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Monthly and seasonal assessment of wind energy potential at Msila region - Algerian highlands

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Abstract

The aim of this paper is to investigate the monthly and seasonal variation of the wind resource in term of wind energy potential using the wind speed data collected between 2008 and 2010 for the meteorological station at Msila location situated in Algerian highlands. The vertical extrapolation of Weibull parameters and mean wind speed at a height of 50m with the analysis of temporal energy efficiency was made using a wind turbine of 600kW rated powers from Fuhrländer manufacturer. The results show that Msila situated in Algerian highlands between Tell in North and Sahara in South has an annual mean wind speed V=4m/s and the annual wind energy production is equal to 1.39GWh/year, while the highest monthly energy produced may be reached in March, and the better seasonal wind energy potential is given in Spring.

Keywords: Wind energy production, Temporal assessment, Weibull parameters, Algerian highlands, Msila.

1. Introduction

Generating electricity in North Africa using renewable energy resource has been around for some time now but has recently gained momentum through several plans as Desertec Industrial Initiative, where an export bundled with wind energy is the most feasible option for North African concentrated solar power [1]. Since North African's countries have high levels of direct solar radiation, the aim of these plans is to create new power production capacity bases on renewable energies, especially by solar and wind on the Mediterranean basin [2] even if it is compellingly and apparently economically sensible to harness the resource most at the place it is most readily available [3].

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In Algeria, the objectives established by the join-stock company NEAL (New Energy Algeria), focused on raising renewable energy production to 1400 MW in 2030 and 7500 MW at the beginning of 2050. Electrical power will be obtained from solar power plants, which are exclusively solar, or from hybrid solar plants, which also use other forms of renewable or conventional energy, preferably natural gas [4]; recently, Boudghene Stombouli has concluded that there is a considerable potential in Algeria for the utilization of renewable energy sources [5] especially with respect to solar and wind power that produce fewer greenhouse gas emissions [6].

The wind is generated due to the pressure gradient resulting from the uneven heating of earth's surface by the sun. As the very driving force causing this movement is derived from the sun, wind energy is basically an indirect form of solar energy; this means that the wind is driven by the temperature difference [7]. Adaramola et al. concluded their study on the importance to thoroughly carry out intensive and detailed measurements of temperature with direction and wind speed on the targeted site over a defined period and the nature of the topology of the site have to be studied [8]. Soler-Bientz et al. give the significance of study of the offshore wind and temperature profiles [9]. Recently Lima et al. made an analysis with several meteorological parameters, where air temperature at two levels, 25 and 50m were studied to make wind resource evaluation at Paraiba region in Brazil, concluding that air average temperature has a strong impact on air density value [10].

Concerning Algeria, even if we note with satisfaction the contribution in the actualization of wind map of Algeria adding the study of Hassi R'mel in the South of the country at the wind atlas by Chellali et al. [11], few studies have been conducted to assess wind resource and the majority of them were focused at the Sahara in South of Algeria[12-17], result to the good wind resource concluded from wind map by Kasbadji [18,19] and Chellali et al. [11] respectively in Adrar and Hassi R'Mel, two regions in Algerian Sahara.

Wind speed is the most important aspect of the wind resource; in fact, Aynuar Ucar et al. shown that the yearly and seasonal variation of long term mean wind speed provides an understanding of the long term pattern of wind speed and also gives confidence to an investor on the availability of wind power in coming years [20].

It is why, in this study, we choose to contribute on temporal wind assessment at the location of Msila in Algerian highlands. For optimal use of wind energy, it is necessary to know the wind speed at heights upward the ground. Since wind speed increases with height, wind energy is usually captured at heights above the height of wind measurements by the National Meteorological Office, which is 10m. As well, the objective of this work is to estimate average wind speed (annual, seasonal and monthly) at anemometer height by numerical simulation and estimating the average wind power density at 50m height.

This paper focuses on a region in Algerian highlands with an arid climate. For optimal use of wind energy, it is necessary to know the wind speed at heights upward the ground. Knowing that wind speed increases with height, wind energy is usually captured at heights above the height of wind measurements by the National Meteorological Office, which is 10m. As well, the objective of this work is to estimate average wind speed (annual, seasonal and monthly) at different heights by numerical simulation and calculating the average energy generated by the Fuhrländer FL600 wind energy conversion systems of 600kW rated capacity at 50m height hub.

