Power Curve Analytics for Wind Turbine

Ms. Parul Muneshwar[1],Ms. Naziya Pathan[2], Dr. Arif Khan[3]

[1]Research Scholar, Nuva College of Engineering and Technology (NCET), Kalmeshwar, Nagpur, India

[2]Assistant Professor, M. Tech. (CSE), NCET, Kalmeshwar, Nagpur, India

[3]Principal, NCET, Kalmeshwar, Nagpur, India

parul.bahekar@gmail.com, pathan.naziya@gmail.com, arif3456@gmail.com

Abstract

The manufacturer-provided power curve for a wind turbine indicates the expected power output for a given wind speed and air density. This work presents a performance analytic that uses the measured power as well as by degradation in performance of worn or failing components and the power curve to compute a residual power. Because the power curve is not site-specific, the residual is masked by it and other external factors. We delineate operational regimes and develop statistical condition indicators to adaptively trend turbine performance and isolate failing components. Power curve provided by manufacturer is mainly use for forecasting, planning and predictive analysis so exact power curve for the Wind turbine is very important factor for prognostic analysis. To include wind turbines legacy for which we may not have a manufacturer's power curve an extended approach introduced to establish a baseline of the power curve. The approach is demonstrated using supervisory control and data acquisition (SCADA) system data.

Keywords- *Wind turbine, Power curve analysis, SCADA*

1. Introduction

Overall cost effectiveness has been impacted by operation and maintenance high cost for wind turbine. And Major part of cost under unscheduled maintenance cost due to unexpected failures.

With the help of automated failure detection algorithms for continuous performance monitoring of wind turbine can improve turbine reliability, reduce the maintenance cost and also prevent the loss of production. This early failure detection reduce the damage repair cost before reaching the component to the catastrophic stage.

Power curve is one of the indicator to check the wind turbine health. Many failures and performance deterioration mechanisms can manifest in the measured power curve. By exploiting this measure with commonly collected supervisory control and data acquisition (SCADA) system information, we can provide early indications of failures or severe performance deterioration [1].

This paper present the approach to find out the performance deterioration of wind turbine within the group of turbines in same wind farm by Power curve analysis.

2. Working of wind turbine

A wind turbine is a rotating machine in which kinetic energy of wind is converted into mechanical energy. If the mechanical energy is used directly to the machinery, such as pump or grinding machine, the machine is usually called windmill. If the mechanical energy is converted in to electrical energy, then the machine is called wind generator or wind turbine, Wind turbine generator (WTG), Wind energy converter (WEC) or aero Generator. The wind turbine technology is the most promising renewable energy technology. It started in 80's decade with a few tens of KW production of power per unit. And today multi-MW size wind turbines are being installed. Wind power production in the beginning, did not have any impact on the power control system and was based on the induction generator where the pulsations in the wind was directly transferred to the grid. There was no control active and reactive power which are the important control parameter to regulate the frequency and voltage. As the power range of the generator increases those control parameters become more important and it is necessary to introduce power electronics as an interface between the wind turbine and the grid. The power electronics is changing the basic characteristic of the wind turbine from being an energy source to be an active power source. There are three main factor which affect the electrical power output of a wind turbine converter (WEC): Wind speed distribution of the particular/selected site, Turbine tower height and the power output of selected turbine model.

Every wind turbine has a unique power curve. Even same rating turbines may give different power output at the same location and at equal wind speed. The important characteristic speeds of the turbine are its cut-in wind speed, rated wind speed and cut-out wind speed. The turbine starts to rotate and generate the power at cut-in wind speed. The power output reaches at Maximum limit of electrical generator at rated wind speed (Figure 1). For the safety reason turbine is stopped at cut-out wind speed to avoid damages.

