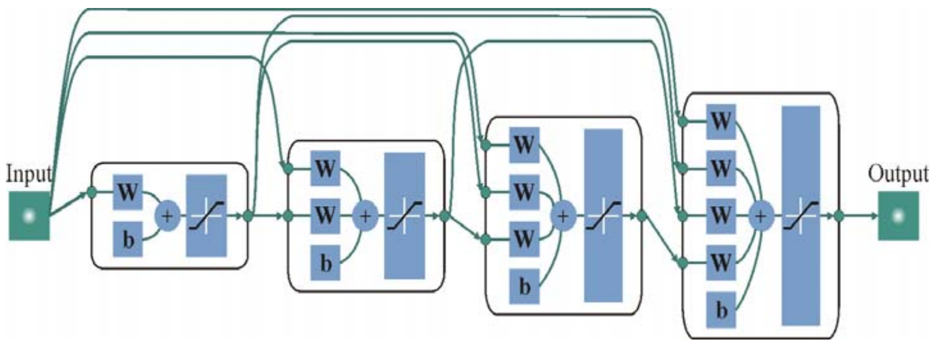

Fig. 1. BP-ANN structure used in applications

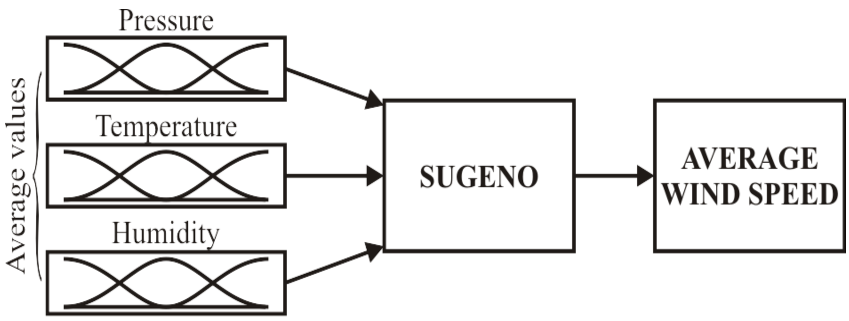

Fig. 2. ANFIS model

ANFIS is an adaptive network that is functionally equivalent to a fuzzy inference system and referred to in literature as "adaptive network based fuzzy inference system" or "adaptive neuro fuzzy inference system" (Tektas 2010).

A fuzzy inference system is a computational framework that combines the concept of fuzzy logic, fuzzy decision rules and fuzzy reasoning. A successful application of fuzzy interference system to a specific problem involves the following steps:

1. Transforming crisp data into fuzzy or linguistic variables by using a type of membership function (fuzzification).
2. Relating input fuzzy variables to the output variables by defining a set of IF-THEN rules.
3. Assigning output weighting factors from the antecedent part (implication).
4. Transforming the final fuzzy result into a crisp value (defuzzification) (Talebizadeh & Moridnejad 2011).

When implementing ANFIS, the learning process takes place with help of a hybrid network which is a combination of the least squares method (LSM) and the back propagated gradient descent method (BP-GDM) and this process is repeated until a prediction error is minimized. The number of iteration (E-poch) where the error is minimal is defined as 500. The established ANFIS model uses a Sugeno type fuzzy inference system and a hybrid learning algorithm (Jang & Sun 1993). Architecture of the used model can be seen in Figure 2. Input variables are pressure, humidity and temperature averages generated as prediction output by BP-ANN and the output is wind speed average.In the final stage, wind speed data predicted by BP-ANN and a proposed hybrid method are compared to measured data. Mean absolute error (MAE), root mean square error (RMSE) and mean square error (MSE) values which are commonly used in literature are calculated for comparison. Equations used in calculations are given below.

$$MSE = \frac{1}{n}\sum_{j=1}^{n}(P_{(ij)} - T_j)^2 \quad (1)$$

$$RMSE = \sqrt{\mathrm{MSE}} = \sqrt{\frac{1}{n}\sum_{j=1}^{n}(P_{(ij)} - T_j)^2} \quad (2)$$

$$MAE = \frac{1}{n}\sum_{j=1}^{n}|f_i - y_i| = \frac{1}{n}\sum_{j=1}^{n}|e_i| \quad (3)$$

Where:

$P_{(ij)}$ - the value predicted by individual program i for sample case j (out of n sample cases);

T_j - the target value for sample case j. For a perfect fit, $P_{(ij)} = T_j$ and $E_i = 0$. Thus, E_i index ranges from zero to infinity, with zero corresponding to the ideal. In Eq.3, $e_i = f_i - y_i$ and f_i is the prediction and y_i is the measured (real) value.

