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Daily Total Wind Energy Estimation by Using Weather Condition

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Abstract. Estimation of the generated wind power is one of the tasks for wind power plant (WPP) companies and these estimations are sent to electricity management system to schedule the electric power plants. There is a transaction trend from traditional carbon-based generation to renewable electricity generation due to their environmental impact. While the generation of energy by traditional methods can be easily controlled, it is not possible to control the generation from renewable sources, because it depends on nature. This uncertainty of the power which will be generated is a disturbing factor for the generation/consumption balance of electricity. In this study, the daily total wind energy estimation is presented for two wind power plants which are in Turkey. While humidity, air pressure, temperature, wind speed, wind direction, season and historical energy generations are selected the system inputs, daily generated wind energy is the output. Adaptive Neuro-Fuzzy Inference System (ANFIS) is considered as forecast method. The normalised mean absolute error (NMAE) values of WPP1 and WPP2 are found as 13.75% and 10.23%, respectively.

1 Introduction

The establishment of new power plants is one the most important items in terms of energy politics of countries to meet the demand increment in the electricity consumption. Each country uses its resources as a primary source of electricity generation in order to provide economic benefits. In the last decade, there has been a change in the source of new generation power plants in the world. While the amount of electricity generated from coal and nuclear energy decreased, the amount of electricity produced from natural gas and renewable energy increased [1]. Air pollution caused by coal and environmental damage caused by nuclear energy in possible natural disasters such as earthquakes are effective in this decrease. The fact that natural gas does not cause air pollution compared to coal and that there is no environmental damage to renewable energy has been effective in this increase.

Wind is a type of energy that has the highest share in the renewable energy with the solar energy. When comparing the two energy types, wind energy has more continuity than solar energy and this makes the wind energy more advantageous over solar energy. While the generation of energy by traditional methods can be easily controlled, it is not possible to control the generation from renewable sources, because it depends on nature. The uncertainty of the power which will be generated is a disturbing factor for the generation/consumption balance of electricity. Ensuring the generation/consumption balance is the responsibility of the institution that manages the country's electricity energy system. In Turkey, Turkish Electricity Transmission Company (TEIAS) and Energy Markets Business Administration Company (EPIAS) manage the electricity system by running the energy markets. In these markets, generation forecasts are demanded from the generation companies for the future and electricity generation/consumption balance is established by using these forecasts. The estimation error adversely affects the whole electrical system in term of both economic and lack of supply. Therefore, forecast errors are penalized by electricity management system and these errors also adversely affect the profitability of WPPs [2].

Wind power estimations in the literature are made in four different categories according to the timescale and these are long-term, medium-term, short-term and very short-term. Long-term is in the range week to months or years and it is used for planning of wind power and power systems. Medium-term is used for forecasts from days to week and it helps to unit commitment decision and maintenance scheduling. Short-term, from hours to days, is used for economic load dispatch, reserve requirement, intraday market and day-ahead market. Very short-term, seconds to minutes, provides advantages in wind turbine control, power system frequency control and balancing power markets [3,4].

There are some studies in the literature on this subject. In the first study, daily total wind power is estimated in two stages. Firstly, wind speed forecast is carried on various time intervals including daily total power forecast. Secondly, forecasted wind speed converted to wind power through with a wind speed-wind power curve. One-year data are selected as train and one-year data are selected as test. Feed-forward Neural Network (FNN) and Recurrent Neural Network (RNN) are selected as forecast method. Mean absolute percentage error (MAPE) is found as 19.53% and 21.17% for FNN and RNN, respectively [5]. In another study, daily wind generation of Romania is forecasted by using FNN method and average of daily wind speed is used for the forecast input. Five different structures are analysed with various historical data as 4, 30, 60, 100 and 365. The structure using 100 historical data give the most successful results [6]. Daily and weekly wind power forecast is presented by using combination of wavelet transform and fuzzy art map in another study. Also, firefly algorithm is used to optimize the combination. One-year hourly data is taken, and four days and four weeks' data are used for test. MAPE and Normalised Mean Absolute Error (NMAE) are found 11.91 and 4.47 for forecast of four days, respectively [7].

