Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 93 (2016) 66 – 73

Energy Procedia

Africa-EU Renewable Energy Research and Innovation Symposium, RERIS 2016, 8-10 March 2016, Tlemcen, Algeria

Wind energy for electricity generation in the far north region of Cameroon

Dieudonné Kaoga Kidmo[a]*, Kodji Deli[a], Danwe Raidandi[a], Serge Doka Yamigno[b]

[a] *Higher Institute of the Sahel, University of Maroua, P.O. Box 46 Maroua, Cameroon*
[b] *Higher Teachers Training College, University of Maroua, P.O. Box 46 Maroua, Cameroon*

Abstract

This paper explores mountain ridges around Kousseri and Maroua in the far north region of Cameroon for assessing the potential for wind energy development and electricity generation. A 28-year (1985-2013) wind speed data measured at 10 m above ground level (AGL) is statistically analysed using Weibull Distribution, a widely accepted model to probabilistically describe wind speeds variations. Weibull scale and shape parameters are determined using an iterative method, namely, the moment method. The power law relationship is considered to extrapolate Weibull parameters and wind profiles at exposed ridge-tops in the range of 100-300 m AGL. The results show that the selected ridge-tops fall under Class 3 or greater of the international system of wind classification and are deemed suitable for most wind turbine (WT) applications. A performance assessment of five commercial WT (50 to 2000 kW) for electricity generation is then realized through the computation of their respective capacity factors, power and energy outputs. Amongst explored WT, YDF-1500-87 (1500 kW) emerges as the most attractive option for installation, with the highest capacity factor and the lowest cost of energy.

*Keywords:*Wind energy; wind turbine; electricity; energy output; capacity factor; cost of energy.

---

* Corresponding author. Tel.: +237 696745644; fax: +237 222 293 112.
*E-mail address:*kidmokaoga@gmail.com

doi:10.1016/j.egypro.2016.07.151

1. Introduction

Electricity is one of the main drivers that contribute to improve economic opportunities and, even a better quality of life. In Cameroon, the annual growth in electricity consumption (7 to 8 %) requires at least 100 MW of new electricity generating capacity. So far, the supply of electricity is lacking far behind. Access to electricity stands at 18.5 and 87.5 % for rural and urban populations, respectively. In the Northern Interconnected Grid (NIG) region, the above rates are estimated at 3 times lower than that of national averages. The need for electricity keeps rising as population continues steadily to grow. For more than 30 years, access to electricity in the NIG region has been achieved through grid extension only. A very high rate of grid losses (24 to 30 %) makes grid extension not a cost-effective option for the National Electricity Utility Company, ENEO. Furthermore, the majority of households are dispersed and have no access to electricity due to low incomes, coupled with high grid-connected cost [1]. On the other hand, off-grid standalone solar or wind energy systems are considered the best alternatives in the NIG region to locally provide electricity.

Globally, wind energy has proved to be one of the cheapest forms of low carbon electricity [2]. Under ambitious growth rates, the wind power could generate between 16.7 and 18.8 % of the global electricity by 2030 and help save over 3 billion tons of CO_2 emissions annually [3]. Worldwide, 52,016 MW of new generating capacity was added at the end of 2014, bringing the total cumulative installed WT capacity to 372,961 MW, to just about 3 % of the global electricity supply [4]. Although solar photovoltaic (PV) experienced the fastest capacity growth rates of any energy technology, with 39.0 and 38.2 % in 2013 and 2014 respectively, wind energy achieved the most power capacity added of any renewable technology. In Africa, sustained growth of commercial scale WT has so far occurred in Morocco, Tunisia, Algeria, Egypt, South Africa, Ethiopia and Cape Verde [5]. Despite representing 0.77 % of the global wind power generation capacity in 2014, the wind industry in the African continent saw the highest capacity growth rates (48.20 %) in the last six years. The continent reached 2,778 MW commissioned by end-2014, against just 1,942 MW online a year earlier. South Africa contributed the most in terms of newly installed wind capacity, with 560 MW brought online at the end of 2014. It was followed by Morocco (300 MW) and Egypt (10 MW) [4]. In Cameroon, the wind energy sector is not well-known and the country has no previous experience in wind power generation. Based on the available literature, very few studies have been accomplished up to now [6–8]. No reference is made to studies on performance evaluation of WT for electricity generation in the country.

