MODEL FOR OPTIMAL SIZING OF A WIND ENERGY CONVERSION SYSTEM FOR GREEN-MOBILE APPLICATIONS

M. S. Okundamiya 1 and A. N. Nzeako 2
1 Department of Electrical and Electronic Engineering, Ambrose Alli University, Ekpoma, Nigeria
2 Department of Electronic Engineering, University of Nigeria, Nsukka, Nigeria

The goal of the green-mobile technology is to attain negligible anthropogenic emissions of carbon dioxide (from the GSM base station generators), which constitute by far the largest part of the emissions of greenhouse gases, thereby making the environment much more friendly and safe. This study established the effect of altitude on the output power of wind turbine generators, and proposed a robust model to account for this effect for optimal sizing of a wind energy conversion system (WECS) for green-mobile applications. The proposed model implementation used a perfectly fitted polynomial expression derived from the manufacturer’s power profile. Adjustment of the observed mean wind speed data to a 75 m lattice tower of a mobile station indicates that the proposed model can be effectively powered by mean wind speed for three different locations (Abuja, Benin City, and Katsina) in Nigeria. Analysis indicates that WECS, with its turbine placed at an altitude of 100 m, loses approximately 1% of its output power.

Keywords: Altitude; Global warming; Green-mobile; Nigeria; Wind energy conversion system; Wind turbine model

INTRODUCTION

Clean and sustainable electricity generation from renewable resources has experienced significant developments in the last three decades. One of these is the aggregation of different energy sources, such as wind and solar energy. This helps to attenuate the intermittency in renewable energy supply. The best solution consists of storing energy captured in excess which should be used during short-supply periods. Although low-energy systems extensively utilized batteries their use in medium and large power applications is not feasible (Battista, Mantz, and Garellia 2006). This is due to their relatively small storage density (energy/volume). A feasible option is the inclusion of super capacitors as part of the energy storage (backup) system to meet the instantaneous power demand (Van Voorden 2008; Okundamiya and Nzeako 2010).

Address correspondence to M. S. Okundamiya, Department of Electrical and Electronic Engineering, Ambrose Alli University, P. M. B. 14, Ekpoma 310006, Nigeria. E-mail: st_mico@yahoo.com
Wind energy is one of the most viable and promising sources of renewable energy globally. Increasing the wind energy conversion system (WECS) is becoming an economically viable alternative, due to the comparatively low cost of the renewable energy technology. However, this requires the optimization of the whole system. The optimisation problem usually maximizes the energy output of the system while minimizing the cost (Eke, Kara, and Ulgen 2005; Balamurugan, Ashok, and Jose 2009; Nafeh 2011). It looks into the process of selecting the best mix of resources and their sizing with appropriate operation strategy to provide efficient, cost effective system and constant and reliable power, and the best possible (optimal) model is one that satisfies the constraints at the lowest net present cost (Hakimi, Moghaddas-Tafreshi, and HassanzadehFard 2011). These constraints relate to the system’s reliability, expressed by the corresponding loss factor. Studies (Xu et al. 2005; Ardakani, Dehkordi, and Abedi 2009) derive reliability index from the component’s failure. Also, the optimization of the system’s components will optimize the efficiency and cost of the systems in establishing a green environment. This, in turn will reduce the dependence on the use of fossil fuel that causes global warming. Global warming has the potential of creating dangerous climate changes and melting polar ice caps. Small changes in average annual temperature (such as two or three degrees) can have devastating effects on certain species and ecosystems (Cetin et al. 2009).

