Probabilistic Assessment of Wind Turbine Produced Power by Considering Fluctuations of Temperature and Velocity

Parisa Mohammadalizadeh[1] and Farzad Mohammadzadeh Shahir[2]

[1]Electrical and Computer Engineering Department, University of Tabriz, Tabriz, Iran
mohammadalizadeh-parisa90@ms.tabrizu.ac.ir
[2]Departmant of Electrical Engineering, Khosroshahr Branch, Islamic Azad University, Khosroshahr, Iran
f.m.shahir@gmail.com

Abstract

Produced power of a wind turbine depends on a mixed variety of factors such as wind speed, air density, wind beat and type of used generator in wind turbine. According to the probabilistic essence of wind speed and temperature which affect the other parameters, the output power of a wind turbine would be probabilistic. In this paper, a new proposal has been presented to predict the wind turbine generation. The results have been yielded based on data that measured in East Azerbaijan distributed company for a 3kw wind turbine. Investigation of turbine's dynamic, temperature changes and wind turbulence by considering wind dynamic make the proposed method to be more precise and reliable. The presented results show the impact of each effective parameter on output power of wind turbine. Also, it has been seen that the output power which is gained in this method is different from the one which only uses the average speed and wind speed standard deviation to assess the wind turbine generation capability.

1. Introduction

The wind, as an energy source, has been attracted great attention for long terms [1]. Due to environmental consideration increase, wind turbine employment has considerably raised up. As regards to probabilistic essence of wind blast in each region, the produced power, also, will be uncertainty. Beside the wind dynamic, considering the parameters such as turbine dynamic that varies by wind speed and wind beat changes, and also the temperature variation which affects the air density and aerodynamic of turbine's blades, will lead to increment in prediction accuracy [2-4]. In usual, the distribution functions such as waybill and normal are used to assess the reliability of wind turbines [5]. Since the wind speed is not stable in a time period and can be changed in various intervals, the multi models can be employed [6]. According to pitfalls of large systems reliability, the simple methods are the employed. Wind fluctuations can greatly affect the turbines' dynamic and the output voltage [7]. Also, it has been shown that the effect of wind turbulence in urban areas is different from coastal sites or those which are far from cities [8-10]. The temperature variation and its effect on air density and also freezing phenomenon in turbine's blades are considerable factors in researches of output power computation [11-12].

In this paper, in order to achieve the output power of wind turbine, first and foremost, it is gained based on the environmental parameters and turbine behavior. Then, their effects are applied in final model. Each parameter can considerably influence the turbine's output. Temperature swing and turbine dynamic are used in order to achieve the producible power of a 3kw small wind turbine in city of Tabriz. In this paper, firstly, the output power of wind turbine has been obtained based on dynamic behavior, distributed wind curve and temperature curve. In the subsequent stage, the impact of temperature oscillation and wind beat has been studied, and eventually, the results have been compared with two available models.

2. Wind Turbines

The wind turbines convert the kinetic energy to mechanical energy, the produced mechanical energy is converted to electricity by using generator. The blades of the turbine are not able to get the whole kinetic energy of the wind. In order to betz theory, from the theoretical point of the view, the maximum wind power which a turbine can change into mechanical energy is 59.3 of the total wind kinetic energy. the converted power by a turbine is obtained as follows:

$$P = \frac{1}{2} C_P \rho A V^3 \tag{1}$$

In above equation, P, C_p, , V and A are the output power, turbine's efficiency factor, air density, wind speed and the air swept surface by turbine's blades, respectively. In practice, the wind turbine is not constant in a time period and it varies. These wind speed alternations cause the C_p to fluctuate. The air density, also, depends on temperature and altitude from the sea. In this paper, in order to achieve the output power of the wind turbine, at first the output power is presented based on environmental parameters and turbine behavior. Then the effect of each elements are applied on exponential model. The studied parameters are obtained from different data classes. The first one that relates to the wind speed and its direction, are achieved from the measured information in Tabriz electric company. The information about the wind speed and temperature are presented in Table 1. The second parameter that pertinent to the turbine's dynamic, is used to investigate the behavior of the turbine against speed variation and also its fluctuations by using nominal data given in [3] and [13]. The sufficient relevant explanations are provided in section 1-2. The third parameter is about temperature changes dynamic. The vital information about mentioned parameter is presented in Table 1. The measured data in the site is applied in simulation. The mentioned parameters will be analyzed in the subsequent levels.

