Wind energy potential assessment for the construction of wind farm based on neural networks and fuzzy modeling

Gharibdoost, Mohammadreza [1,*], Moradi, Mohammad hasan[2], Panahi, Abdolreza[3]

1. Saveh Islamic Azad University, Master of Electrical Engineering
mr.gharibdoost@yahoo.com
2. Saveh Islamic Azad University, Professor
mohamadhasan.moradi@yahoo.com
3. Saveh Islamic Azad University, Professor
abdolreza.panahi@yahoo.com

Abstract: For using wind energy in a region and converting it into electrical Energy, first the construction of wind farms on that region should be assessed from economical point of view. Also, for assessing the construction of a wind farm from economical point of view and also selection of proper Turbine in a region, we should be able to estimate the potential of annual power produced in that region. In the present paper, some approaches have been suggested based on fuzzy modeling and neural network to estimate the annual power produced by wind turbines and with comparing the accuracy of these methods with the accuracy of conventional methods we will show that the suggested methods can estimate the annual power produced by wind turbine in a better manner, compared to conventional methods. With having the average of wind speed, the method of Takagi – Sugeno and radial network have a more appropriate performance comparing to other methods and if in addition to the average of wind speed, square and cubic average of wind speed will also be available, radial network will have a more appropriate accuracy comparing to the other applied methods.

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1. Introduction

Today power production from wind energy have received so much of attention, in a way that the capacity of the installed wind turbines in Germany between 2003 to 2008 has increased to 12 times and in Denmark it has increased to 5 times and other European countries have similar status. This indicates a high inclination of advanced countries to use wind energy for power production. The capacity of the installed wind turbines in the mentioned years in Europe has become 14 times and in North America it has become 6 times which indicate the fact that wind energy gradually is turning into one of the most important resources of electricity energy production. One of the issues which is so much important in the use of wind energy is the development of methods for assessment of the potential use of wind energy in various regions with an appropriate accuracy (Jangamshetti et al, 2006). The reason is that for using wind energy and converting it into power energy in a region, first an appropriate wind turbine should be selected for installation and then the construction of wind farm should be assessed in that region from economical point of view. For selection of an appropriate turbine and for assessing the construction of wind turbine in a region from economical point of view, we should be able to estimate the annual power produced by different turbines in that region (Barthelmie et al, 1996). Each region and each turbine or which the parameter of the return of annual power is a larger value, will be a more appropriate selection (Patel, 1999).

The important point to be mentioned is that we need approaches that can estimate the annual power produced by a specific turbine with only having a few parameters of the wind conditions in one region and some of these approaches have been gathered by Manwell and some by others (Manwell et al, 2008). The aim of the present paper is to develop some methods for more precise and accurate estimations of annual production of power by wind turbines in different regions.

2. Main body

Background of wind energy usage

For many years ago (around 500 years so far) human have been using wind energy for sailing (Patel, 1999). The very first efforts for using wind energy for electricity production goes back to the late 19th century, when in America a 12 KW wind turbine with direct current was designed by Brush (Burton et al, 2009). The first wind turbine with vertical axis was built in 1992 and this type of turbines was also developed at the same time with turbines with a horizontal axis, however; less interest and less research and development expenses were allocated to them and now they have allocated a small share of the markets for wind turbines to themselves (Errikson et al, 2009). A system which is converting wind energy into electrical energy from horizontal axis type in consisted of tower, wind turbine, mechanical gearbox, electrical generator and power control system and the duty of electrical generator is to convert mechanical energy of the turbine to power energy. For this purpose, different electrical generators are used for this purpose (Ackerman, 2010).

Calculating the annual power produced by the wind turbine

There are different methods for estimating he annual power produced by a turbine. So many efforts have been made to find the proper distribution with which the wind pattern of a region can be described and the results of these studies show that Riley and Weibull distributions are two appropriate distributions for presenting the probable distribution of wind speed in one region (Jangamshetti et al, 2006; Patel, 1999; Manwell et al, 2008; Burton et al, 2009 ;Celik, 2003).

