Toward an accurate assessment of wind energy platform of Mohammedia city, Morocco

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Abstract— **Morocco possesses a large potential of renewable energy, such as solar and wind energy. Wind energy is an alternative clean energy source compared to fossil fuel, which pollute the lower layer of the atmosphere. Recently, wind energy conversion is given a great importance and deep reflection in Morocco. In this way, we present an interesting study, based on statistical methods that are used to analyze the wind speed data measured by a wind platform installed in university Hassan II Mohammedia-Casablanca, Morocco. Wind speed is the most important parameter in the design and study of wind energy conversion systems. The wind speed data were obtained from the wind measuring station over a three year period, 2004 to 2006. Thus, a daily, monthly, seasonal and annual analysis is undertaken to know the wind profile and the contribution of each wind direction in term of available energy at the surveyed area. This study uses some fast procedures to estimate perfectly the potential of energy. It shows that the mostly windy direction is the 360°- 22.5° sector for the three consecutive years 2004, 2005 and 2006. With an annual average useful wind speed of 4m/s approximately, an annual energy of 1036.68 KWh could be extracted during the year 2004. The same studies are used for the years 2005 and 2006.**

Keywords: Wind, Wind data, wind energy, data analysis

I. Introduction

Recently many studies highlight the crucial nature of energy efficiency improvements. And the need of all energy sources for a sustainable future with much improved standard of living in the developing world [1]. To meet this energy demand, a large interest is viewed in new and renewable energy sources, especially wind energy for the electricity generation. Indeed, depletion of fossil energy resources and environmental problems caused by the emission of greenhouse gases, have led to use these clean and inexhaustible resources. Wind energy is presently a cost effective renewable technology and provides a continuously growing contribution to: climate change goals, energy diversity and security. In fact, Wind Generators (WG) have been widely used both in autonomous systems for power supplying remote loads and in grid-connected applications. In the literature, different approaches for predicting wind speed and/or wind direction have been presented [2] [3], [4] and [5]. Thus, statistical and spectral analysis approaches have been proposed to investigate wind characteristics and wind energy potential [6][7] and [8]. Other studies on wind energy have been proposed to model wind turbine [9] or to exploit efficiently the wind energy [10][11].

In this study, the goal is to provide an estimation of the wind energy that could potentially be generated at the east region of Mohammedia City, Morocco. To do so, we use the wind speed and wind direction data to estimate available wind energy in this region. Thus, we present the results sorted out from the data provided by a wind measuring station. This station is associated with a low-power wind generator installed at ENSET, University Hassan II, Mohammedia-Casablanca, Morocco. Also, we propose a detailed analysis of wind data: wind average of daily and monthly profiles, wind rose for the power frequency of each wind direction and available energy at the surveyed area.

In a real context, such as that of our platform, wind data (wind speed and wind direction) are sampled at irregular observation times. Thus, we propose a method for filtering and reducing these irregular data. The study, in [12], shows that it is possible to filter non-uniformly sampled signals according to specs defined in the Fourier domain. Such study has presented a method for filtering irregularly sampled data by defining stopband tolerance regions in the Fourier domain and time domain and lower bounds on the signal samples as a part of the filtering process. The proposed iterative filtering algorithm consists of going back and forth between time and frequency domains and imposing the time and frequency constraints on iterates. In our case, we use a technique based on the interpolation of available samples to the regular grid and apply a discrete-time filter to the output data. Thus, we use the padding technique with a variable window for the filtering process. Afterward, we include a detailed analysis of wind data recorded during the period 2004-2006. This is to determine the monthly and annual wind profiles and to estimate of potential energy production in the surveyed area.

This paper is organized as follows: In the next section, we give a description of the wind platform and summary of the data file will be established. In the third section, we introduce the baseline theory of wind energy conversion. Section IV is devoted to the preliminary data processing where, we propose a data preprocessing to weed out data that are faulty or corrupted. In this step, we propose an approach for filtering irregularly sampled data. Wind data analysis is presented in more details in section V. Here, in the first time, we make a monthly and yearly descriptive statics of wind speed. In the next section VI, we determine the contribution of each wind direction in the available energy in the surveyed area. Finally, we conclude this work in the last section VII.

