Study and optimization of a renewable system of small power generation

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ABSTRACT. This paper aims to evaluate an optimized system for producing electricity from one or two renewable energy sources at a site with a high potential for exploitable solar energy and a low wind potential that makes its operation in parallel with that of solar energy part of the focus of this study. This system is intended for autonomous dwellings far from conventional electricity networks. The model used in this study is based on a technique for the analysis and evaluation of these two energy sources, electrochemical storage and charging for a residential residence. This model is introduced into a simulation and calculation program using simple iterations to evaluate the configuration results of optimized systems and select from the results obtained an electrical power generation system coupled or separated from the two energy sources. These two sources being able to ensure a continuous energy balance in relation to the load of the residence that can be used at any time. These two sources are able to ensure a continuous energy balance in relation to the load of the residence that can be used at any time of the day and are the most economical of the systems found. The wind system adopted in the study is of the low start-up speed type for low wind regions similar to the selected region under study, despite the good solar resource present at this site, which will lead to an examination of its feasibility and profitability in covering the inactivity of photovoltaic panels in periods of no sunlight, i.e. a system with a reduced number of photovoltaic panels and storage batteries, the latter having to restore a full day of autonomy. Two configurations were selected and discussed. The first is composed of photovoltaic panels and storage batteries and the other includes the introduction of a wind power system in combination with the storage photovoltaic system resulting in a higher investment cost than the first. Consequently, the results obtained in this study prove that it is preferable to opt for a purely photovoltaic system with storage in this type of site and exclude the interest of adding micro wind turbines adapted for sites with low wind resources.

RÉSUMÉ. Cet article vise à évaluer la fiabilité d'un système optimisé de production d'énergie électrique à partir d'une ou de deux sources d'énergie renouvelables dans un site disposant d'un important potentiel d'énergie solaire exploitable et d'un faible potentiel éolien qui rend son exploitation en parallèle de celle du photovoltaïque une partie de l'objet de cette étude. Ce système est destiné aux habitations autonomes et éloignées des réseaux d'électricité conventionnels. Le modèle utilisé dans cette étude est basé sur une technique d'analyse et d'évaluation de ces deux sources d'énergie, d'un stockage électrochimique et d'une charge pour une résidence d'habitation. Ce modèle est introduit dans un programme de simulation et *de calcul utilisant de simples itérations à fin d'évaluer les résultats de configuration de systèmes optimisés et de sélectionner à partir des résultats obtenus, un système de production d'énergie électrique couplé ou séparé des deux sources d'énergie. Ces deux sources étant en mesure s'assurer un équilibre énergétique continu susceptible de couvrir la charge de la résidence, utilisable à n'importe quel moment de la journée et s'avérant être le plus économique des systèmes trouvés. Le système éolien adopté en étude est de type de faible vitesse de démarrage destiné aux régions à vents faibles semblable à la région sélectionnée à l'étude et ce en dépit de la bonne ressource solaire présente dans ce site .Ce qui mènera à examiner sa faisabilité et rentabilité à couvrir l'inactivité des panneaux photovoltaïques en période de non ensoleillement soit un système comportant un nombre réduit de panneaux photovoltaïques et de batteries de stockage où ces dernières devraient restituer un jour complet d'autonomie. Deux configurations sont retenues et discutées. La première est composée de panneaux photovoltaïques et de batteries de stockage et l'autre inclut l'introduction d'un système micro-éolien en combinaison avec le système photovoltaïque avec stockage induisant un coût d'investissement plus élevé que le premier.*

KEYWORDS: *photovoltaic system, wind system, hybrid photovoltaic-wind-storage system, sizing, optimization.*

MOTS-CLÉS: *système photovoltaïque, système éolien, système hybride photovoltaïque-éolien-stockage, optimisation.*

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1. Introduction

Economic growth requires increasing needs for electrical energy to ensure the development and comfort of human life. The exploitation of fossil fuels has a negative impact on the environment and hence the need for a healthy and sustainable energy transition, such as the exploitation of renewable energy potential, particularly for regions remote from conventional electricity networks.