Appropriate distributions for description of wind speed probable distribution

Three distributions which are used for describing the wind: Riley distribution, Weibull distribution and a distribution based on the principle of maximum entropy distribution and the last distribution was first used by Professor Shannon as a measure for measurement of the lack of certainty for each probable distribution (Shannon, 1948) and Professor Jines also used this concept for finding probability distribution function in those cases in which the available information are limited due to some microscopic reasons (Jaynes, 1959). Also, different methods have been suggested in this regard from which we can mention the following:

Maximum likelihood method, that for the first time was used by Stevens et al., in 1979 (Stevens et al, 1979). The modified maximum likelihood method, which was first used by Seguro et al., in 2000 (Seguro et al, 2000). Another method is a linear regression method, which requires wind information in the form of cumulative frequency distribution. Mean-Standard Deviation method and wind speed (MWS_SD), in which with having the mean wind speed and its standard deviation, Weibull distribution parameters can be estimated, also Li et al., for the first time in 2005 used the principle of maximum entropy for determining the probable distribution of wind speed (Li et al, 2005). Li et al., tried to make the obtained distribution more accurate to get a more appropriate distribution for some regions, but this modification was so much less (Li et al, 2005). On the other hand, Shamilov in 2008 tired to test similar distributions with developed distribution by Li for different regions and observed that for some regions this distribution is better that the suggested distribution by Li, however; again this modification was small (Shamilov et al, 2008).

Conventional methods in estimation of the annual power produced by the wind turbine

Regarding the estimation of the annul energy production of wind turbine there are four methods of: 1-2-3 formula, Turbine power production curve modeling, Kirandous and generating random numbers. 1-2-3 formula method was presented by Carlin in 1997 and in this method it is assumed that the turbine power factor is equal to the maximum theoretical value of it (Carlin, 1997). Wind Turbine power production curve modeling method is modeled by a polynomial. This model is applicable to most of the modern turbines. Powel, Pallabacer, Torres and et al., have used this method for calculating the energy produced by the turbine. Kiranoudis method was first used by Kiranoudis, in which the turbine power factor for a specific turbine is considered as a function of wind speed. In the method of generating random numbers by different methods of random number generation, we can produce a series of random numbers by having the probability density function of wind speed and these numbers can be considered as artificial wind speed in the region.

Modeling methods used in this study

The methods used in this paper can be categorized into two modeling frameworks of fuzzy modeling and modeling with the help of artificial neural networks. In this study, for fuzzy modeling, two methods of Takagi – Sugeno and Sugeno – Yasokawa and for artificial neural networks back-propagation error networks have been used, which will be briefly discussed below.

In modeling with the method of Takagi – Sugeno in 1985 a method was presented which models a system with the use of fuzzy rules. In this method, the system is modeled in the form of some fuzzy rules, in such a way that in each fuzzy rule the output should be in the form of a linear combination of inputs. Sugeno-Yasokawa was introduced by Sugeno and Yasokawain 1993. In this method also a system is modeled by a number of fuzzy rules. The minimum number of fuzzy rules in this model is equal to the fuzzy cluster which are considered in the output. For more study regarding this method refers to references 28, 29 and 30. The modified back-propagation error network of the education act of Widrow-Hoff is for multi-layered networks and differentiable nonlinear converting functions. It should be noted that from theoretical point of view, one-layered biased sigmoid networks with one linear output layer can estimate any function with a finite number of discontinuities. Radial network also is one of the methods used for systems modeling. This type of networks has one hidden layer and one output layer. For more studies about this method refer to references No.

33 and 34. ANFIS network for the first was invented by Jang and in this method Fuzzy Inference System has been used for training the neural network. There is another method with the name of training and test of models which itself includes two methods. In the present study, this method of training and testing model has been used in Takagi – Sugeno, Sugeno – Yasokawa and radial network.

Assessing the density of air on annual power produced by the wind turbine

As it was mentioned earlier, in most of the studies related to assessment of the potential of wind turbine installation and hence estimation of the annual power produced by wind turbine, it is assumed that the air density is independent of wind speed (in all the four conventional method this has been assumed). The reason is that because so far, no proper function has been found to be able to describe the probable distribution of air density. The only valuable conducted study is the work of Label et la. in which they have tried to present a model which can estimate the monthly average produced energy in wind farm installed in Tamil Nadu region in India. In this study the wind statistics related to 10 different location of Iran with different geographical and weather conditions have been studies, which have been prepared by SANA organization during one year.

Estimation of wind turbine energy production with having wind speed mean

For comparing the performance of the conventional methods and new proposed methods for modeling wind turbine, it is required to compare the estimation accuracy of these models with each other, in different regions. For this purpose, 50 stations in different regions of Netherland have been considered, that the wind statistics of them have been gathered in a project named Hydra.

