ALGERIA WIND ENERGY RESOURCES

R. Maouedj*, S. Bousalem, B. Benyoucef

Unité de Recherche des Matériaux et Energies Renouvelables (URMER)
BP 119, 13000 Tlemcen, Algérie
*E-mail: ra_maouedj@yahoo.fr

Received: 24 Sept 2007; accepted: 5 Nov 2007

The wind energy is a solar resource of origin, created by the differences in temperature between the sea, the earth and the air like by the variations in temperature between the equator and the poles of planet. Approximately 0.25 % of the total solar radiations are converted into wind power. The wind power knew a very strong growth during the last decade thanks to the advantages which it has for the environment, with the related technological breakthroughs and with the governmental programmes of encouragement in the world.
This article gives a report on the recent developments concerning the conversion systems of the wind power as well as welfare benefits and environmental which are associated there. It presents also a modelling and simulation of a conversion system wind on the sites of Alger, Oran, Tlemcen, Chlef, Djelfa, Tiaret, Tindouf and In Salah (Algeria) by using the weather and radio parameters metric and the determination of the parameters of Weibull K and C and the power recovered (mean velocities of the wind) according to altitude and of roughness of the site.

Keywords: wind energy, wind conversion system, wind speeds, power

Rachid Maouedj

Organization(s): Tlemcen university, Unit of Research on Materials and Renewable Energies. Tlemcen, URMER, PhD student.
Education: High level degree on physics Tlemcen University, Faculty of sciences (1999-2002), master degree on physics (2003-2005).
Experience: Attached of research to the Unit of Research in Renewable Energies in Saharan Medium URER-MS, Adrar (2006-2008), Scientific research projects: hybrid systems (photovoltaic, wind), application on optic telecommunication in Algeria.
Main range of scientific interests: renewable energies.
Publications: 1 paper in international scientific journal and 2 papers (in press).

Souad Bousalem

Organization(s): Tlemcen University, Unit of Research on Materials and Renewable Energies. Tlemcen (URMER), PhD Student.
Education: High level degree on physics Tlemcen University, Faculty of sciences (1997-2001), master degree on physics (2003-2005).
Experience: Tlemcen University, associate researcher (2006-2007), Scientific research projects: study, modeling and simulation of hybrid systems wind/PV.
Main range of scientific interests: renewable energies: wind and solar.
Publications: 1 paper in international scientific journal (in press).

Pr. Boumediene Benyoucef

Organization(s): Professor at Tlemcen University, Director of the Unit of Research on Materials and Renewable Energies, University of Tlemcen, Faculty of Science, Department of Physics, BP 119, 13000, Tlemcen. Algeria.

Introduction

The estimate of the wind power resources presents a major difficulty. Contrary to the fossil fuel reserves, the quantity of energy available varies with the season and the hour of the day. The wind power of advantage is influenced by topography that solar energy. Moreover, the total quantity of convertible wind power on the territory of a nation depends to a significant degree of the characteristics, the hoped output, the dimensioning and the horizontal distribution of the wind-engines (Tables 1, 2, Fig. 1).

Table 1

Geographical data of the selected sites [1, 2]

Sites	Longitude	Latitude	Altitude (m)	Topographic situation
Alger Oran	03°15′ E 00°37′ W	36°43′N 35°38′N	24 90	Coastal zone
Tlemcen Chlef	01°17′ W 01°20′ E	34°57′N 36°12′N	592 143	North of the Tellien mountains
Djelfa Tiaret	03°15′ E 01°28′ E	34°40′N 35°21′N	1144 977	Highlands
Tindouf In Salah	08°06′ W 02°28′ E	27°40′N 27°12′N	401 268	Sahara

Table 2

Weibull, hybrid Weibull parameters [1, 2, 3]

Sites	Roughness (m)	Frequency at V = 0 m/s (%)	Weibull parameters		V (m/s)
			K	C (m/s)	
Alger Oran	0.01 0.01	34.0 06.0	2.03 1.26	5.0 4.1	2.9 3.6
Tlemcen Chlef	0.01 0.01	52.0 36.0	2.12 1.82	4.7 4.5	2.0 2.5
Djelfa Tiaret	0.08 0.02	36.5 20.0	1.71 1.74	4.4 6.3	2.5 4.3
Tindouf In Salah	0.00 0.02	16.0 23.0	1.90 1.68	5.4 5.8	4.0 4.0

