Probabilistic Evaluation of Wind Power Generation

N.M. Muhamad Razali, Muizzuddin Misbah
Universiti Tenaga Nasional,
Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia

E-mail: noormiza@uniten.edu.my

Abstract. The power supplied by wind turbine generators (WTG) is widely random following the stochastic nature of weather conditions. For planning and decision making purposes, understanding and evaluation of the behaviour and distribution of WTG’s output power are crucial. Monte Carlo simulation enables the realization of artificial futures by generating a huge number of sample paths of outcomes to perform this analysis. The paper presents an algorithm developed for a random wind speed generator governed by the probability density function of Weibull distribution and evaluates the WTG’s output by using the power curve of wind turbines. The method may facilitate assessment of suitable turbine site as well as generator selection and sizing.

1. Introduction

Wind energy has enjoyed robust growth in recent years, driven by a combination of factors; for example advancements in wind technologies, falling capital costs, abundance of the free resource and a number of government initiatives designed to encourage wind energy. Fuelling much of the government support for wind energy are environmental concerns. Although the impact of wind energy on the environment is not negligible, it is much lower than those of current fossil fuel technologies.

During generation planning activities, it is crucial for planners to take into account as many uncertainties and economic factors as possible that may affect the physical construction, financial obligations and operation of the power plant. Risk management practice is normally based on extensive simulations and analysis specific to the fuel type and role of each generation unit and the local grid system. Wind generators however pose an additional challenge, as the power supplied is widely random following the random nature of weather conditions.

Understanding of wind potential will facilitate estimation of how much energy will be produced. Conventional method for determining suitable wind turbine location is by using "wind power classes” which are dependent on the average wind speed and the wind power density indicating how much energy is available at the site for conversion by a wind turbine.

Wind resources are rarely consistent and vary with time, season, terrain type, height above ground, and from year to year, thus thorough investigation is needed before planning any exploitation [1]. Due to the stochastic nature of the wind resource, a probabilistic approach during investment and operational planning may be much more appropriate than the deterministic approach normally used by electricity utilities [2]. Therefore, knowledge of the wind speed frequency distribution is very important to evaluate the wind turbine potential and economic feasibility of any particular site. This paper presents a methodology applying probabilistic analysis to evaluate the WTG output which can assist in site and turbine selection for wind-type generation planning. Monte-Carlo simulations

1 To whom any correspondence should be addressed.

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governed by the PDF of the wind distribution at a particular location imitated the uncertainty of average hourly wind speed. Simulations were conducted on MATLAB platform and utilized the in-built Distribution Fitting Tool and Statistical Toolbox. The wind speed data is based on a coastal location in Malaysia.

2. Probability Distribution of Wind Speed
There are several PDFs which can be used to describe the wind speed frequency curve; the Weibull, Rayleigh and Lognormal, as these functions are able to model skewed distributions. The Weibull can be positively or negatively skewed while the Lognormal can only be positively skewed. On the other hand, Rayleigh is a special case of Weibull function with shape parameter of 2. In other words, the Weibull distribution is a generalization of the Rayleigh distribution. Among the three, Weibull is thus more flexible in describing probability distribution of wind speed which varies from location to location. The general type Weibull distribution consists of three parameters, the shape, scale and location parameters. The location parameter is often not considered as it has zero value when the distribution starts at zero in the x-axis, which is the case with wind speed as the lowest recorded speed is usually 0 m/s. Therefore, the two-parameter Weibull distribution has been the most widely used and accepted model in the specialized literature on wind energy [3] and is normally a good fit to the experimental data.

For this study, the wind speed data used to obtain the WTG output are based on the January wind profile at Mersing, Johor, Malaysia [4]. From the historical data at Mersing, it was determined that the Weibull parameters for the month of January are \( k = 2.776 \) and \( \lambda = 4.900 \) where \( k \) is the Weibull shape parameter and \( \lambda \) is the Weibull scale parameter, therefore, this yield the following Weibull PDF:

\[
f(x) = \begin{cases} 
\frac{2.776}{4.9} \left( \frac{x}{4.9} \right)^{2.776} & x \geq 0 \\
0 & x < 0
\end{cases}
\]

(1)

where \( x \) is the wind speed. The Weibull shape parameter of Mersing approximate a normal distribution as is falls between \( 2.6 < k < 3.7 \). Noting that the historical data collected at the observation site is at the anemometer hub height, the speed is converted to wind speed at wind turbine generator hub according to the following equation [5]:

\[
V_{WTG} = V_r \left( \frac{h_{WTG}}{h_r} \right)^b (1 - 0.01\beta)
\]

(2)

where,
- \( h_{WTG} \) is the wind turbine generator hub height in m;
- \( h_r \) is the reading height for historical wind data in m;
- \( V_r \) is the historical wind speed data in m/s;
- \( b \) is the roughness coefficient, and
- \( \beta \) is the turbulence coefficient

A very low value of roughness coefficient (e.g. in flat grassy plains) results in almost negligible wind speed difference between \( h_{WTG} \) and \( h_r \) while a high value (e.g. in cities and forests) results in significant wind speed difference.

3. The Developed Algorithm
The flowchart for the developed algorithm is presented in figure 1. The methodology employs the concept of Monte Carlo simulation which calculates numerous scenarios of a model by repeatedly picking values from a user-predefined probability distribution for the uncertain variables and using those values for the model [6]. As all those scenarios produce associated results in a model, each scenario can have a forecast. Forecasts are events (usually with formulas or functions) that are defined as important outputs of the model. Sufficient number of repetitions or iterations is required to arrive at a statistically viable result.
For each simulated day, the wind turbine’s Forced Outage Rate (FOR) of 2% [7] is taken into account. In order to model the generator availability, for each day, a uniform random variable, $m$ with value $0 \leq m \leq 1$ is generated and compared with the threshold of the FOR, $\alpha = 0.02$. If the realization of variable $m$ is less than or equal to $\alpha$, the wind generator is unavailable as it is subjected to forced outage. On the other hand, if the realization exceeds $\alpha$, the algorithm generate stochastic wind speed for each hour of the day and convert this speed to generator output using a specified power curve. In this study, the Goldwind 1.5 MW wind turbine model has been used for simulation purposes.

**Figure 1.** The flowchart for wind turbine output

4. **Results and Discussion**

Based on the Cumulative Distribution Function (CDF) of the generated wind speed in figure 2, it was found that 92.1% of the time, the wind speed is less than 6.0 m/s which is lower than the rated wind speed of the turbine. From figure 3, it can be observed that 20% of the time, the wind turbine generator (WTG) produces zero output including the time it was put under forced outage. Only 1.11% of the time the WTG produced the maximum output of 1500 kW. However, more than 40% of the time, the WTG produce output more than 80% which is 1200 kW even though the wind speed is low. This is the result from using a low-speed wind turbine with rated wind speed of 6.5 m/s which is efficient in low-wind speed area.
5. Conclusions

Evaluation of renewable generation technologies which depend on randomly-varying weather conditions such as wind turbine requires stochastic modelling and simulation technique such as the Monte Carlo method in order to capture its inherent behaviour. The results showed that this method is applicable to evaluate the distribution analysis of the wind generator output. The presented method can be used to assess optimal site for WTG as different location would have different wind profile as well as to assist in generator selection and sizing as different types of turbine would have different power curve and rated speed characteristics. The goal of optimizing the design for wind turbine generator in wind farm should be to utilize wind energy as efficiently as possible and to reduce production cost of wind power generation. Another possible application of this analysis is the location-based determination of wind energy tariff and risk management to determine appropriate generation mix and scheduling in a particular system.

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