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Analysis of Wind Power Potential and Electric Energy in the Algerian Sahara Regions

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Abstract
The wind energy is one of the most significant and rapidly developing renewable energy sources in the world and it provides a clean energy resource, which is a promising alternative in the short term in Algeria. The main purpose of this paper is to compared and discuss the wind power potential in three sites located in sahara of Algeria (south west of Algeria) and to perform an investigation on the wind power potential of desert of Algeria. In this comparative, wind speed frequency distributions data obtained from the web site SODA .com are used to calculate the average wind speed and the available wind power. The Weibull density function has been used to estimate the monthly power wind density and to determine the characteristics of monthly parameters of Weibull for these three sites. The annual energy produced by the BWC XL.1 1KW wind machine is obtained and compared. The analysis shows that in the south west of Algeria, at 10 m height, the available wind power was found to vary between 136.59 W/m2 and 231.04 W/m2. The highest potential wind power was found at Adrar, with 21h per day and the mean wind speed is above 6 m/s. Besides, it is found that the annual wind energy generated by that machine lie between 512KWh and 1643.2kWh. However, the wind resource appears to be suitable for power production on the sahara and it could provide a viable substitute to diesel oil for irrigation pumps and rural electricity generation.

Keywords: Wind Power; Electric Energy; Wind Turbine; Operating Hours; Wiebull's Parameters.

INTRODUCTION

The south of Algeria, characterized by the desert nature, presents a very low population density. Less than thirty per cent of the population lives in this part of the country. In addition, in large areas of the southern Algeria there is no existence of main grid line and the extension of the conventional utility grid to the remotely located community is uneconomical. Fuelling of engines in remote areas is difficult and costly [1]. .
The distribution of wind speeds is important for the desing of wind farms, power generators and agricultural applications such as the irrigation. It is not easy task to choose a site for a wind turbine because many factors have to be taken into account .

Compared to the other renewable energy resources, such as tidal or solar energy, wind energy has a more variable and diffuses energy flux. In order to maximize the benefit of this resource it is very important to be able to describe the variation of wind velocity at any given site under consideration for the development of wind energy conversion system.[2-3].
The variation of wind velocity using the Weibull two parameter density function .There are several methods to calculate the two Weibull parameters, c, and k [4-5].If the mean and variance of the wind speed are known can be determined c and k directly, in this paper an acceptable approximation is used [6]..

In Algeria, work on wind energy resource assessment dates back to 1976 when a wind atlas was developed by using wind speed data from 37 locations [7]. This Algerian Wind Atlas containing the wind results statistics of 37 meteorological stations for the period spanned between 1976 -1988.
Dahbi and all [8] calculated the monthly Weibull parameters for Adrar's site at 10m and found that the wind speed was well represented by the Weibull distribution function, the data wind speed measured at the 10th meters and collected during 8760hours by a wind observation station web site weather underground (The global weather data could be obtained from internet). Algeria has a vast uninhabited land area where the south (desert) represents the part with considerable wind regime.

This Paper present the monthly wind speed and wind power density to assess the wind power potential for three Algerian Sahara regions named Tindouf, Bechar and Adrar located South Western of Algeria.
The Weibull density function has been used to estimate the two monthly Weibull parameters, c, and k at these three sites. The monthly electric power output of BWC XL.1 1KW wind turbine and the monthly operating hours are calculated and simulated. Simulation is performed using Matlab software environment.

SIMULATION OF WIND POWER AND WIND TURBINE CHARACTERISTICS

Weibull density function :

The wind speed probability density function can be calculated as [9]:

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

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

Basically , the scale parameter, c indicates how 'windy' a wind location under consideration is, whereas the shape parameter, k , indicates how peaked the wind distribution is (i.e. if the wind speeds tend to be very close to a certain value, the distribution will have a high k value and be very peaked)[9-10].

Once the mean speed $\bar{v}$ is known, the following approximation can be used to calculate the Weibull parameters, k and c [11] :

$$k = 1.09 + 0.2\bar{v} \quad (2)$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \quad (3)$$

Where the average wind speed $\bar{v}$ is

$$\bar{v} = \frac{1}{n_i}\sum_{i=1}^{n} v_i \quad (4)$$

And the gamma function of (x) (standard formula) calculated.[12]:

$$\Gamma(x) = \int_0^\infty e^{-u}u^{x-1}du \quad (5)$$

The main limitation of the Weibull density function is that it does not accurately represent the probabilities of observing zero or very low wind speeds [12].

