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A preliminary analysis of wind turbine energy yield

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Abstract

Despite the rapid and extensive growth of wind power, a challenge still faced by wind power operators is the intermittency of wind speed and thus wind power. On different time scales, the stochastic nature of wind speed has impacts on the energy yield from wind turbines. While long term estimates of wind power are ideal for energy mix planning and policy, knowledge of variations in very short-term output is essential for energy grid management, turbine control system and wind power optimization. This study analyzed energy yield from an 800kW operational wind turbine using 15-seconds time-series data averaged into 1, 5, and 15 minutes time steps for cumulative periods of 1 hour, 4 hours and 12 hours respectively. In the three case scenarios explored, theoretical output under-estimated turbine yield within a range of 5% - 48%. The lowest errors recorded were 5%, 14% and - 0.34% for the time series considered although the estimation errors were larger for the higher time intervals generally. Cases of 0 kW turbine output despite wind speed value above the cut-in speed (i.e u > 3m/s) suggest that wind direction may impact turbine yield. The effect of turbine blade momentum was also more evident in some time-steps where yield was sustained despite fall in wind speed to below 3m/s. The results show that the 15 minutes time steps series is more beneficial in short-term energy yield estimations and show the usefulness of short-term yield estimations for wind power operators, grid management and wind power optimization.

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Keywords: theoretical output; wind time-series, energy grid, wind turbine operators, wind power estimation.

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1. Introduction

The wind energy industry has grown considerably in recent years with advances in global installed wind capacity, turbine design and configurations as well as increased investment in wind power. Countries such as Spain, Denmark, Portugal, Germany, Australia, China etc. have gradually introduced and increased the share of wind energy source in their energy mix portfolio [1-5]. Despite these, community scale application of wind energy especially in developing and emerging economies is still limited.

Wind power intermittency stems from the wind speed variation ranging from seconds to hours and even daily [5-7]. Wind speed variation also means that wind power would be intermittent, as it is determined by wind speed. Wind resource assessment is usually conducted by using a theoretical probability distribution (PDF) such as Weibull distribution derived from mean wind speed or other wind characteristics for the proposed site of a turbine or wind farm [8-11]. More specifically for a particular wind turbine (or wind farm), a specific wind power relationship called the Theoretical Power Curve (TPC) is used for estimating the turbine yield at given wind speeds.

Significant deviations however more commonly exists between the turbine yield and theoretical output (estimated from the TPC) found in the works of [12-15]. Majority of these studies used hourly averages of wind speed and corresponding power to investigate the ability of the Weibull distribution to; estimate wind power, assess wind resources potential and, frame policy intervention. Short time scale time-series performance of wind turbines and wind farms are quite pertinent to the wind energy market, energy conversion and storage systems as well as electricity providers who are concerned about uninterrupted power supply, grid stability and reliability [7].

The target of this study is therefore to assess wind turbine performance under time-series scenario in a bid to guide the operations of the sectors concerned. More importantly also is to identify (if any) external factors or circumstances that may be responsible for deviation of turbine yield from the theoretical output. The focus is not on wind resources assessment but rather performance, and that this study is not an attempt to discredit the wide-spread application of the TPC and Weibull fit distribution.

2. Methodology

Energy yield from an 800 kW wind turbine (WT) was collected in 15 seconds time steps from the 22nd of August 2016 till the 6th of September 2016. The WT has a blade swept area of 1964 m^2 and efficiency ranging from 21% to 42% depending on wind speed. In all, over 75,000 wind speed and turbine yield data pairs were available.

The wind speed and wind power were averaged for categories of 1 minute, 5 minutes and 15 minutes. For these 3 time-steps, random selections were made to incorporate various daily occurrences of wind speed variation. The random selection was conditioned to accommodate everyday situations without bias, bearing in mind the interests of the stakeholders previously discussed in the introduction.

Actual energy yield was then compared with the Theoretical energy output based on the TPC which can be estimated using the Wind Power equation 2 below [7].

$$P = \frac{1}{2} C_p \rho A_b u^3 \qquad (1)$$

Where P = power output, Cp is turbine efficiency/coefficient of performance, ρ is air density, Ab is blade area and u is the wind speed. It is important to recognize three important regions of wind speed in the TPC of every turbine. The cut-in speed (3.0 m/s) below which the turbine blades cannot spin. The rated speed (15.0 > v < 25.0 m/s) which is the wind speed range at which turbine output is maximum producing the rated power. The cut-out speed (25.0 m/s) is the wind speed above which the turbine shuts down to protect itself hence no output at this speed.