Wind Turbine performance with Power Curve Analytics

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Abstract

Power curve of a wind turbine defines the relationship between output power and wind speed as it's an important characteristic of the turbine. Power curve aids in energy assessment and performance monitoring of the turbines. Wind turbines are being installed in diverse climatic conditions, onshore and offshore because of its more demand in market. Accurate power curves models can be an important role in improving the performance of wind turbine. The performance analytic that uses the measured power and the power curve to compute a residual power. The residual power is used to identify degradation in performance of worn or failing components. We delineate operational regimes and develop statistical condition indicators to adaptively identify turbine performance and isolate failing components before they reach to catastrophic stage.

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

1. Introduction

Overall cost expenses towards Wind turbine include major part of operation and maintenance cost. 24X7 monitoring of wind turbine, check the health of the turbine on regular basis. This 24X7 monitoring includes fault detection algorithms and verify the reliability of the turbine. This also reduce the maintenance cost by detecting failure before that reach. The Wind turbine manufacturer provided power curve of wind turbine. This power curve indicates the expected generated power output for a given wind speed on a particular air density. The power curve is not site-specific, calculated the residual power is helps to decide performance of wind turbine. This paper presents wind turbine performance with power curve analytics that uses the measured power and manufactured power for computing residual power of wind turbine. The approach is demonstrated using supervisory control and data acquisition (SCADA) system data. While early indication of failure is needed, it is equally important to minimize false warnings which is observed in SCADA data.

2. Wind Turbine Components

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 turbine.

- **Anemomete**r

  The measurement of wind speeds is usually done using anemometer. The electronic signal from anemometer passes to the controller to start the wind turbine when wind speed reaches to the cut in speed. And computer also stop the turbine as wind speed reaches to the cut out speed. This helps to protect the wind turbine from damage happens due to high wind speed.
- **Wind vane**

  The wind vane signals are used by the wind turbine's electronic controller to turn the wind turbine against the wind. Yaw mechanism used to capture more wind by Wind turbine for producing higher power output.
- **Rotor Blades**

  Rotor blades are the most highly stressed and important component of any wind turbine. Rotor Blades absorb the kinetic power of the wind and convert this energy into a rotary motion for rotating the low speed shaft.
- **Gearbox**

  Gearbox is typically used in a **wind turbine** to increase rotational speed from a low-speed rotor to a higher speed electrical generator.
- **Generator**

  The energy in the **wind** turns three propeller-like blades around a rotor. The rotor is connected to the low speed shaft and then convert energy through high speed shaft which spins a **generator** to create electricity.
- **Nacelle**

  Nacelle is housing cover which include Generator, Gearbox, drive train and brake assembly
- **Tower**

  Tower of wind turbine support the power generating components at a particular height. This tower height is one of the factor which affect the electrical power output.

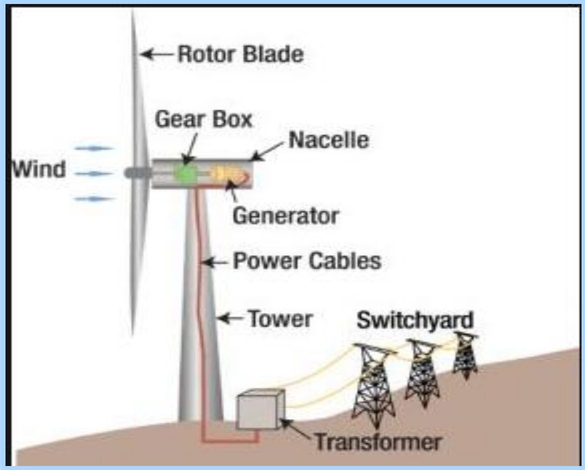

Figure 1: Typical Wind Turbine Components [1]

3. Working of Wind turbine

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 2). For the safety reason turbine is stopped at cut-out wind speed to avoid damages [3]

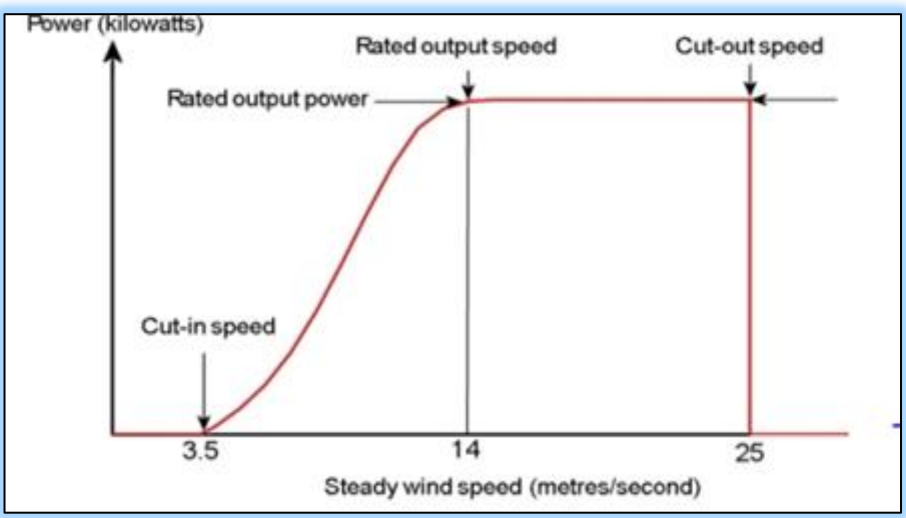

Figure 2: Typical Wind Turbine power output with steady wind speed [2]

The Betz limit is the theoretical maximum efficiency for a wind turbine, conjectured by German physicist Albert Betz in 1919. 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.