5KWh is approximately the average solar energy received daily over most of the northern part of the Algerian territory, which has a low to medium wind resource representing a minor wind potential in some sites (Ministère de l'Energie et des Mines, 2007), which could also be exploited by means of micro-wind turbines with low starting speed.

Tlemcen, a city located in northern Algeria, is home to sites far from conventional electricity networks where a number of research studies have previously been conducted on the operation of photovoltaic and/or wind energy systems. However, no studies have been carried out on sites with low or medium wind potential for energy production systems using micro wind turbines.

Nevertheless, the majority of these studies have demonstrated the reliability and cost-effectiveness of supporting micro wind turbines with photovoltaic panels in low wind sites, and no studies have been conducted using micro wind energy production systems, which will allow the identification of the system adapted to the electrical needs required per house and evaluate this result in comparison to those of studies undertaken on similar sites.

The decrease of absence of yield of photovoltaic panels in periods of low or no sunlight, particularly at night, causes a handicap resulting in the oversizing of a possible battery-powered photovoltaic system. In this case, the study will determine if a micro-wind turbine system has a good energy and economic impact that favours its hybrid integration with the photovoltaic system with the electrochemical storage mentioned above.

The main objective of this study is to determine whether it is more reliably efficient from an energy point of view and economically viable to adopt a photovoltaic system with storage or to opt for the same smaller system by integrating a micro-wind turbine system. The focus is on identifying the optimal configurations of systems aimed at providing a continuous and constant energy balance to an autonomous housing either consumed directly or stored in batteries. The scientific interest in this study is based on a judicious approach and choice of the discreet model and its application to photovoltaic-micro-wind hybrid systems, which is introduced into a simulation and calculation program that performs an hourly simulation of the energy balance between the total daily load of the living residence and the other components of the system during a reference year 2018.

In the end, two optimal configurations are chosen, the first includes a photovoltaic system assisted by electrochemical storage generating a total cost (without installation cost) of 4125 Euros and the second includes the addition of a micro-wind turbine system to a system with fewer photovoltaic panels and batteries and whose cost amounts to 5735 Euros.

It can therefore be noted that the exploitation of the low wind potential by the use of micro-wind turbine system in not very reliable even in a site with a low wind resource similar to our case study and it would be more advantageous to rely on the use of pure photovoltaic system assisted by storage batteries that offer better reliability and energy efficiency and greater economic profitability.

2. Site description and assessment of solar and wind resources and load required

2.1. Implementation site

Les The chosen site is located in Tlemcen in a region of Zenâta in Algeria. The characteristics of the site are displayed on the following Table 1:

Table 1. Characteristics of the Zenâta site (Maouedj, 2005)

Site	*Latitude*	*Longitude*	*Altitude*	*Albédo*
Tlemcen	35.02°N	1.18°E	247 m	0.20

2.2. Solar and wind resource assessment

It is fundamental to know with precision the local resource data (solar irradiation and wind speed) of the selected region. This study is based on a source of daily data from the two sources of solar and wind energy measured at a height of ten meters above ground level related to twelve months and the whole year for ten consecutive years (2000-2010). The data were obtained from the METAR /SYNOP meteorological station in Tlemcen Zenâta (Gumuła and Stanisz, 2009).

2.2.1. Solar resource

Figure 1 shows the monthly average of each year of the solar radiation index for the Tlemcen region.

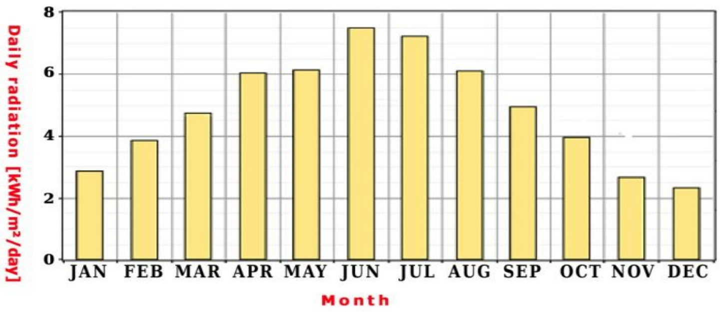

Figure 1. Monthly sun radiation of the Tlemcen site

The solar radiation in Tlemcen reaches its minimum of 2.3 kWh/m²/day in December and its maximum of 7.5 kWh/m²/day in June and the annual average is 4.8 kWh/m²/day.