Several methodologies exist in the literature for optimal sizing of wind turbines and storage batteries in renewable energy applications (Diaf et al. 2007; Katsigiannis and Georgilakis 2008; Ardakani, Dehkordi, and Abedi 2009; Hocaoglu, Gerek, and Kurban 2009a; Dagdougui et al. 2010). Yang and Aydin (2001) carried out a theoretical investigation on windmill and developed a revised model for determining the power density and output power of wind turbine generator (WTG). Malinga, Sneckenberger, and Feliachi (2003) used the basic WTG model and a relationship for the power efficiency of the WTG proposed by Justus (1978) to study the dynamics and control the wind turbine as a distributed resource. Katsigiannis and Georgilakis (2008) applied tabu search algorithm (Glover 1989, 1990) for optimal sizing of a small isolated hybrid power system in which they developed a seventh-order polynomial fitted model to predict the output power of the WTGs. While some of these models (Yang and Aydin 2001; Katsigiannis and Georgilakis 2008) failed to account for the wind shear (variation of wind speed with heights), others (Diaf et al. 2007; Ardakani, Dehkordi, and Abedi 2009; Hocaoglu, Gerek, and Kurban 2009a) utilized a cubic spline interpolation with considered piecewise polynomial function to deduce their last term. They also applied an adjusted wind speed model to account for the wind shear using power law relationship. Dagdougui et al. (2010) applied the logarithmic law resumed by Rodolfo, José, and Bernal (2008) to deduce their adjusted wind speed, taking the surface roughness of the terrain into consideration. However, the log-arithmetic law cannot be used to represent the wind shear for all conditions, since it is mathematically undefined for time when the wind speeds at two different heights are the same. Furthermore, if wind speeds decrease with height, then the calculated surface roughness length for that period is unrealistically large (Ray, Rogers, and McGowan 2006). These models, often used for the simulation, analysis, and optimization of renewable energy generation systems in field applications, neglect the effect of altitude that is essential for accurate prediction of wind energy. Altitude affects air density, which in turn affects the output of WTGs.

This study established the effect of altitude on the output power of WTGs and proposed a robust model that accounts for this effect for optimal sizing of a novel WECS for
green-mobile applications. Simulation study performed determines the applicability of the proposed model in three cities (with different climatic conditions) in Nigeria.

**Overview of Green-Mobile Technology**

A base transceiver station (BTS) is a wireless communications unit installed at a fixed location to enable the functioning of mobile phones, wireless internet, and other gadgets using communication technologies like GSM, WCDMA, and WiFi. It is also referred to as a radio base station (RBS), Node B (in third generation (3G) Network), or simply as a base station (BS).

Energy efficiency is a key managerial concept, due to the high costs associated with the operation of diesel generator-powered base stations. More than 90% of the power consumption of a base station comes from the communications equipment and air conditioning system. These are the two key factors in optimizing energy conservation and emission reduction. Such inefficient energy conversion system calls for the development of more efficient power amplifiers and the reduction of the power requirements for blown air and air conditioning in base stations. This is a vital step towards achieving a green-mobile solution. The power consumption of base stations can be effectively reduced by adopting advanced power magnifier technologies such as a high-frequency digital power amplifier. This further improves by about 45% the efficiency of power amplification (Qiang 2008).

Some mobile vendors claimed to have designed BTS based on the actual local climate conditions. It uses direct ventilation, intelligent ventilation, and heat exchange for heat dissipation in the equipment rooms to reduce the need for conventional air-conditioning (Qiang 2008; Silu 2008). These measures utilize convection air to exchange indoor heat with outdoors, and have efficiently reduced power consumption while maintaining temperature control. The typical power consumption of a CDMA S3/3/3 base station is 2.2 kW and currently with an average of 1.8 kW while their eco-friendly counter-part consumes only 850 W (Tao 2008). The GSM BTS S/4/4/4 has reduced from 1.6 kW to 1.0 kW. Depending on the numbers of carriers, the eco-friendly GSM BTS can consume as much as 2.0 kW (Jianguo et al. 2008).

If mobile service providers update their infrastructure for green technology, the WECS for green-mobile applications would not only reduce greenhouse effects but also reduce the operational and maintenance cost of GSM mobile services. In general, there would be a reduction in the per-second cost of mobile services as compared to the diesel generator (fossil fuel) powered base station (Jianguo et al. 2008; Qiang 2008; Silu 2008).

**Wind Energy Conversion System**

A wind energy conversion system can contain one or more WTGs. It consists of two parts: the wind resource and the actual WTG unit. One of the first steps a utility company considers when developing wind as an energy source is to survey the available wind resource. These data can be used to create site-specific wind speed models. Already, methods exist for synthetically generating wind resource data globally (Brett and Tuller 1991; NREL 2010). Also, site-specific location data can be obtained from meteorological stations. Hence, this study will neglect wind resource modelling and will
The next step is to adjust the wind speed data at anemometer height to wind turbine hub height using appropriate transformation ratio. The adjustment of the wind profile is necessary to account for the effects of wind shear inputs (wind speed increases with height above the ground hence the power output from the wind turbines). Also, accurate assessment of wind power potential at a site requires precise knowledge of the wind speeds at different heights (Al-Abbadi and Rehman 2009; Rehman, Ahmad, and Al-Hadhrami 2010; Rehman and Al-Abbadi 2010). This study applies the power law (Equation 8) to adjust the mean wind speed data at anemometer height to WTG hub height, due to the limitations of the logarithmic law. The power law exponent values for different terrains exist in the literature (Bechrakis and Sparis 2000). However, wind potential is highly site-dependent and cannot be generalised based on the measurements at one site because local topographical features influence it strongly. As such, 10-years mean wind speed data are collected at different heights for the study locations and are used to deduce the power exponent with details presented in the succeeding section (Materials and Methods).