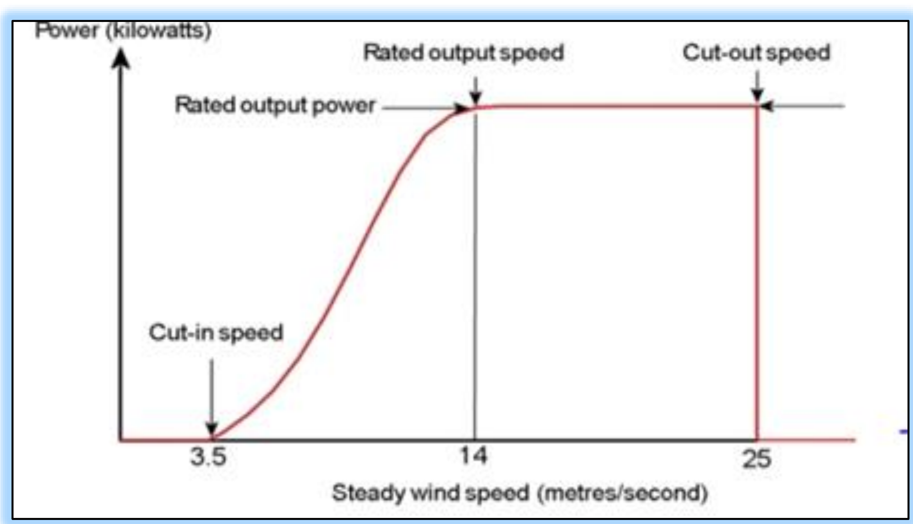

Figure 1: Typical Wind Turbine power output with steady wind speed [6]

The Betz limit is the theoretical maximum efficiency for a wind turbine, conjectured by German physicist Albert Betz in 1919.[2] Betz concluded that this value is 59.3%, meaning that at most only 59.3% of the kinetic energy from wind can be used to spin the turbine and generate electricity. In reality, turbines cannot reach the Betz limit, and common efficiencies are in the 35-45% range.[2]

The theoretical power captured (P) by a wind turbine is given by

$$P = 1/2 \rho Aw\, (\lambda,)3 \qquad [6]$$

Where :
P: Power output of wind turbine (W)
V: Wind speed (m/s)
Aw: Area swept by the rotor blades (m2)
ρ: Air density (kg/m3)
λ: Tip speed ratio
β: Pitch angle (degree)
Cp: Power coefficient of wind turbine

The power production of a wind turbine (WT) thus depends upon many parameters such as wind speed, wind direction, air density (a function of temperature, pressure, and humidity) and turbine parameters [3]

It is therefore difficult to evaluate the output power using the theoretical equation given above as much complexity involved in considering all influence parameters.

3. Necessity of Power curve for Wind Turbine

The power curve reflects the exact generation of power of a particular turbine at various wind speeds.

3.1 Power generation forecasting – Process of estimating energy is done by using the available wind data and wind turbine power curve. The accuracy in estimated power output of the turbine is important as an overestimation can result in poor performance and an underestimation can lead to hamper the reliability of the turbine in considered client site. Need have forecast the power output of turbines should be accurate, so that wind turbine operators will be able to deliver the traded amount of power at the time of trading the power directly to the electricity market.

3.2 Selection of Turbines. The power curve can be used to make generic comparison between models and can aid in the choice of turbine from the available options. The selection of the turbine characteristics which match with the wind regime of the site helps in optimizing the efficiency of wind energy system [4].

3.3 Monitoring the performance of Turbine: Monitoring the performance of turbines with the help of Power curves, calculate reference power curve which represents health condition of the turbine. This reference curve can be calculated from measured power output and wind speed data of wind turbines. The actual curve of the turbine can be compared with this reference curve. The deviations of the actual values from the reference output can indicate underperformance of the turbine or some fault will be occur in nearest future, The difference in the reference power curve and actual power curve of the turbine leads to define the underperformance and over performance of the turbine.

4. Factors affect for Wind Power

4.1 Wind condition at site: Wind is highly stochastic in nature. The wind speed and the direction change continuously. The wind at a particular site is affected by weather phenomena and topology of the site. The turbulence of wind at a given location affects the power production. Obstacles like trees, buildings, and other high structures influence the wind speed.

4.2 Air Density: The pressure, temperature and humidity of site affect the air density hence affecting the power produced. Different air density leads to generate different types of power curve for a same model turbine (figure 2). Temperature has the highest influence on air density.