This paper focuses the daily total wind energy forecast using meteorological weather condition. Two wind power plants which are in Turkey are considered to design a wind forecast system. Wind power plants are named as WPP1 and WPP2. One-year data and six months' data are used for WPP1 and WPP2, respectively. The daily meteorological forecasts are selected for system inputs. Also, some inputs are added to the system such as season and historical power. Adaptive Neuro-Fuzzy Inference System (ANFIS) is selected as the forecast method and actual values are compared with the forecast results to see the forecast success.

The remainder of this paper is organized as follows. In section 2, current status of electric sources and installed wind power in the world and Turkey are presented. While section 3 gives information about data, forecast method and model are presented in section 4. Section 5 is the forecast results and finally section 6 is the conclusion section.

2 Current status of wind energy in Turkey

The distribution of global electricity generation by sources in 2017 is given in Fig. 1 (a). Coal, natural gas and hydroelectricity are the most used sources and their shares in total production are 38.1%, 23.2% and 15.9%, respectively. Then, nuclear energy, renewable energy and oil are listed, respectively. Although renewable energy is the most growing source in the last 10 years with 6.1%, its share in the total is only 8.4%. The reason for this is that renewable energy technology is young compared to other sources [1].

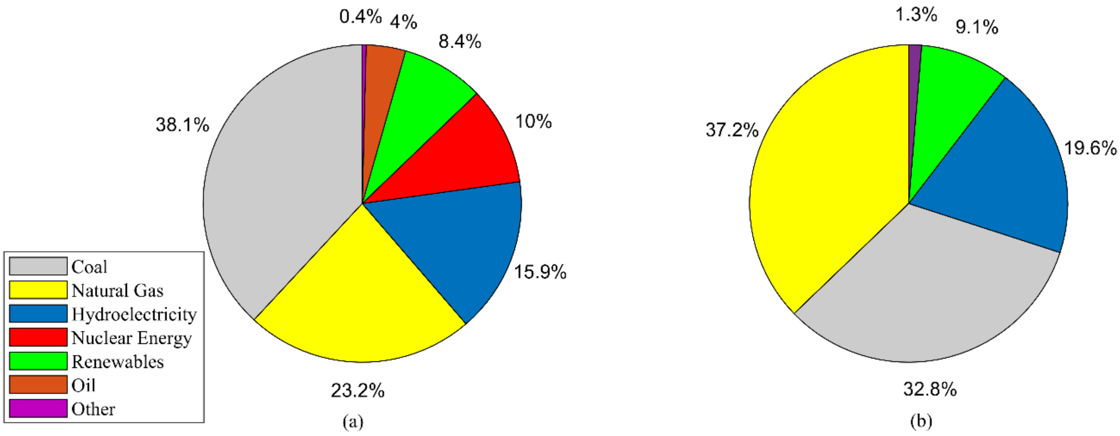

Fig. 1. (a) Distribution of global electricity generation by sources in 2017 (b) Distribution of Turkey's electricity generation by sources in 2017