Detailed scheme of the proposed method and the flowchart of the output selection layer can be seen in Figures 3 and 4, respectively.

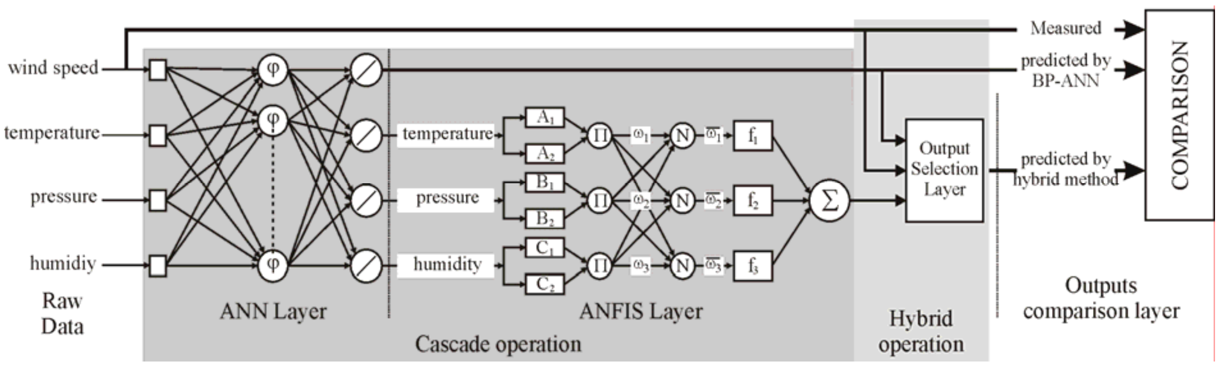

Fig. 3. Architecture of proposed method

3. Results

In this section acquired prediction results acquired are compared. Wind speed prediction results acquired in this study are tested with regard to their proximity to the measured values. Comparison is done graphically and with regard to MSE, RMSE and MAE given in Equations 1, 2 and 3. Figure 5 presents graphics of prediction results and measured values.

As shown in Figure 5, the hybrid method proposed in this study can better predict the wind speed values. By examining the graph of measured values of the selected region, it is clearly seen that the climate of the selected region is rather unstable in terms of the wind speed profile. The proposed hybrid method gives faster response when predicting instant changes of this kind of dynamic structure. Nevertheless, if it is considered that Figure 5 represents a period of one year, making a comparison by examining this figure may not give an accurate result.

For better comparison, error ratios of all three results calculated according to real calculation values are given in Table 1. Calculated RMSE, MSE and MAE values show that the proposed method is able to make prediction certainly with a lower error ratio.

Table 1. Evaluation analysis of output data

Prediction Method	RMSE	MSE	MAE
Conventional BP-ANN	0.55544	0.30851	0.42784
Proposed (Hybrid)	0.54725	0.29948	0.42175