2.2.2. Wind resource

Figure 2 shows the annual average wind speeds in the Tlemcen region.

Wind speeds are considered relatively low throughout the year. January is the windiest month with a wind speed of 3.2 m/s and October is the least windy month of the year with a speed of 1.3 m/s. The annual average wind speed of the Tlemcen site is 2.1 m/s for the period studied. Solar radiation and wind speeds are considered appropriate for the proper functioning of the energy system.

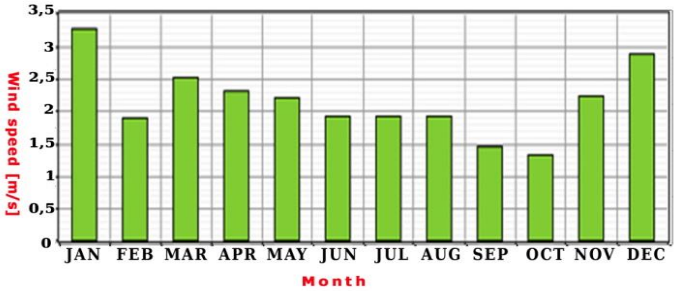

Figure 2. Monthly wind speeds of the Tlemcen site

2.2.3. Temperature

Table 2 displays the monthly average of each year's temperature in the Tlemcen region. The monthly temperature reaches its minimum in January estimated at 6.27°C and its maximum of 28.9°C in July and the annual average is 17°C. These temperatures will not affect the proper operation of the converters in the photovoltaic installation or wind turbines.

Table 2. Average monthly temperature

Month			*Jan*	*Feb*	*Mar*	*Apr*	*Mai*	*Jun*
Temperature (°C)			6.27	8.23	11.6	14.8	19.9	25.4
Jul	Aug	Sep	Oct	Nov	Dec	Annual average		
28.9	28.0	23.1	17.6	11.7	7.65	17.0		

2.3. Characteristics of the chosen apartment and its energy balance

The apartment chosen for the study is of the type not connected to the conventional energy distribution network and equipped with all the appliances to provide comfort to the occupants. In addition, it is permanently occupied throughout the year and domestic equipment operates under a standard 220v 50Hz (mains voltage). Daily consumption is assumed to be constant during the first nine months of the year (September-May) at around 3.260 kWh per day and another constant value during the summer season (June, July and August) estimated at 9.150 kWh per day (see Table 2) (Belhamel *et al.*, 2010).

Figure 3 represents the total consumption of the apartment in a single typical day during the winter season (3,260 kWh) shared over 24 hours.

Figure 4 represents the total consumption of the apartment in a single day during the summer season (June-August): 9,150 kWh, shared over 24 hours.

Table 3 shows the estimate of the daily energy needs of the apartment in wh.

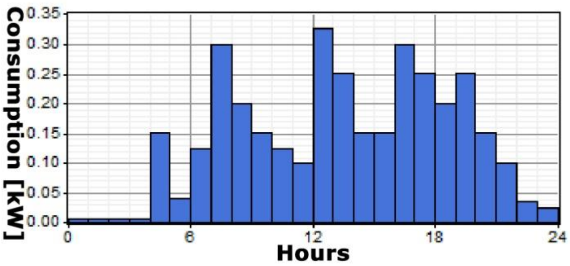

Figure 3. Daily profile (winter season)