II. WIND PLATFORM MATERIALS

A. Wind station

The wind station studied in this paper is installed at "Ecole Normale Supérieure de l'Enseignement Technique – ENSET-Mohammedia", University Hassan II of Mohammedia-Casablanca, Morocco, latitude 33°41'23" North, longitude 7°23'23' West. It possesses:

- A 3 KW Wind Generator (WG) of two blades, 4.6 m in diameter, operating at variable speed. The turbine is located at 21 m above the ground on a tubing tower.
- Non-controlled 6-pulse rectifier (48V AC - 24V DC).
- A battery bank (12V, 210 Ah).
- A 3KW inverter that generated 220V at 50Hz which supplies a single-phase electric pump to feed a water tank, lighting and heating systems in addition to a power dissipater system.

B. Wind data

Wind data was acquired from meteorological station, installed at a height of 8 m in the same location as the platform. Wind data are stored on files as depicted in Table I. This table summarizes some useful meteorological components:

- The column Time indicates the sampling time during the day specified by the column Date.
- The Archive Period denotes the irregular sampling period T_s. This period is set by the administrator of the meteorological station.
- The surrounding temperature in °C. The column Outside Temperature depicts the average value of the recorded temperatures during the sampling period T_s. The maximum and minimum values of the recorded temperature during T_s are respectively depicted by the columns Hi Temperature and Low temperature.
- The wind speed and direction. The column Speed shows the average value of the measured wind during the period T_s. In the column Hi, we denote the wind peaks during this period T_s. The column Wind Direction is useful for identifying the wind direction trend during the period T_s.

III. THEORETICAL BACKGROUND

The well known equation of the available wind power P_w is given by the following expression (1).

$$P_w = \frac{1}{2}\rho.AV_w^{\ 3} \qquad (1)$$

Where,

ρ is the wind density;

A is the turbine swept area;

V_w is the wind speed.

The wind power is converted into mechanical power $P_{turbine}$ by the turbine blades, according to the equation:

$$P_{turbine} = C_p(\lambda).P_w \qquad (2)$$

Where C_p is the power coefficient of the turbine and λ the specific speed which is a function of the wind speed V_w, the blade rotation speed Ω and R_p the radius of the blades:

$$\lambda = \frac{R_p.\Omega}{V_w} \qquad (3)$$

The generated electrical power P_e is defined by:

$$P_e = \eta_{turbine}.P_{turbine} = \frac{1}{2}\eta_{turbine}.C_p(\lambda).\rho.AV_w^{\ 3} \qquad (4)$$

$\eta_{turbine}$ is the generator's efficiency.

To compute the supplied electrical power, it is necessary to estimate wind speeds at various heights. The wind speed increase with height. When record of wind speed exists at different height for a station, the commonly power law can be used to obtain the extrapolated values of wind speed at different heights [13]:

$$\frac{V_w(z)}{V_w(z_0)} = \left(\frac{z}{z_0}\right)^{\alpha} \qquad (5)$$

Where $V_w(z_0)$ is the wind speed measured at anemometer height z_0, $V_w(z)$ is the wind speed at the height z, α is the power law exponent depending on the surface roughness. It is empirically obtained.

In our case, z=21m, $z_0=8m$ and α=0.3. Therefore,

TABLE I. TABLE OF WIND DATA

Wind data		*Outside Temperature*	*Hi Temperature*	*Low Temperature*	*Wind*		*Wind Direction*	*Archive Period*
Date	**Time**				*Speed*	*Hi*		
01/01/2004	00:15	12,3	12,4	12,3	1,3	2,2	NE	15
01/01/2004	00:30	12,3	12,4	12,3	1,3	2,2	SE	15
01/01/2004	00:45	12,5	12,6	12,4	1,8	3,6	SE	15

$$V_w(z) = 1.3356 \times V_w(z_0) \qquad (6)$$

This formula is applied to the velocities from the meteorological station to obtain the corresponding wind speed at 21m high. The electrical supplied power of the studied platform was modeled, in our previous work [11], by:

$$P_e = -0{,}0039 V_w^3 + 0{,}0899 V_w^2 - 0{,}2706 V_w + 0{,}1937 \qquad (7)$$

Where P_e is the supplied electrical power (KW) and V_w is the wind speed (m/s)

As noticed in [11], the transfer function of our WG showed that the wind speed must be greater than 3m/s to start on the turbine. In such case, the available energy is given by:

$$E = P_e.t \quad (\text{KWh}) \qquad (8)$$

IV. PRELIMINARY DATA PROCESSING

In this study the recorded wind data during the year 2004 have been analyzed. As it was reported, wind data (wind speed and wind direction) are sampled at irregular observation times. So, all the raw wind data were tested and filtered to weed out data that are faulty or corrupted. Hence the resulting data are analyzed to assess the wind energy.

