Journal of Green Energy Research and Innovation

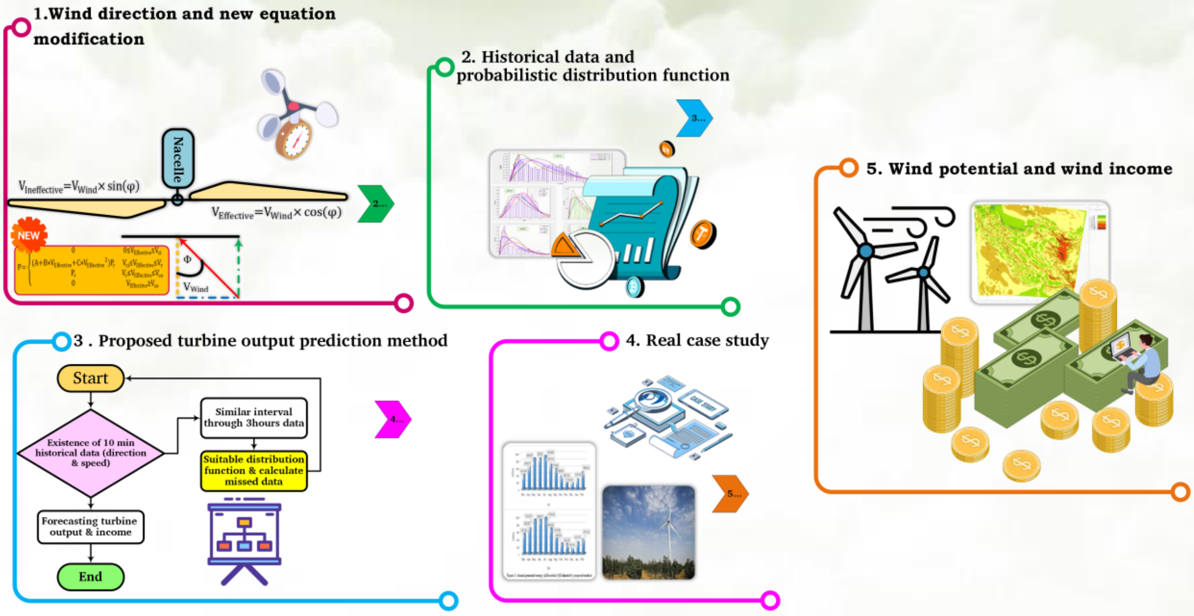
The Impact of Wind Direction on Wind Farms' Output Power and Income

AliAsghar Karimi Taleb, Hojatollah Makvandi, Ashknaz Oraee

Highlights

- ❖ Modifying The quadratic power curve equation
- ❖ The derivation of new parameters for predicting the output power of a WT
- ❖ Wind direction and its variation for predicting power and income of a WT
- ❖ Proposing a new approach to study the wind power potential of a region

Graphical Abstract



Use your device to scan and read the article online

Citation

A. A. Karimi Taleb, H. Makvandi, and A. Oraee " The Impact of Wind Direction on Wind Farms' Output Power and Income," *Journal of Green Energy Research and Innovation*, vol. 1, no. 1, pp. 34-47, 2024.

https://doi.org/10.61186/jgeri.1.1.34

JGERI
Journal of Green Energy Research and Innovation

Journal of Green Energy Research and Innovation 1(1) (2024) 34–47

Online ISSN: 3041-9018

Journal of Green Energy Research and Innovation

Journal Homepage: www.jgeri.araku.ac.ir

The Impact of Wind Direction on Wind Farms' Output Power and Income

Ali Asghar Karimi Taleb [1*], **Hojatollah Makvandi** [2], **Ashknaz Oraee**[3]

[1] Khuzestan Water and Power Authority, Ahvaz, 613481395, Iran.
[2] Abadan Oil Refining Company, Abadan, Iran.
[3]Faculty of Electrical and Medical Engineering, Sadjad University of Technology, Mashhad, Iran.

** Corresponding Author: a.karimii.t@gmail.com*

ARTICLE INFO

Keywords:
Wind energy,
Wind speed prediction,
Wind turbine,
Wind farm income.

Article history:
Received: 26 November 2023;
Revised: 10 January 2024;
Accepted: 21 January 2024;

Article type:
Research Article

ABSTRACT

The main methodology in every wind power prediction model involves converting wind speed into power using the power output curve of the wind turbine. However, preceding studies that have introduced models for such curves have not considered the impact of wind direction and its recurring fluctuations over time on predicting wind turbine power output. The main focus of these studies has just been on the magnitude of wind speed and the relationship between wind speed and turbine power. The present study models the effect of wind direction on wind turbine power output and uses it to modify the quadratic power curve equations. Using these modified equations and considering the turbine mechanism to follow the wind direction, a method is presented for predicting wind turbine power output under frequent changes in wind direction over time. To deal with the lack of access to long-term and high-resolution wind data, registered historical data and probabilistic distribution functions are used to produce lost data with software. To demonstrate the efficacy of the suggested approach, the real data recorded for a 1.5 MW turbine installed in Khaf in Razavi Khorasan, Iran, are used as a case study. Finally, the potential wind power and potential income of the four windy regions in Iran were assessed based on the payment mechanism of the Organization of Renewable Energy and Electricity Efficiency of Iran, assuming the same installed capacity. The effect of wind direction and its variations over time, which can affect power output of wind turbine and income, is the main focus of this section of paper.