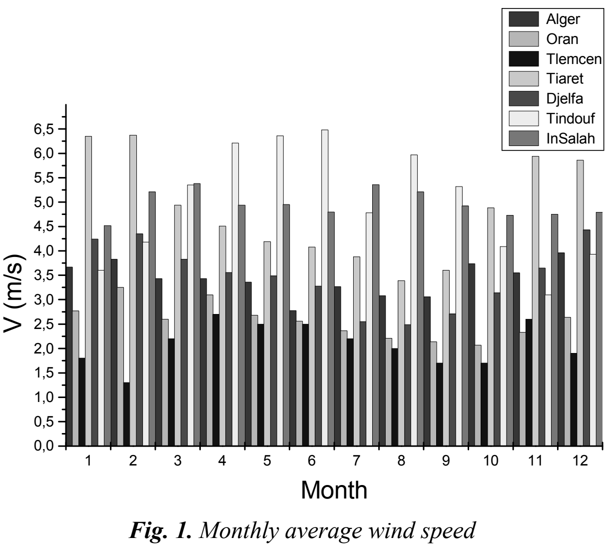


Fig. 1. Monthly average wind speed

Power available in the wind spectra [3, 4, 5]

The kinetic energy of a stream of air with mass m and moving with a velocity V is given by

$$E = \frac{1}{2} m v^2 \tag{1}$$

Consider a wind rotor of cross sectional area A exposed to this wind stream. The kinetic energy of the air stream available for the turbine can be expressed as:

$$E = \frac{1}{2} \rho_a v V^2 , \tag{2}$$

where ρ_a the density of air and V is the volume of air parcel available to the rotor.
The air parcel interacting with the rotor per unit time has a cross-sectional area equal to that of the rotor (A_T) and thickness equal to the wind velocity (V). Hence energy per unit time, that is power, can be expressed as

$$P = \frac{1}{2} \rho_a A_T V^3 . \tag{3}$$

From Eq. (3), we can see that the factors influencing the power available in the wind stream are the air density, area of the wind rotor and the wind velocity.
Effect of the wind velocity is more prominent owing to its cubic relation ship with the power.

Variation of the density of the air with the temperature, the pressure and of altitude

Factors like temperature, atmospheric pressure, elevation and air constituents affect the density of air. Dry air can be considered as an ideal gas. According to the ideal gas law [4, 6],

$$pV_G = nRT , \tag{4}$$

where p is the pressure, V_G is the volume of the gas, n is the number of kilomoles of the gas, R is the universal gas constant and T is the temperature. Density of air, which is the ratio of the mass of 1 kilomole of air to its volume, is given by:

$$\rho_a = \frac{m}{V_G} . \tag{5}$$

From Eqs. (4) and (5), density is given by:

$$\rho_a = \frac{mP}{RT} . \tag{6}$$

If we know the elevation Z and temperature T at a site, then the air density can be calculated by:

$$\rho_a = \frac{353.049}{T} e^{\left(-0.034\frac{Z}{T}\right)} . \tag{7}$$

The density of air decreases with the increase in site elevation and temperature as illustrated in Fig. 2-3.The air density may be taken as 1.225 for most of the practical cases. Due to this relatively low density, wind is rather a diffused source of energy. Hence large sized systems are often required for substantial power production.