In this case, it is necessary to filter irregularly sampled data. Thus, we propose an approach for filtering non-uniformly sampled signal in time-domain. First, we interpolate recorded samples to the regular grid using the padding technique with global normalization. Secondly, we apply a discrete-time filter to those data. So, it is necessary to consider all sampling periods $T_{i=1,2,3,\ldots,M}$ where M is the number of the irregular sampling periods. Let S be the set of sampling periods T_i:

$$S=\{T_1, T_2, T_3, ..., T_M\} \qquad (9)$$

In the set S, there is one T_s which represents the minimum of all T_i:

$$T_s=\min(T_{i=1,2,3,\ldots,M}) \qquad (10)$$

Our goal is to split any T_k sampling period into $n.T_s$ subintervals. In this case, T_s is called the regular sampling. This splitting technique must keep the same combined energy in both cases. For example, if T_s=5min, the first row of Table I will be transformed into Table II after the splitting step.

Now recall that during each period $T_{i=1,2,3,\ldots,M}$, we cumulate an energy E_i such as:

$$E_i = P_{ei} \times T_i \qquad (11)$$

If T_i is splitting in n regular intervals, then E_i can be written as:

$$E_i = \sum_{k=1}^{n} E_k \qquad (12)$$

where $E_k = P_{ek} \times T_s$

Since P_{ek} is constant during $T_i = n \times T_s$ then:

$$E_i = n \times P_{ei} \times T_s \qquad (13)$$

Now, let us define the samples $x_d[T_i]$, i=0, 1, 2,…, L-1, as the recorded samples of wind speed with different sampling periods T_i belonging to S. L is the number of the recorded samples that must verify L≥M. Let us denote $x_d[T_s]$ the resulting uniformly sampled version of the observed wind speed where T_s is the regular sampling period. The number N of $x_d[T_s]$ is greater than or equal to L. Notice that, in the case of a regular sampling, we have:

M=1 and S={T_s}, so L=N.

Henceforth, the discrete signal $x_d[n.Ts]$, n=0,1,2,…, N-1, is denoted by x[n]. Each sample x[n] will produce an energy E_x during the sampling period T_s. The processing depicts that $T_s = 5\,\text{min}$ for all recorded data in the year 2004. Having those new regular data, we will perform two principal tasks:

- *Data reduction*: It is trivial that the data size has increased in the new regular grid. So we must reduce this large amount of this resulting data. This aims to enhance the processing time or to fit more data on limited size media. In fact, a sampling period of 5min allows us to reach almost 8640 samples per month. So, we need to make an oversampling of those data. Let T_{ns} be the new sampling period. T_{ns} must be chosen without loss of wind data information related to the wind energy.
- *Data filtering*: The uniform sampled wind data can be low-pass filtered. This is to eliminate abrupt changes and smooth the sampled data. The proposed filtering algorithm is a moving average filter defined by:

TABLE II. WIND DATA SPLITTING STEP

Wind data		***Outside Temperature***	***Hi Temperature***	***Low Temperature***	***Wind***		***Wind Direction***	***Archive Period***
Date	**Time**				***Speed***	***Hi***		
01/01/2004	00:15	12,3	12,4	12,3	1,3	2,2	NE	5
01/01/2004	00:15	12,3	12,4	12,3	1,3	2,2	NE	5
01/01/2004	00:15	12,3	12,4	12,3	1,3	2,2	NE	5

$$y[n] = \frac{1}{W}\sum_{k=0}^{W-1} x[n+k] \qquad (14)$$

Where: y[n] is the output of this filter and W is the width of the window's filter in which we compute the mean of the W samples. W must be chosen to ensure the same energy at the primer data.

To implement the two previous tasks, we propose to solve an optimization problem, where we must find the two principal parameters W and T_{ns}, so that the associated cost function must be minimal. This cost function $F(W,T_{ns})$ corresponds to the mean square error of energy:

$$F(W,T_{ns}) = MMSE(W,T_{ns}) = \min\left\{E\left[\left(E_x - E_f\right)^2\right]\right\} \qquad (15)$$

The MMSE is calculated for the group of input samples. This optimization problem is presented by its functional sheet in figure 1.