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

$$P = 1/2 \rho Aw\ (\lambda,)3$$

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

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].

4. Importance of Power curve

4.1 Wind Power Forecasting: Power curve of wind turbine helps to estimate the energy generation using available wind speed. Wind Power forecasting is important to decide the performance of the turbines. If overestimation can result the poor performance of the turbine while underestimation may be hamper the reliability of the turbine output. Power output directly impact to the electricity market as traded amount.

4.2 Turbine selection: Power curve of the turbine helps to decide the comparison between the models of the turbines also add the choices of the turbines for generation of power output.

4.3 Wind Turbine performance: Power curve of the turbine helps to decide the performance of Wind turbine. As wind turbine manufacturer provided the reference power curve of the turbine. Actual generated power has been compare with the reference power curve also helps to decide the performance of the wind turbine. Underperforming turbine needs physical component checkup while over performing turbine needs health checkup properly.

5. Generation of Power curve

We use power curves provided by the manufacturer when available as the base power curve model. In the absence of a manufacturer-provided power curve SCADA data can be used to generate one. There are number of factors affected to power curve of the turbine like wind condition, air density, wind speed and turbine condition. Different temperature, pressure and humidity varies the air density to the different site (figure 3)

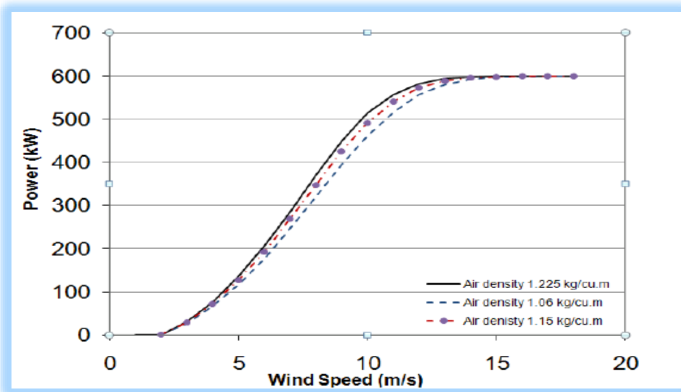

Figure 3: Power curve for different values of air density [4]

The actual power curve may deviate from the nominal one due to site-specific factors [5], A complex terrain, as opposed to a benign one (as defined in the standards), and different meteorological conditions, such as varying wind direction, wind shear, and turbulence intensity can cause shifts in the power curve from the nominal [4]

6. Power curve comparison

Power curve comparison is important part for check the health of the turbine and also isolate the failing component. Power curve usually used to forecasting planning and predictive analysis so exact power curve of the turbine is very important factor for prognostic analysis.

6.1 Reference power curve: Manufacturer provided the power curve, which is generic for the model of turbine in spite of site condition, wind speed and temperature.

6.2 Site specific power curve: Wind turbine owner has to calculate site specific power curve for individual model of the turbine. This power curve is vary model to model of the turbine. SCADA data is major role to calculate the site specific power curve of the turbine. This also consider the air density factor for particular site of the wind turbine with respect to the actual generated power.

7. Generation of Residual power

SCADA data is valuable resource which can be retrieved actual power of the turbine. The Residual power can be calculate with the help of Expected power and the actual power of the turbine. The difference between actual power and expected power is the residual power. Before calculating the residual power of the turbine need to calculate expected power of the turbine. Expected power depends on the air density which can be calculated using either of the following equation

$$\rho = p / RT$$

or

$$\rho = (p0 / RT) \exp(gz/RT)$$

where ρ is the air density at location in kg/m3, $p0$ is the standard sea level atmospheric pressure, p is the air pressure in Newtons/m2, T is the ambient air temperature in Kelvin, z is the location altitude in meters, and R is the specific gas constant (287 J kg-1 Kelvin-1).
When air density, wind speed, and, in turn, the expected power are available, the power residual can be readily calculated:

Power_residual = Power_actual – Power_expected [4]

Test Cases:
We have tested the power curve analytics approach with SCADA data from a particular wind farm with same models turbines and finding out deviated turbines within the wind farm on the basis of percentage of loss of residual power.