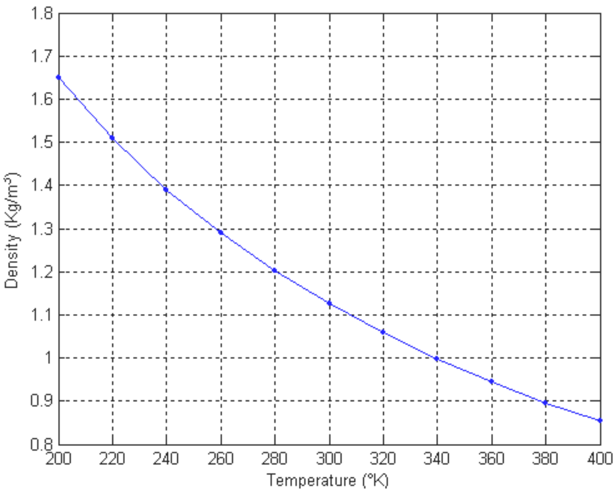


Fig. 2. *Effect of elevation on air density*

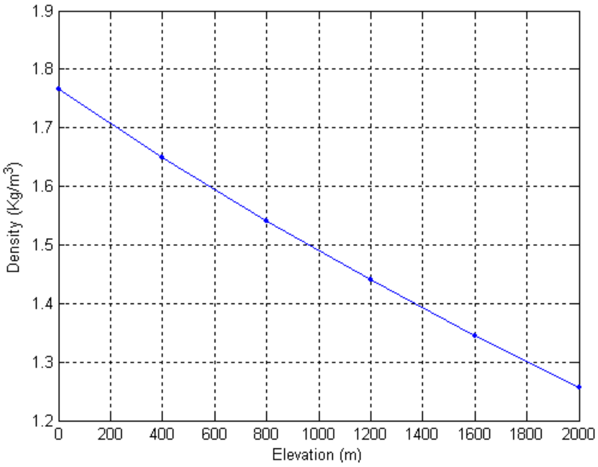


Fig. 3. *Effect of temperature on air density*

Effect of height

The wind shear at ground surface causes the wind speed increase with height in accordance with the expression [6, 7]

$$V_2 = V_1\left(\frac{h_2}{h_1}\right)^{\alpha}, \qquad (8)$$

where V_1: wind speed measured at the reference height h_1; V_2: wind speed estimated at height h_2; α: ground surface friction coefficient.

The friction coefficient is low for smooth terrain and high for rough ones (Fig. 4).

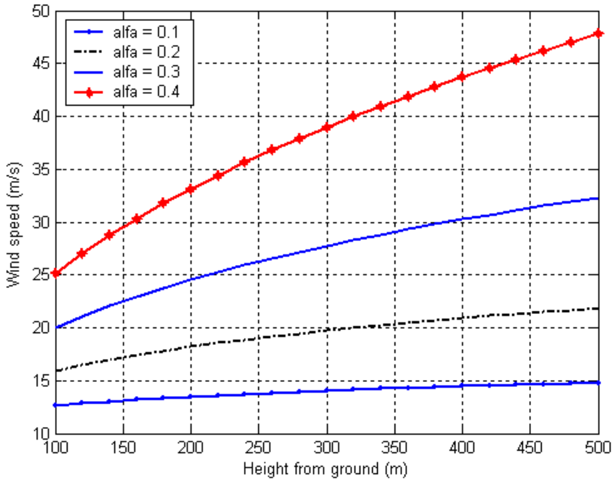


Fig. 4. *Wind speeds variation with height over different terrain. Smooth terrain has lower friction, developing a thin layer above*

The values of α for typical terrain classes are given in Table 3.

Table 3

Friction coefficient of various terrains

Terrain type	Friction coefficient α
Lake, ocean and smooth hard ground	0.10
Foot high grass on level ground	0.15
Tall crops, hedges, and shrubs	0.20
Wooded country with many trees	0.25
Small town with some trees and shrubs	0.30
City area with tall buildings	0.40

Transmission and generator efficiencies

The basic system is then as shown in Fig. 5. We star with the power in the wind, P_w. After this power passes through the turbine, we have a mechanical power P_m at the turbine angular velocity ω_m, which is then supplied to the transmission. The transmission output power P_t is given by the product of the turbine output power P_m and the transmission efficiency η_m [8],

$$P_t = \eta_m P_m. \qquad (9)$$

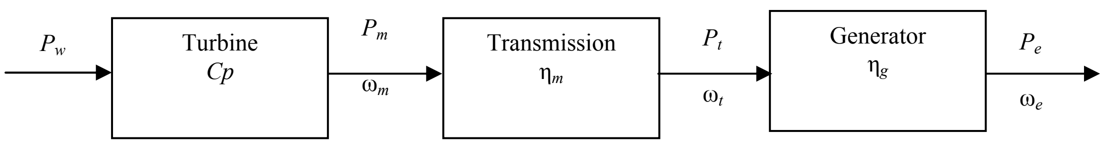


Fig. 5. *Wind electric system*

Similarly, the generator output power P_e is given by the product of the transmission output power and the generator efficiency η_g:

$$P_e = \eta_g P_t. \tag{10}$$

The generator output power P_e can be expressed as:

$$P_e = C_p \eta_m \eta_g P_\omega. \tag{11}$$

At rated wind speed, the rated electrical power output can be expressed as

$$P_{eR} = C_{PR} \eta_{mR} \eta_{gR} \frac{\rho}{2} A V_R^2, \tag{12}$$

where C_{PR} is the coefficient of performance at the rated wind speed V_R, η_{mR} is the transmission efficiency at rated power, η_{gR} is the generator efficiency at rated power, ρ is the air density, and A is the turbine area.
The quantity $C_{PR}\eta_{mR}\eta_{gR}$ is the rated overall efficiency of the turbine. We shall give this quantity a symbol of its own, η_0:

$$\rho_0 = C_{PR} \eta_{mR} \eta_{gR}. \tag{13}$$

Power curve of the wind turbine [9, 10]

The important characteristic speeds of the turbine are its cut-in velocity (V_I), rated velocity (V_R) and the cut-out velocity (V_0). The cut-in velocity of a turbine is the minimum wind velocity at which the system begins to produce power. It should not be confused with the start-up speed at which the rotor starts its rotation. The cut-in velocity varies from turbine to turbine, depending on its design features. However, in general, most of the commercial wind turbines cut-in at velocities between 3 to 5 m/s (Fig. 6).