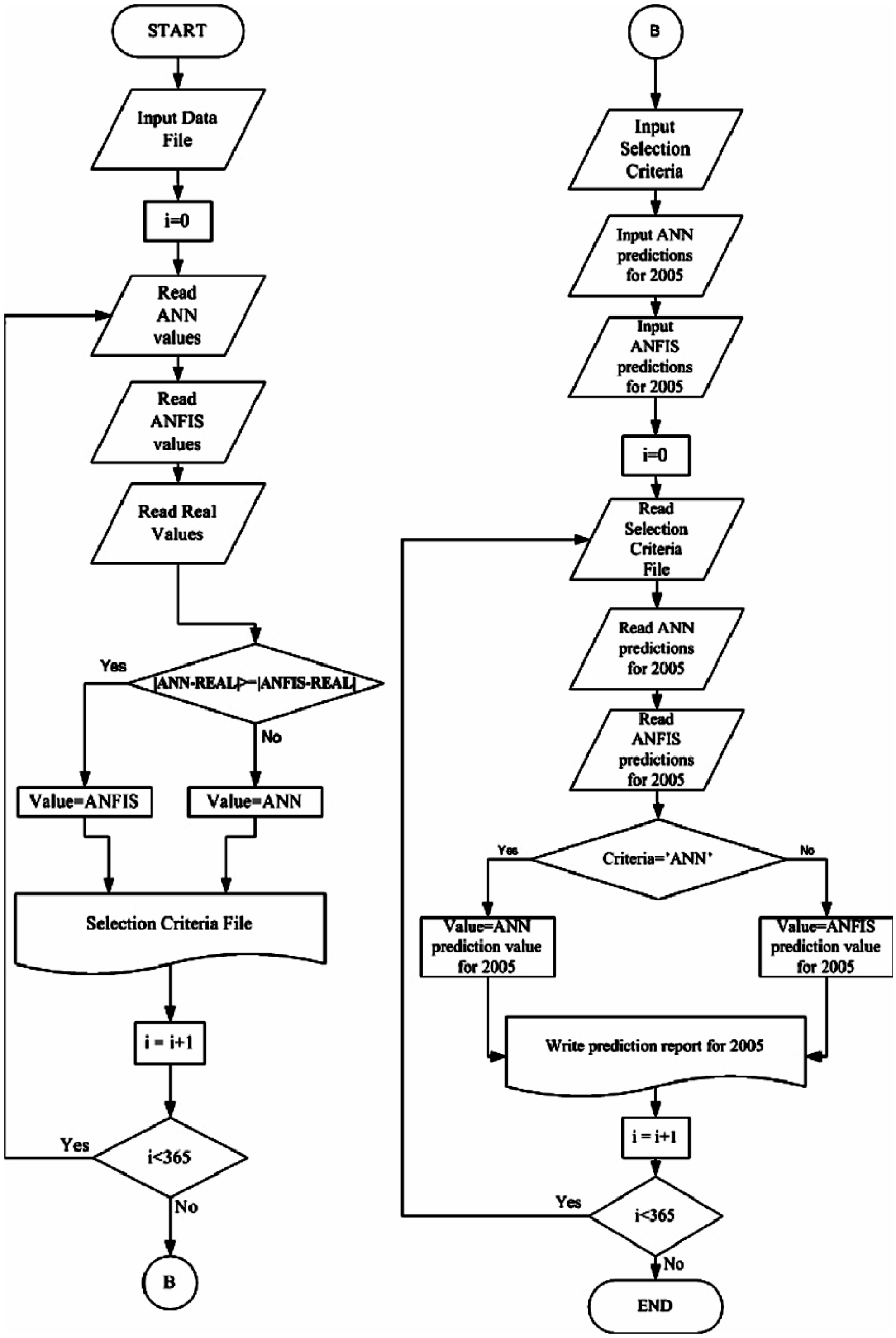

Fig. 4. Flowchart of the output selection layer

4. Conclusions

BP-ANN and ANFIS models are more regularly used in wind speed prediction and they both have their advantages and disadvantages.

This study presents in two stages an implementation that generates the prediction result which is the best suitable values acquired from BP-ANN wind speed prediction and wind and from ANFIS model which is driven by humidity, temperature and pressure values predicted by BP-ANN trained with 15 year meteorological data. Application values are derived from the measurement station of Lüleburgaz situated in the northwest part of the country. This analysis is performed about the wind climate of the region never before examined in detail and never mentioned in concerned literature. The selected region is known for its dynamic climate and frequent wind changes. Because of these characteristics it is possible to say that it is difficult to predict the wind speed when it changes instantly.

Results generated by the hybrid operation via an output selection layer are defined as reliable prediction results. The proposed hybrid model has 3% lower MSE, 2.5% lower RMSE and MAE compared to BP-ANN. This result suggests that the proposed model is more successful in wind speed prediction compared to BP-ANN.