1. Introduction

With the increase in the effect of wind power in power systems, new challenges have emerged due to wind energy variability and uncertainty [1, 2]. A precise prediction of the power generation of a wind farm (WF) is a great help in dealing with these challenges [3]. Transforming wind speed to wind power using a wind turbine power curve (WTPC) is the main approach of wind power prediction models. In the past decades, there has been increasing interest in the WTPC as a part of wind energy research [4, 5]. The power generation of a wind turbine (WT) is influenced by various factors, including wind speed, wind direction, air density (determined by temperature, pressure, and humidity), and turbine settings [6]. Properly assessing the effects of all the influencing parameters involves significant intricacy. The WTPC, which represents the turbine's power output at a given wind speed, offers a practical method for modeling the performance of WTs [7]. The approaches for modeling power curves can be categorized as discrete, deterministic/probabilistic, parametric/nonparametric, and stochastic methods. Alternatively, they can be classified based on the data utilized for modeling [8]. Generally, it is preferred to use the general equation in WTPC modeling in wind energy potential studies. The parametric methods rely on solving mathematical model equations, and nonparametric methods have been adopted to discover how input data of wind and turbine power output are interrelated [6]. Authors in [9] introduced parametric modeling's of the WTPC constructed using four and five-parameter logistic equations. The parameters of these expressions were determined by sophisticated methods such as genetic algorithm (GA), evolutionary programming (EP), particle swarm optimization (PSO), and differential evolution (DE). A comparative analysis was conducted to examine several approaches for mathematically modeling WTs, specifically focusing on three WTs that are currently available in the market. The analysis utilized an algorithm developed and described in reference [10]. In their study, authors in [11] suggested incorporating operational data from WTs to generate bivariate probability distribution functions that may accurately describe the power curve of existing turbines. This approach enables the detection of any deviations from the expected behavior. The utilization of empirical copulas is suggested. The statistical concept of copulas enables the individual distribution shape of wind speed and power to be described independently from the information regarding their interdependence. The study conducted by [12] involved the utilization and comparison of three distinct machine learning models: a self-supervised neural network known as Generalized Mapping Regressor (GMR), a feed-forward Multi-layer Perceptron (MLP), and a General Regression Neural Network (GRNN). The objective was to estimate the correlation between wind speed and power generation in a WF. Precise representations of power curves are crucial for predicting power output and conducting real-time monitoring of turbines.

Several methodologies have been suggested in different studies to simulate WTPCs. Many academics have employed these methods, which involve adopting data from manufacturers' specifications and actual data from WFs in a range of wind power applications [13]. Choosing the proper power curve models can enhance the efficiency of wind energy systems [14]. The most recent approach employed in papers involves the use of Sigmoid models, which are characterized using a comprehensive expression comprising several parameters. Currently, two types of models are being utilized, namely exponential models (EM) and algebraic models (AM) [15, 16]. WTPCs clearly illustrate the correlation between wind speed and the amount of electrical power generated by a WT. The manufacturers offer them as the primary choice, and they can also be presented in a tabular style using pairs of values [17]. Researchers commonly believe that in a horizontal axis WT (HAWT), the turbine will generate a specific amount of power when the wind speed is recorded directly in front of its hub [18, 19]. Alternatively, the manufacturers can provide a graph that allows the derivation of such value pairs by observation. Stakeholders and promoters can utilize these values to determine both the anticipated power output and the energy value that a specific WT can harness from the wind. The only additional information required is the probability distribution of wind speeds at the location in question. The International Electrotechnical Commission (IEC) has provided a defined technique for establishing curves in its paper IEC-61400-12-1 [20]. In this fashion, the measured WTPC is commonly obtained by applying the so-called method of bins for the normalized data sets. In practical applications, WTs and, consequently, WFs encounter operating conditions that deviate from the ideal conditions observed in controlled environments such as manufacturer laboratories and wind tunnels where WTPCs are assessed. Within a WF, WTs are typically exposed to various conditions, influenced by factors such as air temperature, moisture, turbulence caused by phenomena like the wake effect and shear effect, the presence of ice, reduced performance due to aging, and other potential factors [21]. The modeling of WTPC is crucial in various analysis applications, research endeavors, and software tools due to the need to handle such curves. The WTPC models have diverse and extensive uses. They can also be used to determine a WF's suitable position and arrangement [22] and examine the impact of external influences [23, 24].