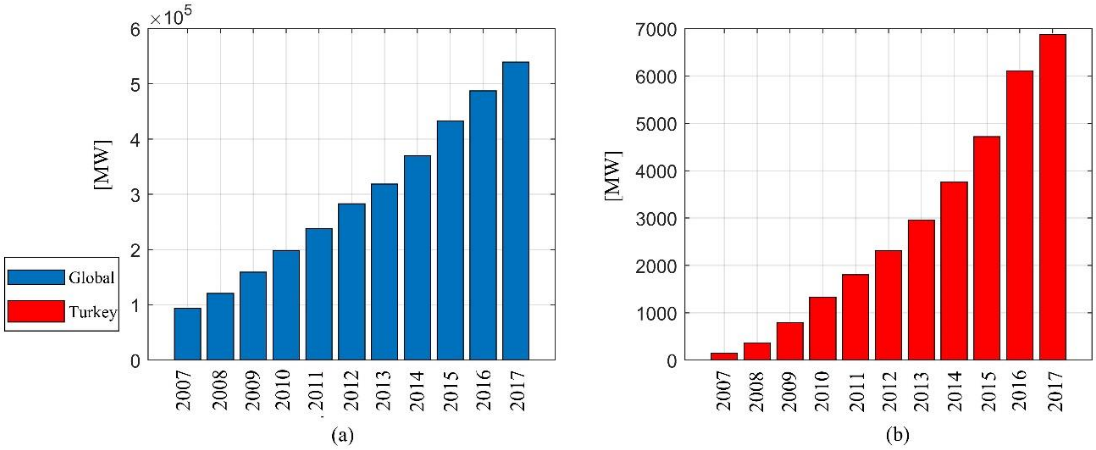

Fig. 2. (a) Cumulative installed global wind power (b) Cumulative installed wind power of Turkey

The source distribution of electricity generation of Turkey in 2017 can be seen in Fig. 1(b). The natural gas; coal and hydroelectric power have respectively 37.2%, 32.8% and 19.6% shares in the top three. Then renewables and other sources are sorted with rates of 9.1% and %1, respectively. The wind, geothermal and sun are in the renewables with 6%, 2.1% and 1% rates. The power generated from the wind in Turkey increased by 15.4% compared to the previous year [8].

Installed global wind power is shown in Fig. 2(a). In the last 10 years, the installed capacity has increased nearly by 5 times and reached to 539GW by the end of 2017. The increase of installed power in the last two years was 12.6% and 10.63%, respectively. Three countries have 62% of all installed wind power in the world. These countries are China, USA and Germany with rates 35%, 17% and 10%, respectively [9]. Installed wind power in Turkey can be shown in Fig. 2(b). In the last decade, the installed wind power has increased to 6872 MW from 146 MW in Turkey. The increase of installed power in the las two years was 29.41% and 12.55%, respectively [10]. While Turkey had 0.12% of the installed wind power in the world at 2007, it had 1.27% of the installed wind power in the world at the end of 2017. In 2017, Turkey announced the renewable energy program (YEKA) to add a new 1 GW capacity. It was tendered, and winning price is determined as US$ 3.48 cent/kwh. The consortium which won the tender will also build a local nacelle factory to meet local content requirements according to the tender conditions. In addition, candidate places for the first offshore wind power plant is determined and it is planned to be tendered in 2009. Turkey's wind capacity is expected to ground 4GW in the next three or four years [9].

3 Weather forecast data and wind power data

Number of daily wind data is 365 and 180 days for WPP1 and WPP2, respectively. These wind power plants are located in different city of Turkey. Some weather forecast parameters of the WPP sites are used for this study and these parameters are taken from NASA website [11]. These parameters are humidity, air pressure, maximum temperature, minimum temperature, daily average of temperature, minimum wind speed, maximum wind speed, daily average of wind speed, and daily average of wind direction. Totally 13 variables are taken from next day weather forecast. Also seasons of the year are considered as another input by grouping the months of years to the seasons. December, January and February is considered as winter months, and season input data of winter months set to 1. Seasonal data of the other months were entered as 2, 3 and 4 respectively in spring, summer and autumn. Besides generation of previous three days are added as historical data inputs and these are named as E(d-1), E(d-2) and E(d-3). Where E is the daily generated energy, d is the day. Totally forecast system is composed of 17 inputs. All inputs are given in Table 1.

Table 1. System inputs

No	Input name	No	Input name
1	Humidity at 2 m.	10	Max. wind speed at 10 m.
2	Air pressure at 2 m.	11	Daily avg. wind speed at 10 m.
3	Max. temp. at 2 m.	12	Daily avg. wind direction at 10 m.
4	Min. temp. at 2 m.	13	Daily avg. wind direction at 50 m.
5	Daily avg. temp. at 2 m.	14	Season
6	Min. wind speed at 50 m	15	E(d-1)
7	Max. wind speed at 50 m	16	E(d-2)
8	Daily avg. wind speed at 50 m	17	E(d-3)
9	Min. wind speed at 10 m.		