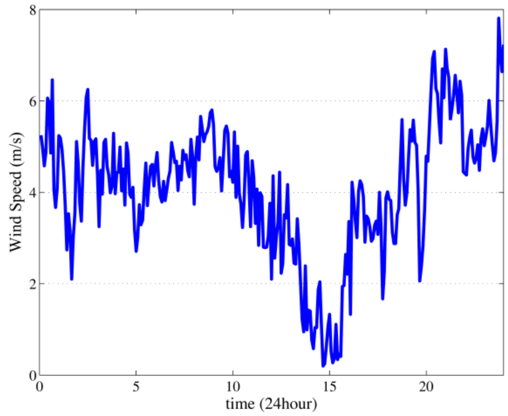

Fig. 1. Wind speed in a sample day

2.1. The Wind Dynamic

The wind speed and also its direction alter by elapsing the time. It has been shown that wind speed distribution function can be achieved by weibull curve [5]. The normal distribution curves, also, are employed to obtain the wind speed contingency function [7]. In case the normal distribution function is used, the average and standard deviation (μ,σ) would be required. The probabilistic distribution would depend on μ and σ , if the wind speed distribution is constituted as normal. In this paper, the wind speed has been considered as normal function, as well. Fig 1 shows the wind speed during a day in the site. In case the wind speed is considered as equation (2), it will have two variables. The V variable equals to wind speed average in studied time frame. The function is sinusoidal with frequency of f ,which it average in studied time period is zero. The wind speed is described as follows:

$$v(t) = V + u \tag{2}$$

$$u = A\sin 2\pi ft \tag{3}$$

If the u function is constituted as equation (3), the wind speed variance would depend on amplitude of this component. Turbulence intensity is the most common parameter to explain the effect of turbulence on turbine's output. In this period, the turbulence intensity is obtained as below:

$$TI = \frac{V}{\sigma} \tag{4}$$

In equation (4), the V is the average of speed in a period and σ is standard deviation. It has been shown that the air turbulence causes the efficiency to reduce.

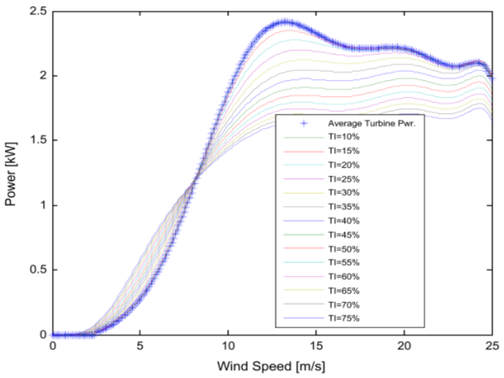

Fig. 2. Output power for turbin variation

2.2. The Turbine's Dynamic

The turbine's behavior variation is due to the wind instant spent change. In case the frequency f in function u is small value, the speed alterations would not affect the system's behavior. All the same by increasing the f , turbine's dynamic influences the output power [13]. There are various types of turbines which are manufactured by great producers. As regards to the fact that each turbine could have different dynamic behavior, firstly, the type of turbine has to be determined, then the dynamic behavior of that kind of turbine will be gained. In this paper, the small urban turbines with 3kw nominal power has been used. $V_{cut,in}$, V_{rated} and $V_{cut,out}$ for these types of turbines are 2.5, 12 and 25 meter per second, respectively. Turbulence causes the output power to decline. A static model of turbulence has been presented in [2]. A total dynamic model of turbine and speed turbulence has been provided in [3], as well. In both references, in order to gain the output power, the wind speed information has to be measured in 10 minute time frames. By employment of recording and measurement equipment, the wind speed in the site has been measured in 5 minute periods, and the turbulence rate has been calculated. In this paper, as regard to measured data, TI equals to 17%. The achieved consequences for efficiency computations of studied turbine in different turbulences have been shown in Fig 2. The plotted curve for considered turbulence has employed 10 degree estimation for obtained spots as follows:

$$\begin{aligned} P_{curve} &= -(1.62\times10^{-10})u^{10} + (1.89\times10^{-8})u^{9} - (9.17\times10^{-7})u^{8} \\ &+ (2.38\times10^{-5})u^{7} - (3.55\times10^{-4})u^{6} + (3.07\times10^{-3})u^{5} \\ &- (1.50\times10^{-2})u^{4} + (4.00\times10^{-2})u^{3} - (3.49\times10^{-2})u^{2} \\ &+ (1.66\times10^{-2})u - (9.07\times10^{-3}) \end{aligned} \tag{5}$$