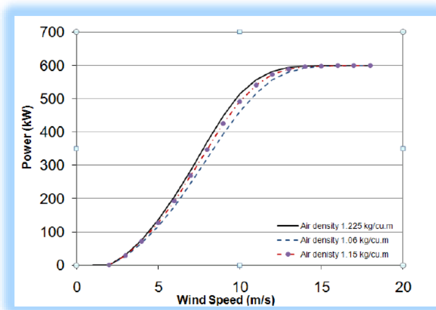

Figure 2: Power curve for different values of air density [1]

4.3 Extrapolation of Wind Speed: The wind speed changes with height. This wind shear effect is affected the roughness of terrain. The power curve uses the wind speed measured at the hub height of turbine, but this height varies with different models and manufacturers, and it is not always possible to measure the wind speed at particular height. Also, the wind speed measured at the masts is different from the wind speed at the turbine location. Sometimes when the wind speed values at the particular site are not available the wind speed measurements from a nearby location are also used to determine the wind profile of this site. The accuracy of conversion of the measured wind speed to wind speed at hub height and at the turbine location depends on factors such as the vertical wind profile at the site, position of masts relative to the turbine, and the method used for extrapolation.

4.4 Turbine condition: The power curve is affected by the condition of turbine and associated equipment's. Aging and wear-tear of turbine anomalies and faults, blade conditions (ice and dust deposited on blades), Yaw and pitch misalignment, controller settings may leads to depart power curve from actual values.

5. Power curve Models classification

The power curve modelling methods can be classified into discrete, deterministic, probabilistic and stochastic methods or they can be classified on the basis of data used for modelling.

5.1 Discrete Models: In this method as described in IEC 61400-12 all the wind speeds are discretized into 0.5m/s bins . The power output for each bin is then modelled. This is a simple method as it does not require mathematical functions for describing the curve. Also it takes into account the nonlinear wind speed-power output relation. However a large number of data are required in this method to develop a reliable model [6].

5.2 Deterministic models: A deterministic power curve model had been a rigid relation between the output power and wind speed. But when a fleet of wind turbines are deployed on a particular site, turbines of the same type may produce different amount of power for the same wind speed, this may be affect due to terrain effect for that particular wind site.

5.3 Probabilistic Models: A probabilistic power curve model define the relationship between wind speed and actual output powers of the turbine with the help of variations in the power of the turbine.

5.4 Presumed Shape models: The models of power curves can be classified according to the data being used for modelling. Models of power curve based on presumed shape of curve utilize only the cut-in, cut-off, and rated speeds and the rated power of the selected turbine when the manufacturer's power curve data is available, models can be developed by fitting one or more appropriate expressions to the actual curve. The models derived from actual data of wind farm need the actual wind speed and power output data from an operational wind farm. If the effect of the influencing parameters is also included in the model, then the data of the included parameters is also required. This data can be obtained from the wind farm's SCADA system [6].

5.5 Stochastic Models. The stochastic method consists of characterizing the power performance of wind turbine by evaluating dynamic response against the fluctuating wind speed inputs [7, 8]. The dynamic power output is separated into a deterministic stochastic part in this model. In [9] the Markov chain theory is used to describe the power output of WT. The resulting model is independent of turbulence intensity; however, the effect of other influencing parameters is not taken into account in this method.

6 Approaches for Power curve

6.1 Data Preprocessing: The power curve derived from actual wind speed and power output data of wind turbines uses SCADA data from the wind turbines. This data is prone to errors due to measurement, sensor, and communications system errors. The data is also affected by nonproduction of turbines when it is shut down by the control system for some reason other than anomalous operation. SCADA system can have null entries or erroneous data which can result in inaccurate models. Hence it is necessary to remove these misleading entries before using this data for further analyses. The most common method is to remove the data manually. These outliers can be identified by visual inspection of wind speed power output plot and can be removed before proceeding for development of model. However the method can lead to inaccurate results as the data from SCADA system is voluminous and it is difficult to differentiate between correct and erroneous data. These outliers have been removed by different statistical methods in various works before development of models. In [10] the analysis of residuals together with control charts is used to filter potential outliers. The outliers can be detected by classical least mean square (LMS) method which minimizes the sum of the squares over all the measurements and if a measurement is found to be far away from the correct value it prevails in the resulting fitting; however, in this method a single outlier point can destroy the fitting. In [11] least median of squares method is used for data preprocessing in which instead of the sum as in LMS method sum of medians is minimized to identify the outliers. It is shown that this method is very robust; however it requires iterative solution. The wind data preprocessing is done in four steps in [12] which include validity check, data scaling, missing data processing, and lag removal [6].