At first, the wind characteristics was investigated, using the wind speed data collected between 2008 and 2010, a study of the temporal variation of Weibull parameters (A and k) and the mean wind speed V was made for whole years, the four seasons and the twelve months year. Vertical extrapolation of wind speed has been made in the second time by an empirical model, and estimates the average energy density recovered by the wind energy conversion systems versus years, seasons and months.

2. Site and time series

In this paper, data from the station situated at MSila region have been analyzed. The geographical coordinates of this meteorological station and the years of measurements are given in Table 1.

Table 1. Geographical coordinates of the data collection station used in the study

Station	Longitude (°)	Latitude (°)	Altitude (m)	Duration (years)	Time Series
MSila	4.5	35.66	442	03	01/01/2008-31/12/2010

3. Wind analysis model

The Weibull function is used to characterize the frequency distribution of wind speeds over time [21]. It is defined by the following equation

$$f(v) = \left(\frac{k}{A}\right)\left(\frac{v}{A}\right)^{k-1} \exp\left[\left(\frac{v}{A}\right)^{k}\right] \quad (1)$$

Where $f(v)$, is the probability of observing wind speed v, k is the dimensionless Weibull shape parameter, and A is the Weibull scale parameter.

The average wind speed can be calculated on the basis of the Weibull parameters as given below [22,23]:

$$V_m = A.\Gamma\left(1+\frac{1}{k}\right) \quad (2)$$

Where V_m is the average wind speed, and Γ is the Gamma function.

3.1. Wind power density

The power of the wind that flows at speed v through a blade sweep area S (m²) as the cubic of its velocity and is given by [24]:

$$P(v) = \frac{1}{2} S\rho v^3 \quad (3)$$

Where, ρ (kg/m3) is the air density.

The power available in wind can be calculated as follows:

$$P = \frac{1}{2} S\rho A^3 \Gamma\left(1+\frac{3}{k}\right) \quad (4)$$

3.2. Extrapolation of the Weibull parameters at hub height

If the wind distribution is desired at some height other than the anemometer level, the advantage of the use of the Weibull distribution is that A and k values can be adjusted to any desired height by different relations. According to the literature and responds to the study region, the relation proposed to assess the Weibull scale parameter A_2 at hub height Z_2 is given by the model of Justus [25] expressed by:

$$\frac{A_2}{A_1} = \left(\frac{Z_2}{Z_1}\right)^m \tag{5}$$

Where the power law exponent m is given by:

$$m = \left(\frac{0{,}37 - 0{,}0881.\ln A_1}{1 - 0{,}0881.\ln\left(\frac{Z_1}{10}\right)}\right) \tag{6}$$

And the relation proposed to evaluate the Weibull shape parameter k_2 at hub height is given by:

$$\frac{k_2}{k_1} = \left(\frac{1}{1 - 0{,}0881.\ln\left(\frac{Z_2}{Z_1}\right)}\right) \tag{7}$$

3.3. Wind turbine capacity factor, power and energy output

Capacity factor CF represents the fraction of the average power output over a period, to the rated electrical power P_n. The average power output P_{avg}, and capacity factor of a wind turbine can be expressed thus [26]:

$$P_{avg} = P_n.CF \tag{10}$$

$$CF = \left(\frac{e^{-\left(\frac{V_c}{A}\right)^k} - e^{-\left(\frac{V_r}{A}\right)^k}}{\left(\frac{V_r}{A}\right)^k - \left(\frac{V_c}{A}\right)^k} - e^{-\left(\frac{V_f}{A}\right)^k}\right) \tag{11}$$

Where V_c, V_r and V_f are the cut-in wind speed, rated wind speed and cut-off wind speed respectively.

3.4. Wind energy density

The temporal gross electricity production (annual, seasonal or monthly) of a wind turbine is calculated according to the following relation [27]

$$E_{avg} = P_{avg}.T \tag{12}$$

Where $T = d.24$ and d is days number.