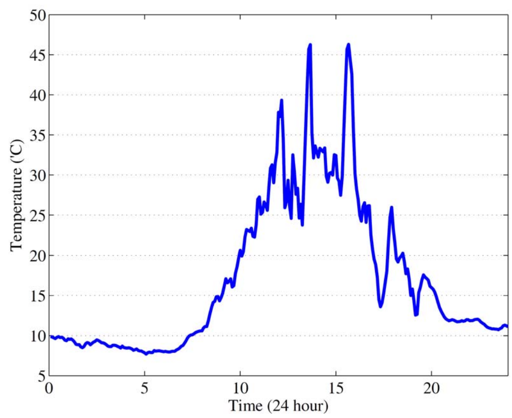

Fig. 3. Temperature curve in a sample day

2.3. The Temperature Dynamic

The temperature's statue can influence the wind turbine's production level in two conditions. The first one relates to variation and dependence on air density, which will be investigated in this section. The impact of low temperature on aerodynamic of turbine's blades will be the second one that has been entirely analyzed in [12]. The air density varies according to the air height and atmosphere conditions such as pressure and heat level. The output of wind turbine is in proportion to the transmitted air. The ratio of the air density in various altitudes to the air density in the sea level altitude is named DRA [4]. The air density is altered by different temperature degrees to air density at 15.5^c is called DRT. The DRA at 15.5^c in altitudes 2500, 5000, 7500 and 100000 foots equal to 1, 0.832, 0.912, 0.756 and 0.687 respectively. The DRT at sea level for 0, 20, 40, 60, 80 and 100 F equal to 1.3, 1.083, 1.04, 0.963, 0.029 and 0.897 respectively [4]. In case the air density is written based on DRA and DRT, the practical power of the wind turbine is calculates as follows:

$$P = K.C_p.DRA.DRT.A.V^3 \qquad (6)$$

In equation (6), k is pertinent to selected units. According to dimensions V and A, the temperature curve of a day in the studied site is shown in Fig 3.

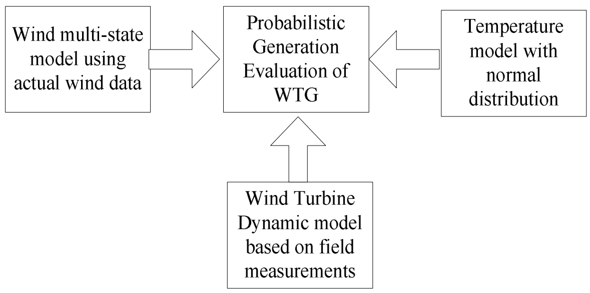

Fig. 4. Proposed model for output power estamination

3. The Probabilistic Assessment of Generation

In order to compute the output power of the wind turbines, the average speed and annually wind distribution are extremely significant. In this paper, the normal distribution curve and those resemble Fig.2 are used to calculate the output power of turbine throughout a year. The proposed algorithm in this paper, associates the turbine's output power with three parameters. The first one depends on annually wind distribution curve, which obtained from the applied measurements in the site. The second parameter relates to the turbine's efficiency and turbine's dynamic, as this parameter itself depends on turbulence intensity, wind speed and its fluctuations. The discussed third parameter is about the temperature and its alterations during a year. The temperature changes make the DRT to vary. Following this, the output power of the turbine will be modified. A case in point is that temperature variations cause blades freezing phenomenon, which has not been studied in this paper. In proposed procedure of this paper, firstly, according to the wind distribution curve and dynamic behavior of wind turbine, the its output power has been achieved. Then, the temperature fluctuations effect is applied based on the temperature normal distribution curve. The TI value, also, is gained equivalent to 17% according to data in 5 minute time periods. The turbine's probabilistic generation level would be achieved by convolution of annual wind distribution, efficiency changes distribution with wind speed alterations and normal distribution for DRT. The diagram of the proposed model is shown in Fig.4. The results of the comparison of the proposed method with the one which is based on the average speed and the wind speed standard deviation employed in [7], are presented in Table (2). Due to the low wind speed in studied day, the energy generation rate, according to the turbine's capacity, is low. The impact of each of three parameters, which are examined in this paper, is shown in these tables. As it can be seen in Table 2, the probabilistic generation of wind turbine and its security are varied by considering each three parameters. The contrast between proposed method results and the one mentioned in [7], demonstrate the fact that in the sites with low wind stability coefficient, it is inappropriate to use the normal distribution for the wind.