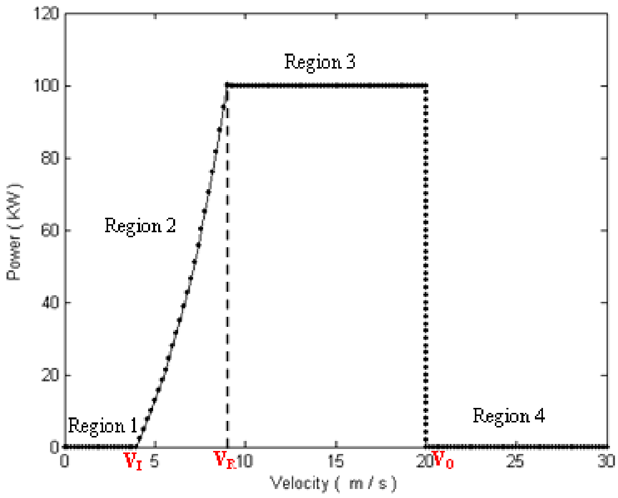


Fig. 6. *Ideal power curve of a pitch controlled wind turbine*

Due to technical and economical reasons, the wind turbine is designed to produce constant power – termed as the rated power (P_R) – beyond its rated velocity.

Table 4

Performance regions of a wind turbine

Velocity range	Power
Region 1: 0 to V_I	No power as the system is idle
Region 2: V_I to V_R	Power increases with V
Region 3: V_R to V_0	Constant power P_R
Region 4: Greater than V_0	No power as the system is shut down

Hence, the turbine has four distinct performance regions as indicated in Table 4. The power produced by the system is effectively derived from performance regions corresponding to V_I to V_R and V_R to V_0. Let us name these as region 2 and 3. The velocity-power relationship in the region 2 can be expressed in the general form

$$P_V = aV^n + b, \tag{14}$$

where a and b are constants and n is the velocity-power proportionality. Now consider the performance of the system at V_I and V_R. At V_I, the power developed by the turbine is zero. Thus

$$aV_I^n + b = 0. \tag{15}$$

At V_R power generated is P_R. That is:

$$aV_R^n + b = P_R. \tag{16}$$

Solving Eqs. (15) and (16) for a and b and substituting in Eq. (14) yields

$$P_V = P_R\left(\frac{V^n - V_I^n}{V_R^n - V_I^n}\right) \tag{17}$$

Finally we get:

$$\begin{cases} Pv = 0 & v < v_I \\ Pv = P_R\left(\dfrac{V^n - V_I^n}{V_R^n - V_I^n}\right) & v_I \le v \le v_R \\ Pv = P_R & v_R \le v \le v_0 \\ Pv = 0 & v > v_0 \end{cases} \tag{18}$$

Energy production and capacity factor

The average power output from a wind turbine is the power produced at each wind speed times the fraction of time that wind speed is experienced, integrated over all possible wind speeds [8].
In integral from, this is:

$$P_{e,ave} = \int_0^\infty Pvf(v)dv. \tag{19}$$

After calculate in finds

$$P_{e,ave} = P_R\left(\frac{\exp\left[-\left(\frac{v_I}{C}\right)^K\right]-\exp\left[-\left(\frac{v_R}{C}\right)^K\right]}{\left(\frac{v_I}{C}\right)^K-\left(\frac{v_R}{C}\right)^K}-\exp\left[-\left(\frac{v_0}{C}\right)^K\right]\right). \quad (20)$$

$P_{e,ave}$ can be expressed as:

$$P_{e,ave} = P_R(CF) = \eta_0 \frac{\rho}{2} A v_R^3 (CF), \quad (21)$$

where CF is the capacity factor.

