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The importance of mean time in power resource assessment for small wind turbine applications

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A B S T R A C T

Wind turbine for low power applications is a clean energy alternative to contribute global warming mitigation. The correct description of wind speeds is crucial to determine the economic viability of a wind power project. The sampling technique used in resource assessment is supported by van der Hoven's work, which concludes that minimum dispersion occurs between 0.1 and 2 hours mean time. International standards for wind turbine power characterization are also based on this work. Here we analyze the influence of using different mean times over data dispersion and wind resource assessment and analyze an adequate mean time for small wind turbine (*SWT*) applications that contributes to the development of reliable resource assessments. We found a maximum dispersion around 1 minute mean time. The stable wind conditions region was not found in the dispersion analysis presented here. Using this time in *SWT* resource assessment will detect the largest amount of changes in the time series that may contribute to power production. Resource assessments calculated show that using 1 and 10 minutes as mean times generates power resource assessments with a difference around 17%, which may be a factor that prevents *SWT* penetration. There exist at least two factors to obtain reliable power resource assessment, the *SWT* selection and ensemble mean time.

Introduction

The Intergovernmental Panel on Climate Change (*IPCC*) working group III report indicates that in 2010, the building sector consumed 32% of the final used energy in the world. One of the mitigation options is the renewable energy building integration (IPCC, 2014). The resource assessment for small wind turbine (*SWT*) urban applications is studied given the complexity of the system (Ledo et al., 2011) where the knowledge about wind interaction with suburban topology and the turbulence fields are determinant factors for *SWT* adequate location (Araújo et al., 2012; Drew et al., 2013; Sunderland et al., 2013). Recent works (Abraham et al., 2012; Ayhan and Sauglam, 2012; Bhutta et al., 2012) affirm that wind turbines recommended for building sector are the vertical axis wind turbines (*VAWT*); they showed the advantages of *VAWT* over horizontal axis wind turbines (*HAWT*) for small scale power generation.

Furthermore, some features of locally manufactured *SWT* used in rural electrification are the potential to accelerate the local economy as long as all processes involved must be socially embedded ensuring long-term sustainable development (Leary et al., 2012; Zhang and Qi, 2011). Besides, *SWT* as renewable energy source provides a clean source of electric energy that contributes to the increase in the human development index (Leary et al., 2012). Therefore, a key factor for this source penetration is to develop reliable resource assessment methodologies.

The main differences between small and large wind power generation systems are the power demand to meet, the devices' characteristics (Abraham et al., 2012; Dragomirescu, 2011; Kamada and Mikkelsen, 2011), their interactions with complex urban or suburban topography (Ledo et al., 2011; Mertens et al., 2003; Walker, 2011), the fewer requirements of installation, transportation, and technical skills to install, operate, maintain, and repair. Furthermore, deployment of small wind turbine systems avoids substantial investment needed for generating, transmitting, and distributing electricity. Therefore, small and large wind turbine applications should do not be analyzed as equal problems (Ameku et al., 2008; Elizondo et al., 2009).

One of the arguments against massive implementation of small wind turbines is the possibility of perturbing the stability of the electrical grid. However, recent studies have shown that the use of decentralizing power sources, as small scale wind turbines, may facilitate the onset of synchronization in modern power grids (Rohden et al., 2012).

The main element that determines wind power penetration is the resource assessment. This process consists of using only theoretical knowledge of wind speed region conditions, power curves of wind turbines properly selected, and their related costs to estimate power

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production cost. This methodology not only allows studying a particular region but is also useful to model country viability studies (Bortolini et al., 2014), so it can be considered a common and important methodology.

Accurate wind resource assessments are crucial to the successful development of wind farms (Singh et al., 2006). In common practice, the data acquisition system should have a sampling rate of the wind speed at least 0.5 Hz (one measurement per 2 seconds). This raw data is then processed into 10 minute averages where the data sets should be composed of mean, standard deviation, and maximum and minimum values (IEC, 2005).

Ten minute mean ensemble described before is based on van der Hoven's results (van der Hoven, 1957). He introduced the idea that stable wind conditions may be represented by the 10 minute mean ensembles time series. According to their observations, 10 minutes was the time with minimum dispersion among different mean times. The study used data measured in Brookhaven National Lab, Long Island, Upton, New York, located at 40° 52′ 24″ N, 72° 52′ 19″ W. Phenomena of stable wind conditions were also reported by (Wan, 2005). However, in a similar analysis, Rodriguez-Hernandez et al. (2013) described changes in statistical parameters from data located at the intertropical region.

In addition, previous work (Rodriguez-Hernandez et al., 2013) showed that the method of wind resource assessment based on 10 minute mean ensemble could lead to an underestimation of the energy production. The use of averaged velocities eliminates the highest values of the sample leading to lower dispersion values as well central tendency values. Also, it has been shown that different sampling interval of wind speed has an important bearing on the cumulative frequency curves. This will in turn lead to different wind turbine performances calculated based on these data (Makkawi et al., 2009).