Wind turbines have different power output performance curves and as such there are different models used to describe the performance of wind turbines. Some authors (Lu, Yang, and Burnett 2002; Koutroulis et al. 2006; Diaf et al. 2007) assumed that the wind turbine power curves have a linear, quadratic, or cubic characteristic. Bueno and Carta (2005), and Hocaoglu, Gerek, and Kurban (2009a, 2009b) approximated the power curve with a piecewise linear or polynomial function with few nodes. Liu et al. (2009) proposed a piecewise support vector machine model, to improve the precision of short-term wind-power prediction systems, based on the characteristics of the power curves of WTG systems and the principles of the support vector machine. Although, the results of parameter optimisation confirmed the robustness of their model, such a model is not particularly suitable for predictions on a very short time scale. Akdag and Guler (2010) applied Weibull distribution model to determine the energy output of 30 commercial wind turbines ranging from 335 to 3000 kW for Amasra, Turkey. Yang, Lu, and Zhou (2007) and Nafeh (2011) modelled the output power of a WTG according to the cube law. However, a WTG model should be developed according to its power output performance curve, given by the manufacturer.

The output of a WTG depends strongly on the wind regime as well as on the performance characteristics and the efficiency of the generator. Developing a WTG model requires the consideration of three factors (Billinton and Bai 2004; Karki and Hu 2005; Gao 2006). The first factor is the random nature of the site resource, which must be included, in an appropriate model to reflect the chronological characteristics of the wind at the site. The second factor is the relationship between the power output and the site resource. This relationship can be determined using the WTG operational parameters and specifications as provided by the manufacturer. The third factor is the unavailability of the WTG expressed by the forced outage rate. This factor can be accounted for using reliability indices. These factors directly affect the generator’s output.

The power output of the WTG is determined as a function of the wind speed using the relationship between power output and wind speed. This function is described by the operational parameters of the WTG. The parameters commonly used (Katsigiannis and Georgilakis 2008; Ardakani, Dehkordi, and Abedi 2009; Hocaoglu, Gerek, and Kurban 2009a, 2009b; Nafeh 2011) are the cut-in wind speed (at which the WTG starts to generate power), the rated wind speed (at which the WTG generates its rated power), and the cut-out wind speed (at which the WTG is shut down for safety reasons). The WTG characteristic
Table 1 Characteristics of the Selected WTGs

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Symbol (Unit)</th>
<th>Generic 10kW Model G10</th>
<th>Bergey 7.5kW Model XL-R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hub height*</td>
<td>( z_h ) (m)</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Rated power</td>
<td>( P_r ) (kW)</td>
<td>10</td>
<td>7.5</td>
</tr>
<tr>
<td>Cut-in speed</td>
<td>( v_{ci} ) (m/s)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Cut-out speed</td>
<td>( v_{co} ) (m/s)</td>
<td>24</td>
<td>25</td>
</tr>
</tbody>
</table>

*The hub heights of the WTG are assumed to be equal to the lattice tower height of the mobile base station.

Figure 1 Block diagram of proposed wind energy conversion system for green-mobile applications.

The power curve describes its power output as a function of its hub height wind speed. The characteristics of the selected WTGs are shown in Table 1.

The proposed system intended to power the green-mobile BTS consists of the WTG unit, DC-AC converter (inverter), and energy storage (ES) unit as shown in Figure 1. The decision variables (parameters) in the optimization process are the size (rated power) of the WTGs and converters, and the storage capacity (size) of the energy storage unit. In order to simplify the scope of this study, the energy storage model, reliability, and power control strategy as well as the optimal sizing of the system’s components have been omitted. These are to be discussed in subsequent studies.
**Effects of Increasing Altitude**

From the ideal gas law (Huffman 1999; Laugier and Garai 2007), air density is:

\[
\rho = \frac{P}{RT},
\]

where \(\rho\) is air density (kg/m\(^3\)), \(P\) is pressure (Pa), \(R\) is the gas constant (J/kg/\(^\circ\)K), and \(T\) is the absolute temperature (K). Using the 1976 International Standard Atmosphere (ISA) standard sea level conditions (i.e., standard pressure, \(P_o = 101.325\) kPa, and standard temperature, \(T_o = 15\)° C = 288.15 K), the ISA air density, that is, the density of dry air (Laugier and Garai 2007), \(\rho_o\) is

\[
\rho_o = \frac{P_o}{RT_o}.
\]