The choice of rated wind speed will not depend on the rated overall efficiency, the air density, or the turbine area, so these quantities can be normalized out. Also, since the capacity factor is expressed entirely in normalized wind speed, it is convenient to do likewise in normalizing Eq. (21) by dividing the expression by C^3 to get term $(V_R/C)^3$. We therefore define a normalized average power P_N as:

$$P_N = \frac{P_{e,ave}}{\eta_0\left(\frac{\rho}{2}\right)AC^3} = (CF)\left(\frac{v_R}{C}\right)^3. \quad (22)$$

The yearly energy production of such a turbine is:

$$W = P_{e,ave}(time) = (CF)P_R(8760), \quad (23)$$

where 8760 is the number of hours in a year of 365 days and P_R is expressed in kilowatts.

Mathematical models

The average wind velocity is given by [2, 4, 6]:

$$\bar{V} = \int_0^\infty f(V)dV, \quad (24)$$

where the standard GAMMA function Γ is defined by the following relation:

$$\Gamma(x) = \int_0^\infty \exp(-t)t^{x-1}dt \quad (25)$$

with $x > 0$.

The average cubic speed of the wind is given by the following relation:

$$\langle V^3 \rangle = \int_0^\infty V^3 P(V)dV. \quad (26)$$

The variance:

$$\sigma^2 = \int_0^\infty (V - \langle V \rangle) f(V)dV. \quad (27)$$

Weibull distribution

In Weibull distribution, the variations in wind velocity are characterized by the two functions; (1) The probability density function and (2) The cumulative distribution function.

The probability density function $f(v)$ indicates the fraction of time (or probability) for which the wind is at a given velocity V. It is given by [2, 4, 6]:

$$f_W(V) = \left(\frac{k}{C}\right)\cdot\left(\frac{V}{C}\right)^{k-1}\exp\left[-\left(\frac{V}{C}\right)\right]^k. \quad (28)$$

Here, K is the Weibull shape factor and C is scale factor. The cumulative distribution function of the velocity V gives us the fraction of time (or probability) that the wind velocity is equal or lower than V. Thus the cumulative distribution $F(V)$ is the integral of the probability density function. Thus,

$$F(V) = \int_0^\alpha f(V)dV = 1 - e^{-\left(\frac{V}{C}\right)^K}. \quad (29)$$

Average wind velocity of a regime, following the Weibull distribution is given by

$$\bar{V} = C \cdot \Gamma\left(1 + \frac{1}{k}\right). \quad (30)$$

The average cubic speed of the wind is given by the following relation:

$$\langle V^3 \rangle = C^3 \cdot \Gamma\left(1 + \frac{3}{k}\right). \quad (31)$$

The variance:

$$\sigma^2 = C^2\left[\Gamma\left(1+\frac{2}{K}\right) - \Gamma^2\left(1+\frac{1}{K}\right)\right]. \quad (32)$$

Rayleigh distribution

Rayleigh distribution is a simplified case of the Weibull distribution which is derived by assuming the shape factor as 2. Owing to its simplicity, this distribution is widely used for wind energy modelling. Under the Rayleigh based approach, the cumulative distribution and probability density functions of wind velocity are given by [3, 4]:

$$f_R(V) = \frac{\pi}{2}\frac{V}{C^2}\exp\left[-\frac{\pi}{4}\left(\frac{V}{C}\right)^2\right]. \quad (33)$$

Similarly, the cumulative distribution is given by:

$$F(V) = 1 - e^{-\frac{\pi}{4}\left(\frac{V}{C}\right)^2}. \quad (34)$$

The average wind velocity is given by the distribution of Rayleigh by:

$$\bar{V} = 0{,}8862C. \quad (35)$$

The average cubic speed of the wind is given by the following relation:

$$\langle V^3 \rangle = 1{,}3293C^3 . \qquad (36)$$

The variance:

$$\sigma^2 = 0{,}2146C^2 . \qquad (37)$$

***Hybrid of Weibull distribution** [11]*

$$\begin{cases} f(V) = (1-ff_0)\left(\dfrac{k}{C}\right)\left(\dfrac{V}{C}\right)^{k-1} \exp\left[-\left(\dfrac{V}{C}\right)\right]^k & V > 0 \\ f(V) = ff_0 & V = 0 \end{cases} \qquad (38)$$

The mean velocity of the wind is given by the hybrid distribution of Weibull by:

$$\overline{V} = (1-ff_0)C \cdot \Gamma\left(1+\frac{1}{k}\right). \qquad (39)$$

The average cubic speed of the wind is given by the following relation:

$$\langle V^3 \rangle = (1-ff_0)C^3 \cdot \Gamma\left(1+\frac{3}{k}\right). \qquad (40)$$