Previous studies have just used the magnitude of the wind velocity vector and the relationship between velocity and power to estimate turbine power output. None of these studies have considered the effect of wind direction and its repeated variations over time in calculating the turbine power output. This paper models the wind direction and uses it to modify the quadratic power curve equations, which is the most widely used method for estimating WT power output. The contributions of the article are as follows:

- Modifying the quadratic power curve equation
- Deriving new parameters for predicting a WT output power
- Considering wind direction and its variations in predicting the power output of a WT and farm income
- Proposing a novel method to study the wind power capacity of a region

This part describes the organization of the paper. Section 2 describes the model. Next, Section 3 tests the proposed methodology on the WT of Khaf, Iran, to show its effectiveness and discusses the results thoroughly. Finally, the conclusions and perspectives for future work are provided in Section 4.

2. Model Analysis

2.1. Modified quadratic power curve

As already stated, the quadratic power curve (QPC) is the method most commonly used to estimate the power output of a WT [25, 26] based on the wind velocity's magnitude. Wind direction and its variations are not considered in the quadratic power curve.

Variability is inherent to wind, which strongly affects the power output of a WT. Wind direction changes even within seconds. Therefore, regardless of the wind direction, its variations cause a great deal of error in estimating WT power output, so it needs to be included in these calculations. The perpendicular component of wind velocity to the plate of the turbine blades is the factor that rotates the turbine blades. As shown in Figure 1, if the wind angle with the line perpendicular to the plate of the turbine blades is φ, then Vwind × cosφ and Vwind × sinφ are two components of Vwind. Vwind cosφ is the vertical component that rotates turbine blades and is called VEffective, which should be modified based on QPC equations. The modified form (MQPC) is shown in Equation (1).

In these equations, V_{ci}, V_{co}, V_r, P_r, and P are the cut-in speed, cut-out speed, rated speed, rated power, and estimated turbine power, respectively. In Equation (1), $V_{Effective}$ is not the size of the wind speed. This variable is the perpendicular component of the wind velocity to the plate of turbine blades, named effective wind speed ($V_{Effective}$). $V_{Effective}$ rotates the turbine's blades. Another important point to mention in Equation (1) is that when the wind direction is taken into account, $V_{Effective}$ changes in the intervals of Equation (1). For example, regardless of the direction of the wind, at a given time, if the wind speed was within the range between the nominal speed and the cut-in speed, the turbine power output could be calculated by using the polynomials in Equation (1), which is greater than zero.

On the other hand, by considering the wind direction, given that $cos\varphi$ is smaller than 1, $V_{Effective}$ will be lower than the wind speed ($|V_{wind}|$), and it may also be lower than the cut-in speed. So, the power output will be zero. Another instance is when the wind speed is higher than the cut-out speed. If the wind direction was not considered, the power output would be equal to zero. However, if the wind direction is taken into account, the effective wind speed ($V_{Effective}$) may be lower than the cut-out speed, so the turbine power output will be equal to the rated power. The parameters A, B, and C are the same in both QPC and MQPC because they depend on the turbine's construction and are independent of the regional wind's characteristics.

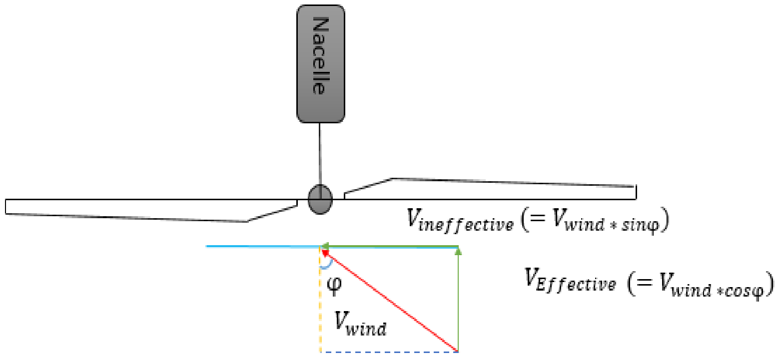


Figure 1. Wind speed components.

$$P = \begin{cases} 0 & 0 \le V_{Effective} \le V_{ci} \\ (A + B \times V_{Effective} + C \times V_{Effective}{}^{2})\ P_r & V_{ci} \le V_{Effective} \le V_r \\ P_r & V_r \le V_{Effective} \le V_{co} \\ 0 & V_{Effective} \ge V_{co} \end{cases} \tag{1}$$

$$A = \frac{1}{(V_{ci} - V_r)^2}[V_{ci}\,(V_{ci} + V_r) - 4V_{ci}V_r(\frac{V_{ci} + V}{2V_r})^3]$$

$$B = \frac{1}{(V_{ci} - V_r)^2}[4(V_{ci} + V_r)(\frac{V_{ci} + V}{2V_r})^3 - (3V_{ci} + V_r)]$$

$$C = \frac{1}{(V_{ci} - V_r)^2}[2 - 4(\frac{V_{ci} + V}{2V_r})^3]$$

2.2. The proposed method for predicting WT power output

This paper proposes a method for predicting turbine output, focusing on the effect of wind direction and its variations on WT output power. In the proposed method, the turbine mechanism in tracking the wind direction is the most important factor, a factor not considered in previous studies. Furthermore, the proposed method includes the turbine's monthly stop period for turbine services, grid errors, turbine start-up, etc., in power calculations.