Air density ratio, that is, the ratio of the actual air density (Equation 1) to ISA air density (Equation 2) is

\[
\frac{\rho}{\rho_o} = \frac{P}{P_o \left( \frac{T}{T_o} \right)^{g/RB}}.
\]

Thus, altitude affects both pressure and temperature. Using the ISA simplifying assumption (up to an altitude of 11,000 m), temperature decreases linearly with altitude according to

\[
T = T_o - Bz, \tag{4}
\]

where \(B\) is the temperature lapse rate (K/m) and \(z\) is the altitude (m). The air pressure depends on the altitude according to

\[
P = P_o \left( \frac{T_o - Bz}{T_o} \right)^{g/RB} \tag{5}
\]

where \(g\) is the gravitational acceleration (m/s\(^2\)). Substituting Equations 4 and 5 into Equation 3, we have:

\[
\frac{\rho}{\rho_o} = \left( \frac{T_o}{T_o - Bz} \right) \left( \frac{Bz}{T_o} \right)^{g/RB} \tag{6}
\]

Equation 6 shows that the air density ratio is only a function of altitude, \(z\), since \(B\), \(g\), \(R\), and \(T_o\) are all constant. Denoting the air density ratio by the altitude factor \(zf\), Equation 6 becomes

\[
zf = \left( \frac{T_o}{T_o - Bz} \right)^{1 - (g/RB)} \tag{7}
\]
MATERIALS AND METHODS

Data

A 10-year (July 1983–June 1993) monthly mean wind speed data at 10 m, 50 m, and 100 m above the surface of the earth for flat rough grass surface are collected from the archives of the National Aeronautics and Space Administration (NASA). The surface meteorology and solar energy (SSE) datasets provided by NASA are derived from a variety of earth-observing satellites and re-analysis research programs. These satellites and model-based products provide reliable meteorological resource data over regions where surface measurements are sparse or nonexistent, and offer two unique features: the data are global, and, in general, contiguous in time (NASA 2011). These datasets are collected for three cities in Nigeria (Abuja, Benin City, and Katsina).

Geography and Climate

The geographical coordinates of these three cities in Nigeria are shown in Table 2.

Abuja. Abuja, Nigeria’s capital city, is located in the central part (north-central geopolitical zone) of Nigeria. Abuja under Koppen climate classification features as tropical savannah (wet and dry) climate and experiences three weather conditions annually. This includes a warm, humid rainy, and a blistering dry season. The rainy season begins from April and ends in October, when daytime temperatures reach 28–30°C and nighttime lows hover around 22–23°C. The rainy season peaks in September, during which there is abundant rainfall in the form of heavy downpours. Dry season, from December to March, is hot and dry. A continental tropical air mass laden with dust from the Sahara Desert prevails throughout this period. In between these two periods, there is a brief interlude of “harmattan” occasioned by the north-east trade wind, with the main feature of dust haze, intensified coldness, and dryness. Annual temperature ranges from 18.45°C to 36.05°C, with an annual rainfall of about 1500 mm.

Benin City. Benin City is the capital of Edo State, located in the southern part (south-south geopolitical zone) of Nigeria. The area characterized as tropical rain forest experiences two distinct seasons: the rainy and the dry seasons. The rainy season spans from April to October with temperature ranges from 25°C to 29°C. The rainy season peaks in July with a brief dry spell (i.e., break) in August. The average rainfall during this period is about 1500–2000 mm. The dry season spans from November to March with temperature ranges from 24°C to 28°C and is significantly marked by the cool “harmattan” dusty haze from the north-east trade winds. However, the average rainfall during this season is much lower (usually no more than 300 mm) compared to the rainy season. Annual temperature ranges from 21.6°C to 30.7°C, with an annual rainfall of about 2074 mm.