In this study, a 28-year (1985-2013) wind speed data measured at 10 m AGL has been statistically analysed using the Weibull Probability Density Function (PDF). Weibull PDF, among various other distributions functions models [9] such as Rayleigh, Pearson, lognormal, normal, gamma to name few, is by far preferred by the majority of the researchers involved in wind speed and energy modelling as a consequence of its simplicity and up to standard precision level [10]. The present study has considered the moment method (MM), an iterative calculation process to estimate and extrapolate Weibull parameters, in addition to predict wind energy outputs, capacity factors and cost of electricity generated by five commercial WT ranging from 50 to 2000 kW. The objective of this study is to assess the performance of WT for electricity generation as well as to estimate the costs of wind energy production at hilltops and exposed ridge-tops around Kousseri and Maroua. The wind flow at selected hilltops with well exposed sites is considered within the scope of linear models for vertical extrapolation of wind speed data measured at 10 m AGL. Therefore, the power law relationship is considered to extrapolate Weibull parameters and wind profiles at exposed ridge-tops in the range of 100-300 m AGL.

1.1. Description of the localities and region

Kousseri and Maroua are located in the Far North Region of Cameroon, in semi-arid sudano-sahelian climate. The Far North is characterized by annual rainfall of between 400-900 mm during a rainy season that lasts about four months, between July and October. Maroua, is located at latitude 10°35’50” N and longitude 14°18’57” E, with an elevation of 384 m above sea level. On the other hand, Kousseri, which is approximately 184 km (air distance) far from Maroua, is positioned at latitude 12°04’42” N and longitude 15°01’51” E, with an elevation of about 271 m above sea level. The districts of Kousseri and Maroua are surrounded by highlands, hilltops and inselbergs that are part of the Mandara Mountains.

2. Methodology

2.1. Weibull PDF

The Weibull PDF is explicitly used to model wind speeds as well as wind power and energy densities variations. It is best described by its probability density function $\boldsymbol{f(v)}$ of observing wind speed $\boldsymbol{v}$ as follows [11]:

$$f(v) = \left(\frac{k}{C}\right).\left(\frac{v}{C}\right)^{k-1}.exp\left[-\left(\frac{v}{C}\right)^{k}\right] \tag{1}$$

Where $\boldsymbol{C}$ is the Weibull scale parameter (m/s) and $\boldsymbol{k}$ is the Weibull shape parameter (dimensionless). The corresponding cumulative distribution function $\boldsymbol{F(v)}$ of observing wind speed $\boldsymbol{v}$ is expressed as given:

$$F(v) = 1 - exp\left[-\left(\frac{v}{C}\right)^{k}\right] \tag{2}$$

The shape parameter describes the width of wind speed data distribution, while the scale parameter indicates how ‘windy’ the considered location is [12]. Different two-parameter Weibull PDF methods are available in the literature to estimate Weibull scale and shape parameters [8,13]. Although graphical method, maximum likelihood method, modified maximum likelihood method, moment method, empirical method, and energy pattern factor are extensively used, in the current study the moment method (MM) is preferred for estimating Weibull scale and shape parameters. Weibull parameters are computed using mean wind speed $\boldsymbol{v_m}$ and standard deviation $\boldsymbol{\sigma}$. The MM method is solved through numerical iterations. **C** and $\boldsymbol{\sigma}$ are respectively defined as [14]:

$$C = \frac{v_m}{\Gamma\left(1+\frac{1}{k}\right)} \tag{3}$$

$$\sigma = C\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]^{1/2} \tag{4}$$