The turbine mechanism in following the wind direction depends on turbine technology and operator setting, which varies for each turbine and site. The wind tracking mechanism of WT aims to set the blades' plate in a direction perpendicular to the wind, thereby increasing the effective wind speed. This will highly increase the power output of the turbine. The settings considered in how to follow the wind direction and turbine yawing in the present work are as follows:

Yaw velocity: yaw velocity is one of the most important characteristics of a turbine. The faster the yaw speed is, the faster the turbine will follow the wind's direction. So, the turbine will have a shorter time deviation angle with the wind direction, which increases the power output.

Maximum yaw error: Due to mechanical considerations and to avoid the reduction in the useful life of the turbine, turbines should not yaw in small changes of yaw angle. The maximum angle between wind velocity and the line perpendicular to the blades' plate that the turbine does not yaw is called maximum yaw error.

Yaw lag: Due to variations in wind direction at certain times, the yawing system waits a while until the wind stabilizes. This delay is yaw lag.

Maximum angle: In some sudden and momentary changes in wind direction that are very large, it is technically and economically better that the turbine does not yaw. The maximum yaw angle that the yaw system works is called the maximum angle. If the angle between the wind direction and the line perpendicular to the blades' plate (yaw angle) gets larger than the maximum angle, the turbine will turn off, and it should be driven under favorable conditions.

Launch time: For various reasons, such as annual maintenance and $V_{Effective}$ higher than the cut-out speed, the WT will be switched off. When launching, the power output becomes zero, which is considered in the proposed method.

Simulation steps of the proposed method: To estimate turbine power output, wind speed and wind direction data are first predicted for a desired time period (e.g., 1 year) at appropriate time intervals (e.g., 10 minutes). Then, in order to obtain the power output in each interval, the wind speed and the direction variations of the wind to the previous interval are used. At last, $V_{Effective}$ is obtained, and the power output is calculated using Equation (1) and according to the turbine yawing setting. In the yaw lag period, the wind direction variations are considered for some next intervals, and if the wind direction variations are unstable, the turbine does not yaw. If the wind direction change is greater than the maximum angle, in addition to turning off the turbine, a launch time is also considered. Another important point in simulating is when the yaw angle exceeds the maximum yaw error. In this situation, the turbine yaw system should follow the wind direction to increase power output. In this case, by considering yaw velocity (φ rad/s), $V_{Effective}$ is calculated, and by using MQPC equations, the power output of WT is calculated. Finally, by adding the power output in each second, the average power output in each interval is calculated. Disconnected periods due to turbine maintenance and grid errors are also considered.

2.3. Wind speed and wind direction data

A challenge in WT power output studies is the lack of access to long-term and high-resolution wind data (e.g., 10 minutes). Therefore, for an acceptable result, the wind data must be completed or produced for an appropriate time period. In the Organization of Renewable Energy and Electricity Efficiency of Iran's (SATBA) website [27], incomplete wind speed and direction data are available at 10-minute intervals for different regions. Therefore, wind data should be completed over a proper interval for more accurate analysis and proper study.

For this purpose, the 3-hour resolution wind speed data and wind direction in a longer interval (e.g., 15 years) provided by Iran's Meteorological Organization, the MATLAB software, and wind speed and wind direction characteristics (such as the relationship between speed variations and wind direction with height) were used. So, 3-hour synoptic data of wind speed and direction were first analyzed, and the trend of wind speed and wind direction variations was studied. The time periods with the same trends in a year were identified. To complete wind data for intervals without any information, the time period of the intervals was first identified. Secondly, similar time intervals with registered data were detected. Now, to produce wind data for intervals with no recorded data, the most suitable distribution function was chosen among the most widely used probabilistic distribution functions, including Rayleigh, Normal, Logarithmic Normal, and Gamma, by using MATLAB software and its most suitable fitted parameters were calculated. Using the probability distribution obtained, wind speed and wind direction data were produced for intervals without recorded data. In addition to finding similar intervals, wind directional features were adopted to complete wind data.

At varying heights, the direction of the wind does not change, and these changes can be ignored. Furthermore, according to the study area, the direction of the wind had similar orientations during certain periods of the year. By considering these wind characteristics, one-year wind data were completed in different areas.

2.4. Cost calculation for generated wind power in Iran

In Iran, the government guarantees the purchase of the generated renewable energy. A 20-year warranty contract is made between SATBA and wind energy producers for wind energy. SATBA monthly pays for wind energy produced. According to the government's decree on February 10, 2016, the purchasing base rate of guaranteed wind power for WFs with a capacity of more than 50 megawatts and equal to or less than 50 megawatts is set at 3400 and 4200 Rials per kilowatt-hour, respectively.