For the purpose of estimation of annual power produced by wind turbine with the use of Takagi – Sugeno method two index factor of determination and root mean square of line and approximately the error of this method for mean of wind speeds between 5.5 to 6.5 m/s is less than other intervals and is smaller than 5%.

On the other hand, only for 4 stations the error of this method is larger than 10%. In the estimation method of the annual power produced by wind turbine with the use of Sugeno - Yasokawa method also like Takagi – Sugeno the model has been trained and tested with training data equal to 15, 25 and 35 and finally it was determined that with increasing the training data, the accuracy of the model improves. In the estimation method of annual power produced by wind turbine with the use of back-propagation error network for modeling with the use of artificial neural networks, the data have been similarly divided into two groups of A and B and group A has been used in building the model and group B has been used for testing the model. In an estimation method of annual power produced by wind turbine with the use of radial network, considering the fact that the value of determining factor for this model in the case of training data equal to 25 is 0.934, the obtained accuracy of this model is appropriate. The best result has been obtained from the training data containing 25 data. As it was specified, increasing the training data doesn't have much effect on the accuracy of this model, however; decreasing it reduces the model accuracy considerably. In estimation method of annual power produced by wind turbine with the use of ANFIS network the number of training data has a great effect on the obtained accuracy of the model from ANFIS. It should be noted though that in the case of training data equal to 25, the accuracy of ANFIS method is lower than the accuracy of Takagi – Sugeno method.

Using conventional methods for estimation of the annual power produced by the wind turbine

The aim of this section is to compare the accuracy and complexity of these methods with fuzzy and neural network methods. First, we acted based on 1-2-3 formula method and it is shown that the error of this method has rather a linear relationship with the wind speed mean and for the low wind speed means, the relative error of this method is around 30% and for high means of wind speed, the relative error is up to 100%. In wind turbine production power curve modeling method, after modeling with the method it is shown that the accuracy of this model largely depends on the nominal speed value selected for the turbine, which is one of the flaws of this model. The other flaw or issue is that in this method for obtaining a higher accuracy, the nominal speed of the turbine mentioned in the catalogue should not be used. In Kiranoudis method it is seen that the accuracy of this model completely depends on the selection of the selected nominal speed for the turbine. From this perspective also, this model is not an appropriate model. The accuracy of this method is only appropriate for the average wind speeds between 65 and 7.5 and outside this threshold, the accuracy falls severely. In the method of generation of random numbers it is determined that the accuracy of this method is also good, however; it is lower comparing to some of the previous methods. On the other hand, one of the flaws of this method is that with each time of implementation, the outputs of this method are different values which are due to it being random. Also the error of this method for average wind speeds lower than 5.5 m/s is not desirable and appropriate.

Application of estimation methods of wind turbine energy production with having mean and standard deviation of wind speed

After estimation of annual power produced by wind turbine with the use of Takagi – Sugeno method it is determined that if the wind speed standard deviation will be also used as the input for Takagi – Sugeno model, for training the model we will need more training data. Hence for equal training data, the model which has only used the average of wind speed will have a better performance. After estimation of the annual power produced by wind turbine with the use of Sugeno – Yasokawa method, it is determined that in this estimation in spite of the fact that wind speed standard deviation has been used as the other input of the mode, no improvement is observed in the model accuracy. In estimating the annual power of wind turbines with the use of back-propagation error network method, it is seen that by using wind speed standard deviation as auxiliary data, the accuracy of this model improves considerably, however; still it is far from the desirable accuracy. Another point to be noted is that again with increasing the number of training data, the accuracy of the model decreases. Hence; this model also altogether is not an appropriate method for estimating the annual power produced by the wind turbine. In estimating this value with the use of radial network, it is observed that with having wind speed standard deviation, no improvement is obtained in the model accuracy and by increasing the training data the model accuracy increases as well. In estimating the annual power produced by wind turbine with the use of ANFIS network, considering the obtained results from this method, for equal number of training data it is determined that considering wind speed standard deviation doesn't have a significant effect on model accuracy obtained with the use of ANFIS model.

