New study on the extension of a current wind farm; case of Kaberten park in Algeria

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Abstract: By increasing their electricity production capacity, this work focuses on a new wind farm configuration study currently in service. More specifically, a study that aims to enlarge the production area of the ventilated sites by implanting more wind turbines in optimal positions behind the existing turbines. In order to achieve this goal, we use Jensen's linear wake pattern to describe the behavior of wind speed in wake, as well as a method based on the generation of a sequence of modified pseudo-random numbers as Mathematical approach to optimize the location of the wind turines. To perform numerical simulations, a program under MATLAB has been developed using the characteristics of the Gamessa G52 turbine and the data of the site in the production of Kaberten in Algeria. The results obtained from this study are presented and discussed.

Keywords: Wind Farm, Wind turbine, Jensen Model, Wake Model, Wind Park, Optimal Distribution, Kaberten, Pseudo-Random Numbers.

1.Introduction

Wind energy is a renewable energy; clean, inexhaustible source and does not produce greenhouse gases or polluting waste to the environment. To meet the increased demand for electricity, this resource, which represents a promising option for energy production, has been the subject of several installations of wind farms around the world in recent decades, offshore and onshore. Currently, the largest operational onshore wind farms produce more than 8000 MW/year and it is expected to reach 15000 MW/year by the year 2030. Through rapid growth in wind technology and support for all influencing factors, energy from wind has become among the most competitive to conventional energy sources such as coal, oil and natural gas, wind turbines exceeding 100 m in height and 4 MW nominal power have been built and marketed for installation in large wind farms.

Normally, the installation of a wind farm is done naturally where there is a sufficient level of wind throughout the year to allow permanent and regular production of electricity. Therefore, for a profitable exploitation of this renewable energy source, precise knowledge on the evaluation of the wind deposit is extremely necessary before any wind installation, the speed and the direction of the wind are the main factors which determine the quality of this deposit. for possible exploitation. In this context, in Algeria which currently has all the necessary assets for the development of wind energy, several studies by the CDER (Center for the Development of Renewable Energies) have been carried out on wind meteorology for the development of a wind atlas. One of the first wind mapping works of the country was carried out in by **Dr. Nachida Kasbadji Merzouk** (**2006)** at 10 m from the ground [1], although this preliminary atlas gives useful information for the quantification of the existing potential, it remains insufficient for the choice of sites eligible for the establishment of wind farms. Another study on the wind farm in Algeria was established by Dr. **Farouk Chellali et al. (2011)**, the latter introduced a spectral analysis to study the cyclical phenomenon of the wind and contributed to updating the wind map in Algeria by introducing the site of Hassi-R'Mel which had been underestimated in previous works [2]. The most recent study was carried out in 2013 by Dr. **Sidi Mohammed Boudia (2013**) who updated the map of the winds at 10m above the ground [3], by introducing more recent meteorological data and a greater number of measurement points by compared to previous work.

All of this work has shown that the region from Kaberten to Adrar in southwest Algeria is the windiest. It has enormous wind potential, with an average annual wind speed of around 6 m / s at 10 m from the ground, so the average available power density is greater than 280 W / m2 [4]. On the basis of these data and these works, several studies were carried out on the possibility of producing electricity from wind power through the installation of a wind farm in Kaberten, these studies used meteorological data and the Wind atlases produced by the CDER (renewable energy development center). It seems that the first work carried out on the configuration of a wind farm in Algeria was presented in a study by **Merdaoui et al. (2010)**, their study consisted of evaluating and quantifying the wind energy potential of the Kaberten site using the WASP software [5], several typical configurations of a wind farm with ten turbines were simulated in order to determine the best arrangement of the wind turbines on the chosen site allowing for optimum energy efficiency and considerable financial gain. Then, in 2011, another study aiming at the possibility of setting up a wind farm in Adrar was published by Djamai et al [6], this study based on the wind map, shows that the region has all the arguments that argue in favor of a wind power plant for the production of electricity. **Ben Mbarek et al. (2017)** proposed another study based on hourly measurements of wind speeds and direction taken by the Adrar regional weather site for the year 2012 [7], using WASP and GH software, the best layout for each wind turbine on the chosen site is obtained on several calculated arrangements, which allows to obtain an optimal energy efficiency and therefore a minimal drag effect. Based on the quantification of the wind farm at Kaberten, **Zergane et al (2019)** presented a new study of the optimal configuration of a wind farm with 42 turbines for the production of electricity [8]. Recently, a wind farm of 10 MW of nominal power to be proposed there in a project attributed to the Algerian-French consortium (Cegelec) considering on a straight line and facing the predominant direction of the wind, 12 turbines of GAMESA G52 type each with 850 kW nominal power. The energy produced by the farm is fed into the existing electrical network

