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Development of Decision Support Tool For The Exploitation of Wind Energy Systems Adapted to the Tunisian Sites

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Abstract

The construction of a wind park passes mainly by two phases. The first involves the wind analysis of the selected site. The wind data can be directly measured or extrapolated. Two approaches of spatial extrapolation are developed, and therefore, we give the suitable choice of the adapted aero-generator using a developed decision-making tool. The optimization consists in maximizing the performance parameters.

Keywords-Wind, Wind energy, Meteorological, Weibull,Spatial Extrapolation, Decision-making tool in Matlab.

1. Introduction

Tunisia has recently been integrated wind energy among its choices. Indeed, the first wind power plant of electricity production was carried out in 2000 in Sidi Daoud, near El Haouaria in the north-east of the country. Other plants are under construction in Bizerte, in the North of Tunisia. In fact, the realization of any wind turbine installation, must take into account the wind resource. Therefore, the study of the deposit is a fundamental component of a wind project.It determines the annual producible and allows the project manager to establish his business plan. A low-percentage error in the assessment of wind energy potential can have disastrous consequences on the future profitability of the project.

The purpose of this article is to develop a support tool for decision dedicated to the study of the viability of the deposits and operation of wind systems adapted to the Tunisian synoptic sites.

First, we are interested in the study of wind characteristics of the twenty seven reference sites distributed over the whole country. Then, we will assess the characteristics of wind speed for each site (average speed, strongest speed and the most common one) and wind energy available at a height of 11m above the ground and in the open field using two statistical methods. Similarly, to highlight the prevailing winds in a site, that is to say the winds whose directions are the most common, we represented the distribution of wind speed for each site by the wind rose in 16 directions.

Thus, we present a calculation method of transposing the available wind speeds (those of National Institute of Meteorology stations 11 m above the ground and in the open field) in homogeneous sites that interest users, depending on the height and roughness of the ground. In this context, two extrapolation approaches (direct and indirect) are developed and applied to the spatial extrapolation (vertical and horizontal) of wind characteristics in Tunisia. Finally, we propose a support tool for estimating the energy produced by a wind turbine whose operating parameters are known (especially the power curve and characteristic speeds).

2. Study of the characteristics of wind in Tunisia

Tunisia opens on the Mediterranean with 1298 kms of coastline, bounded on the west by Algeria and on the south by Libya. Tunisia is a flat country as a whole, except the Northwest and West are mountainous areas.

2.1 Analysis of actual wind data in Tunisia

For goods locations of wind turbines in Tunisia, our tool provides a study of the temporal variability of wind speeds (analytical methods and Weibull Method experimental weather) and the vertical variation (laws of vertical shear). Thus, the wind roses are used to characterize the change in wind direction.

2.1.1 Study time

a. Meteorological method

From the tables of the National Institute of Meteorology (INM) indicating the occurrence frequency Fc (v), wind speeds V or the above-classified speeds, the frequency of occurrence f(v) is defined by the following relationship [1]:

$$f(V) = F_C(V) - F_C(V+1) \quad (1)$$

ρ represents density of the air which is equal to 1,225 Kg/m^3 to a temperature of 15 ° C and a pressure of 1013 mb, Vi is the wind speed, f(Vi): Frequency of occurrence and n: Number of observations (provided by INM).

b. Weibull method

The Weibull distribution is the most widely-used analytical model to describe the distribution frequency of the wind speed. It allows characterizing this distribution on a given period (one year, a month or a day, etc.). [19]

The probability density is defined by the following equation:

$$f(V) = \frac{k}{C_w}\left(\frac{V}{C_w}\right)^{(k-1)} e^{-\left(\frac{V}{C_w}\right)^k} \quad (2)$$

k form factor, c: scale factor, C_w :correction factor to11 m above the ground .