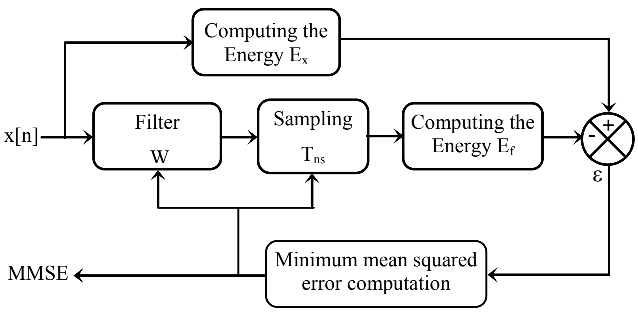


Figure 1. Diagram of optimization problem solving

The test performed on the recorded data during the year 2004, has allowed us to find the solutions of this optimization problem. So, the width's window and resampling period minimizing the mean-squared approximation error on the global energy are 2h15mn and 1h00mn respectively. Thus, to filter the regular sampling data, we use a moving average filter with window's width of 2h15mn. We recall that the regular sampling period is 5mn. So, the width of filtering window contains 27 samples. Figure 2, provides a shape of the first 1000 samples of original and filtered wind speed recorded in the year 2004.

V. Wind Data Analysis

It is very important to know the statistical properties of the wind to determine and predict the energy output of a wind energy conversion system. It is also significant to determine the contribution of each wind direction in the production of this energy. Because of the high variability in space and time of wind energy, it is important to verify that the analyzing method used for the measuring wind data will yield the estimated energy collected that is close to the actual energy collected. In the following, we will focus on the variation of wind speed and wind direction.

Wind speed and direction used in this study were given by our measurement station. Those data were used to evaluate frequencies of some wind speed as the monthly and annual mean wind speeds.

A. *Wind speed variation*

The wind at a given site usually varies frequently in direction and its speed may change rapidly under gusting conditions. As shown in Table I, recorded wind speed data are generally available in time series format. Each recorded data represents a mean wind speed in the considered sampling time.

The variations of average wind speed on a daily basis at our site during Mars 2004 are plotted in Figure 3. In this figure we plot the filtered data using the previous preprocessing procedures of section IV. As shown, the pattern is predominantly random with local filtered maximum of 8.0661m/s. However, during this month, peaks of wind speed occur at different days with an instantaneous maximum value of 15.4929 m/s. The average value of these 8528 observations is 2.4687 m/s.

Table III provides an overview of descriptive statistics for all data for each month of the year 2004. This gives us a clear idea about the wind distribution in the study site. It is immediately obvious that the Skewness factor is overall greater than 3. This implies that most wind speed values are concentrated on left of the mean value, with extreme values to the right. As well known Kurtosis's values are greater than 3, show that the wind speed distribution's peak is narrower than the normal distribution with values concentrated around the mean value and thicker tails. The value in standard deviation

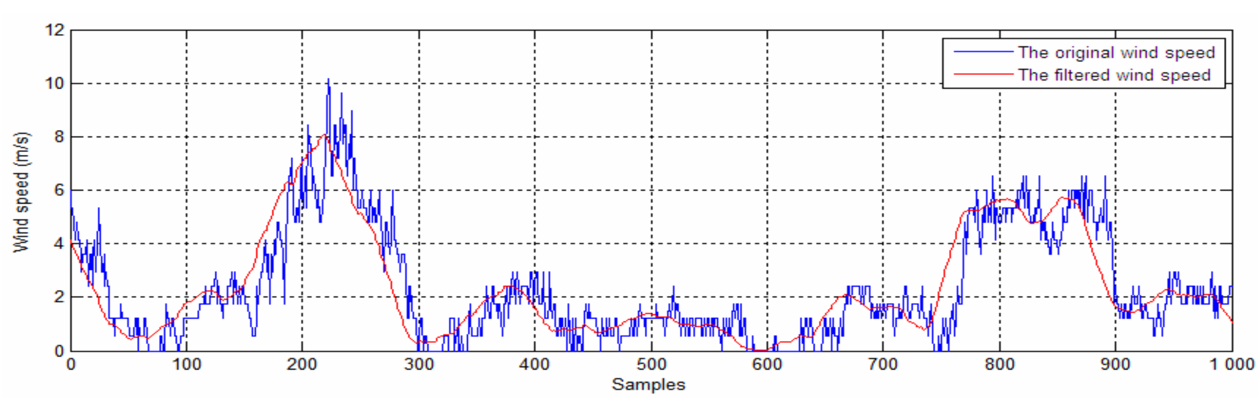


Figure 2. Original and filtered wind speed

indicates the dispersion of measurements around the mean value for each month.