Taking advantage of the significant potential of this wind farm in southwest Algeria, we present in this article a new study which aims to extend the current Kaberten wind farm in service. The idea is to install an optimal number of turbines downstream of the 12 existing first row turbines while minimizing the effect of wake through an optimal location of the wind turbines. To achieve this end, Jensen's wake model [9] is used to describe the wind speed in the park, as well as the optimization method based on the generation of pseudo-random numbers [9] and the function objective of the cost of the wind turbine installation [8]. Unlike previous optimization methods, the wind speed on the turbines to optimize their installations undergoes a reduction on the front. To this end, a calculation program has been developed under Matlab by introducing the characteristics of the turbine according to the GAMESA G52 function and the data from the Kaberten site. The results obtained from this study are analyzed and discussed taking into account the optimal turbine capacity and the rate of power reduction.

It should be noted that the present study is the continuation of an earlier study [8] which deals with the evaluation of the wind field and the establishment of a possible wind company in the Kaberten region.

2.Method Used

The method used is based on Jensen's wake model to model the wind speed in the park, and the mathematical approach of generating pseudo-random numbers [9] to position the wind turbines in the park.

2.1.Jensen's Wake Model

The wake is an aerodynamic zone behind a front turbine which is characterized by a reduction in speed, resulting in a decrease in the power developed in the park. For modeling the wind speed in the park, we adopt Jensen's wake model [9], often used in commercial optimization codes, on this model, we assume that the speed in the wake has a profile " in hat " described as follows [10], [11]:

$$U_w = U\left(1 - \frac{R^2\left(1-\sqrt{1-C_T}\right)}{(R+\alpha x)^2}\right) \quad (1)$$

where α, R, U and U_w are respectively, the training coefficient, the radius of the turbine, the speed upstream and the speed in the wake.

The wind speed in the wake is strongly related to the distance x downstream of the front turbine, the further away from the front turbine, the more the wind speed tends to return to its initial value in the infinite downstream.

The turbine thrust coefficient, C_T, is related to the axial induction factor a of the turbine by the following relation [10] [12]:

$$C_T = 4a(1-a) \quad (2)$$

The training constant α is empirically described by the relation [13]:

$$\alpha = \frac{0.5}{\ln\left(\frac{Z}{Z_0}\right)} \quad (3)$$

Where Z and Z_0 represent respectively the height of the wind turbine and the roughness of the soil

2.2.The Mathematical Optimization Approach

Appeared in an international publication, this mathematical approach is used in the configuration of wind farms by [8], by positioning the turbines in optimal arrangements. It is an iterative method based on the remainder of the division on an integer m to generate in sequences of pseudo-random numbers according to the following sequences:

$$X(n+1)=(aX(n)+b)mod[m] \quad (4)$$

where m and $mod[m]$ represent respectively the number of cells of the proposed park and the modulo operator which determines the remainder of the division on m, a and b are positive integers. By choosing the element $X(0)$ less than m, the number of elements in the sequence corresponds to the number of wind turbines to be installed.

3.Methodology For Installing Wind Turbines In The Park

The kaberten wind farm currently supplies 10 megawatts (MW) as nominal power to the country, the arrangement of 12 turbines in operation of this park is in a straight line facing the predominant direction of the wind (Fig. 1). To increase electricity production capacity from wind power, this study plans to expand the area of the Kaberten wind farm by installing an optimal number of turbines of the same type. The proposed park area is 60Dx60D, the first 12 cells of which are occupied by GAMESA G52 type wind turbines. The idea of optimization is based on the implantation of an optimal number of turbines in arrangements in the rest of the other unoccupied cells while minimizing the objective function [14], this objective function represents the coup of the installation wind turbine on the total power produced, it therefore determines the capacity factor of the proposed park, it is defined as follows:

$$F_{obj} = min\left(\frac{Cost}{P_{tot}}\right) \quad (5)$$

The power curve and the characteristics of the GAMESA G52 wind turbine are shown in figure 2 and table 1 [8] [15], respectively:

Fig. 1 The arrangement of 12 turbines in the park proposed

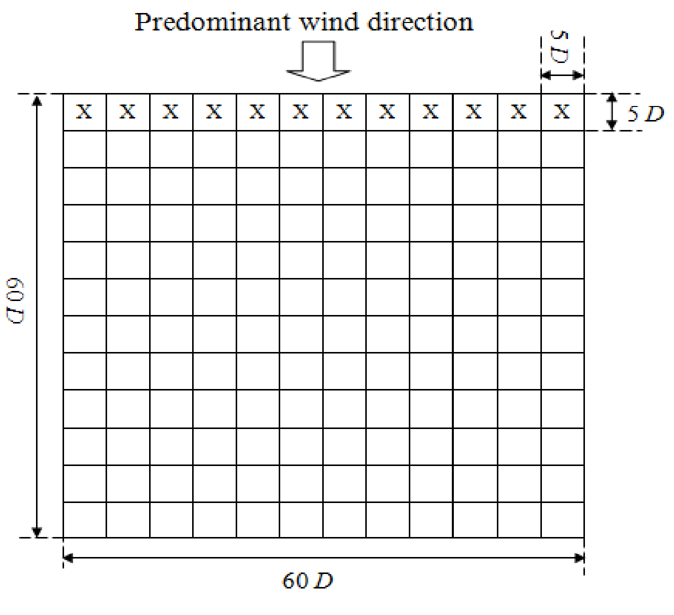
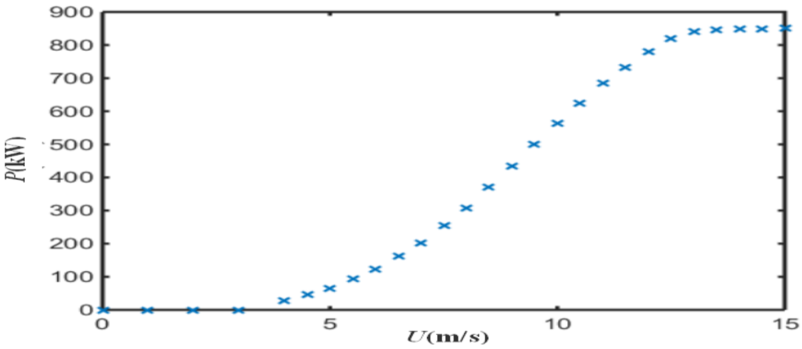


Table 1 Characteristics of the GAMESA G52 turbine

Rotor diameter	52m
Rotor height (Z)	55 m

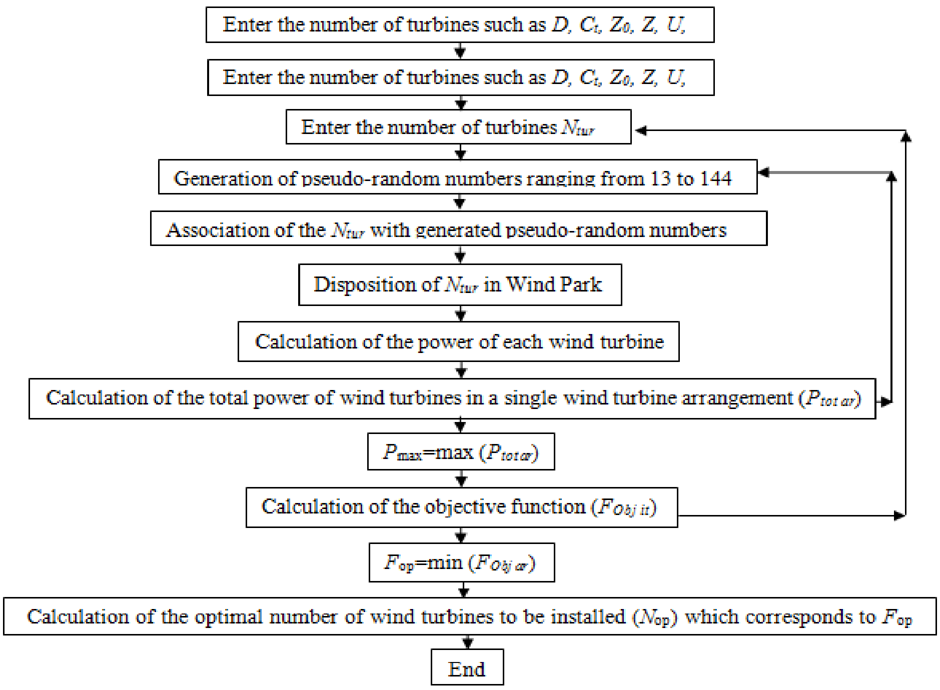
Rated power (P)	850 kW
Rated speed	13 m/s