The Average Power in the Wind :

The average power in the wind can be expressed as [13]:

$$\bar{p} = \frac{1}{2}\rho A\int_0^\infty v^3 f(v)\, dv \quad (6)$$

The average wind power, expressed in $\left[W/m^2\right]$, can be calculated using the following equation:

$$\bar{p} = \frac{\rho \bar{v}^{3}\Gamma\left(1+\frac{3}{k}\right)}{2\left[\Gamma\left(1+\frac{1}{k}\right)\right]^3} \quad (7)$$

Where $\bar{p}$ is the average power in the wind [W/m^2]; Γ is the gamma function ; k is the Weibull shape parameter; $\bar{v}$ is the average wind speed[m/s], ρ is the air density (Kg/m3).

Power Output Characteristics of Wind Turbine :

As different generators have different power output performance curves, so the model used to describe the performance is also different .In literature [14-15], the following equation is used to simulate the power output of wind turbine:

$$P_w(v) = \begin{cases} P_R * \frac{v^k - v_C^k}{v_R^k - v_C^k} & (v_C \le v < v_R) \\ P_R & (v_R \le v < v_f) \\ 0 & (v \le v_C \;\&\; v > v_f) \end{cases} \quad (8)$$

Where P_R is the rated electrical power [W]; v_c is the cut-in wind speed[m/s]; v_R is the rated wind speed[m/s] ; v_f is the cut-off wind speed of the wind turbine[m/s]; k is the Weibull shape parameter.

The operating hours of the wind turbine :

The cumulative distribution function can be used for estimating the time for which wind is within a certain velocity interval. The monthly operating hours in a year can be calculated like follow [16]:

$$p(v_c < v < v_f) = \left[\exp\left[-\left(\frac{v_c}{c}\right)^k\right] - \exp\left[-\left(\frac{v_f}{c}\right)^k\right]\right].t_m \quad (9)$$

Where v_c is the cut-in speed, v_f is the cut-of speed, t_m is the monthly hours number (30 day chosen for each month) , k is the Weibull shape factor and c is the Weibull scale factor.

CASE STUDY FOR WIND POWER POTENTIAL ANALYSIS

Three Algerian Sahara sites named Tindouf, Bechar and Adrar located South Western of Algeria was selected in this work. It was based around an oasis of the Sahara Desert . A meteorological data collected during 365day by a wind observation station web site www. SoDa.com (Services for Professionals in Solar Energy and Radiation)[17]. (The global whether data could be obtained from internet) is used for analysis in this paper. Which geographical coordinates are presented in the table 1 [7].

Table.1: Geographical Coordinates of Selected Sites

Sites	Longitude	Latitude	Altitude
Bechar	02°15'W	31°38'N	806m
Adrar	00°17'E	27°49'N	263m
Tindouf	08°08'W	27°40'N	402m

Yearly Weibull Density Function :

The calculation results meet the Weibull distribution. From the recorded wind data, the yearly Weibull parameters k, c and mean wind speed of three Algerian Sahara sites are presented in the table 2.

Table 2 : Weibull Parameters of Selected Sites.

Sites	K	C(m/s)	Vmean(m/s)
Bechar	1.85	4.31m/s	3.83
Adrar	2.43	6.66m/s	5.84
Tindouf	2.03	5.33m/s	4.72

Using Equ.1.The Weibull distribution is shown in **fig.1** for the three selected sites.

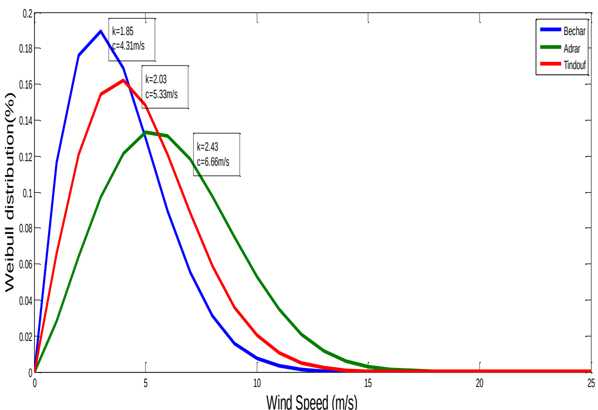

Fig. 1 : The Yearly Weibull distribution of Selected sites

It is clear from the figure that the site of Adrar has the highest value of k and c compared with the site of Bechar and Tindouf. The analysis of Weibull parameters shows that the shape parameter k varies between 1.85 and 2.43 while the scale parameter c varies between 4.31m/s and 6.66m/s. It can be seen that the highest values of k and c are found in Adrar, located in the southwest part of the country. Whereas the lowest values of the two parameters were found in Bechar. It can be seen, that the Weibull approximation of these sites encouraging prospect for wind energy applications.

Monthly Weibull Parameters and Wind Power Density :

Once the monthly mean wind speed is known, the monthly Weibull parameters k and c can be obtained.