2.2. Wind power density estimation

The wind power density (***WPD***) is simultaneously used with the wind speed as the best indicator of the wind resource at a considered location. The ***WPD*** based on the Weibull PDF can be calculated as given [15]:

$$WPD = \frac{1}{2}\cdot\rho\cdot C^3\cdot\Gamma\left(1+\frac{3}{k}\right) \tag{5}$$

Where $\boldsymbol{\rho}$ = air density at the site. The air density is calculated using the following expression [16]:

$$\rho_a = \frac{353.049}{T}e^{\left(-0.034\frac{Z}{T}\right)} \tag{6}$$

Where *Z* is the elevation and *T* is the temperature at a considered site.

2.3. Extrapolation of wind speed and Weibull parameters at different heights

In this study the considered wind shear model to extrapolate wind profiles is the empirical power law. **Eq. (7)** is therefore used to adjust wind speeds measured at 10 m AGL to WT tower hub heights in addition to selected hilltops or exposed ridge-tops [17]:

$$V_z = V_{10} * \left(\frac{z}{10}\right)^{\alpha} \tag{7}$$

Where V_z and V_{10} are wind speeds, respectively at hub heights of z and 10 m height AGL.
The power law exponent α is defined as:

$$\alpha = 0.37 - 0.088\, ln(V_{10}) \tag{8}$$

On the other hand, C_{10} and k_{10}, respectively Weibull scale and shape parameters determined at 10 m height AGL are adjusted to any desired z height AGL as expressed [18]:

$$C_z = C_{10} * \left(\frac{z}{10}\right)^n \tag{9}$$

$$k_z = \frac{k_{10}}{1 - 0.00881\, ln(z/10)} \tag{10}$$

Where k_z is the Weibull shape parameter at z m height AGL. C_z is the Weibull scale parameter at z m height AGL. The power law exponent n is given by:

$$n = [0.37 - 0.088\, ln(C_{10})] \tag{11}$$

2.4. Power output of wind turbine and capacity factor

Each wind energy conversion system (WECS) is planned to operate at its maximum efficiency within its designed rated wind speed and power. As a result, once Weibull scale and shape parameters are estimated, the performance of a WT at a given location can be easily computed using the average power output ($\boldsymbol{P_{e,ave}}$) and capacity factor ($\boldsymbol{C_f}$). In this work, the electrical power output ($\boldsymbol{P_e}$) of a model WT is simulated using [19,20]:

$$P_e = \begin{cases} 0 & (v < v_c) \\ P_{eR} \frac{v^k - {v_c}^k}{{v_R}^k - {v_c}^k} & (v_c \le v \le v_R) \\ P_{eR} & (v_R \le v \le v_F) \\ 0 & (v_F < v) \end{cases} \tag{12}$$

Where P_{eR} is rated electrical power, v_c is cut-in wind speed, v_R rated wind speed and v_F cut-off wind speed.The average power output ($\boldsymbol{P_{e,ave}}$) of a WT can be given as [21]:

$$P_{e,ave} = P_{eR} \left\{ \frac{e^{-\left(\frac{v_c}{C}\right)^k} - e^{-\left(\frac{v_R}{C}\right)^k}}{\left(\frac{v_R}{C}\right)^k - \left(\frac{v_c}{C}\right)^k} - e^{-\left(\frac{v_F}{C}\right)^k} \right\} \tag{13}$$

And the capacity factor $\boldsymbol{C_f}$ which is described as the ratio of the average power output to the rated output power of the WECS is given by Eq. (14):

$$C_f = \frac{P_{e,ave}}{P_{eR}} \tag{14}$$

2.5. Economics of wind power

There are several ways of computing the cost of wind-generated electricity for a given WECS. In this work, the adopted method to analyse the economics of WECS is the cost per kWh of electricity generated using the Present Value of Costs (PVC) of electricity produced per year. PVC is expressed as given [22]**:**

$$PVC = I + C_{om}\left(\frac{1+i}{r-i}\right) * \left(1 - \left(\frac{1+i}{1+r}\right)^{n}\right) - S\left(\frac{1+i}{1+r}\right)^{n} \tag{15}$$