However, we can see that all means of wind speeds given in Table III are lower than 3m/s. This is because we have computed the means of all samples during the year 2004. So, during this year, there were silent winds that generate no wind speeds. This leads to low average wind speed. In order to be accurate, we will consider the useless and the useful wind. The useless wind is the wind having speed's value less than 3m/s. The useful wind has speed's value higher than or equal to 3m/s.

TABLE III. MONTHLY AND YEARLY DESCRIPTIVE STATISTICS OF WIND SPEED IN 2004

Months of year	***Mean value***	***Maximum value***	***Standard deviation***	***Skewness***	***Kurtosis***
January	1.7290	6.2671	1.2099	0.5692	3.0762
February	2.2823	9.2088	1.5952	0.8148	3.5804
March	2.3823	9.7204	1.7178	0.7896	3.3626
April	2.2662	9.7204	1.7923	1.2970	4.6351
May	2.3341	10.8715	1.6405	0.7963	4.0396
June	1.5013	6.2671	1.3110	0.9526	3.5246
July	2.0657	8.5693	1.8410	1.1122	4.0193
August	1.7615	6.2671	1.4816	0.7637	3.0521
September	1.2056	7.4182	1.1648	1.0683	4.0632
October	1.9622	9.2088	1.5586	0.9959	4.0569
November	1.6593	12.0226	1.4860	1.7269	8.7790
December	2.2022	9.2088	1.4956	0.8230	4.0829
Annual	1.9460	12.0226	1.5245	1.0650	4.5601

Figure 4 depicts the monthly average wind speed variation of useless and useful wind. In this figure, the curve (a) represents the mean wind speed of the useless wind. It is shown that these wind speeds are unable to start on the WG.

However, we note, in (c), that this wind category possesses some peaks exceeding 7.5 m/s. The average of the instantaneous maximum speed's value is plotted on (b). The dotted curves (d), (e) and (f) show that the useful speed is always higher than 3m/s. This is the case that we consider to estimate the wind energy potential of our site.

B. *Diurnal variation of wind speed*

The diurnal variation of wind speed is a predominant feature discernible at many sites around the globe. This is to determine the wind average daily and nightly profiles. This useful data is used in a subsequent comparison with demand whenever we can work out to what degree is wind present or otherwise at a peak demand times. Table IV depicts the means of day and night useful wind speed per month for the year 2004. From the data presented, it can be seen that there is significant variation in the annual mean speed, with minimum and maximum values ranging from 3.3076 m/s to 12.5546 m/s. The maximum values indicated in this table correspond to the mean values of useful wind speed recorded during the sampling period. However, there is instantaneous peaks of wind speed can reach 24.0408 m/s during the months of May and November at 21m high.

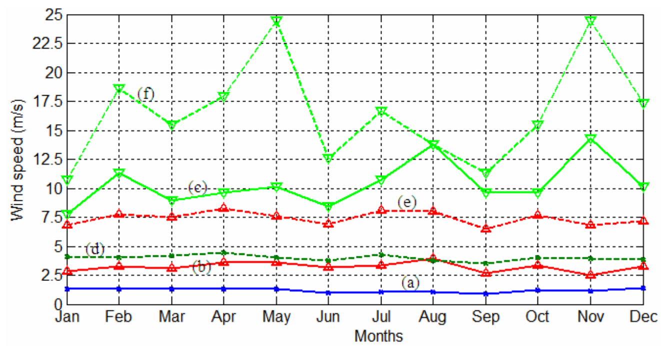


Figure 4. Monthly average wind speed during 2004

The figure 5 provides the shape of daily and nightly average wind speed. The curves (a), (b), (c) and (d) depict respectively the nightly average wind speed, nightly maximum wind speed, daily average wind speed and daily maximum wind speed. This figure provides that the means of wind speeds are higher during the day than in the night except in July, October and December. Accordingly, the greater amount of energy is produced during the day. This is mainly attributed to localized variations induced by land or sea breezes in proximity to a coastline as widely discussed in [14].