SATBA's method for calculating the price of produced energy per hour is as follows:

- Equivalent production = Pure hourly production * CPF (Cost of Preparation Factor)
- New purchasing rate = Contract purchasing rate * Adjustment factor
- Price of energy produced per hour = New purchasing rate * Equivalent production

In these equations, CPF is a coefficient given by Iran's Grid Management Co. (IGMC) every hour of the day. This coefficient varies for different hours of the day and for days, weeks, and months of the year. In fact, this coefficient is used to pay the cost of being ready to produce wind power to the producer. Pure hourly production refers to the wind energy generated per hour in kilowatt-hours. The contract purchasing rate is equal to the rate quoted in the contract between SATBA and the wind energy producer, and the adjustment factor is used to compensate for the effects of currency depreciation and inflation.

In this study, the adjustment coefficient is ignored since the aim is to compare the wind energy produced in one year. For this study, CPF from June 21, 2016 to June 21, 2017, which are available on IGMC's website, was used [28].

3. Case Study and Results

This study used the real data of a 1.5 MW WT installed by the Behin Ertebat Mehr Co. in Khaf as a case study. The installed turbine is a WD77-1.5MW model of WINDEY Company, with a cut-out speed, cut-in speed, and nominal speed of 25, 3, and 11 m/s, respectively, and a tower height of 80 meters. The simulation used the recorded data in 10-minute intervals of the average wind speed and direction at an 80-meter height at Khaf farm. Also, the settings for tracking the turbine based on information from the Khaf turbine are as follows:

Yaw velocity: 0.47 degrees per second

Maximum yaw error: 5 degrees

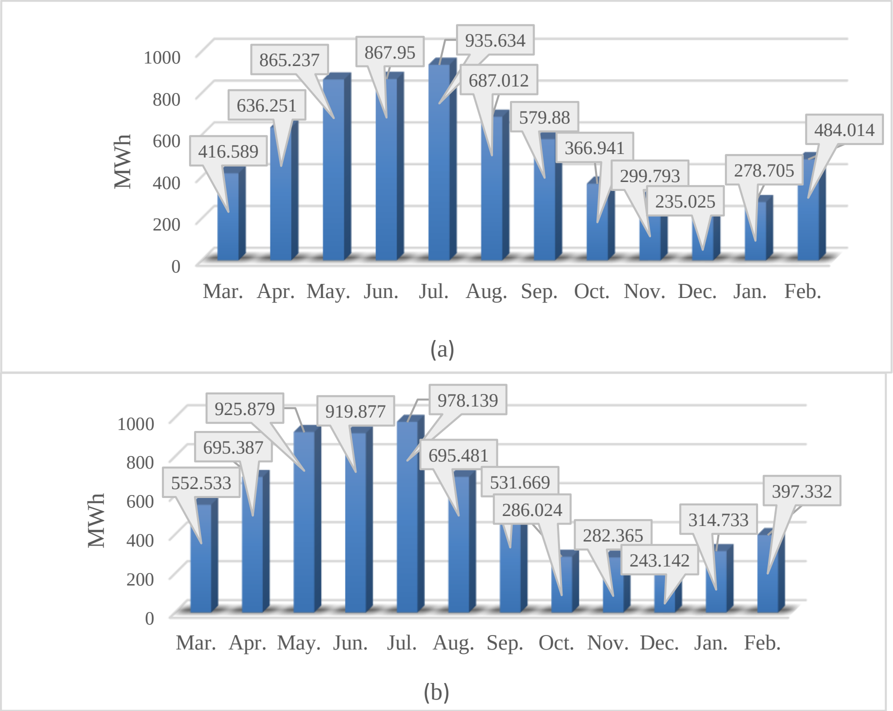
Yaw lag: 4 minutes

Maximum angle: 80 degrees

Launch time: 2 minutes

3.1. Forecasting output power for a 1.5 MW WT

Figure 2a displays the recorded monthly data of generated energy. According to this data, the total annually generated energy is 6653.031 MWh. Without considering wind direction and its variation and using QPC equations, the common method of previous studies, the estimated generated energy would be 7568.794 MWh. Figure 2b shows the monthly estimated generated energy using Equation (1) and the proposed method. According to this estimated data, the total annually generated energy is 6833.365 MWh. The results for annually generated energy in various modes are presented in Table 1. Accordingly, without wind direction calculations, the estimated power output will highly deviate from the actual generated power (about 14%). In fact, the energy generation estimated by this method (without considering wind direction and generation interruption) is the maximum energy that the turbine can generate, in which the wind is assumed to be perpendicular to the turbine plate at all moments, and there are no failures or interruptions for the turbine. The results on the proposed approach are very close to the real power output of the WT so that the difference is only about 2.5%, which is a relatively small error. This low error indicates the efficacy of this approach. Moreover, the energy generated by the proposed method, regardless of the interruption effect, is also calculated, representing the impact of the wind direction on the turbine power output calculations.



(a)

(b)

Figure 2. Annually generated energy: (a) recorded and (b) estimated by the proposed method.

Table 1. Annual energy generation and estimated error in each scenario.