Another use of the 10 minute mean ensemble is the methodology described in the international standard (IEC, 2005) about wind turbine power performance, which is mainly oriented to large wind turbines applications. Annex H of the standard is related to *SWT* performance test and is defined as the characterization time of the 1 minute average. Therefore, it is necessary to modify the characterization process in order to improve the reliability of the power curves calculated (Whale et al., 2013) since they are the key factors in techno-economic feasibility studies (Simic et al., 2013); however, there is no mention about the time to use in *SWT* resource assessment.

Moreover, *SWT* applications following this methodology by a user who intends to supply energy for home is not an easy task, which is an obstacle that prevents the penetration of this renewable energy source as electric supplier in domestic applications reducing the social sustainability impact that this renewable energy is capable to provide.

The work presented by Lubitz (2012) showed that for *SWT* under turbulent conditions, the power production is affected. It also mentioned that power curves calculated using IEC methodology do no account this effect of turbulence. Resource assessment using the methodology of the wind turbine power curves and probabilistic distributions presents limitations for the application of *SWT* in urban areas (Walker, 2011).

Here, we analyze the resource assessment methodology with statistical elements that are easy to reproduce and interpret that to help determine project reliability and contribute to social penetration in *SWT* applications. Besides, in the specific case of *SWT*, it is determined if the mean time presented in the standard is a valid value in the intertropical region.

To reach the objective, we discuss and present a mean time adequate for *SWT*. We take into consideration the capacity of small wind turbines to react to sudden gusts, the wind speed power spectrum dispersion analysis, complemented by a study of the influence of the average time in terms of power resource assessment.

Several resource assessments are calculated in order to demonstrate the impact of using a shorter mean time under mean ensemble technique. Three wind speed data samples were calculated by mean ensemble technique from a sampling rate of the wind speed of 1 second. Data used were recorded at Instituto de Energías Renovables, during a period of 50 days at Temixco, Morelos, México. (18° 50′ 23″, 99° 14′ 11″). The data were measured during a period of time of 50 days, with an anemometer "Vaisala Weather Transmitter WXT510" with an accuracy of ±2% installed at 24 m high from ground level, data logger was adjusted to measured and record wind speed with a frequency of 1 Hz. The mean times were established as 1/60, 1/12, and 1/6 of 1 hour. These new data sets, together with power curves of three models of small wind turbines, were used to compute wind power production.

Although it would be reasonable to question the 50 days used in this work, we consider it enough time because we are interested in studying the differences among mean times for a fixed period. In analogy power performance testing for a wind turbine section (n) of Annex H of IEC61400-12-1 (IEC, 2005), only 60 hours of data with specific characteristics are used. Increasing the period of time assessed will result in larger amounts of energy estimated; however, the analysis objects still are the energy differences under several mean times, which are presented and analyzed by percentage amounts.

This paper is organized as follows: first, we present the theoretical elements related to mean ensemble time technique, then we develop the conceptual frame, analysis, and discussion to wind speed dispersion spectrum and *STW* resource assessment. To complement our analysis, a wind resource assessment calculation is developed in order to clearly establish a relation between mean ensemble time and power resource assessment. Finally, the main conclusions are presented.

Wind speed spectrum for *SWT*

In this section, a wind dispersion analysis for wind data is proposed to determine an appropriate average time for *SWT* applications for intertropical regions. Next, the conceptual elements related to mean ensemble techniques are presented, and finally, the power resource assessment using a *SWT* power curve and the experimental data is calculated and explained.

Mean ensemble

Studies related to wind resource assessment are based on data sets calculated by mean ensemble sampling technique with a mean time of 1/6 of 1 hour. With the purpose of establishing a clear idea of this technique, we briefly explain it below.

Let U_{1s}, the set of all wind speeds recorded at intervals of 1 second[1] and has the form

$$U_{1s} = \{u_1, u_2, u_3, u_4, \ldots, u_n\}, \tag{1}$$

Where u_i is the velocity recorded at the i-second. That is, for all U_{1s}, the mean ensemble m with k-seconds as mean time is given by the Eq. (2),

$$\begin{aligned} m_K &= \frac{1}{k}\left(\sum_{w=1}^{k} U_w, \sum_{w=k+1}^{k+k} U_w, \ldots, \sum_{w=jk+1}^{jk+k} U_w\right) \\ &= (m_k, m_{k+k}, \ldots, m_{jk+k}), \end{aligned} \tag{2}$$

where j is the number of sets with k elements that can be computed from a sample with n elements.

As a result of using Eq. (2) over the 1 second record data, it is possible to obtain an extra time series for the standard deviation for each k set. This information is obtained from Eq. (3), were sub-index K corresponds

[1] We assume in this work continuous data.