The associated cumulative distribution function is:

For "less than or equal to" speed rated speed Vi:

$$F_c(V \le V_i) = 1 - \exp\left(-\left(\frac{V_i}{C_w}\right)^k\right) \quad (3)$$

For "greater than or equal to" speed rated speed Vi:

$$F_c(V \ge V_i) = \exp\left(-\left(\frac{V_i}{C_w}\right)^k\right) \quad (4)$$

2.1.2 Spatial interpolation of the measured wind speeds

The profile of the wind speed is logarithmic and can be described by the following expression: [20].

$$V(h) = \frac{U_*}{k} Log\left(\frac{h}{Z_0}\right) \quad \text{pour} \quad h \ge Z_0 \quad (5)$$

V (h) is the average flow velocity at altitude h.

U_* is the rate of friction or rubbing. It shows the increase in wind speed in the logarithm of the ratio height.

Z_0 is the roughness length; it is the height below which the wind speed is zero. It is based on the state of land surface (presence of vegetation, housing).

κ: the Von Karman constant.

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2.2. Corrections of height and roughness

landscapes Categories	Landscapes Categories	Z_0 (m)	A
Large body of water (ocean, sea, lake)	**1**	**0.005**	**0.166**
Flat short grass prairie without trees or building	**2**	**0.02**	**0.182**
Flat expanses with possibly some isolated obstacles (trees scattered around) - Open Country - Airport	**3**	**0.07**	**0.2**
Companion crops with high (but, vine, small fruit trees) grove loose, scattered settlements	**4**	**0.25**	**0.229**
Weakly urbanized areas	**5**	**0.3**	**0.232**
Dense grove, orchards, woodlots, suburbs suburban	**6**	**0.4**	**0.240**
Urban or industrial areas, forests, etc.	**7**	**1**	**0.266**
Center of large cities	**8**	**2.5**	**0.292**

Table 1: Z_0 roughness length and A parameter for different categories of land

2.2. Corrections of height and roughness

2.2.1. Transposition of the data to a site like

In Tunisia, weather stations (reference sites) are located in an airport environment (clean Z_{0RC} roughness campaign) to standard height of 11 m above the ground. So, for the site type to which one wishes to bring 10m wind in the open field, we speed V0 such as:

$$V_0 = \frac{U_{*RC}}{k} Log\left(\frac{10}{Z_{0RC}}\right) \tag{6}$$

Therefore, if we compare the measured speed (or reference) Vref (11 m) to the speed of the site kind V_0, we obtain a correction factor C (11 m) such that:

$$C(11m) = \frac{V_{réf}(11m)}{V_0} = \frac{U_{*RC} \cdot Log\,\frac{11}{Z_{0RC}}}{U_{*RC} \cdot Log\,\frac{10}{Z_{0RC}}} = 1.0192 \tag{7}$$

C (11 m) represents the pitch correction only.

If the reference site is no longer open country (of any roughness Z_{0ref}) and it is h_{ref} meters above the ground, then the correction factor C (h_{ref}) used to retreat to the type site becomes

$$C(h_{réf}) = \frac{V_{réf}(h_{réf})}{V_0} = \frac{U_{*réf} \cdot Log\,\frac{h_{réf}}{Z_{0réf}}}{U_{*RC} \cdot Log\,\frac{10}{Z_{0RC}}} = A \cdot Log\,\frac{h_{réf}}{Z_{0réf}} \tag{8}$$

With:

$$A = \frac{U_{*réf}}{U_{*RC}} \cdot \frac{1}{Log\,\frac{10}{Z_{0RC}}} \tag{9}$$

C (h_{ref}) represents both pitch correction and roughness.

This correction only applies to sites whose roughness is uniform in all directions over a sufficiently large area (at least 5 km from the point of measurement); it cannot be used for mountain areas or complex sites; such as roughness change area, a cliff, a hill, etc. The table below (Table 1) gives the values of Z_0 for various types of landscapes and the corresponding A values to return to a type website (10 m in the open field).