Where the following assumptions are made to estimate the costs of the kWh of energy produced by the WT:

- **I** is the investment cost (the WT price in addition to 20% for civil works and other connections). The WT price based on the rated power is provided in Table 1; **n** is the useful lifetime of turbine in years (20 years);
- $\mathbf{C_{om}}$ is the operation and maintenance costs (7.5% of the investment cost);
- **S** is the scrap value (10% of the WT price);
- $\mathbf{i_o}$ is the nominal interest rate (16%) and **i** is the inflation rate (3.6%).
- The discount rate (**r**) is determined using the following expression [16] :

$$r = \frac{i_0 - i}{1+i} \tag{16}$$

The availability of the wind power resource for generating electricity is taken as ***A***=75% and the total energy output over the WT lifetime (in kilowatt-hour) is computed as:

$$E_{WT} = 8760 * A * n * P_R * C_f \tag{17}$$

Therefore, the Cost of Electricity per unit kWh using the PVC method is expressed as given:

$$COE = \frac{PVC}{E_{WT}} \tag{18}$$

Table 1. Range of specific cost of WT based on the rated power [23].

WT Size (kW)	Specific Cost per kW	Average Specific Cost per kW
<20	2200 - 3000	2600
20 - 200	1250 - 2300	1775
>200	700 - 1600	1150

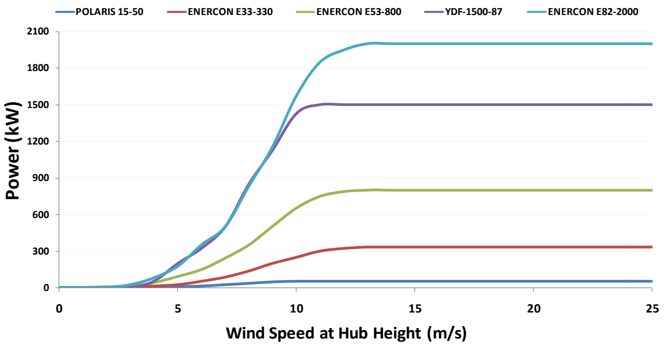

Fig.1. Power curves of selected wind turbines.

Table 2. Characteristics of the selected wind turbines [24–26].

Characteristics	P-15-50	Enercon E33	Enercon E53	YDF-1500-87	Enercon E82
Hub height (m)	50	50	70	75	130
Rated power Pr (kW)	50	330	800	1500	2000
Diameter (m)	15.2	33.4	52.9	87	82
Cut-in wind speed (m/s)	2.5	2.5	2.5	3.0	2.5
Rated wind speed (m/s)	10.0	13.0	13.0	10.2	12.5
Cut-off wind speed (m/s)	25	25	25	25	25

Table 3. Performance of selected WT and cost of electricity at hilltops around Kousseri.

Hilltops (m AGL)	Hub height (m)	P_{OUT} (kW)	P_{ER} (kW)	C_f (%)	E_{WT} (MWh/yr)	$C_{US\$}$ (US$/kWh)	C_{XAF} (XAF/kWh)
			P-15-50				
100	50	20.7	50	41.40	136.00	6.71	40.55
300	50	28.9	50	57.80	189.87	4.81	29.04
			ENERCON E33				
100	50	67.32	330	20.40	442.29	8.83	53.31
300	50	110.55	330	33.50	726.31	5.37	32.46
			ENERCON E53				
100	70	179.2	800	22.40	1 177.34	8.04	48.55
300	70	303.2	800	37.90	1 992.02	4.75	28.70
			YDF-1500-87				
100	75	639	1500	42.60	4 198.23	4.23	25.53
300	75	903	1500	60.20	5 932.71	2.99	18.07
			ENERCON E820				
100	130	620	2000	31.00	4 073.40	5.81	35.08
300	130	900	2000	45.00	5 913.00	4.00	24.17

Table 4. Performance of selected wind turbines and cost of electricity at hilltops around Maroua.