Using conventional methods for estimating the annual power produced by the wind turbine

After using the modeling method of wind turbine production power curve it is determined that the use of Weibull distribution instead of Riley distribution improves the model accuracy, in such a way that determining factor of it improves from 0.8797 to 0.8984. With the use of Kiranoudis, it is determined that considering Weibull distribution improves the accuracy of this model and the sensitivity of this model toward the selection of turbine's nominal speed also reduces to some extent. But the accuracy of this model still doesn't reach an acceptable level. After using the method of generation of random number, it is observed that no significant change has occurred in the model accuracy. This shows that in this method using Riley distribution instead of Wiebull is more appropriate for describing the wind speed, because the accuracy of these two distributions in this case is similar but the Riley distribution only requires one parameter, while Weibull distribution requires two parameters. Generally, with comparison of the accuracy of the methods applied in this section, it is observed that for estimating the annual power produced by the turbine by having two parameters, the accuracy of the new methods hasn't changed considerably, however; the accuracy of the conventional methods has mostly increased. But this increase is somehow non-significant. In spite of this the accuracy of Takagi – Sugeno and radial network still are better than other methods. Hence; it can be said that with having wind speed standard deviation, in addition to average of wind speed, no improvement is obtained in accuracy of the estimation of the power produced by turbine and hence for this purpose using only the average wind speed is preferred.

Estimating the annual power produced by wind turbine with having three parameters of wind speed

In estimating the annual power produced by wind turbine with the use of Takagi – Sugeno method it is observed that the accuracy has decreased compared to the cases in which the average and standard deviation of wind speed have been used as input in the model. Also, it is observed that the obtain model accuracy from estimation of annual power of turbine with having three parameters of wind speed is better compared to the model obtained with having 1 and 2 parameters. In estimating the annual power produced by wind turbine with the use of radial neural network it is observed that in this case also the accuracy has reduced compared to the case in which average and standard deviation of wind speed have been used as model inputs. Also, it is observed that with having three parameters of wind speed, radial neural network can estimate the annual power produced by the turbine with a very good accuracy and in this case this model performs better than Takagi – Sugeno model.

In estimating the annual power production with the modeling method of turbine production power curves it is observed that the accuracy of this model has a good increase with application of distribution based on maximum Entropy compared to Weibull distribution, in a way that in the case of selecting the nominal speed of the turbine equal to 12, the determining factor increase from 0.9047 to 0.9306. In estimating the annual the annual power of wind turbine with the use of the method of generating random numbers it is observed that with having three parameters comparing to two parameters, the determining factor increases from 0.9178 to 0.9371, which indicates that maximum entropy based distribution can describe the wind status in a better way comparing to Weibull distribution.

Comparison of the methods used in this study

With having average of wind speed, using the proposed hybrid method is more appropriate and for obtaining better accuracy this network should be trained with approximately 5 training data. In the case that in addition to wind speed average, wind speed standard deviation is also available, using radial network method and Takagi - Sugeno model is recommended. In this case, we need more data for training the model (compared to the case in which only wind speed average is used as model input) and with increasing the number of training data a more desirable accuracy is obtained. By calculating the obtained average error percentage from implementation of hybrid method with 25 training data, this number is equal to 5.17% and with calculating this value for radial network method with 25 training data, this value will be equal to 4.73%. These two values help us to use one parameter or all the three parameters based on the required accuracy in each project.

Using the designed model for another turbine

The obtained results in this regard indicate that the accuracy of the designed model with the use of radial network is better than the accuracy of the conventional method of random generation. The point to be noted it that when we use this designed model for another turbine for estimating the power produced by the turbine, the obtained accuracy will be less than the accuracy of the conventional methods. Hence; considering the obtained results, in this case using conventional methods is preferred to using the model designed for another turbine.

Conclusion

Among the proposed estimation methods respectively the determining factors of Takagi - Sugeno, radial network, generation of random numbers and turbine production power curve modeling methods are better than other methods. If in addition to wind speed average, the standard deviation of wind speed will be also available for a specific region, it can be said that with considering the speed standard deviation, we need more training data comparing to the case in which only the average wind speed is being used, in a way that with increasing the training data, a more desirable accuracy is obtained. With comparing the accuracy of the applied methods it is determined that in this case the accuracy of the proposed methods and also the accuracy of the conventional methods has increased considerably. But among these methods, the accuracy of radial network is better than other methods considerably and on the other hand, it doesn't have the limitations of the conventional methods such as dependency of the model accuracy to selection a nominal speed to model (in turbine production power curve modeling method) and change of model output for each run or implementation (generation of random numbers model). Hence; in this case the obtained model of neural network is preferred. Also the possibility of using the designed model for a turbine for another turbine has been studied and with comparing the accuracy of this model with the model designed with the use of radial network and generation of random numbers method, it is determined that the model accuracy designed for another turbine is lower than the accuracy of the model with the use of conventional methods and new methods used for the same turbine.

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