In Fig. 2, are shown histograms of the monthly mean wind speed at selected sites. The monthly Weibull parameters k and c are fitted in the fig.3 and fig.4 respectively,

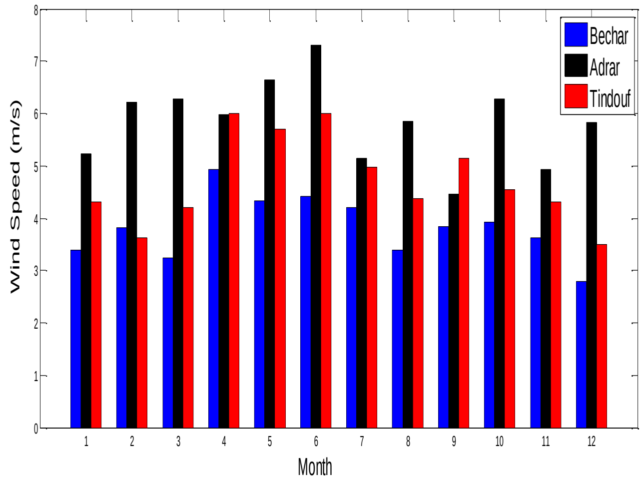

Fig.2: Monthly mean wind speed for selected sites

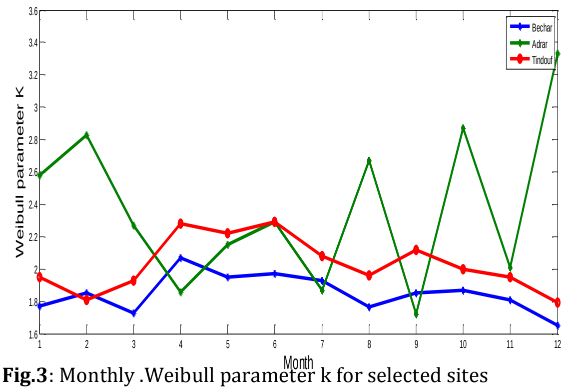

Fig.3: Monthly .Weibull parameter k for selected sites

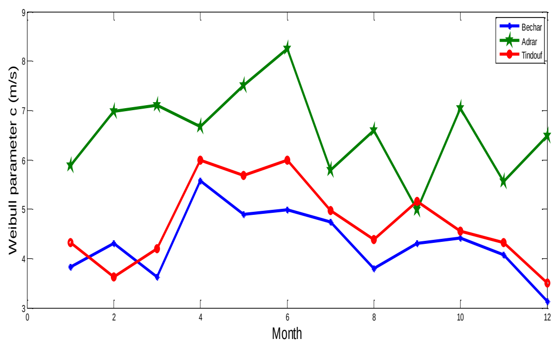

Fig.4: Monthly .Weibull parameter c for selected sites

It is clear from the fig.3 and fig.4 ,that the shape parameter k varies between 1.79 and 2.29 while the scale parameter c varies between 6.77m/s and 3.93m/s at Tindouf. It can be seen that the highest values of k and c are found in June .

Whereas the lowest values of the two parameters were found in December.

It is clear from these figures that the shape parameter k varies between 1.72 and 3.3 while the scale parameter c varies between 8.25m /s and 4.99m /s at Adrar. It can be seen that the highest values of k and c are found in June. Whereas the lowest values of the two parameters were found in September.

The analysis of Weibull parameters shows that the shape parameter k varies between 1.65 and 2.07 while the scale parameter c varies between 3.13 m/s and 5.57 m/s at Bechar.

It can be seen that the highest values of k and c are found in April . Whereas the lowest values of the two parameters were found in December.

The results show that the parameters are distinctive for different months in a year at the selected sites, which means the monthly wind speed distribution differs over a whole year. It is clear that the mean wind speed increases during spring months and decrease during fall months.

Monthly Wind Power Density :

With the above equation and the monthly Weibull parameters, the monthly wind power density can also be calculated. The results are given in fig.5 .

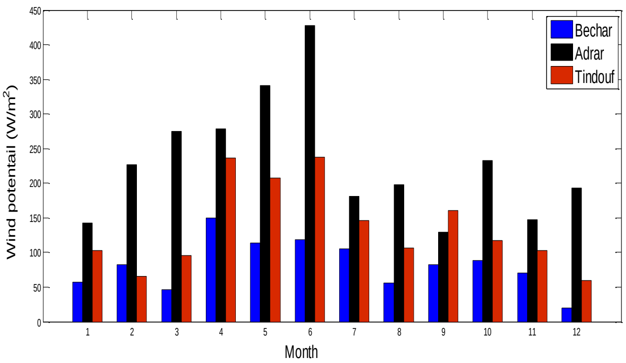

Fig.5: Monthly wind potential at selected sites.

In Figure 5, are shown histograms of the wind potential at selected sites.