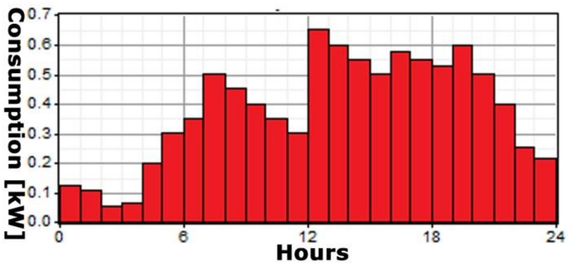

Figure 4. Daily profile (summer season)

Table 3. Assessment of daily energy needs of apartment

		Power(w)	Duration of use (hours)	Daily consumption (Wh)
Lighting	*Adults' room*	11	4	44
	Children's room	22	5	110
	Living room	22	6	132
	Corridor	22	2	44
	Bathroom	22	2	44
	Toilets	11	1	11
	Kitchen	11	7	77
Appliances	*Refrigerator*	120	8(winter), 12(summer)	96(winter), 1440(summer)
	Television LCD	72	5h30	397.26
	Air conditioner	1100	0(winter), 6(summer)	0(winter), 6600(summer)
	Others	100	2	250
Total lighting of apartment				3260/9150

3. Methodology

The essential step in the dimensioning of an energy production system is the determination of its optimal size which depends essentially on the climatic data of the site and the characteristics of the parameters included in this system. This part deals with the models used in this study to determine the optimal size of the electrical energy production system to meet the electrical needs of the residence.

3.1. Incident global radiation and energy produced by the photovoltaic generator

Incident global radiation on a photovoltaic panel is calculated according to the HDKR (Hay, Davies, Klucher, Reindl) model (Reindl *et al.*, 1990):

$$G_T = (G_b + G_d A_i) R_b + G_d (1 - A_i) \left(\frac{1 + \cos\beta}{2} \right) \left[1 + f \sin^3 \left(\frac{\beta}{2} \right) \right] + G \rho_g \left(\frac{1 - \cos\beta}{2} \right) \quad (1)$$

The energy produced by a photovoltaic panel is estimated from the data of the global irradiation on inclined plane, ambient temperature and the manufacturer's data of the photovoltaic module used. It is given by El Hadidy (2002):

$$P_{pv} = R_{pv} . S_{pv} . P_f . H . N \quad (2)$$

The performance of the photovoltaic generator is represented by the following equation:

$$R_{pv} = \eta_r \left\{ 1 - \gamma (T_c - T_{STC} \right\} \quad (3)$$

$$T_C = T_a + G_{inc} \left(\frac{NOCT - 20}{800} \right) \quad (4)$$

where:

G_d–Beam radiation, kW/m^2

G_d–Scattered radiation, kW/m^2

G–Global horizontal radiation on the surface of the Earth, kW/m^2

A_i–Anisotropy coefficient=G_b/G_0 when G_0 is the horizontal extra-terrestrial radiation, kW/m^2

R_b–Ratio of beam radiation on an inclined surface to beam radiation on a horizontal surface

f–Factor used to account for lightening the horizon=$\sqrt{\frac{G_b}{G}}$

S_{pv}–The total surface of the photovoltaic generator, m^2

R_{pv}–The performance of the photovoltaic generator

H–Solar irradiation on an inclined plane, kW/m^2

P_f–Module fill factor, equal to 0.9

η_r–The reference performance of the photovoltaic generator

T_a–Average ambient daily temperature, °C

T_c–Daily temperature of average cell, °C

G_{inc}–Illumination junction in operating conditions

T_{STC}–Temperature of photovoltaic cell in standard test conditions (25°)

β–Surface slope

ρ_g–Ground reflectance (albedo)

γ–Considering the variation in performance of the photovoltaic module according to the temperature, which is take at (0.0045/°C)

N–Number of modules constituting the photovoltaic module

NOCT–Nominal operating cell temperature, °C

3.2. Wind speed distribution and energy produced by the wind generator

The Weibull function is used to characterize the distribution of wind frequencies during the period studied and is defined by Khahro *et al.*, (2014):

$$f(V) = \left(\frac{k}{A}\right)\left(\frac{V}{A}\right)^{k-1} \exp\left[\left(\frac{V}{A}\right)^{k}\right] \tag{5}$$