Table 2 The Geographical Coordinates of the Study Locations

<table>
<thead>
<tr>
<th>Cities</th>
<th>Latitude (°N)</th>
<th>Longitude (°E)</th>
<th>Altitude (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abuja</td>
<td>9.08</td>
<td>7.53</td>
<td>573</td>
</tr>
<tr>
<td>Benin City</td>
<td>6.34</td>
<td>5.63</td>
<td>93</td>
</tr>
<tr>
<td>Katsina</td>
<td>13.00</td>
<td>7.60</td>
<td>416</td>
</tr>
</tbody>
</table>
Katsina. Katsina City is the capital city of Katsina State, located in the northern part (north-west geopolitical zone) of Nigeria. The area characterized as tropical dry climate, varies considerably according to months and seasons. It experiences a cool dry (harmattan) season from December to February, a hot dry season from March to May, a warm wet season from June to September, and a less marked (dry warm) season after rains during the months of October to November, characterized by decreasing rainfall and gradual lowering of temperature (Adamu 2000; Ati, Iguisi, and Mohammed 2010). It has an average rainfall of 623 mm.

Application

MATLAB curve fitting tool is applied to compute the power exponents using the annual mean wind speed datasets by best curve fitting method. The monthly mean wind speed datasets discussed above are adjusted to the 75 m WTG hub height at the self-supporting lattice tower of the mobile BTS sites for the different locations using

\[ v_h = v_a \left( \frac{z_h}{z_a} \right)^{\lambda}, \]  

where \( \lambda \) is the power law exponent, \( z_h \) is the hub height of the WTG (m), \( z_a \) is the anemometer height (m), \( v_h \) is the wind speed at WTG hub height (m/s), and \( v_a \) is the wind speed at anemometer height (m/s). Homer software (NREL 2010) generates the hourly mean wind speed data from the adjusted monthly mean daily data of Equation 8. Figure 2 shows the adjusted hourly mean wind speed data at 75 WTG hub height using the 10-year monthly mean daily datasets for the study locations.

Two WTGs (Generic 10 kW and Bergey Excel-R 7.5 kW) are chosen. Their power profiles are obtained from their manufacturers. The available wind resource (wind speed data) informed the choice of the selected WTGs. We have also considered the ability of these WTGs to generate power from limited mean wind speed data. The accuracy of the results reported by the manufacturers and those published in reviews is satisfactory. Computer codes developed in MATLAB programming language at Ambrose Alli University computes the altitude. The parameters of Equation 7 are \( B = 0.0065 \text{ K/m}, g = 9.81 \text{ m/s}^2 \), \( R = 287 \text{ J/kg/K} \), and \( T_o = 288.15 \text{ K} \). The MATLAB curve fitting tool is also applied to compute the WTGs models of Equations 9 and 10. The model implementation used a perfectly fitted polynomial expression based on the manufacturer’s data. A polynomial model is chosen since it produced the best fit. Equations 13 and 14 show the proposed WTG models for WECS for green-mobile applications.

RESULTS

The power law exponents deduced are presented in Table 3.

Figure 3 shows the variation of altitude factor with altitude. Figures 4 and 5 show the power profiles for Generic 10 kW and Bergey Excel-R 7.5 kW along with their simulated models, respectively.

Based on the power profiles of Figures 4 and 5, the mathematical model for Generic 10 kW and BWC 7.5 kW WTGs (in kW) at standard temperature and pressure (STP) are
OPTIMAL SIZING OF A WIND ENERGY CONVERSION SYSTEM

Figure 2 The adjusted hourly mean wind speed data at 75 m WTG hub height using the 10-year monthly mean daily datasets for (a) Abuja, (b) Benin City, and (c) Katsina, respectively.

Table 3 Power Law Exponents for the Study Locations

<table>
<thead>
<tr>
<th>Cities</th>
<th>Power law exponents ($A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abuja</td>
<td>0.1476</td>
</tr>
<tr>
<td>Benin City</td>
<td>0.1481</td>
</tr>
<tr>
<td>Katsina</td>
<td>0.1477</td>
</tr>
</tbody>
</table>

$$P_{WTG, STP} = 1.144 \times 10^{-6} \times \nu_h^7 - 0.0001138 \times \nu_h^6 + 0.004607 \times \nu_h^5 - 0.9653 \times \nu_h^4 + 1.097 \times \nu_h^3 - 6.532 \times \nu_h^2 + 19.19 \times \nu_h - 21.79$$

for $\nu_{cl} \leq \nu_h \leq \nu_{co}$ (9)
and

\[
\begin{align*}
\text{P}_{\text{WTG}}_{\text{STP}} &= -1.128 \times 10^{-8} \times v_h^9 + 1.46 \times 10^{-6} \times v_h^8 - 8.038 \times 10^{-5} \times v_h^7 + 0.002451 \times v_h^6 \\
&- 0.04521 \times v_h^5 + 0.519 \times v_h^4 - 3.688 \times v_h^3 + 15.69 \times v_h^2 - 35.96 \times v_h + 33.6 \quad \text{for} \quad v_{ci} \leq v_h \leq v_{co}
\end{align*}
\] (10)
respectively. However, since altitude affects air density, which in turn affects the WTG output power, the available output power of the WTG under real temperature and pressure is the product of the ideal output power (power at STP) and the air density ratio. Thus, the available output power (in kW) becomes

\[ P_{WTG \text{ Avail}} = z_f P_{WTG \text{ STP}} \] (11)

and

\[ P_{WTG \text{ Avail}} = z_f P_{WTG \text{ STP}} \] (12)