6.2 Clustering Methods. Clustering is grouping of similar data into classes or clusters. A wind farm having many wind turbine generators has variable power outputs due to variation of wind speed. Efficient power curve can be found by applying clustering methods. Power curve characterization by cluster center, fuzzy C-means, and subtractive clustering methods is done in. Fuzzy clustering applies the concept of fuzzy sets to cluster analysis and belongingness of each point of data set to a group is given by a membership function. The method has the advantage of adapting noisy data [6].

6.3 Data Mining. Data mining refers to extracting or mining knowledge from large amounts of data [13]. Developments in data mining offer promising approaches for modelling power curves of wind turbines. Selection of appropriate data mining method and algorithm is important to get accurate, stable, and robust power curve. Different data mining algorithms, namely, MLP, REP tree, M5P tree, bagging tree, and k- nearest neighbor algorithms, are used to build models for power prediction and online monitoring in [10].

7 Selection of Power curve modelling methods

There are many approaches and models are proposed to decide the Wind turbine power curve. Deciding the proper model and approach adopted for a specific application is important and is a difficult task. On the basis of reviewed literature the following points are identified for selection of modelling methodology.

7.1 Wind Turbine power curve models required for initial wind resource assessment need handy methods for estimation of energy. Wind power output calculation and energy estimation which are done during designing of wind based systems need a power curve model with fair degree of accuracy. When only specification values (cut-in, cut-off, and rated speeds and the rated power) for a wind turbine are available, the polynomial models based on presumed shape can be used. These models can also be used as a handy tool for calculation of wind turbine output during design stage of wind farms because of the simplicity of calculations. When the manufacturers' curve data is available it is preferable to fit a polynomial function to the data as it results in better accuracy. These models are thus suitable for modelling of single turbines for predicting power for small systems where fairly accurate accuracy is desired [6].

7.2 Wind farm SCADA data is valuable resource which can be retrieved wind speed and power output for a group of turbines. These group of turbines, power output can be used to calculate the Site average of these group of turbines. This site average know as Site average Power curve.

Test Cases:

We have tested the power curve analytics approach with SCADA data from a particular wind form with same models turbines.

Method I

We obtained SCADA data for a wind farm having 15 turbines with same model. SCADA data is available for 10 min interval along with the turbine manufacturer provided "Reference curve". The Calculated reference curve having the air density 1.225 kg/cu.m. As show in Figure 2, the power curve is in upward direction of the air density 1.225 kg/cu.m.

The power curve plot for each turbines of the wind form with respect to the Reference power curve.

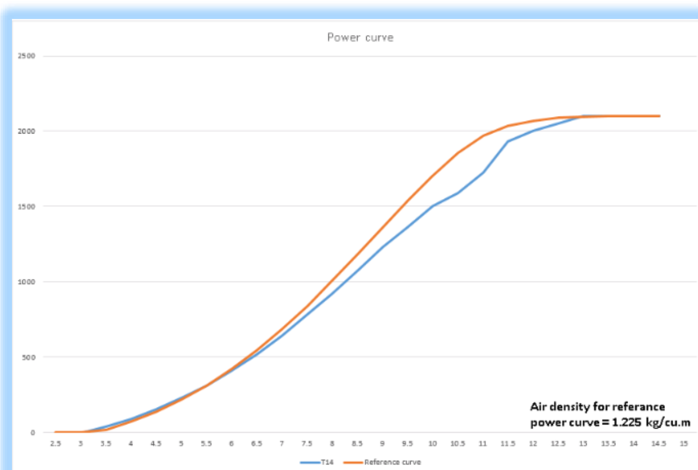

Figure 3: Power curve of turbine with respect to Reference power curve

Figure 3 shows a Power curve of Wind turbine, comparison with reference power curve which is provided by the manufacturer. But this is generic power curve which had been calculated with air density constant. And due to which the huge difference shown by graph. By the plot this show underperforming turbine in that particular wind farm. Due to underperforming, loss in unit price shows more.