C. *Wind direction analysis*

The main objective of this part is to assess the contribution of each direction in the available energy at the surveyed area. Indeed, when analyzing the wind resource, its profile calculation is taken into account for identifying the average

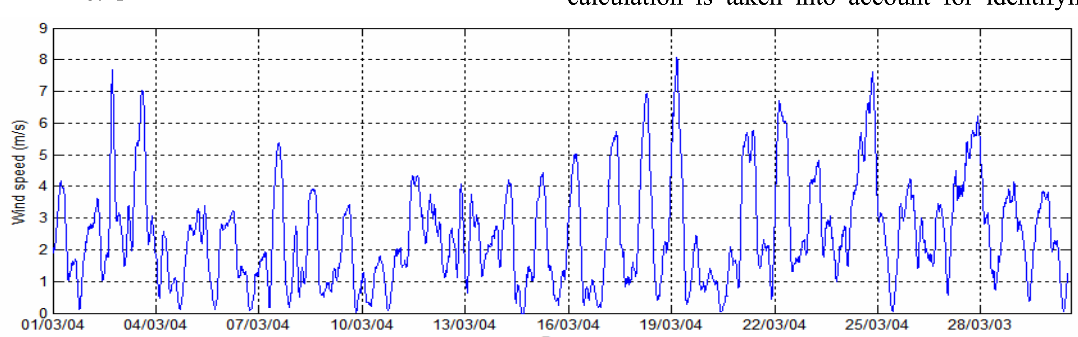


Figure 3. Filtered wind speed recorded in our site during Mars 2004

wind direction and its energy according to each direction. Thus, we will establish the seasonal and annual wind rose.

The wind rose is a polar graph that compiles the wind energy to each of the 16 wind directions recorded by our measuring station as depicted in Table I. This is to show the mostly windy direction over all months of year.

In Figure 6 we present the annual wind rose graph for the wind direction profile in each of three years: 2004 in (a), 2005 in (b) and 2006 in (c). Those figures prove that the wind profile show a preferential North (N) direction. More exactly, the annual wind energy follows of direction in the section between N and North-North-East (NNE) which contribute respectively by 30% and 21% of the global energy produced in the year 2004. In the same section we notify the contribution of 38% and 19% in the year 2005 and by 31% and 25% in the year 2006 respectively.

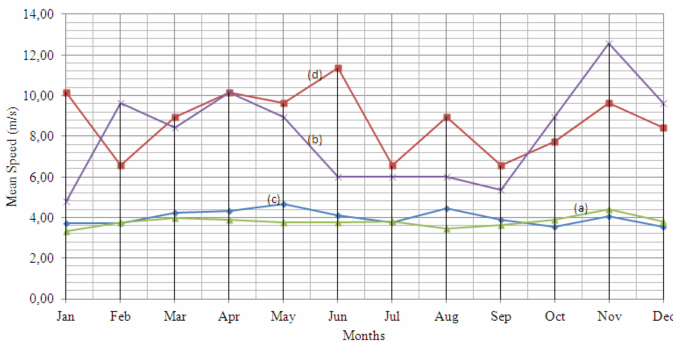
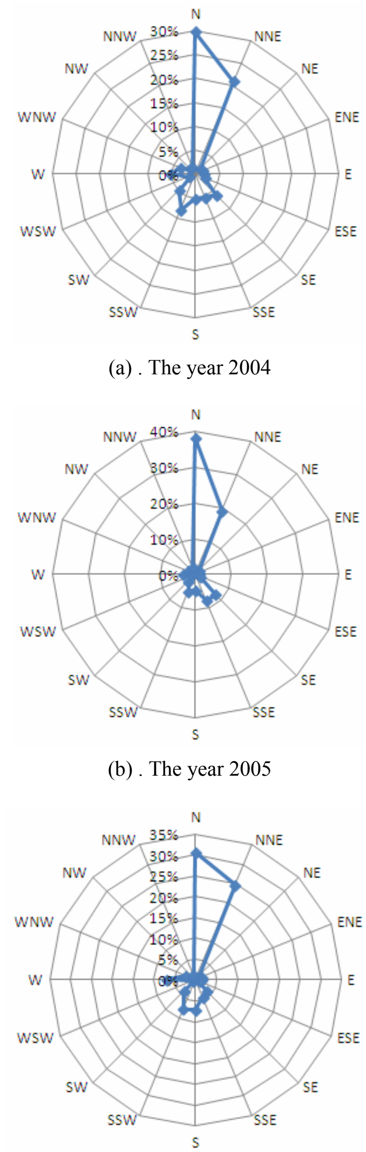