2.2.2. Algorithm for calculating the parameters A and C

The different steps of calculating the parameters A and C of the correction factor are summarized in the following chart:

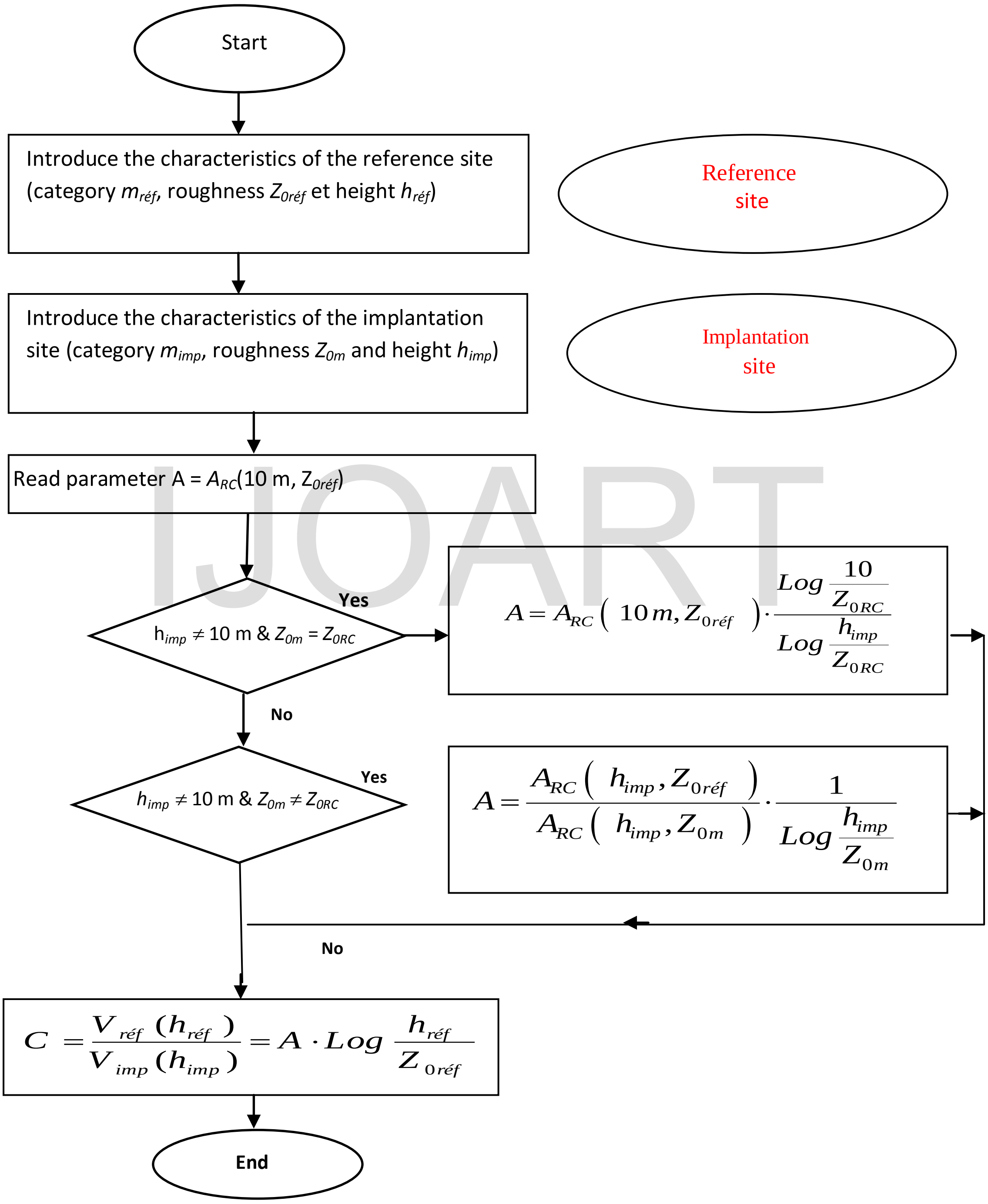


Figure1. Flowchart of calculating the parameters A and C.

Knowing the frequency of occurrences, it is possible to estimate the characteristics of the wind (average speed, the speed of most wind energy, the speed of the most frequent wind).