Hilltops (m AGL)	Hub height (m)	P_{OUT} (kW)	P_{ER} (kW)	C_f (%)	E_{WT} (MWh/yr)	$C_{US\$}$ (US$/kWh)	C_{XAF} (XAF/kWh)
			P-15-50				
100	50	15.8	50	31.60	103.81	8.79	53.12
300	50	22.4	50	44.80	147.17	6.20	37.47
			ENERCON E33				
100	50	60.72	330	18.40	398.93	9.79	59.11
300	50	93.06	330	28.20	611.40	6.39	38.57
			ENERCON E53				
100	70	159.2	800	19.90	1 045.94	9.05	54.65
300	70	251.2	800	31.40	1 650.38	5.73	34.64
			YDF-1500-87				
100	75	480	1500	32.00	3 153.60	5.63	33.99
300	75	697.5	1500	46.50	4 582.58	3.87	23.39
			ENERCON E820				
100	130	520	2000	26.00	3 416.40	6.93	41.83
300	130	730	2000	36.50	4 796.10	4.93	29.80

3. Results and discussion

Once the scale and shape parameters are determined using the MM method, it is observed that the monthly wind speeds vary from 3.29 to 4.38 m/s in Kousseri, while its values fluctuate between 2.67 and 3.19 m/s in Maroua. Additionally, the monthly values of wind power densities (WPD) vary between 29.82 and 60.27 W/m² in Kousseri, while its values range from 16.69 to 29.93 W/m² in Maroua. At 10 m AGL, the scheme proposed by Battelle—Pacific Northwest Laboratory (PNL) suggests that Kousseri and Maroua fall under class 1 and are considered unsuitable locations for generating electricity. Therefore, the 10 m AGL Weibull shape k and scale C parameters as well as monthly averages wind speed and power density for each of the two sites are extrapolated to 100, 200 and 300 m AGL, which represent selected hilltops and exposed ridge-tops. The wind flow at selected hilltops is considered within the scope of linear models for vertical extrapolation of wind data. Consequently, Weibull parameters and wind profiles are extrapolated at exposed ridge-tops using the empirical power law relationship. After the extrapolation, wind speeds (from 6.45 to 8.79 m/s) and power densities (from 200.16 to 533.20 W/m²) reveal that ridge-tops located 100, 200 and 300 m AGL around Kousseri fall under class 4, 6 and 7, respectively. As a result, wind potential is deemed suitable for large scale electricity generation at the selected ridge-tops around Kousseri. On the other hand, around Maroua, wind speeds (5.37 – 7.32 m/s) and power densities (137.65 – 373.16 W/m²) established that on average, exposed ridge-tops located 100, 200 and 300 m AGL fall under class 3, 5 and 6, respectively. Therefore, at hilltops and exposed ridge-tops higher than 200 m AGL around Maroua, wind potential is suitable for large scale electricity generation.

Table 2 shows the characteristics of selected WT, with rated power ranging from 50 to 2000 kW and hub heights between 50 and 130 m. Figure 2 illustrates power curves of selected WT, all of which have pitch control system. Annual energy outputs, capacity factors of selected WT as well as costs estimates of energy at hilltops and exposed ridge-tops around the districts of Kousseri and Maroua are summarized in tables 3 and 4. The highest capacity factors are observed using YDF-1500-87 (1500 kW), P-15-50 (50 kW) and Enercon E820 (2000 kW) WT, while Enercon E33 (330 kW) and E53 (800 kW) show the lowest capacity factors. In the meantime, the lowest costs are observed with large WT, which offer the highest capacity factors. P-15-50 turbine shows higher capacity factors but higher costs of the kWh of energy produced when compared to Enercon E820, since smaller WT are more expensive than larger ones (table 1).