Wind speeds (Vm) can be calculated based on Weibull (K) and (A) parameters as shown below (Gumuła *et al.*, 2006):

$$V_m = A\Gamma\left(1+\frac{1}{k}\right) \tag{6}$$

The wind density power of a site based on the probability density function can be expressed as follows [9-10]:

$$P_{eol} = \frac{1}{2} S_{eol} \rho V^3 \Gamma\left(1+\frac{3}{k}\right) \tag{7}$$

Once the wind density power is given, the energy produced by a wind generator for a desired period can be calculated by Akpinar and Akpinar; Gumuła and

Woźniak (2005; 2016):

$$\frac{E}{S_{eol}} = \frac{1}{2}\rho V^3 \Gamma\left(1 + \frac{3}{k}\right).T \tag{8}$$

where:

V–Wind speed, m/s

K–Shape factor

A–Scale parameter, m/s

S_{eol}–The area swept by the wind turbine blade, m^2

ρ–Air density, 1.225kg/m^3

3.3. Battery size

The battery input power (PBAT) can be positive or negative depending on the charge or discharge mode of operation. The battery power is obtained from:

$$P_{bat} = P_{eol} + P_{pv} - P_{Load} \tag{9}$$

The state of charge (SOCBAT) is deduced from the battery power and efficiency (Kolokotsa, 2006):

$$SOC_{bat} = \int (P_{bat,charg ind} \times \eta_{bat} - P_{bat,decharg ing})dt \tag{10}$$

At any hour, the storage capacity (CBAT(t)) is subject to the following constraints:

$$C_{bat,\min} \le C_{bat}(t) \le C_{bat,\max}$$

Where (CBAT, max) and (CBAT, min) are the maximum and minimum allowable storage capacity, respectively. The capacity of storage batteries is determined from the maximum charge requested, it is expressed by Keyhani *et al.* (2010):

$$C_{batt,tot} = \frac{P_{load,\max}}{\eta_{bat}.U_{bat}.P_{dd}.N_m}.N_{ja} \tag{11}$$

3.4. Power management strategy

The power difference (Enet) between the generation sources and the load demand (Pload) is calculated as:

$$P_{net} = P_{pv} + P_{eol} - P_{load} \tag{12}$$

A governing control strategy is adopted, where at any time, any excess micro-wind and photovoltaic generated power (Enet>0) is supplied to the battery. Therefore the power balance equation given in (12) can be written as:

$$P_{pv} + P_{eol} = P_{load} + P_{bat,Charging} \tag{13}$$

When there is a defect in power generation (Enet<0), the battery begins to produce energy for the load. Therefore, the power balance equation for this situation can be written as:

$$P_{pv} + P_{eol} + P_{bat,Discharging} = P_{load} \tag{14}$$

where:

N_{ja}–Number of day autonomy

P_{dd}–Depth of battery discharge

N_{bat}–Energy efficiency of batteries

U_{bat}–Battery operating voltage

N_{m}–Number of days in a month with full load

3.5. Modelling of system reliability

Several approaches are used to achieve the optimal configurations of hybrid systems in terms of technical analysis. In this study, the technical sizing model is developed according to the concept of LPSP to evaluate the reliability of hybrid systems (Lu *et al.*, 2002). The methodology used can be summarized in the following steps:

The total power (Ptot), generated by the micro-wind, photovoltaic generator at hour t is calculated as follows:

$$P_{tot}(t) = P_{eol}(t) + P_{pv}(t) \tag{15}$$

The total power (Ptot) is divided into two parts. If the fraction of the (Ptot) given by the photovoltaic system is (f), then the complementary that is (1-f) of the (Ptot) must be satisfied by the wind system. The limit values of (f) correspond to pure systems. Indeed, f=1 corresponds to a 100% use of the photovoltaic system and f=0 represents 100% of the wind system.