Method I

We obtained SCADA data for a wind farm having 50 turbines with same model. SCADA data is available along with the turbine manufacturer provided power curve i.e. Reference Power curve .
Out of 50 turbines considered 5 turbines of same wind farm. The power curve plot for these turbines of the wind farm (figure 4)

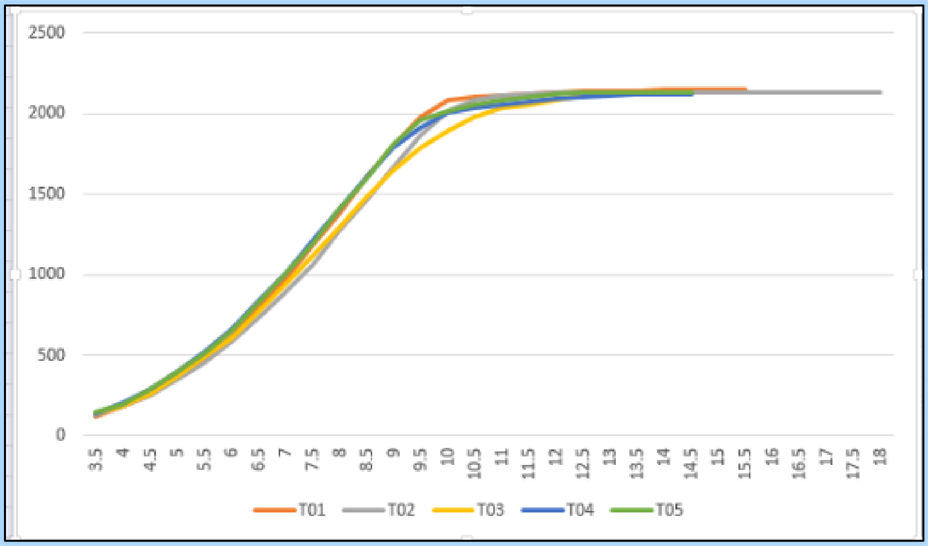

Figure 4: Power curve for same model turbines of a wind farm

Figure 4 shows the power curve of each turbine, but it's unable to identify the power curve deviated turbine from the cluster of the wind in the wind farm.

And if comparing these cluster turbines with respect to the Reference power curve (figure 5)

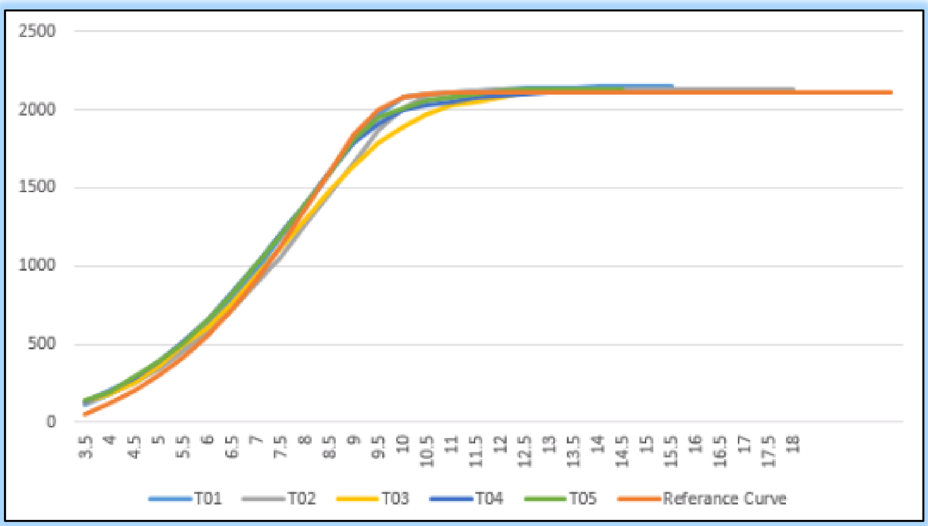

Figure 5: Power curve for same model turbines of a wind farm compare with reference power curve

Figure 5 shows power curve of cluster of the turbines with reference power curve and this helps to identify the underperforming turbine from the cluster of turbines of wind farm.

Method II

We retrieved same SCADA data for same 50 turbines of same model of wind farm. And calculated actual power of each turbines and also get the Expected power from Manufacture provided reference power curve for particular wind speed. These two values helps to calculate residual power of each turbine (Table 1).

Residual Power helps to find the total power loss of the turbine with respect to expected power

Turbine	Actual Power	Expected Power	Residual Power	% Power loss
T01	37384.69	36521.67	863.02	2.36%
T02	46957.47	47073.95	-116.48	-0.25%
T03	29716.56	30191.15	-474.59	-1.57%
T04	32945.14	32301.33	643.81	1.99%
T05	33107.68	32301.33	806.35	2.50%

Table 1: Calculated residual Power and Power loss percentage

Table 1 shows the total percentage power loss of each turbines and T03 is more power loss percentage than other four turbines.

8. Conclusion

We showed that the Reference power curve analytic is useful for assessing wind turbine performance with calculating the air density of that particular wind farm site. And this helps to 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 calculation of Residual power is need of output power loss percentage which helps to find the outlier turbine from the cluster of the turbine. This percentage helps to define the criticality of the component diagnostics.

Comparing the power curve of the turbine with manufactured Reference power curve finds the outlier from wind farm. But with the calculated loss of power of each turbine helps to decide the underperforming turbine within the cluster of wind farm. Power curve with percentage loss in power helps to finding outlier turbine from the cluster. This finding outlier turbine indicator adds components diagnostics and prognostic check criticality wise.

9. References

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