Estimated data			**Recorded data**	
Without turbine direction	**Including wind direction and turbine interruption**	**Including wind direction without turbine interruption**		
5768.794	6822.561	7105.094	6653.031	**Annual generated energy (MWh)**
13.76	2.55	6.79	-	**Error (%)**

3.2. Interactive effect of wind direction and speed on wind power production

The difference between the two conventional methods and the proposed method, without considering the variations in wind direction in the calculation of produced energy of the Khaf turbine, indicates the effect of wind direction variations. Table 2 presents this difference (as a percentage of the real energy produced in each month) and the average wind speed. Wind power generation is highly sensitive to wind speed. Hence, it is expected that the higher the wind speed, the higher the generated power. However, the evaluation of Figure 2 and Table 2 indicates interesting results. The output power is low in October and November despite high average wind speed. The reasons for the low power generation in these two months can be found in Table 2, which shows that wind direction variations are very high in these two months. The high wind direction variations reduce wind power production despite the high wind speed in these months. These calculations show the significant role of wind direction and variations in WT power output. The important conclusion is that to potentiate the wind power of an area, one should not only evaluate wind average speed but also consider wind direction and its changes over time. This factor is not only effective but also decisive.

Table 2. The difference in the estimated energy between the proposed method and the conventional method in Khaf.

Month	**Ave. wind speed (m/s)**	**Diff. in estimated energy (%)**
Mar.	6.2	9.82
Apr.	7.5	4.46
May.	8.5	1.96
Jun.	11.2	0.77
Jul.	13.5	0.89
Aug.	15.2	5.75
Sep.	15.0	11.57
Oct.	14.7	26.28
Nov.	10.2	12.87
Dec.	9.6	16.52
Jan.	6.4	14.58
Feb.	6.2	8.55

3.3. Estimating energy generation and WF income in Iran

This section analyzes the energy production and income of an identical WF (identical in installed capacity and turbines) in four regions of Iran, including Manjil, Kahak, Binalood, and Khaf. These WFs are located in Gilan, Qazvin, Khorasan Razavi, and Khorasan Razavi provinces, respectively. These zones are the only areas in Iran where WFs have been built. Among these areas, Khaf in Khorasan Razavi is an exceptional zone in terms of potential wind energy. These zones are analyzed using the previous method (without considering wind direction) and the method proposed in this paper (without considering interruption in energy production).

For this purpose, data on wind speed and direction at a height of 40 meters and in 10-minute intervals are used. Moreover, the identical WF consists of 66 × 1.5 MW turbines (turbines with the same characteristics as the Khaf turbine). So, the total capacity of WF is 99 MW. In this calculation, the effect of turbines on each other is ignored, and the wind speed and direction of the whole site are assumed to be identical for all turbines. Table 3 summarizes the results.

Table 3. Annually generated energy and income of a 99MW WF.

		Khaf	**Manjil**	**Binalood**	**Kahak**
Previous Method	**Net Production (GWh)**	459.186	361.918	370.396	306.424
	Equivalent Production (GWh)	499.723	357.641	412.362	359.761
	Income (Billion Toman)	169.906	121.598	140.203	122.319
Proposed Method	**Net Production (GWh)**	407.290	319.092	339.355	254.167
	Equivalent Production (GWh)	449.063	313.537	381.085	299.544
	Income (Billion Toman)	152.682	106.602	129.569	101.845
Diff. (Billion Toman)		17.224	14.996	10.634	20.474

According to Table 3, the difference in energy production and revenue calculated for the two methods are the highest in Kahak and the lowest in Binalood due to wind direction variations in these areas.

Most of the Kahak WF production is during peak demand hours. So, CPF is often higher than 1, so its equivalent production is significantly higher than its net production. Therefore, although Kahak WF's net production is much lower than that of the other areas, its income is appropriate. Unlike Kahak WF, just a fraction of Manjil wind production is during grid peak hours.

Therefore, CPF is often lower than 1, and its equivalent production is significantly lower than its net production. So, although Manjil WF's net production is appropriate, its income is not that good. Khaf and Binalood WF's equivalent production is 10.26% and 13.20%, respectively, which is higher than net production due to the predominance of CPFs greater than one.

4. Conclusions

A precise prediction of the power output of a WF is a great help in facing the variability and uncertainty of wind energy. The present work modified the quadratic power curve equation according to wind direction and its variation. Using the modified quadratic power curve equation and yawing system of WT, a method was developed for predicting the power output of a WT. To solve the problem of the lack of access to data on long-term and high-resolution wind speed and wind direction, historical data and probabilistic distribution functions were used to produce wind data for intervals with no recorded data.

In this method, wind direction and its variation were considered. The suggested method was applied to the actual recorded values, and the results supported the efficiency of the proposed method. Also, they showed a significant impact of the wind direction and its variations on the turbine power output. Another important result of this study is that to study the potential wind power of an area, besides wind speed, the wind direction and its variations over time should be taken into account.