The variance:

$$\sigma^2 = (1-ff_0)C^2\left[\Gamma\left(1+\frac{2}{K}\right)-\Gamma^2\left(1+\frac{1}{K}\right)\right]. \qquad (41)$$

Results and discussion

Weibull, Rayleigh, Hybrid of Weibull probability density function, Weibull, Rayleigh, Hybrid of Weibull cumulative distribution function for different shape factors (different sites) are presented in Fig. 7-12.
Calculation of the wind potential by the methods of Weibull, Rayleigh and Hybrid of Weibull distribution is presented in Table 5

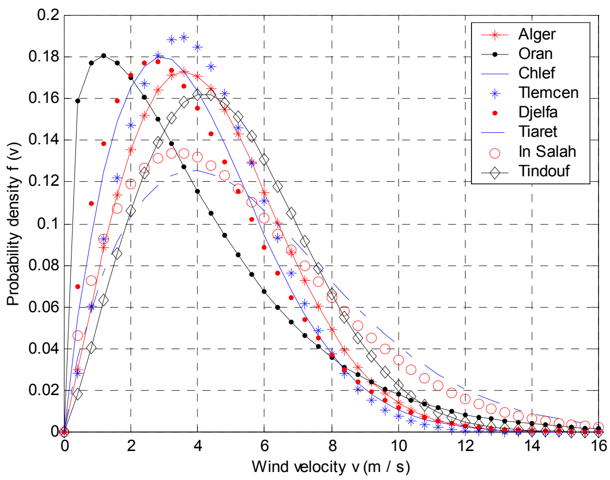


***Fig. 7.** Weibull probability density function for different shape factors (different sites)*

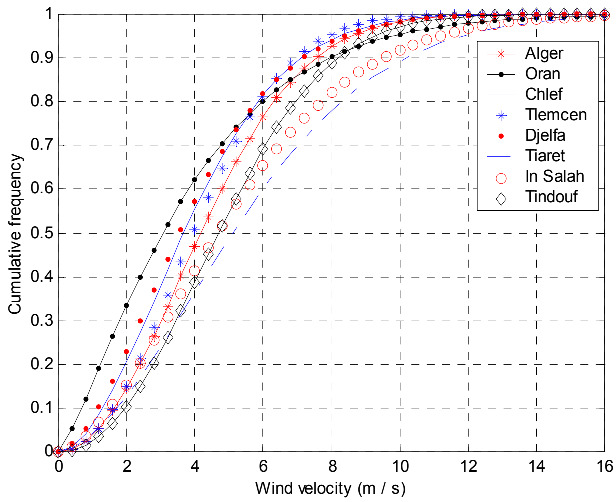