Fig. 2 GAMESA G52 wind turbine Power curve [8]



In order to expand the current Kaberten park and calculate the optimal capacity of N_{op} turbines which can be installed downstream of the 12 GAMESA G52 [14] type turbines already in operation, a computer program is developed under MATLAB as illustrated on figure 3. First, the site data, the characteristics of the 12 turbines and the annual mean wind speed are entered in this program. At first, the site data, the characteristics of the 12 turbines and the annual average wind speed are entered into this program. Contrary to the previous study [8], the program for generating pseudo-random numbers has been modified; the generated sequences (sequences) of PRN are between 13 and 144 because the first numbers going from 1 to 12 are associated with the 12 first line turbines with fixed positions. Then, we choose a determined number of wind turbines and we generate PNR sequences so that each sequence corresponds to iteration. By associating the pseudo-random numbers generated with the turbines newly installed in the park, then, a location arrangement is obtained. This operation is reproduced according to the number of iterations, thus, the total power ($P_{tot\ ar}$) of the wind turbines of the park is evaluated at each arrangement, among these arrangements, the optimal location of the positioned turbines corresponds to the arrangement which offers a maximum power (P_{max}). By varying the number of turbines, the optimal turbine capacity (F_{op}) to be installed at Kaberten Park, which represents the ratio between the dimensionless cost of the wind turbine installation per unit of power, defined by Mosetti et al. [14] could be easily determined, this corresponds to the minimum value of the factor f_{obj},

Fig. 3 Flowchart of the method



4. Results And Discussions

In terms of figures, the objective of this study is based on the calculation of the cost (C_{ost}) and the total power of an optimal arrangement ($P_{tot\ ar}$) at each determined number of wind turbines, then, the minimum cost per unit of power that represents the optimal objective function.

It is necessary to note that in what follows, we use the annual average speed of 6 m / s of and a roughness of the ground of 0.3 m characterizing the site of kaberten [8].

4.1.Cost Of A Kaberten Wind Power Installation

The total dimensionless cost of a wind power plant defined by equation (5) is used to estimate the objective function $F_{Obj\ ar}$ of an arrangement [16].

$$Cost = N_{tur}\left(\frac{2}{3} + \frac{1}{3}exp^{-0.00174\,N_{tur}^2}\right) \tag{5}$$

As can be seen, this cost only depends on the number of wind turbines to install N_{tur}, the greater the number of wind turbines, the more it tends towards $\frac{2}{3}N_{tur}$.

4.2.Optimal Number Of Wind Turbines That Can Be Installed

The optimization program illustrated in Figure 3, is designed to calculate with each number of wind turbines introduced, the positions of the wind turbines installed, the total power and the objective function of the optimal arrangement for 1000 iterations. The same work is reproduced with a new number of wind turbines. The results obtained from $F_{Obj\ ar}$ are recorded automatically, the optimal number of N_{op} turbines that can be installed in the extension of the Kaberten park, corresponds to the minimum value of the objective function F_{op}.

The simulation results which are illustrated in figure 4 clearly show that the minimum value of the objective function F_{op} is 0.007269924, it corresponds to the optimal number of wind turbines of 55, including the 12 turbines of the first row. The optimal arrangement of these wind turbines in an arrangement is shown in Figure 5.