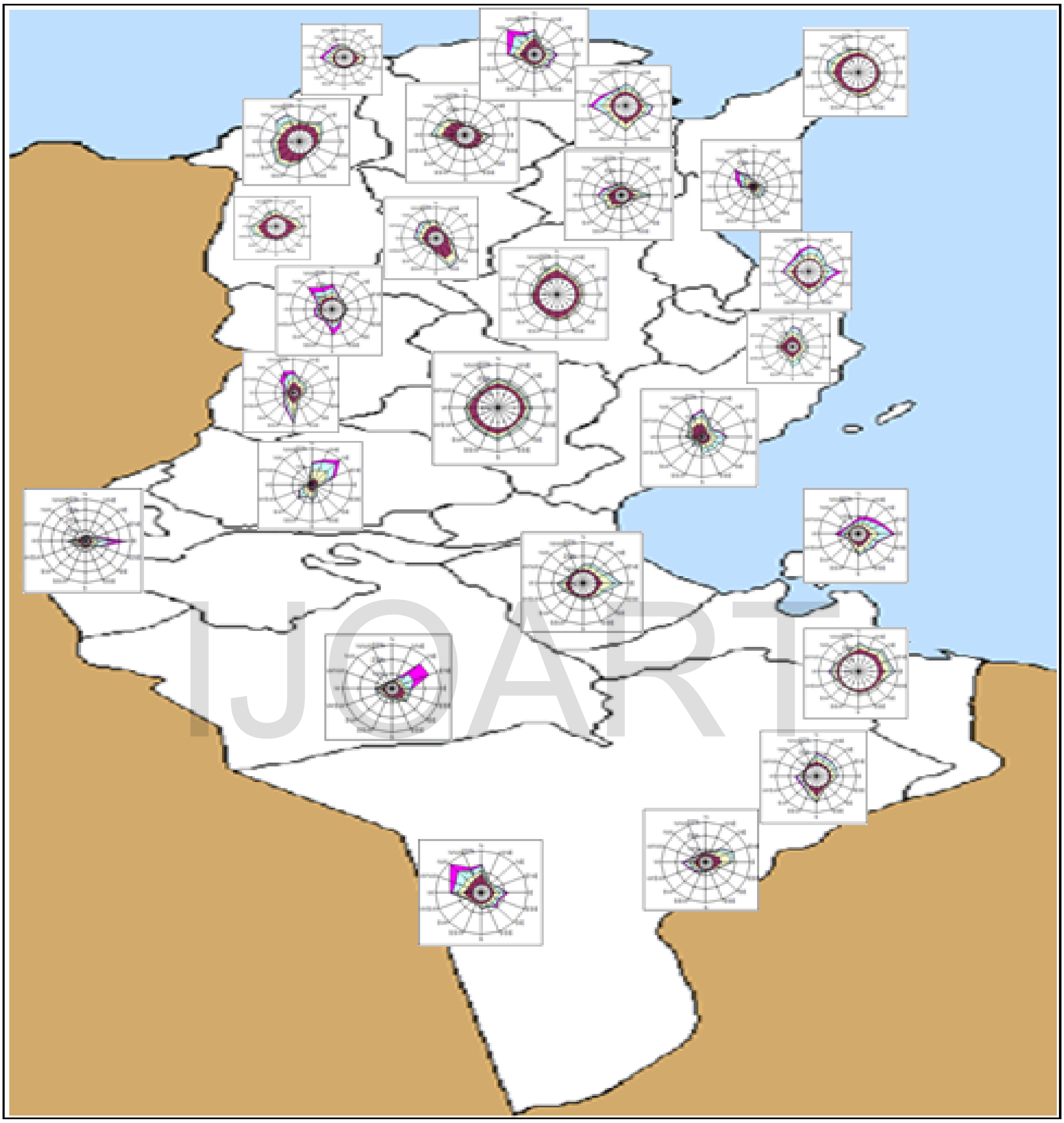
	Experimental method Weather	Analytical method Weibull
The speed of the most frequent wind (m / s)	$V_{fc} = V_{ci}(f(V_{ci})\max i) = \frac{V_i}{C}(f(V_i)\max i) = \frac{V_f}{C}$	$V_f = C_w\left(\frac{k-1}{k}\right)^{\frac{1}{k}}$
The speed of most wind energy (m / s)	$V_{Ec} = V_{ci}(E(V_{ci})\max i) = \frac{V_i}{C}(E(V_i)\max i) = \frac{V_E}{C}$	$V_E = C_w\left(\frac{k+2}{k}\right)^{\frac{1}{k}}$
Average wind speed (m / s)	$V_{mc} = \sum_i V_{ci} f(V_{ci}) = \sum_i \frac{V_i}{C} f(V_i) = \frac{V_m}{C}$	$V_m = C_w \Gamma\left(1+\frac{1}{k}\right)$
Annual wind energy potential(W / m ^ 2)	$P_c = \frac{1}{2}\rho\sum_i V_{ci}^3 f(V_{ci}) = \frac{1}{2}\rho\sum_i\left(\frac{V_i}{C}\right)^3 f(V_i) = \frac{P}{C^3}$	$P = \frac{1}{2}\rho C_w{}^3 \Gamma \frac{k+3}{3}$