When considering hilltops 100 m AGL around Kousseri and Maroua, YDF-1500-87 WT is selected based on its capacity factors, which are the highest. Capacity factors and costs of energy (COE) on monthly basis are therefore computed and presented in figure 3. Around Kousseri, the highest capacity factors are observed between February and June, while around Maroua, the highest values of C_f are seen from January to August.

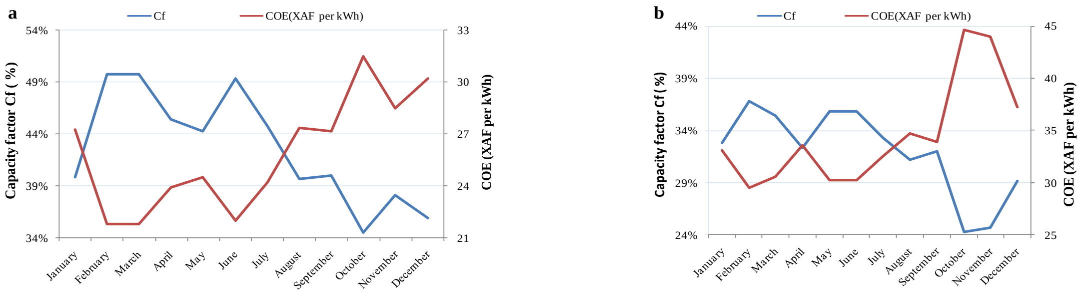

Fig.2.Monthly basis capacity factor of YDF-1500-87 and cost of electricity at hilltops 100 m around Kousseri (a) and Maroua (b).

Additionally, it is observed that the greatest winds, which are observed during the dry season in the far north region, correspond to months with the highest C_f of WT. In the heart of the dry season, electricity shortage is common in the region and beyond, hence the need to explore options for the cheapest forms of low carbon electricity. The COE are lower during the dry season than during the rainy season, which starts in late July and ends around mid October. On average, the costs of energy using P-15-50 are 40.55 and 53.12 XAF/kWh, respectively around the districts of Kousseri and Maroua. As for YDF-1500-87, the costs per kWh of electricity produced are 25.53 and 33.99 XAF/kWh around the districts of Kousseri and Maroua, in that order.

4. Conclusion

Wind energy, as one of the most widespread renewable energy technologies in the world, in terms of installed capacity, has the potential to significantly contribute to greenhouse emissions reductions. In Cameroon, wind energy at mountain ridges can be utilized to improve access to cost-effective low carbon electricity. The findings in this paper provide preliminary assessments of the wind energy potential, performance of wind turbines for electricity generation and costs of wind energy production at hilltops and exposed ridges tops around the districts of Kousseri and Maroua in the far north region of Cameroon. The main outcomes of our study are presented as follows:

- At hilltops and exposed ridge-tops ranging from 100 to 300 m AGL around Kousseri and Maroua, wind potential is most suitable for wind turbines applications;
- YDF-1500-87 is the preferred WT for generating electricity for large communities since it shows the highest capacity factor and the lowest cost of energy;

- P-15-50 is the most interesting option for small communities or wind farms, with the highest capacity factor and the lowest cost of energy for its range of specific cost based on the rated power.