4 Method

The ANFIS method developed by Jang in the early 1990s is a hybrid method of fuzzy inference system and an artificial neural network. Although the fuzzy inference method has some advantages such as implementing easily, expressing with linguistic variables, modelling uncertain and non-linear situations, it has no any learning ability. An expert opinion is needed for the rule base used in fuzzy inference. The artificial neural networks have a strong learning ability. ANFIS is a method that combines the advantages of both methods. Expert opinion which is necessary in fuzzy inference methods is generated automatically in ANFIS by the artificial neural networks according to the data. An ANFIS structure of Sugeno type is illustrated in Fig. 3 for two inputs and one output. In order to simplify the disclosure and to take into account the rules, only two if - then rules are shown in Fig. 3 [12]:

Rule 1: if x is A1 and y is B1 then $f1 = p1 * x + q1 * y + r1$ (1)

Rule 2: if x is A2 and y is B2 then $f2 = p2 * x + q2 * y + r2$ (2)

Where x and y are the inputs and p, q and r are the parameters. The ANFIS structure consists of five layers, which are respectively the fuzzification layer, the rule base layer, the normalization layer, the defuzzification layer and the collection layer. The transition from one layer to another is indicated by arrows. Each square and circle in the figure are nodes, and the square nodes have parameters, while the circle nodes do not have any parameters. The task of each layer is explained in detail below.

Layer 1: Each node in this layer is a square node and the square node function is as follows:

$$O_i^1 = \mu A_i(x), i = 1,2 \quad (3)$$

i is the node number, A_i is the linguistic label (small, middle, big), O_i^1 is the membership function of A. In this study, triangular membership function is considered with maximum equal to 1 and minimum equal to 0.

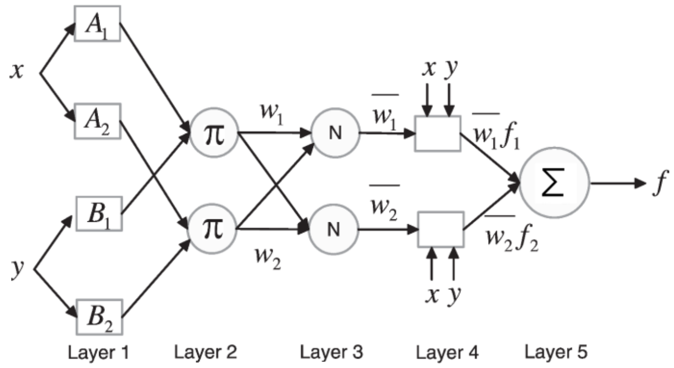

Fig. 3. ANFIS structure

$$\mu A_i(x) = \begin{cases} 0, x \le a \\ \dfrac{x-a}{b-a}, a \le x \le b \\ \dfrac{c-x}{c-b}, b \le x \le c \\ 0, c \le x \end{cases} \quad (4)$$

Triangular is a function of x and depends a, b and c parameters. In this layer a, b and c parameters are determined and these parameters are named as premise parameters. In every loop, parameters are recalculated according to output error.

Layer 2: The rules are found in this layer. The nodes in the layer are circle nodes and labelled as π. These nodes represent number of rules generated according to the Sugeno fuzzy logic system. Each node multiples the incoming signals and send them to the next layer.

$$w_i = \mu A_i(x) x \mu B_i(y), i = 1,2. \quad (5)$$

Layer 3: Normalization is performed in this layer. This layer contains circle nodes and these buttons are labeled N. The output of the ith node is divided by the sum of the outputs of all nodes and sent to the next layer.

$$\overline{w_i} = \frac{w_i}{w_1 + w_2}, i = 1,2. \qquad (6)$$

It takes all nodes coming from the previous layer as an input value and calculates the normalized value of each rule.