Table 1. The average values of wind speed and temperature of Tabriz

Month	Average of wind speed	Average of temperature
January	2.50	-0.5
February	3.20	1.1
March	3.60	6.2
April	3.60	12.1
May	3.70	17.4
June	4.10	23.2
July	4.69	26.3
August	4.29	26.8
September	3.40	21.8
October	2.80	15.4
November	2.30	6.9
December	2.30	18

Table 2. Analyzing results of parameters effects on generation

Conditions	Output power capacity (kW/day)
Assuming speed normal distribution [7]	3.38
The method stated in [7] alongside the temprature effect	3.761
Assuming turbulences, without temprature [2]	4.432
Proposed method	4.083

4. Conclusions

In this paper a novel approach is presented to assess the wind turbine probabilistic generation. The proposed technique includes turbine's dynamic and temperature's dynamic in addition to wind distribution curve. The information used for wind's dynamic, turbine's dynamic and temperature variations were genuine, as they were obtained from measurement and experiment. The effect of the each parameter has been presented separately in order to analyze the impact of them on turbine probabilistic generation. Also, the obtained results were compared with the method based on turbine's probabilistic generation extraction with normal distribution for wind and the generation by considering wind turbulence. The consequences comparison shows that employment of normal distribution would not be suitable for the locations which has low wind stability coefficient. Utilization of the normal distribution not only makes an error in turbine's produced power density, but also it causes a fault in modeling the turbine's behavior. Moreover, it has been shown that using the method which is based on turbulence without considering atmosphere conditions includes error, as well.

5. References

[1] N. Jenkins, R. Allan, P. Crossley, D. Kirschen, and Goran Strbac, *"Embedded Generation"*, 2000, pp. 31-38.

[2] A. Albers, Turbulence normalisation of wind turbine power curve measurements, Deutsche Wind Guard Consulting GmbH.

[3] A. Rossen, Y. Sheinman, "The average output power of a wind turbine in a turbulent wind," *Jur. Wind Eng. Ind. Aero. Dyn.*, vol.51, pp. 287–302, 1994.

[4] M. R. Kaviani, "Wind Turbines and an Evaluation of the positional Energy of Wind in Iran," *Geographical research, university of Isfahan*, vol.36, pp. 127-144, 1995.(in Persian).

[5] Tai-Her, Yeh, and Li Wang, " A Study on generator capacity for wind turbines under various tower heights and rated wind speeds using weibull Distribution" *IEEE Trans. on Energy Conversion*, vol. 23, pp. 592-602, 2008.

[6] Rajesh Karki, Po Hu and Roy Billinton, "A simplified wind power generation model for reliability evaluation*," IEEE Transactions on Energy Conversion,* Vol. 21, No. 2, June 2006.

[7] L. Wu, J. Park, J. Choi, A. A. El-Keib, M. Shahidehpour, and R. Billinton, "Probabilistic reliability evaluation of power systems including wind turbine generators using a simplified multi-state model: A case study," in *Proc. IEEE PES Gen. Meet.*, Calgary, AB, Canada, Jul. 26–30, 2009.

[8] A. Rosen, Y. sheinman, "The power fluctuations of a wind turbine" *Jur. cWind Eng. Ind. Aero. Dyn.*, vol. 59, pp. 51-68, 1996.

[9] K. Sunderland, T. Woolmington, J. Blackledge and M. Conlon, " Small wind turbines in turbulent (urban) environments: A consideration of normal and Weibull distributions for power prediction, " *Jur. Wind Eng. Ind. Aero. Dyn.*, vol. 121, pp. 70–81, 2013.

[10] Wagner, R., Courtney, S.M., Torben, L.J., Paulsen, S.U., "Simulation of shear and turbulence impact on wind turbine power performance." Riso DTU (National Laboratory for Sustainable Energy), 2010.

[11] M. Zahedi, B. Salahi, M. Jamil, " Calculation of wind density and potentials for use of wind energy in ardebil ", *Physical Geographical research Quarterly, Tehran University*, vol.53, pp. 41-55, 2005. (in Persian)

[12] Matthew C.Homola, Muhammad S.Virk, Tomas Wallenius, Per J.Nicklasson, Per A.Sundsbø, " Effect of atmospheric temperature and droplet size variation on ice accretion of wind turbine blades," *Jur. Wind Eng. Ind. Aero. Dyn.,* vol. 98, pp.724-729, 2010.

[13] Y. Sheinman, A. Rosen, "A dynamic model of the influence of turbulence on the power output of a wind turbine." *Jur. Wind Eng. Ind. Aero. Dyn*., vol. 39, pp. 329–341. 1992.

[14] J, Majid, "Wind power statistics and evalution of wind energy density, "*Wind Engineering*. vol 18. No. 5, pp. 227-240, 1994.