So the previous equation (15) become:

$$P_{tot,f}(t) = f.P_{pv}(t) + (1-f)P_{eol}(t) \tag{16}$$

Then, the inverter input power (Pinv(t)), is calculated using the corresponding load power requirements, as follows:

$$P_{inv}(t) = \frac{P_{load}(t)}{\eta_{inv}} \tag{17}$$

where (Pload(t)) is the power consumed by the load at hour (t), (ηinv) is the inverter efficiency (93% in this study).

Three states may be appearing:

a) The total power generated by the micro-wind turbine and photovoltaic cell is greater than the power needed by the load, (Pinv). In this case, the energy surplus is stored in the batteries and the new storage capacity is calculated using (eq.10) until the full capacity is obtained.

b) The total micro-wind and photovoltaic power is less than the power needed by the load (Pinv), the energy deficit is covered by the storage and a new battery capacity is calculated using (eq.10).

c) In case of inverter input and total power equality, the storage capacity remains unchanged.

In case (a) when the batteries capacity reaches a maximum value (CBAT, max), the control system stops the charging process. The wasted energy, defined as the energy produced and not used by the system, for an hour (t) is calculated as follows:

$$WE(t) = P_{tot}(t)\Delta t - \left(\frac{P_{load}(t)}{\eta_{inv}} \Delta t + \left(\frac{C_{bat,\max} - C_{bat}(t-1)}{\eta_{cha}} \right) \right) \tag{18}$$

In case (b), if the batteries capacity decreases to its minimum level (CBAT, min), the control system disconnects the load and the energy deficit, loss of power supply for an hour (t) can be expressed as follows (Bogdan and Salameh, 1996):

$$LPS(t) = P_{load}(t)\Delta t - \left((P_{tot,f}(t))\Delta t + C_{bat}(t-1) - C_{bat,\min} \right) \eta_{inv} \tag{19}$$

where Δt is the step of time used for the calculations (in this study Δt=1h).

The loss of power supply probability, for a considered period (T), can be defined as the ratio of all the LPS(t) values over the total load required during that period. The LPSP technique is considered as technical implemented criteria for sizing a hybrid micro-wind/photovoltaic system employing a battery bank. The technical model for hybrid system sizing is developed according to the LPSP technique (Ai *et al.*, 2003).

$$LPSP = \sum_{t=1}^{T} LPS(t) / \sum_{t=1}^{T} P_{load}(t)\Delta t \tag{20}$$

3.6. Simulation and optimization

The reliability study model is introduced according to an algorithm into a calculation program. This program models the performance of several system configurations every hour of the year to determine its technical feasibility. The simulation process determines how a particular system configuration, a combination of system components of specific sizes, and an operating strategy that defines how those components work together, would behave in a given setting over a long period of time.

In the optimization process, simulates many different system configurations in search of the one that satisfies the load of the residence at the lowest cost. Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each.

4. Description of the system

The studied system contains photovoltaic panels connected in the DC bus and storage batteries. Each storage battery is connected in series with the 120v DC bus. A converter is used to convert the energy produced from photovoltaic panels, wind turbines and energy stored in batteries into alternating current (AC). The energy produced by the system is supplied to the apartment. The energy not consumed after serving the charge is stored in batteries.

The photovoltaic system produces a direct voltage which is stored in the battery after passing through a charge controller of the photovoltaic system. The wind turbine produces alternating current that is converted to direct current and stored in the battery. A discharge load is also connected to the battery to deflect excess charge when the battery is fully charged. The diagram that groups each possible component of the system is illustrated in Figure 5 (Gergaud, 2002).

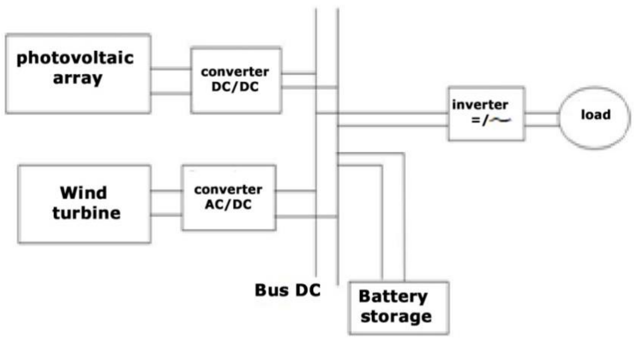

Figure 5. Flow diagram of the system

The technical specifications of the main components of the energy system are given in Table 4 (Gergaud, 2002; Protogeropouios *et al.*, 1997).