References

[1] Abanda FH. Renewable energy sources in Cameroon: Potentials, benefits and enabling environment. Renew Sustain Energy Rev 2012;16:4557–62.
[2] Germany OH, Infi D. Wind Energy. Wind Energy; 2001.
[3] Gwec, Greenpeace. Global Wind Energy Outlook; 2006.
[4] Statistical Review of World Energy 2015. http://www.bp.com/en/global/corporate/about-bp/energy-economics/statistical-review-of-world-energy.html (accessed March 12, 2016).
[5] Mukasa AD, Mutambatsere E, Arvanitis Y, Triki T, Kayizzi-mugerwa S, John C. Development of Wind Energy in Africa. 2013.
[6] Tchinda R, Kendjio J, Kaptouom E, Njomo D. Estimation of mean wind energy available in far north Cameroon. Energy Convers Manag 2000;41:1917–29.
[7] Tchinda R, Kaptouom E. Wind energy in Adamaoua and North Cameroon provinces. Energy Convers Manag 2003;44:845–57.
[8] Kidmo DK, Danwe R, Doka SY, Djongyang N. Statistical analysis of wind speed distribution based on six Weibull Methods for wind power evaluation in Garoua , Cameroon. Revue des Energies Renouvelables 2015;18:105–25.
[9] Safari B. Modeling wind speed and wind power distributions in Rwanda. Renew Sustain Energy Rev 2011;15:925–35.
[10] Mostafaeipour A, Jadidi M, Mohammadi K, Sedaghat A. An analysis of wind energy potential and economic evaluation in Zahedan, Iran. Renew Sustain Energy Rev 2014;30:641–50.
[11] Safari B, Gasore J. A statistical investigation of wind characteristics and wind energy potential based on the Weibull and Rayleigh models in Rwanda. Renew Energy 2010;35:2874–80.
[12] Fyrippis I, Axaopoulos PJ, Panayiotou G. Wind energy potential assessment in Naxos Island, Greece. Appl Energy 2010;87:577–86.
[13] Mohammadi K, Mostafaeipour A, Alavi O, Goudarzi N, Jalilvand M. Assessing different parameters estimation methods of Weibull distribution to compute wind power density. Energy Convers Manag 2016;108:322–335.
[14] Chang TP. Performance comparison of six numerical methods in estimating Weibull parameters for wind energy application. Appl Energy 2011;88:272–82.
[15] Kose R. An evaluation of wind energy potential as a power generation source in Kutahya, Turkey. Energy Convers Manag 2004;45:1631–41.
[16] Mathew S. Wind energy: Fundamentals, resource analysis and economics; 2007.
[17] Cabello M, Orza J a G. Wind speed analysis in the province of Alicante, Spain. Potential for small-scale wind turbines. Renew Sustain Energy Rev 2010;14:3185–91.
[18] Doran JC, Verholek MG. A Note on Vertical Extrapolation Formulas for Weibull Velocity Distribution Parameters. J Appl Meteorol 1978;17:410–2.
[19] Akpinar EK, Akpinar S. An assessment on seasonal analysis of wind energy characteristics and wind turbine characteristics. Energy Convers Manag 2005;46:1848–67.
[20] Paul SS, Oyedepo SO, Adaramola MS. Economic assessment of water pumping systems using wind energy conversions in the southern part of Nigeria. ENERGY Explor Exploit 2012;30:1–18.
[21] Oyedepo SO, Adaramola MS, Paul SS. Analysis of wind speed data and wind energy potential in three selected locations in south-east Nigeria. Int J Energy Environ Eng 2012;3:7.
[22] Rehman S, Halawani T. O, Mohandes M. Wind power cost assessment at twenty locations in the kingdom of Saudi Arabia. Renew Energy 2003;28:573–83.
[23] Diaf S, Notton G, Diaf D. Technical and Economic Assessment of Wind Farm Power Generation at Adrar in Southern Algeria. Energy Procedia 2013;42:53–62.
[24] Yuanda Tech Electr 2016. http://www.cnydme.com/index.php/2014-10-10-05-44-46/ydf-1500-87 (accessed February 25, 2016).
[25] ENERCON 2016. http://www.enercon.de/en/home/ (accessed March 12, 2016).
[26] P-15-50 2016 . http://www.polarisamerica.com/turbines/technology/ (accessed February 3, 2016).