4. Wind energy yield estimation

The monthly, seasonal and annual wind energy potential will be assess using Fuhrländer FL600 wind energy conversion systems installed at 50m above ground level, which gave the best results between six other WECS with the same rated capacity [28]. Energy calculations require the wind turbine related parameters given by the manufacturer which are summarized in Table 2.

Table 2: Wind turbine parameters

Model	Fuhrländer FL600
Rated power (kW)	600
Rotor diameter (m)	50
Hub height (m)	50
Swept area of rotor (m²)	1962
Cut-in-wind speed (m/s)	3
Rated wind speed (m/s)	13
Cut-out-wind speed (m/s)	19

5. Results and discussion

The wind speed data at the region of Msila have been analyzed taking into account the monthly and seasonal variations. The monthly variation of the mean wind speed at 10 and 50m with the mean power density at 10m above the ground level are listed in Table 3.

Table 3: Monthly variations of mean wind speed and power density at the studied site

Stations	Msila		
Elevation	10		50
Parameters	V (m/s)	P (W/m²)	V (m/s)
January	4,12	277,06	5,77
February	4,31	206,65	6,09
March	4,97	281,16	6,91
April	4,70	163,49	6,66
May	5,14	178,29	7,24
June	3,97	80,93	5,80
July	3,48	59,37	5,17
August	3,24	46,10	4,86
September	3,69	70,91	5,43
October	3,10	74,21	4,59
November	3,73	238,76	5,28
December	4,22	269,57	5,91

It can be observed that the monthly mean wind speed at 10 m varies between 3.10m/s in October and a maximum value of 5.14m/s in May, while at the hub height the monthly wind speed varies between 4.59 and 7.24m/s. Furthermore, at 10m, the mean power density varies between 46.10W/m² in August and 281.16W/m² in March.

Table 4: Seasonal variations of mean wind speed and power density at the studied site

Stations	Msila		
Elevation	10		50
Parameters	V (m/s)	P (W/m²)	V (m/s)
Autumn	3,66	146,17	5,27
Winter	4,28	270,64	6,01
Spring	4,82	165,70	6,83
Summer	3,45	54,98	5,14

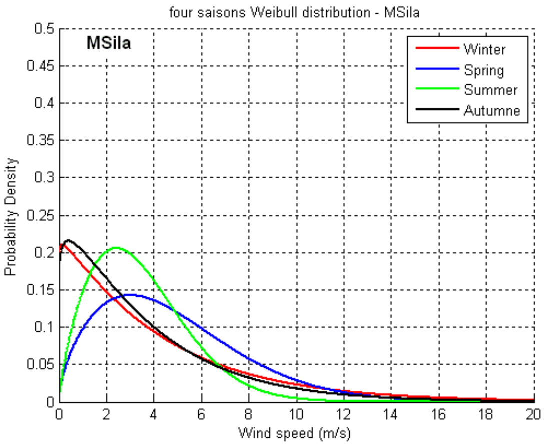

Fig. 1 Seasonal Weibull wind distribution at 10m.

From Table 4 and Fig. 1, it is noticed that the wind speed covers a large range of variation in Autumn, Winter and Spring seasons, and which reaches [0–19m/s], whereas in Summer the higher range is limited at 11m/s. It can be observed that the seasonal mean wind speed varies between 3.45m/s is Summer and 4.82m/s in Winter; we rated also that the seasonal mean wind power density varies between 54.98W/m² and 270W/m².

The annual wind speed frequencies with fitted Weibull distribution at 10m are shown in Fig. 2. where, histogram of the wind speed observations is shown at the studied site with fitted Weibull frequency function. The wind speed covers a range of variation and which reaches 14m/s. In suitability with the monthly and the seasonal studies, the results at 10m from Table 5 give the annual mean wind speed equal to 4m/s and the annual mean wind power density equal to 142W/m².