Table 2: wind characteristics

2.3 Wind Rose

The wind rose is a spatial representation of the variation of the wind direction for a given site. The results of the analysis of the compass are essential prior to implementation of a power plant or a wind farm. It illustrates the prevailing wind direction on a site and allows you to schedule the installation of wind turbines to minimize wake effects caused by nearby obstacles. The frequency distribution of wind speed at each site is represented by a wind rose to 16 directions .This presentation allows to highlight the prevailing winds of a station, i.e., wind speeds, the most common directions.

In Tunisia, the wind roses vary from one point to another in the country and are strongly influenced by the nature of the environment (homogeneous, inhomogeneous or complex) near and far from the site of implantation of the wind system. The review of this card roses shows that Tunisia is dominated by winds from the Northeast and Northwest.



Map 1: distribution of wind roses on the Tunisian territory.

4. Support Tool to the decision of setup operations wind systems

4.1. Presentation Tool

The installation of a wind system requires a detailed analysis of the different elements that will allow an optimized selection of the system, both the energy and economic point of view. The steps leading to this choice are:

1. The determination of energy requirements;
2. Estimation for wind and wind energy at the implantation site;
3. The choice of the wind system best suited after consideration of various marketed machines.

The developed tool makes the user aware of the different steps linked to the implementation of a wind turbine on any site and particularly the variation in time and space of the wind speed. It shows in which proportion the energy in the wind can be retrieved and how the environment and the characteristic parameters of the machine effect essentially wind energy production systems. The various features of this tool are presented in the chart of Figure 3:

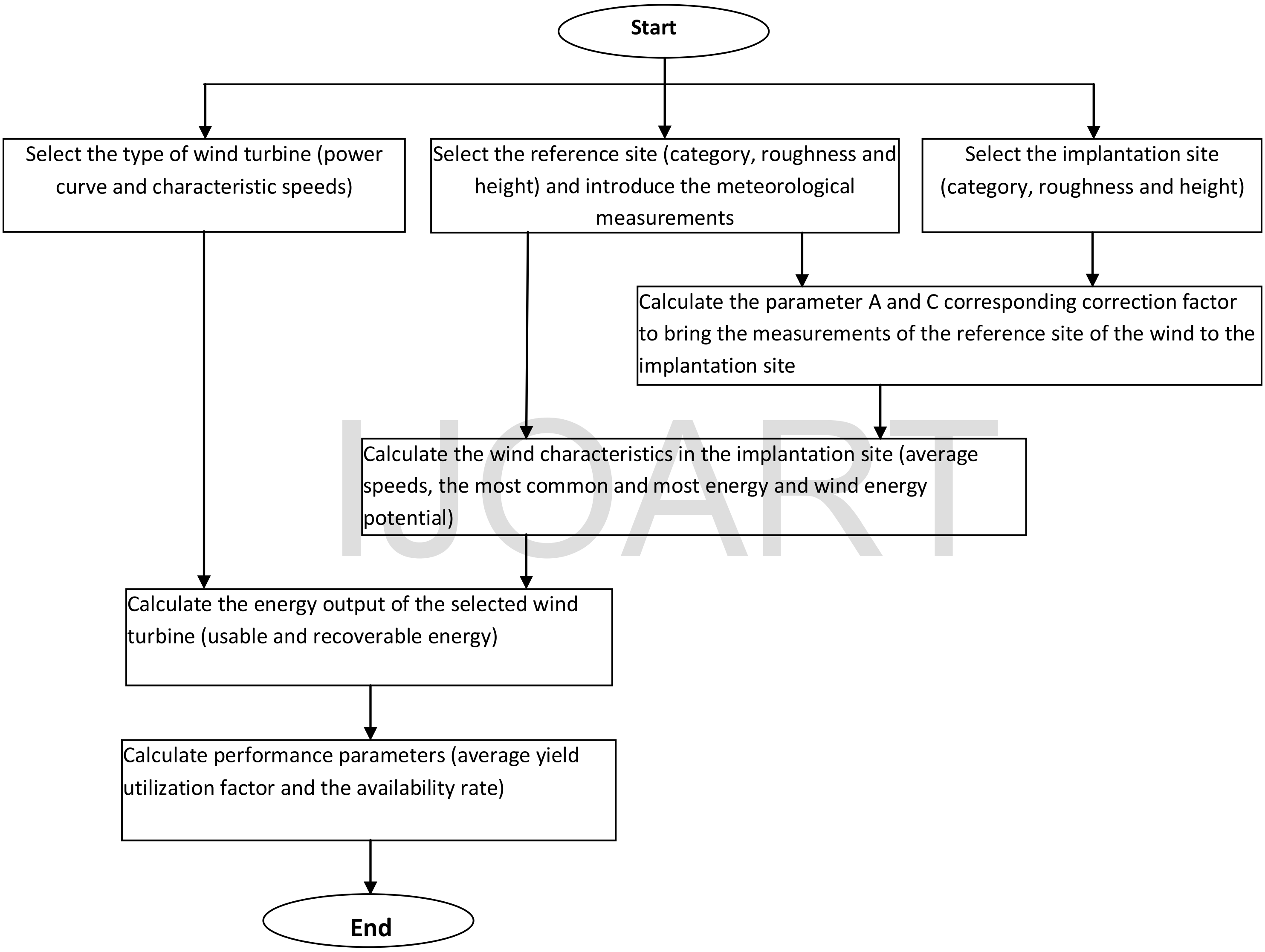


Figure 2: Flowchart of the decision support tool of wind systems

It allows assessing using two methods: experimental technique (meteorological) and analytical one (that of Weibull):

- Wind characteristics of the implantation site selected by means of the correction factor C (defined in the previous chapter) and the characteristics of the wind (defined in Chapter 2) of the nearest measuring station.

- The available wind energy, to make clear the decision of the installation of a wind turbine in reasonable economic conditions and optimize the choice of the characteristics of the wind system.
- The energy produced by a chosen marketed wind generator whose operating parameters are known (especially the curve power and features speeds).

The performance parameters of each wind turbine (yield, usage factor and availability rates) are used to assess its energy efficiency.
This tool is applied to study the performance of four types of wind turbines sold (Made AE-32, AE-46, AE-52 and AE-61) with a horizontal axis of the wind power plant Sidi Daoud. From their characteristic parameters, we studied their performance parameters (yield, usage factor and availability rates) within twenty six Tunisian sites. This process is finished with a phase optimal choice of the most suitable sites at each wind turbine taking into account the demands of energy efficiency and the system reliability.

4.2. Programming environment

The computer code of this support tool is developed in the environment of Matlab software-GUIDE (Graphical User Interface Development Environment). GUIDE commands to create interfaces between different types of objects (buttons, editbox, listbox, etc.) called handles. The interaction between the objects is carried out through links. To create a graphical interface development environment (Figure 3),we just type the command GUIDE in the command window of Matlab.