The potential wind power of the four regions of Manjil, Khaf, Binalood, and Kahak was estimated based on the proposed methodology and considering the common effect of wind speed and direction. It was determined that the Khaf zone had a great potential wind power. On the other hand, despite the high average wind speed in the Kahak zone, the potential wind power was lower than that of the other regions due to high wind direction variations.

The correlation between wind power production and grid peak hours was another main result of this study, which highly influences WF income. So, WFs that are more productive at the grid peak hours can earn more because of applying CPF greater than one. In this regard, among the studied regions, Kahak is the best. But, Manjil has the worst situation among the four studied areas.

Future researchers are recommended to consider the effect of wind direction on reliability indices. It is also suggested to model wind direction and its variations in various methods for predicting wind power, both parametric and nonparametric. Furthermore, it is advised to employ the proposed methodology to investigate the potential of wind power in a particular region.

References

[1] F. Bilendo, H. Badihi, N. Lu, P. Cambron, and B. Jiang, "An Intelligent Data-Driven Machine Learning Approach for Fault Detection of Wind Turbines," *in 2021 6th International Conference on Power and Renewable Energy (ICPRE)*, pp. 444-449, 2021.

[2] M. F. Nezhadnaeini, M. Hajivand, M. Abasi, and S. Mohajeryami, "Optimal Allocation of Distributed Generation Units Based on Two Different Objectives by A Novel Version Group Search Optimizer Algorithm in Unbalanced Loads System," *Rev Roumaine des Sciences Techniques-Series Electrotechnique et Energetique,* vol. 61, no. 4, pp. 338–342, 2016.

[3] M. Abasi, M. Joorabian, A. Saffarian, and S. G. Seifossadat, "A Comprehensive Review of Various Fault Location Methods for Transmission Lines Compensated by FACTS Devices and Series Capacitors," *Journal of Operation and Automation in Power Engineering*, vol. 9, no. 3, pp. 213-225, 2021.

[4] X. Jin, Z. Xu, and W. Qiao, "Condition Monitoring of Wind Turbine Generators Using Scada Data Analysis," *IEEE Transactions on Sustainable Energy*, vol. 12, no. 1, pp. 202-210, 2020.

[5] M. Sadeghi, and M. Abasi, "Optimal Placement and Sizing of Hybrid Superconducting Fault Current Limiter for Protection Coordination Restoration of The Distribution Networks in The Presence of Simultaneous Distributed Generation," *Electric Power Systems Research*, vol. 201, 107541, 2021.

[6] C. Carrillo, A. F. Obando Montano, J. Cidras, and E. Diaz-Dorado, "Review of Power Curve Modelling for Wind Turbines," *Renewable and Sustainable Energy Reviews*, vol. 21, pp. 572-581, 2013.

[7] M. Abasi, A. T. Farsani, A. Rohani, and M. A. Shiran, "Improving Differential Relay Performance During Cross-Country Fault Using a Fuzzy Logic-Based Control Algorithm," *in 2019 5th Conference on Knowledge Based Engineering and Innovation (KBEI)*, pp. 193-199, 2019.

[8] M. Abasi, M. Falah Nezhadnaeini, M. Karimi, and N. Yousefi, "A Novel Metaheuristic Approach to Solve Unit Commitment Problem in the Presence of Wind Farms," *Rev Roumaine des Sciences Techniques-Series Electrotechnique et Energetique*, vol. 60, no. 3, pp. 253–262, 2015.

[9] M. Lydia, A. I. Selvakumar, S. S. Kumar, and G. E. P. Kumar, "Advanced Algorithms for Wind Turbine Power Curve Modeling," *IEEE Transactions on Sustainable Energy*, vol. 4, no. 3, pp. 827-835, 2013.

[10] V. Thapar, G. Agnihotri, and V. K. Sethi, "Critical Analysis of Methods for Mathematical Modelling of Wind Turbines," *Renewable Energy*, vol. 36, no. 11, pp. 3166-3177, 2011.

[11] S. Gill, B. Stephen, and S. Galloway, "Wind Turbine Condition Assessment Through Power Curve Copula Modeling," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 1, pp. 94-101, 2011.

[12] A. Marvuglia, and A. Messineo, "Monitoring of Wind Farms Power Curves Using Machine Learning Techniques," *Applied Energy*, vol. 98, pp. 574-583, 2012.

[13] J. Yan, H. Zhang, Y. Liu, S. Han, and L. Li, "Uncertainty Estimation for Wind Energy Conversion by Probabilistic Wind Turbine Power Curve Modelling," *Applied Energy*, vol. 239, pp. 1356-1370, 2019.

[14] D. Villanueva, and A. Feijoo, "A Review on Wind Turbine Deterministic Power Curve Models," *Applied Sciences*, vol. 10, no. 12, 4186, 2020**.**

[15] S. Seo, S. D. Oh, and H. Y. Kwak, "Wind Turbine Power Curve Modeling Using Maximum Likelihood Estimation Method," *Renewable Energy*, vol. 136, pp. 1164-1169, 2019.