Table 5: Annual variations of mean wind speed and power density at the studied site

Elevation	10		50
Parameters	V (m/s)	P (W/m²)	V (m/s)
Msila	4,03	142,13	5,79

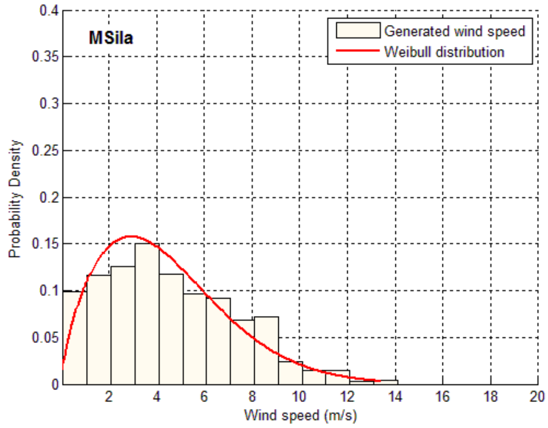

Fig. 2 Annual wind speed frequency with fitted Weibull distribution at 10m.

To estimate the energy output of the wind turbine for each period, the Capacity Factor was calculated, with which the mean power output was calculated, whereupon, the energy gross wind energy production is estimated versus the desired period.

For the annual study, the Capacity Factor is equal to 25.8% with an annual wind energy production equal to 1.39GWh/year.

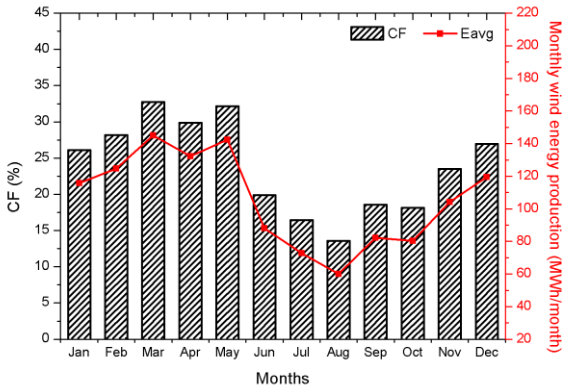

Fig. 3 Monthly gross wind energy production and monthly Capacity factor.

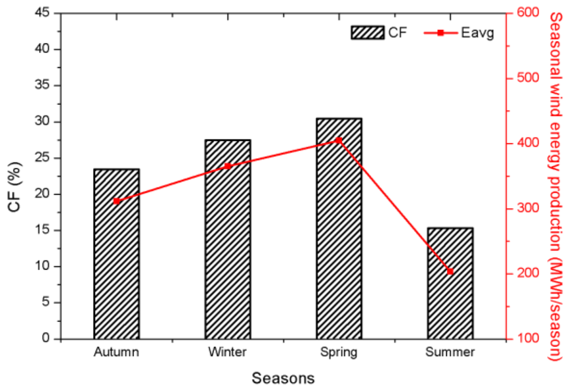

Fig. 4 Seasonal Monthly gross wind energy production and monthly Capacity factor.

Form Fig.3, it is noticed that the monthly yield of the wind turbine varies, the maximum value of the capacity factor is given in March thus giving a wind energy production equal to 145MWh/month and the minimum value is noticed in August with 60MWh/month.

From Fig.4 and in adequacy with the precedent results, it is noticed with the seasonal study that the performance of the wind turbine increases in Spring and decreases in Summer where the better Capacity factor is given in Spring with 30.45% producing 0.4GWh/season and the worse value of capacity factor is noticed in Summer equal to 15.33% given thus a production of 203MWh/season.

6. Conclusion

Through this study, the monthly, seasonal and annual Weibull parameters, mean wind speed and wind power densities are determined at a height of 10 and 50m in monitoring site at the location of Msila situated in Algerian highlands, in order to provide information of wind resources. It is believed that Msila is swept by winds and presents an average wind potential, where the annual mean wind speed determined equal to 4m/s, the monthly mean wind speed determined between 3.10 and 5.14m/s in May and the seasonal mean wind speed between 3.45 and 4.82m/s in Spring at a height of 10m. Further assessment of the monthly, seasonal and annual wind energy output of a wind turbine 600kW rated power have been done at the site, and give March as the great month and Spring for season in term of wind energy production with respectively 203MWh/month and 0.4GWh/season, while the annual wind energy production is equal to 1.39GWh/year. It can be concluded that Msila situated in Algerian highlands are not considered to be suitable for most wind turbine applications but seasonal and monthly studies give that it may be adequate for non-connected electrical and mechanical applications like battery charging and water pumping.

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