Figure 5. Daily and nightly average wind speed

TABLE IV. DAILY AND NIGHTLY AVERAGE WIND SPEED

	Day		Night	
Months of year	***Mean value** (m/s)*	***Maximum value** (m/s)*	***Mean value** (m/s)*	***Maximum value** (m/s)*
January	3.6961	10.1506	3.3076	4.8082
February	3.6961	6.5444	3.7425	9.6163
March	4.2518	8.9485	3.9542	8.4143
April	4.3074	10.1506	3.8770	10.1506
May	4.6619	9.6163	3.7560	8.9485
June	4.0906	11.3526	3.7536	6.0102
July	3.7389	6.5444	3.8055	6.0102
August	4.4564	8.9485	3.4518	6.0102
September	3.8732	6.5444	3.6188	5.3424
October	3.5264	7.7465	3.8834	8.9485
November	4.0496	9.6163	4.3854	12.5546
December	3.5514	8.4143	3.8062	9.6163
Annual	4.0185	8.5843	3.8213	8.3293

In figure 7 we show the seasonal wind rose of the year 2004. Figure 7 (a) depicts that the winter season is marked by a predominance of winds from the North-North-East (NNE) direction, but with a significant winds from Southeast-



(a) . The year 2004

(b) . The year 2005

(c) . The year 2006

Figure 6. Annual wind rose at 21m high

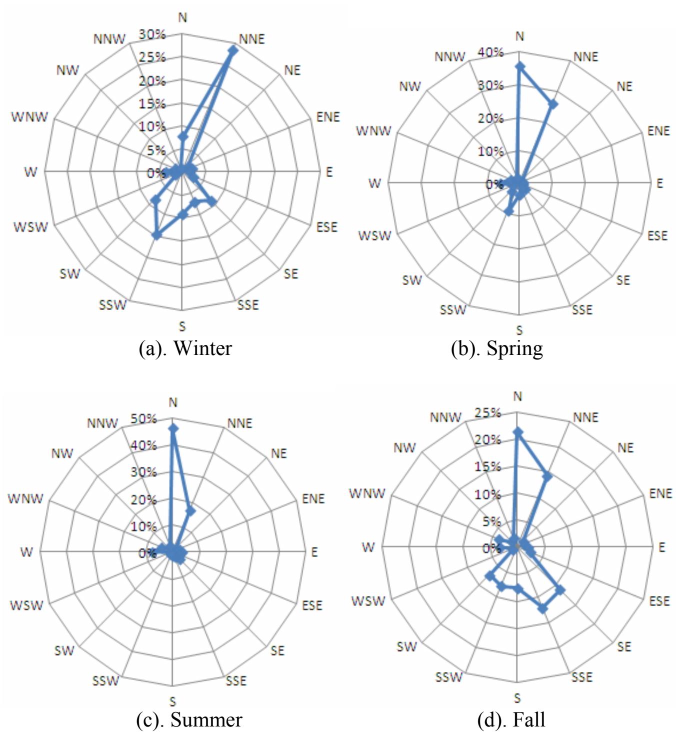
Southwest (SE-SW) sector which contributes up to 15% of the energy supplied in this season. For the spring and fall seasons, in figure 7 (b) and (d) respectively, we note that all available energy is provided by the N direction, except for the fall season, we see a significant contribution SE-SSE sector. Figure 7 (c) shows that the majority of energy is provided by the N direction with a slight contribution of NNE direction. Finally, we may conclude that the windiest direction in Mohammedia city is the North direction.

In figure 8, we present the frequency of occurrence of the useless and the useful wind for each direction during the year 2004. This frequency expresses the number of occurrence of each wind category according to each direction during all months. For example, in the north direction the frequency of useless and useful wind is respectively of 51% and 49%. At first sight, it can be seen that the most frequently wind is the useless wind. This means that this area is not very windy.