***Fig. 8.** Weibull cumulative distribution function for different shape factors (different sites)*

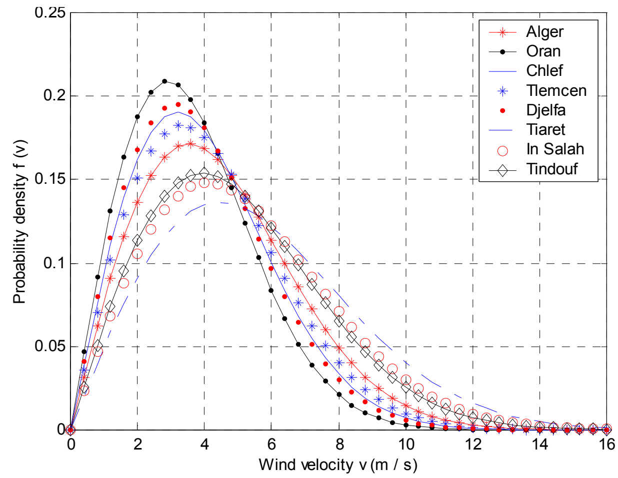


***Fig. 9.** Rayleigh probability density function for different shape factors (different sites)*

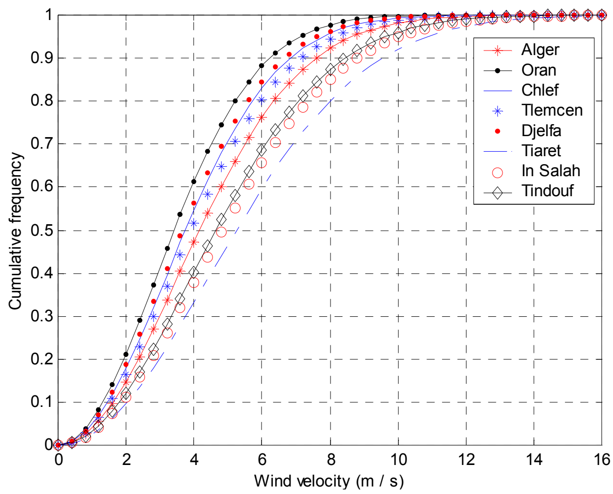


***Fig. 10.** Rayleigh cumulative distribution function for different shape factors (different sites)*

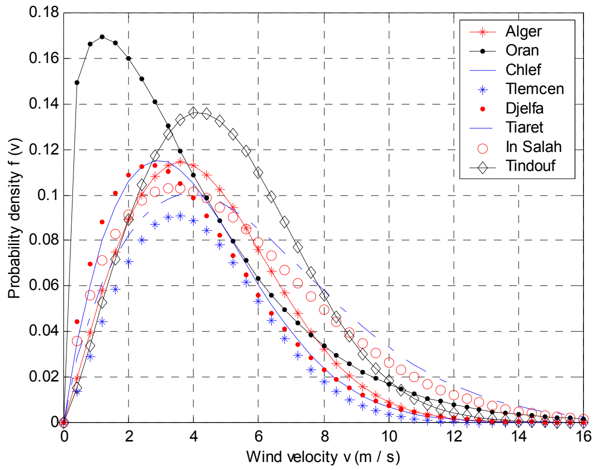


Fig. 11. *Hybrid of Weibull probability density function for different shape factors (different sites)*

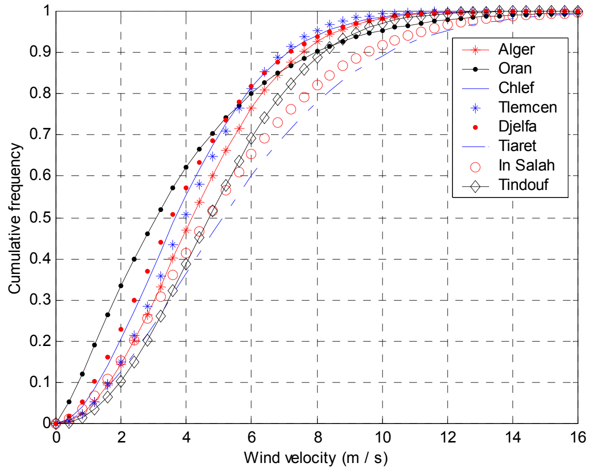


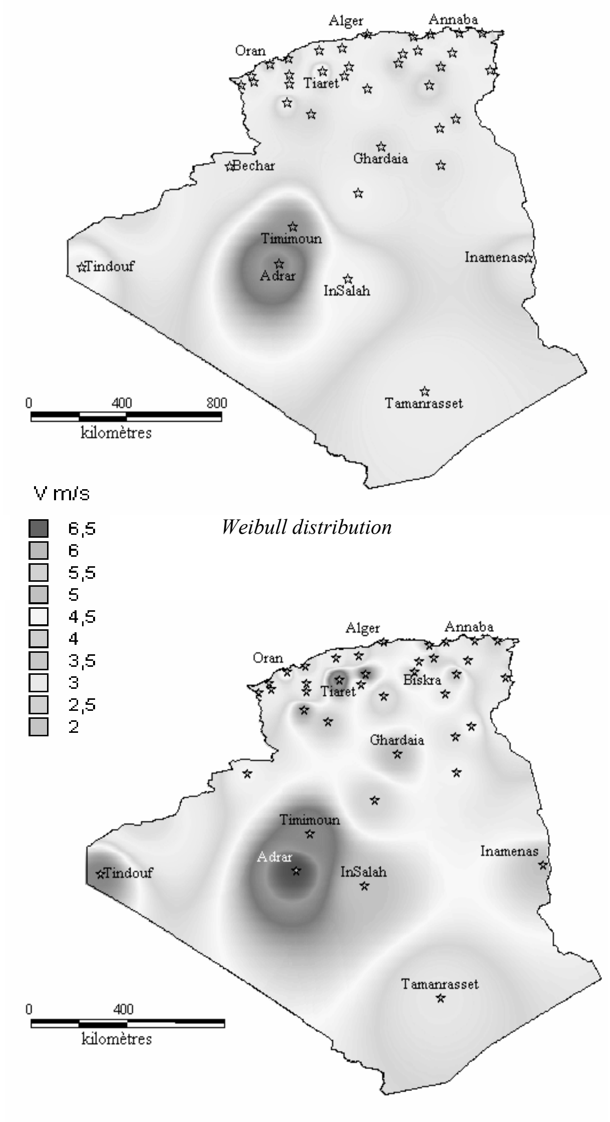
Fig. 12. *Hybrid of Weibull cumulative distribution function for different shape factors (different sites)*