[16] D. Villanueva, A. Sixto, A. Feijoo, A. Fernandez, and E. Miguez, "Methods to Apply A 3-Parameter Logistic Model to Wind Turbine Data," *Applied Sciences*, vol. 10, no. 9, 3317, 2020.

[17] S. M. Sadeghi, M. Daryalal, and M. Abasi, "Two-Stage Planning of Synchronous Distributed Generations in Distribution Network Considering Protection Coordination Index and Optimal Operation Situation," *IET Renewable Power Generation*, vol. 16, no. 11, pp. 2338-2356, 2022.

[18] M. Abasi, A. Saffarian, M. Joorabian, and S. G. Seifossadat, "Location of Double-Circuit Grounded Cross-Country Faults in GUPFC-Compensated Transmission Lines Based on Current and Voltage Phasors Analysis," *Electric Power Systems Research*, vol. 195, 107124, 2021.

[19] S. Han, Y. Qiao, et al., "Wind Turbine Power Curve Modeling Based on Interval Extreme Probability Density for the Integration of Renewable Energies and Electric Vehicles," *Renewable Energy*, vol. 157, pp. 190-203, 2020.

[20] G. Demurtas "Power Curve Measurement with Spinner Anemometer According to IEC 61400-12-2.", DTU Wind Energy. DTU Wind Energy I No. 0440, 2015.

[21] M. Abasi, A. T. Farsani, A. Rohani, and A. Beigzadeh, "A Novel Fuzzy Theory-Based Differential Protection Scheme for Transmission Lines," *International Journal of Integrated Engineering*, vol. 12, no. 8, pp. 149-160, 2020.

[22] S. Markarian, F. Fazelpour, and E. Markarian, "Optimization of Wind Farm Layout Considering Wake Effect and Multiple Parameters," *Environmental Progress & Sustainable Energy*, vol. 38, no. 5, 13193, 2019.

[23] R. K. Pandit, D. Infield, and J. Carroll, "Incorporating Air Density into A Gaussian Process Wind Turbine Power Curve Model for Improving Fitting Accuracy," *Wind Energy*, vol. 22, no. 12, pp. 1675-1687, 2019.

[24] S. Diaz, J. A. Carta, and J. M. Matias, "Performance Assessment of Five MCP Models Proposed for the Estimation of Long-Term Wind Turbine Power Outputs at a Target Site Using Three Machine Learning Techniques," *Applied Energy*, vol. 209, pp. 455-477, 2018.

[25] P. Giorsetto, and K. F. Utsurogi, "Development of a New Procedure for Reliability Modeling of Wind Turbine Generators," *IEEE Transactions on Power Apparatus and Systems*, vol. 102, no. 1, pp. 134-143, 1983.

[26] M. Abasi, N. Heydarzadeh, and A. Rohani, "Broken Conductor Fault Location in Power Transmission Lines Using GMDH Function and Single-Terminal Data Independent of Line Parameters," *Journal of Applied Research in Electrical Engineering*, vol. 1, no. 1, pp. 22-32, 2021.

[27] Ministry of Energy, Renewable Energy and Energy Efficiency Organization (SATBA).

[28] Iran Grid Management Company.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, redundancy, have been completely observed by the authors.

Credit Authorship Contribution Statement

AliAsghar Karimi Taleb: Conceptualization, Formal analysis, Project administration, Supervision, Validation, Roles/Writing - original draft. **Hojatollah Makvandi:** Conceptualization, Investigation, Methodology, Resources, Visualization, Writing - review & editing. **Ashknaz Oraee:** Formal analysis, Investigation, Software, Roles/Writing - original draft.

Bibliography

AliAsghar Karimi Taleb received the B.Eng. degree in Electronic Engineering from Razi University Kermanshah, Kermanshah, Iran., in 2014, and the MSc. degree in Power System Engineering from Sharif University of Technology, Tehran, Iran, in 2017. He is a PhD candidate in Electrical Power Engineering in Shahid Chamran University of Ahvaz, Ahvaz, Iran. He works as a design and supervision expert for the installation of electrical facilities and structures, Khuzestan Water and Power Authority (KWPA), Ministry of Energy of Iran, Ahvaz, Iran. His current research interests include smart grid and microgrid and influence of renewable energy on power systems.

Hojatollah Makvandi was born in 1975 in Iran. He received the Ph.D. degree in Electrical Power Engineering in 2020 from the Dezful Branch, Islamic Azad University, Dezful, Iran. He is a utility and power plant manager in the Abadan Oil Refining Company. His research interests include gas and steam turbine, micro-grid and islanding, and FACTS devices.

Ashknaz Oraee (Member, IEEE) received the B.Eng. degree in Electrical Engineering from Kings College London, London, U.K., in 2011, and the Ph.D. degree in Electrical Engineering from Cambridge University, Cambridge, U.K., in 2015, focusing on electrical machine design and optimization. She is a member of faculty in Sadjad University, Mashhad, Iran. Her current research interests include electrical machines and drives for renewable power generation.