Table 4. Technical details of the system

Parameters	Values	Parameters	Values
Photovoltaic panels	Price: 65.00€/ panel	Battery	Prix: 305.00€ / battery
Nominal capacity (kW)	0,05	*Nominal voltage (V)*	12
Panel Performance (%)	13	*Capacity (Ah)*	230
Voltage Mpp (V)	18	*Maximum voltage (V)*	14,4
Intensity Mpp (A)	2,78	*Starting current (A)*	1150
Short-circuit current (A)	3,16	*Charge voltage (%)*	10
Open-circuit voltage (V)	22,2	*Series-connected batteries*	10
Warranty (years)	10	*Life at 50% of discharge (cycle)*	200
Size (length/width/height)(mm)	630 x 545 x 25	*Size (length/width/height)(mm)*	518 x 276 x 242
Weight (Kg)	4	*Weight (Kg)*	56,75
Life time (years)	20	*Warranty (years)*	1
Wind turbine	Price: 2000.00€/ turbine	Convertor	Prix: 1000.00€/ convertor
rated capacity (W)	1000	*Maximum power (kW)*	1210
Maximum power (W)	1500	*Maximum voltage (V)*	400
Start speed (m/s)	2	*Voltage range PV, MPPT (V)*	139 - 320
Nominal speed (m/s)	10	*Max input current (A)*	10
Stop speed (m/s)	55	*Nominal power (kW)*	1000
Wind turbine efficiency (%)	96	*Output current (A)*	5,6
Noise level (dB)	45	*Nominal voltage range (V)*	220-240 / 180-260
Warranty (years)	5	*Frequency range network (Hz)*	50 - 60
Life time (years)	25	*Maximum efficiency (%)*	93
Weight (Kg)	78	*Size (length/width/height)(mm)*	434 x 295 x 214
Rotor length (m)	2,8	*Weight (Kg)*	22
Rotor width (m)	2	*Noise level (dB)*	39

5. Results and discussion

This part shows the influence of the characteristics of solar and wind energy resources on the sizing and profitability of an electrical energy production system. After entering the necessary data into the calculation program, it will run several simulations by modifying the parameters and determining optimal solutions. The result of the simulation shows the most feasible configuration of the energy system as well as the energy production of each source. The results obtained from the recovered photovoltaic energy are illustrated in Figure 6.

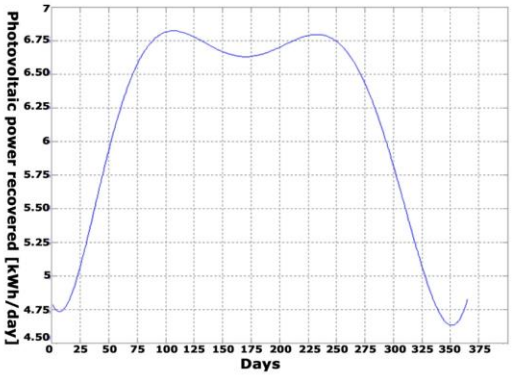

Figure 6. Solar photovoltaic energy received in the site on an inclined plane

Figure 6 shows the variation profile of the recovered photovoltaic solar energy. Two maximum values are distinguished: the 110th day the recovered energy reaches 6.87 kWh and 6.80 kWh the 237th day.

Wind energy recovered in relation to wind speeds for the Tlemcen region is shown in Figure 7.