Table 5

Calculation of the wind potential by the three methods [12, 13]

	Weibull distribution	Rayleigh distribution	Hybrid of Weibull distribution
Alger			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	4.43 163.62 100.22	4.43 166.17 101.78	2.92 107.99 66.14
Oran			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	3.81 201.34 123.32	3.63 91.62 56.12	3.58 189.26 115.92
Chlef			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	3.99 135.17 82.79	3.99 121.14 74.20	2.56 86.51 52.98
Tlemcen			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	4.16 130.25 79.78	4.16 138.02 84.54	1.99 62.52 38.29
Djelfa			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	3.92 137.50 84.22	3.90 113.24 69.36	2.49 87.31 53.48
Tiaret			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	5.61 393.80 241.20	5.58 332.40 203.59	4.49 315.04 192.96
In Salah			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	5.18 323.21 197.97	5.14 259.37 158.86	3.99 248.87 152.44
Tindouf			
$\bar{V}$ (m/s) V^3 (m^3/s^3) P (W/m^2)	4.79 221.61 135.73	4.79 209.32 128.21	4.02 186.15 114.02

In the Fig. 13 we can see various wind regimes in Algeria [2].



Weibull distribution

Hybrid of Weibull distribution

Fig. 13. *Various wind regimes in Algeria*

Conclusion

The most important remark is that Algeria has an appreciable wind energy potential, particularly in the south of the country and in some microclimates of the north. In the northern part, with a mean speed of the order of 5.6 m/s, Tiaret is the region that offers the most possibilities.

The three caused methods were compared for Algerian sites. These sites were selected because of the variety which represent the curves of distribution (difference of the shape factor *K* and of form and scale factor *C*) and in more difference average monthly speeds for the sites.

For a more precise evaluation of the performances of the wind-engines, it is preferable to use the law of distribution of Weibull. This method is based on the use the mean velocity of the wind and the two parameters of Weibull (*K* and *C*), even the method of Rayleigh gives good results for the sites characterized by a factor of form $K \approx 2$ like the site of Alger and Tlemcen, on the other hand on the site of Oran and In Salah in remark a great difference between the model of Rayleigh and the others models calculation.

The exploitation of the wind power is possible for several of the Algerian sites even for the installations of great power.

References

1. Capderou M. Atlas solaire de l'Algérie, Tome 2, Aspect énergétique.

2. N. Kasbadji Merzouk. Evaluation du gisement énergétique éolien contribution a la détermination du profil vertical de la vitesse du vent en Algérie. Thèse de doctorat, Université de Tlemcen. Algérie. Mai 2006.

3. Maouedj R., Bousalem S., Benyoucef B. Etude des performances d'un système éolien pour le site d'Adrar. Le 7eme congrès national de la physique et ses applications (CNPA' 2006) a Béchar du 18 au 20 Décembre 2006.

4. Sathyajith M. Wind energy fundamentals, resource analysis and economics. Faculty of Engineering, KCAET. Tavanur, Malapuram, Kerala. India.

5. Burton T., Sharpe D., Jenkins N., Bossanyi E. Wind energy handbook. England, 2001.

6. Justis C.G. (Traduit et adapté par J.L. Plazy). Vent et performances des éoliennes. Paris, 1980.

7. Extrait du rapport de synthèse ECRIN L'electronique de puissance vecteur d'optimisation pour les energie renouvelables. Paru mai en 2002. Paris.

8. Johnson G.L. Wind energy systems. November 21, 2001.

9. Bianchi F.D., De Battista H., Mantz R.J. Wind turbine control systems principles, modelling and gain scheduling design. Germany.

10. Hau E. Wind turbines fundamentals, technologies, applications, economics, 2nd edition, Germany.

11. N. Kasbadji Merzouk. Wind energy potential of Algeria // Renewable Energy. 21 (2000). P. 553-562.

12. Maouedj R., Deliou A., Benyoucef B. Estimation du potentiel énergétique éolien sur les sites de Tlemcen et d'Adrar. Le congrès international sur les énergies renouvelables et le développement durable ICRESD_07. Tlemcen, du 21 au 24 Mai 2007.

13. Maouedj R., Bousalem S., Khelifi C., Draou D., Benyoucef B. Modélisation et simulation d'un système de pompage éolien. Inernational conference on modeling and simulation MS'07, July 02-04, 2007. Algiers.