The results indicate that a potential of 231.04 W/m2, at 10 m a.g.l., is available for the site of Adrar representing the maximum value, while the lowest value is found at Bechar site with a potential of 82.37 W/m2, but the site of Tindouf ranks in the second position with a wind power density of 136.59 W/m2. It is clear from the results that the average wind power density is distinctive for different months at selected sites. In February to June, the wind power is high, but low in the fall months. This is due to the variation of the wind speed and Weibull parameters between summer months and winter months at each selected sites.
It can be seen that the highest values of wind power potential is found in Adrar compared to the other sites.
The analysis of the results indicates that there is potential for wind energy utilization in southwest of Algeria. The wind resource is good enough in southwest of Algeria, especially Adrar and Tindouf, to supply people with basic energy needs.

MONTHLY WIND POWER PRODUCED BY BWC XL.1 TURBINE

To analysis the effect of the wind turbine characteristics on the wind power generation, a wind turbine of BWC XL.1 1KW generator with a synchronous permanent magnets machine is chosen in this study based on the calculated monthly mean wind speed (is high to 2.5 and low to 13m/s). The cut-in speed is 2.5m/s , the cut-off speed is 13m/s and the rated electrical power of the turbine is 1kW(at rated wind speed 11m/s).Using the Eq.7 and Eq.8 ,the average monthly power generated by the wind turbine and the operating hours of the wind turbine in a year can be calculated for the three Algerian Sahara sites .
The analysis of the results indicates that the operating hours changes in different selected sites. The highest 21h/day occurs Adrar while the lowest is 16h/day at Bechar's site. The operating hours of the site of Tindouf is 19h /day .the trend is not in accordance with the trend of monthly wind power density, because the operating hours is determined not only the wind data distribution but also by the performance of the wind turbine. For selected sites, the monthly energy generated by the BWC XL.1 wind machine generated is calculated and the results are given in fig6.
The results shows that for each month the energy generated is different, varying from 66.97KWh to 221.08KWh at Adrar site . The wind turbine can generate electrical power in the site of Adrar amounting to 1643.2kWh per year. The monthly energy generated by the BWC XL.1 wind machine varies between 28.74 KWh and 143.41 KWh at Tindouf. The lowest energy output is generated in the Bechar's site, it is varies the 7.05 KWh to 89.32 KWh.
The total annual wind energy output is 512KWh per year and 979.97KWh per year at Bechar and Tindouf respectively

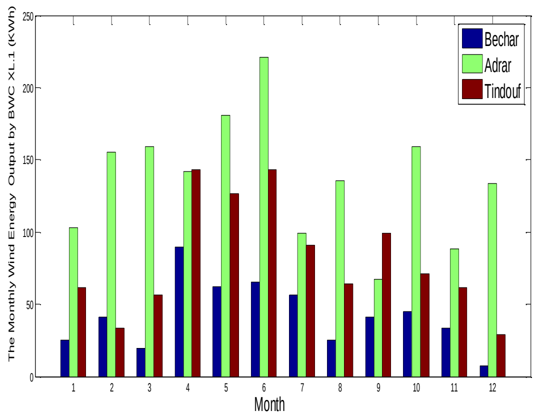

Fig.6: Monthly wind energy output of Bergy XL.1 turbine

CONCLUSION

The proposed simulation model is found applicable for assessing the potential of wind power generation at a location. From the case study, it is found that it is imperative to account for the monthly difference of wind speed using Weibull estimation as the wind energy potential can vary significantly. According to result's of simulation, it is shown that the parameters of Weibull influence directly the wind power available like over the duration of production of electrical energy .

In the Adrar site, the total annual wind energy is 1643.2kWh with one duration of availability of 21h per day. In the site of Tindouf, the wind energy available is 979.97KWh with one duration of availability of 19h per day.

In the case of Bechar, it is 512KWh with one duration of availability of 16h per day.

The analysis of the results of comparison of total annual wind energy generated by the BWC XL.1 wind machine for the selected sites indicates that the maximum energy obtained from this type of wind machine is for Adrar, region in the southern Algeria with high wind speed compared with Tindouf and Béchar.

The analysis shows that there are good prospects for wind energy utilization in the selected Algerian Sahara site. The southwest area located in the west of 0° longitude and between 25° N and 30° N latitudes is the windiest part of southern Algeria with an average win speed exceeding 6 m/s for Adrar and 5 m/s for Tindouf at a height of 10 m.

In the case of selected Algerian Sahara sites, it is fortunate that the windy season coincides with the high temperature seasons (45°-55°) which causes an increased demand for electricity could be covered by exploitation of wind energy. Therefore, accurate wind predictability and its correlation with electricity load demand may allow for a high penetration of wind energy and could make it an economically attractive supplement to diesel-fuelled power station. It is recommended to undertake further studies to explore other locations in the Sahara of Algeria and to develop this renewable energy resource.

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