VI. Available Energy at the Surveyed Area

In this section, we determine the power likely to be supplied from the wind blowing through the measuring station in our surveyed area. As had been previously discussed, we distinguish two categories of winds: the useless wind and the useful wind.

We focus on the energy generated by the second category of wind. The annual energy cumulated during the three years 2004, 2005 and 2006 is spread over the twelve months as depicted in figure 9. We note that April provides 13% of this annual energy.



(a). Winter (b). Spring

(c). Summer (d). Fall

Figure 7. Seasonal wind rose during 2004

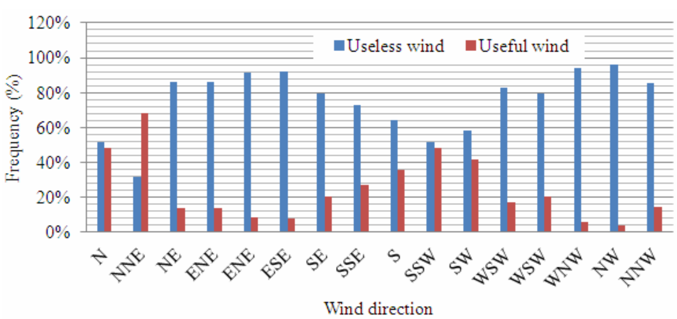


Figure 8. Overall observed wind direction frequency in the year 2004

Whilst, each one of the Mars, May and July months contribute by 10% of this energy. An analysis of useful wind speed, allowed us to distinguish three categories of winds. This classification is based on the contribution of each category on the annual energy production. The first category is called high wind's contribution whose speed's value is in the interval [3m.s, 4.5m/s]. In the second category, called medium wind's contribution, the wind speed belonging]4.5m/s, 6m.s]. The third category, called low wind's contribution, where the wind speed is higher than 6m/s. Figure 10 depicts the contribution of each category in the global energy of the years 2004, 2005 and 2006. This available energy is 1036.68 KWh in the year 2004, 1070.69 KWh in the year 2005 and 1046.60 KWh in the year 2006.We note here that during the three years, the most part of energy is supplied by the wind speed's value between 3m/s and 4.5m/s. We recall that this can be easily used for electric energy storage in battery bank, water pumping, lighting and heating systems as reported in [11].

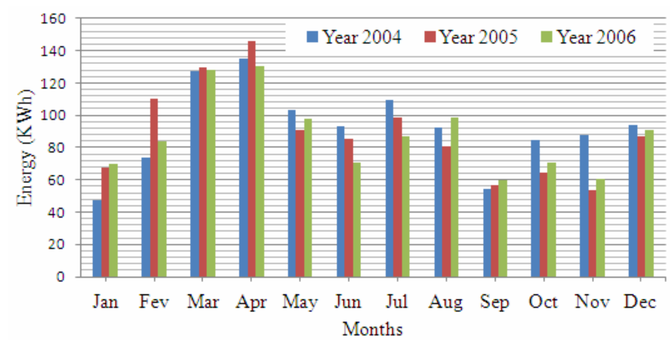
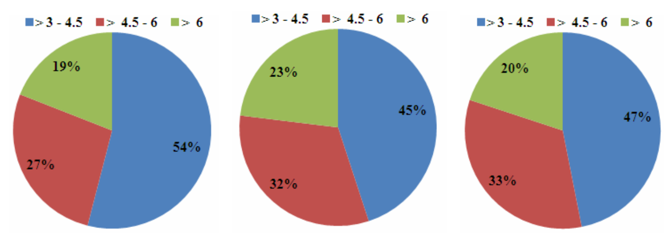


Figure 9. Available energy per month



(a). The year 2004 (b). The year 2005 (c). The year 2006

Figure 10. Contribution of each category of wind in the annual energy

VII. Conclusion

The main goal of this study is the analysis of the wind data and the assessment of the wind energy in Mohammedia city, Morocco. To do this, some data analysis was undertaken to weed out the faulty and corrupted data. The data resulting from the preprocessing procedure had been analyzed. The wind flows analyzed denote an annual average wind speed of 4m/s at 21m high with some peaks of 24m/s at the same high in May and November months. We have noted here that the greater amount of energy in this area was produced by the daily wind speed. Also, the annual wind direction analysis for the years 2004, 2005 and 2006 showed that the annual energy follows from the wind direction between 360° and 22.5°. This energy can be used for electrical water pumping, lighting and heating systems.

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