Layer 4: The parameters in this layer are the result parameters, and the nodes in this layer are the square nodes. The node function is expressed as follows:

$$O_i^4 = \overline{w}_i f_i = \overline{w_I}(p_i * x + q_i * y + r_i) \qquad (7)$$

Layer 5: This layer is known as total layer. In this layer, there is only one circle node and this node is labelled ∑. Real output value of ANFIS system is obtained by summing the output values of the previous layer [12].

$$O_i^5 = \sum_i \overline{w} = \frac{\sum_i \overline{w_i} f_i}{\sum_i \overline{w_i}} \qquad (8)$$

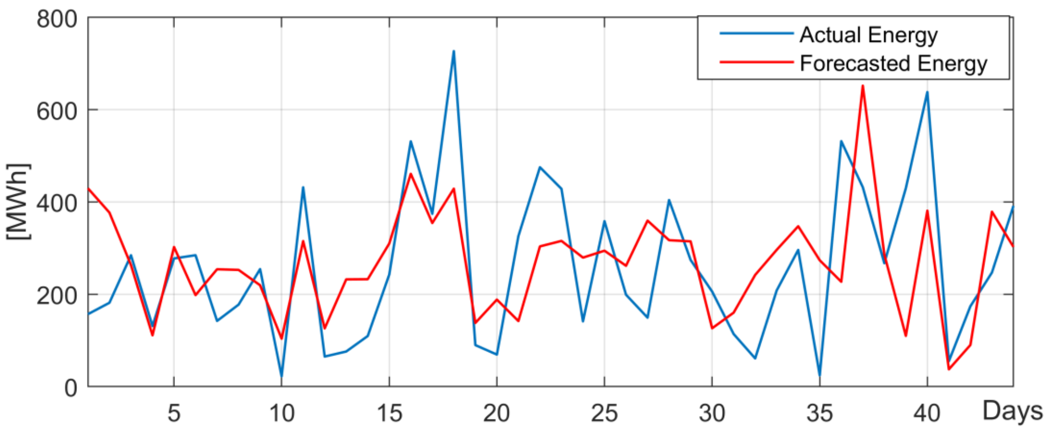

Fig. 4. Actual and forecasted daily wind energy for WPP1.

5 Results

Estimation errors are presented using various error criteria to show the accuracy of used method. In wind power estimation studies, percentage error is not preferred. This is because the power generated by a WPP can be zero. If generation is zero, percentage error criterion gives an infinite value. Therefore, absolute or square errors are mostly preferred in literature studies. Normalized Mean Absolute Error (NMAE) is selected to measure the accuracy in this study. NMAE is defined as follows:

$$NMAE = \frac{\frac{1}{d}\sum_{i=1}^{d}|R_i - F_i|}{C} * 100 \qquad (9)$$

Where i is the day, d is number of day, R is the measured daily wind energy, F is the estimated daily wind energy and C is the installed daily wind power capacity. The absolute error must also be normalized. If it is not normalized, error value changes with the installed wind capacity. This is not good for comparison of errors with other studies. The normalized values have been calculated by dividing MAE to installed wind power capacity.

Totally one-year measured data are used for WPP1. The 300-day part of data is utilized to train the estimation model. The remaining 60-days are selected for testing to show the model accuracy. Totally half year measured data are considered for WPP2. While the 150-day part of data are utilized to train the model, the remaining data is taken as test data. Train NMAE value is found 12.55% and test NMAE value is found 13.75% for WPP1. While 10.02% is the train NMAE for WPP2, 10.23% is the test NMAE for WPP2. Some actual and forecasted values can be shown in Fig. 4.

6 Conclusion

This paper presents a daily wind power forecast of two wind power plants which are located in Turkey. The inputs of system are the weather forecasts at the WPP site such as humidity, temperature, wind speed, and wind direction. Also season and daily generated energy of previous three days are added to the system as inputs. Therefore, the forecast system has 17 inputs and one output. The output is the daily total wind power. ANFIS is selected as forecast method. NMAE values of WPP1 and WPP2 are found as 13.75% and 10.23%, respectively. In wind power forecast studies generally weather forecasts are the system inputs. Since the system inputs are also forecasted values, generally higher error rates occur in wind power forecast studies.

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