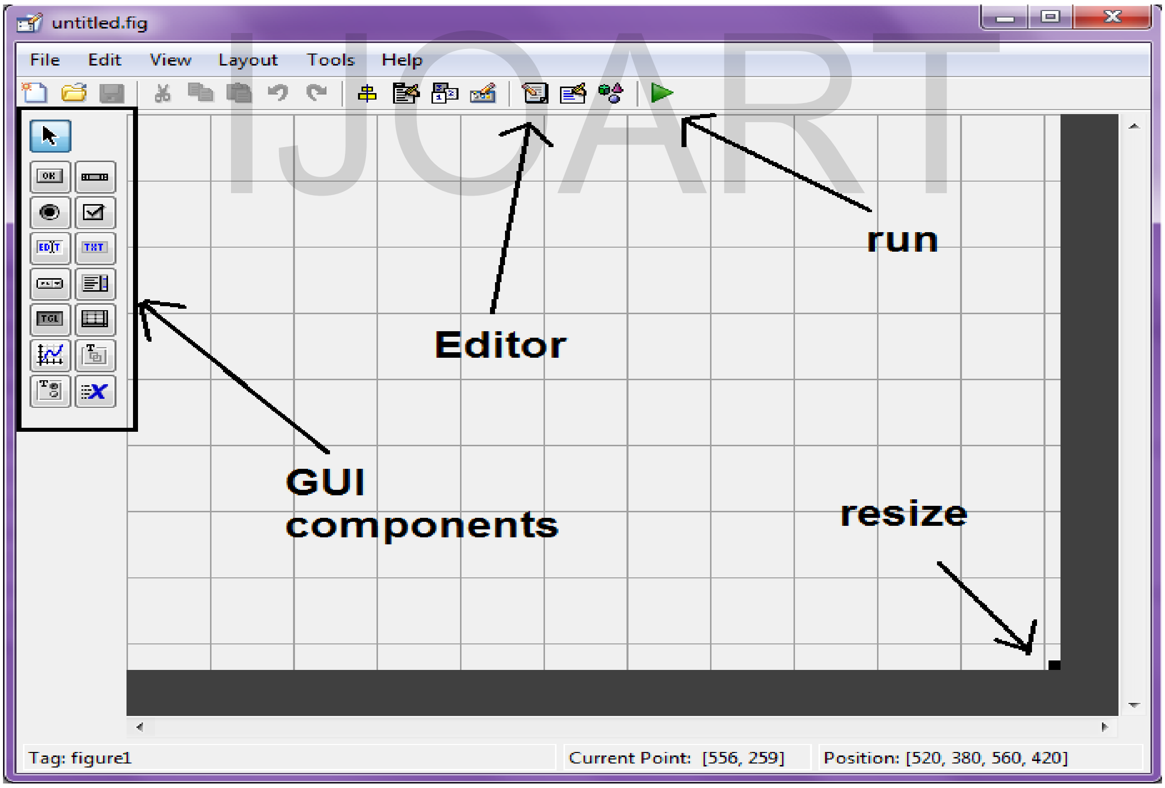


Figure 3: Development environment of a GUI (GUIDE).

The developed graphical interface, which manages the flowchart of the proposed support tool, is shown in Figure 4.