Method II

The power curve plot for each turbines of the wind form with respect to the Reference power curve.

We have same 15 turbines data for the wind farm, And along with calculated wind speed binwise average power output for those 15 turbines which is known as the Site average power curve.

Figure 4: Power curve of turbine with respect to Site average power curve

Figure 4 shows the Turbine power curve, comparison with Site average power curve. As Site average power curve taking into consideration result the matching of power curve with actual turbine power curve of same site.

The same wind farm having same model turbine and considering the site Average power curve helps to find out the Outlier turbines within the wind farm. This finding outlier turbine indicator for component diagnostic or prognostics.

8 Conclusion

We showed that the Site average power curve analytic is useful for assessing wind turbine performance and generating robust indicators for component diagnostics and prognostics. The analytic takes advantage of a universal measure of wind turbine performance with commonly collected SCADA information and provides outlier with in the wind farm.

Purpose of considering the Site average power curve is to identify the outlier within wind farm. This wind farm must be having equal air density, humidity and temperature for all the turbine.

It's very difficult task to choice the appropriate method find the Prognostic component failure turbine with the wind farm with respect to the reference power curve. As reference power curve is generically define with considering single air density value for each model for the turbine. So the deviation must be found in the actual power curve of the turbine with reference power curve. So to overcome this issue and finding out the outlier turbine within the wind farm , considering the site average power curve is the good choice for each wind farm.

9 References

[1] Power curve analytic for wind Turbine Performance monitoring and prognostics

[2] REUK, Betz Limit - Wind [Online], Available: http://www.reuk.co.uk/Betz-Limit.html

[3] M. Schlechtingen, I. F. Santos, and S. Achiche, Using data-mining approaches for wind Turbine power curve monitoring: a comparative study," IEEE Transactions on Sustainable Energy,vol. 4, no. 3, pp. 671–679, 2013.

[4] T. Ustuntas and A. D. Sahin, "Wind turbine power curve estimation based on cluster center fuzzy logic modeling," Journal of Wind Engineering and Industrial Aerodynamics, vol. 96, no. 5, pp. 611–620, 2008

[5] https://www.researchgate.net/publication/261046090_Effects_of_complex_wind_regimes_and_meteorlogical_ parameters_on_wind_turbine_performances

[6] A Critical Review on Wind Turbine Power Curve Modelling Techniques and Their Applications in Wind Based Energy Systems

[7] P. Milan, M. Wachter, and J. Peinke, "Stochastic modeling and performancemonitoring ofwind farmpower production," Journal of Renewable and SustainableEnergy, vol. 6, no. 3,Article ID 033119, 2014.

[8] E. Anahua, F. B¨ottcher, S. Barth, J. Peinke, and M. Lange, "Stochastic analysis of the power output for a wind turbine," in Proceedings of the EuropeanWind Energy Conference (EWEC '04), London, UK, November 2004.

[9] E.Anahua, S. Barth, andJ.Peinke, "Markovianpower curves for wind turbines," Wind Energy, vol. 11, no. 3, pp. 219–232, 2008.

[10] A.Kusiak, H. Zheng, and Z. Song, "Models formonitoring wind farmpower," Renewable Energy, vol. 34,no. 3, pp. 583–590,2009.

[11] E. Sainz, A. Llombart, and J. J. Guerrero, "Robust filtering for the characterization of wind turbines: improving its operation andmaintenance," Energy Conversion andManagement, vol. 50, no. 9, pp. 2136–2147, 2009.

[12] M. Schlechtingen and I. Ferreira Santos, "Comparative analysis of neural network and regression based condition monitoring approaches for wind turbine fault detection," Mechanical Systems and Signal Processing, vol. 25, no. 5, pp. 1849–1875, 2011.

[13] J. Han and M. Kamber, Data Mining: Concepts and Techniques, Morgan Kaufmann, San Francisco, Calif, USA, 2006.