The proposed model for optimal sizing of a novel WECS for green-mobile applications is

\[ P_{WTG \text{ Avail}} = z_f \left( 1.144 \times 10^{-6} \times v_h^7 - 0.0001138 \times v_h^6 + 0.004607 \times v_h^5 - 0.9653 \times v_h^4 + 1.097 \times v_h^3 - 6.532 \times v_h^2 + 19.19 \times v_h - 21.79 \right) \]

for \( v_{ci} \leq v_h \leq v_{co} \) (13)

and

\[ P_{WTG \text{ Avail}} = z_f \left( -1.128 \times 10^{-8} \times v_h^9 + 1.46 \times 10^{-6} \times v_h^8 - 8.038 \times 10^{-5} \times v_h^7 + 0.002451 \times v_h^6 - 0.04521 \times v_h^5 + 0.519 \times v_h^4 - 3.688 \times v_h^3 + 15.69 \times v_h^2 - 35.96 \times v_h + 33.6 \right) \]

for \( v_{ci} \leq v_h \leq v_{co} \) (14)

where \( P_{WTG \text{ Avail}} \) and \( P_{WTG \text{ Avail}} \) are the available power (in kW) for the Generic 10 kW and BWC 7.5 kW WTGs, respectively.

**DISCUSSION**

The shape of the wind shear profile typically depends on several factors, most notably the roughness of the surrounding terrain and the stability of the atmosphere. Since the atmospheric stability changes with season, time of day, and meteorological conditions, the power law exponent also tends to change in time. The calculated power law exponents (Table 3) are slightly higher than the assumed value (i.e., \( \alpha = 0.14 \)) typically used for areas of flat terrain (Bechrakis and Sparis 2000) since local, topographical features strongly influence wind potential. Clearly, analyzing the wind data is an important aspect of accurately predicting the hub height wind speeds.

Figure 3 shows that the altitude factor is inversely proportional to altitude. An altitude of 105 m indicates a decrease of the altitude factor hence the output power of wind turbine by approximately 1%. For optimal sizing of the WECS, it is necessary to account for this effect in the WTG model for improved performance. The proposed models (i.e., Equations 13 and 14) account for this effect.

A seventh-order polynomial expression (Equation 9) has been selected for the Generic WTG while a ninth-order polynomial expression (Equation 10) for Bergey WTG.
This is because they both provide accurate correlation (i.e., with a coefficient of determination of 0.9983 and 0.9994, respectively) with the real data. They also present exclusively positive values for the generated power (Figures 4 and 5) at the interval ($v_{ci}$ and $v_{co}$) under ideal (ISA) conditions.

The adjusted mean wind speed data available at the WTG hub height (when mounted on the 75 m self-supporting lattice tower of the mobile BTS sites as illustrated in Figure 2) indicate that the proposed models (Equations 13 and 14) can be effectively powered by the wind speed for the different locations under study. Optimal sizing is necessary to account adequately for the load demand of the green-mobile stations. In order to limit the scope of this study, optimal sizing of the system’s components has been omitted. This will be discussed in subsequent studies.

CONCLUSION

In this study the effect of altitude on air density, which in turn affects the output power of WTGs, is established and a robust model to account for this effect proposed for optimal sizing of a novel WECS for green-mobile applications. The effect of altitude is important for accurate determination of wind turbine models for optimal performance. Analysis indicates that WECS loses approximately 1% of its output power if its turbine is placed at an altitude of 100 m. The power law exponents presented in this study are calculated using the mean annual wind speeds data collected at three different heights (10 m, 50 m, and 100 m) above the surface of the earth. This study recommends a value of power law exponent of approximately 0.148 for the calculation of wind speed at different heights (for open land with short grasses), if wind measurements are available at one height.

ACKNOWLEDGMENTS

This work was partly funded by ETF 2009 AST&D Intervention (Reference no. AAU/REG/ETF.560/475).

REFERENCES