Fig. 4 Variation of the objective function with the number of turbines

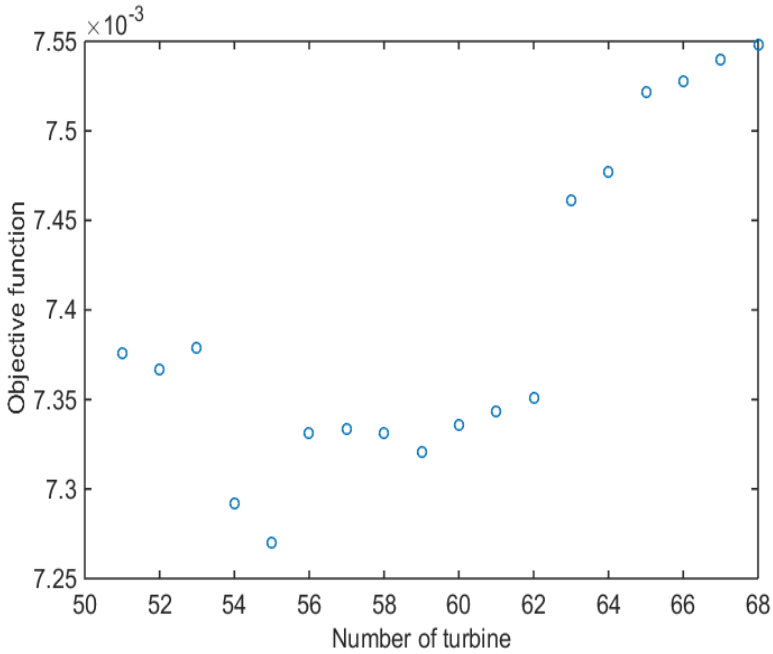
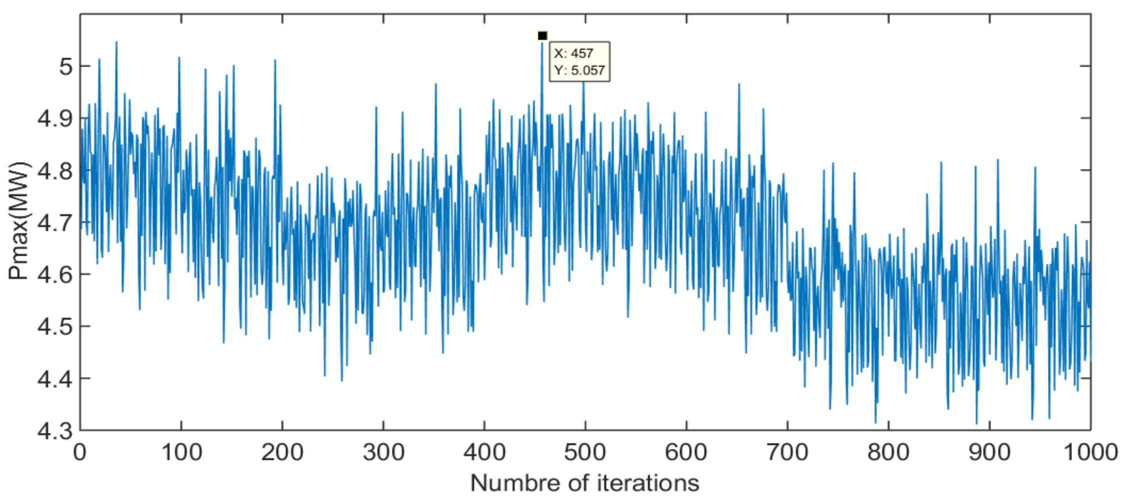


Fig. 5 Optimal arrangement

X	X	X	X	X	X	X	X	X	X	X	X
	X	X									
X				X	X	X	X				
		X	X	X							
								X	X	X	X
	X	X	X			X	X				
X								X	X	X	X
	X	X									
				X	X	X	X				
	X	X	X								
X							X	X	X	X	
			X	X	X	X					X

For the optimal number of wind turbines, the powers obtained from 1000 arrangements (iterations) form a point cloud as shown in Figure 6, so the maximum power can be easily determined.

Fig. 6 Powers of 1000 arrangements for optimal wind turbine number



5.Conclusion

In the present work of this study, the Jensen wake model and a modified mathematical approach of generation of modified pseudo-random numbers, were used to show that the current kaberten wind farm can be extended by implanting an optimal number of wind turbines behind the 12 turbines. By looking for the minimum objective function, the simulation results obtained by the computer code developed under MATLAB have shown that the optimal capacity of the proposed park corresponds to 55 GAMESA G52 type wind turbines. Also, with an annual average speed of 5.6 m / s, the total power produced and the objective function of this park were estimated at the optimum values of 5.058 MW and 0.007269924 respectively.

Finally, we conclude that this method could be used well in the expansion of wind farms while keeping the current wind turbines, because the previous studies are more appropriate for the configuration of the new parks.

As a perspective and continuation of this work, plan in future studies to take into account the imposing meteorological factors of extreme regions characterized by a hot climate and a sandy wind.

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