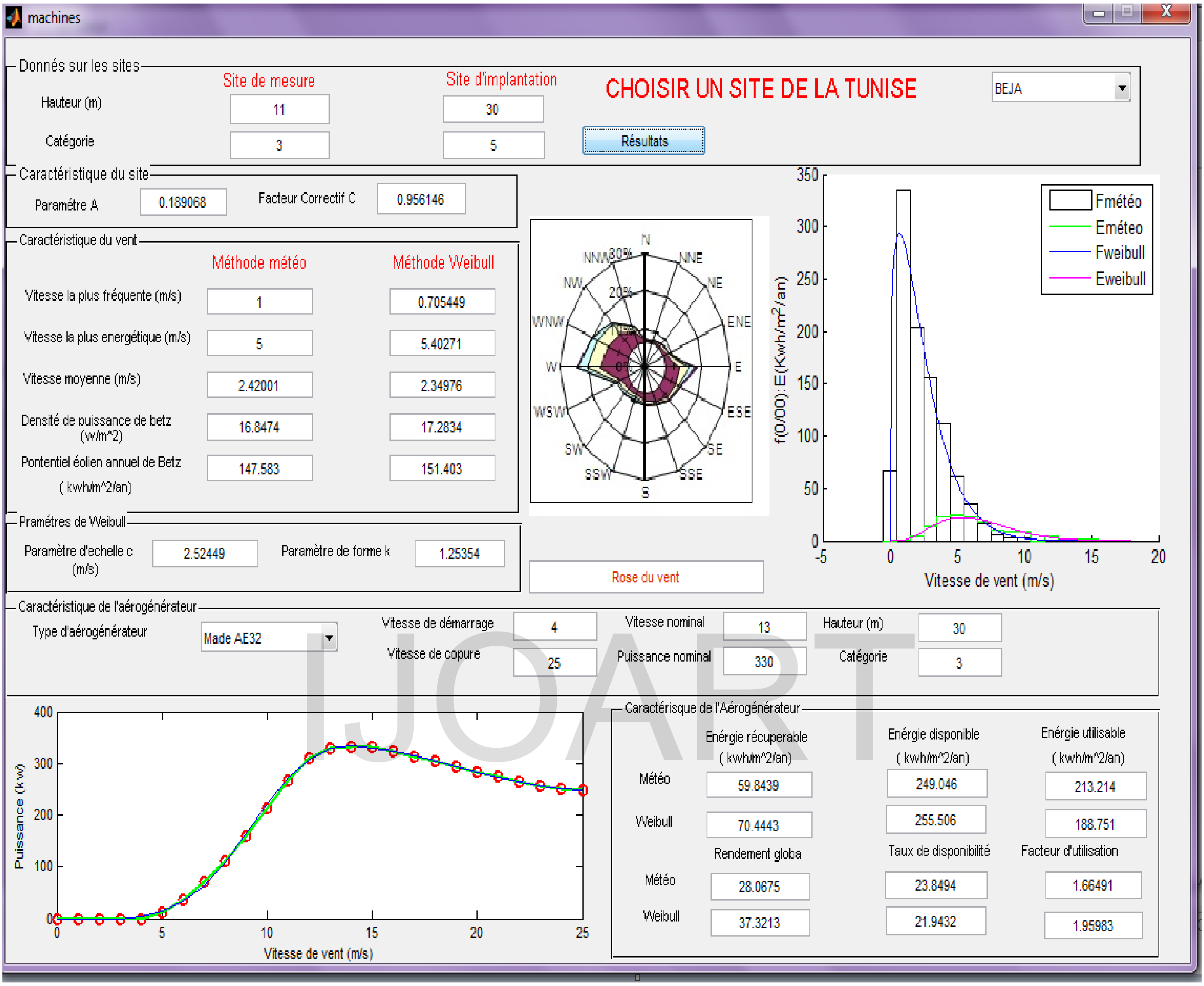


Figure 4. *The developed guide for the support tool in the proposed decision*

5. Conclusion

The study of issues related to the wind turbine installation on any site, and particularly the spatial variation (vertical and horizontal) of the wind speed has been the subject of this article. We are mainly interested in understanding the characteristics of wind speed and the determination of the basic elements necessary for the design of a wind system (startup speed, nominal speed, rated power, rotor diameter, etc.) and for the choice of the implantation site (available density). This work consists essentially in developing a calculation program, resulting from the implementation of the two meteorological methods and Weibull, which allow us to determine the characteristic speeds of the wind (average speed, strongest speed and the most common one), of the available wind energy and rose in 16 wind directions.

The developed tool is designed to guide step by step the user who wants to estimate the energy that will produce the wind system that he envisages to set up on a chosen site. It, also, helps minimize the bad wind locations which may have bad effects on energy production.

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