The proposed model includes a highly successful algorithm despite its complicated structure. In this study, a one year long term wind speed prediction has been carried out. Its hourly, daily and weekly prediction performance will be tested in future studies. Since the proposed study combines advantages of ANN and cascade models, it has a flexible structure that can be used for prediction in many different areas where ANNs are used.

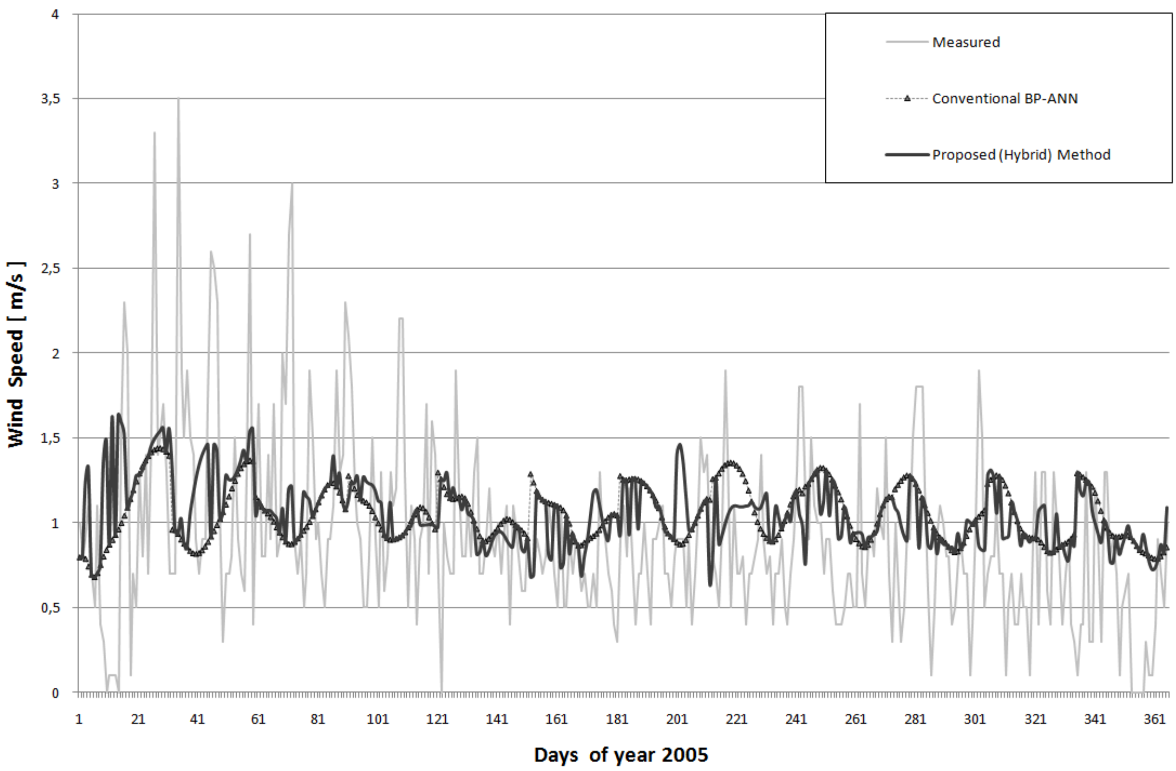

Fig. 5. Daily changes of measured and predicted values of wind speed

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Naujas mišrus vėjo greičio prognozavimo metodas ir jo taikymo pavyzdys Liuleburgazo regione

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Straipsnyje aprašomas tyrimas, kuriuo siekiama pagrįsti mišraus pakopinio modelio, jungiančio atvirkštinio skleidimo neuroninių tinklų ir adaptyviųjų neuroninių neraiškiųjų išvedimo sistemų metodus, siekiant prognozuoti vėjo greitį. Siūlomas modelis testuotas remiantis konkrečiais stebėjimų stoties duomenimis, rezultatai patikrinti, lyginant juos su statistiniais duomenimis. Tyrimų rezultatai rodo, kad taikant mišrų modelį galima pasiekti tikslesnius rezultatus nei taikant kitus metodus.

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