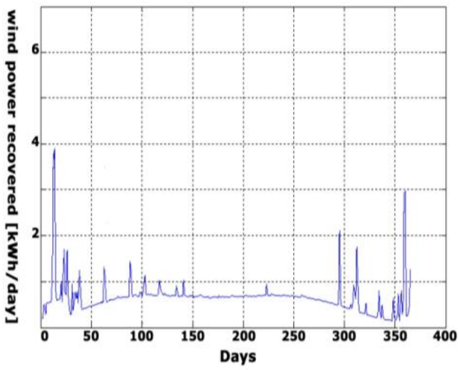

Figure 7. Daily wind energy collected in Tlemcen

Figure 7 shows that January and December are the most profitable months of the year; the recovered wind energy reaches the value of 14.2 kWh per day. For the rest of the year, the energy is very low, which leads this region to use more photovoltaic than wind electricity. The wind rose and wind speed frequency distribution were evaluated with respect to the entire year to determine if the wind is blowing in one direction throughout the year at a respective intensity. The annual results are shown in Figure 8.

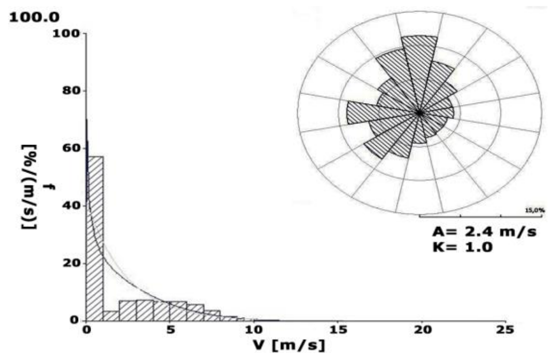

Figure 8. Wind speeds frequencies according to the Weibull distribution Ans diagram of the wind rose at 10m height

The final value of the 'K' and 'A' parameters obtained are 1 and 2.42 m/s respectively. The value of 'K' is estimated at 1 m/s, this low wind density is not conducive to the continuous operation of the wind system all day. Therefore, Tlemcen presents very low conditions in terms of wind resource. Concerning the wind rose diagram, it is notable that the prevailing wind directions come from the north side of Tlemcen. The hybrid energy received for the Tlemcen region is shown in Figure 9.

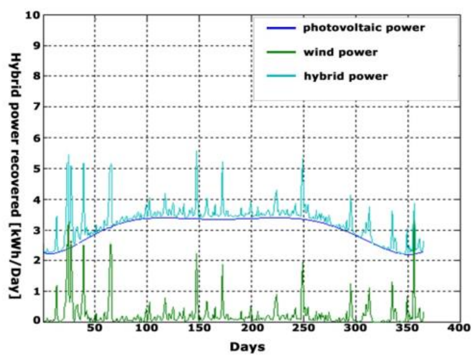

Figure 9. hybrid energy (photovoltaic - wind) received

Figure 9 is interpreted over the following periods:

The first period: from the first day to the 90th day, the apartment's load is fixed at 3.26 kWh/day (see Table 3). This winter period has 8 days in deficit which are : (1, 3, 5, 8, 10, 12, 15 and 16) days. This gives a day of autonomy since the days are not successive, so the storage in the batteries is introduced to cover the charge of the apartment.

The second period: from 91st day to 274th day, the apartment's load is fixed at 9.15 kWh/day. This summer period does not include deficit days; the system works normally without batteries, the energy produced is fairly constant in this period and reaches the maximum value of 5.6 kWh/day.

The third period: from the 275th day until the end of the year, the load of the apartment is fixed at 3.26 kWh/day. This winter period has other days in deficit which are: (235, 237, 239, and 242) days, that gives one day of autonomy.

Because the required load is constant for each period, the results show that the most unfavourable month is the month with the lowest solar irradiation to wind speed ratio. According to the results, the most unfavourable month is December.

5.1. Calculating the number of batteries

The number of days of autonomy is estimated at one day (24 hours). The daily energy demand during this day is set at 3260ah. The storage system will compensate for the interruption of the power generation system. The electricity that comes out of the batteries does not reach the electrical appliances entirely: a part is lost in the wires and during the DC-AC conversion by the converter, the amount of energy to be restored is 3.95 kWh. For the batteries to have a longer life a maximum depth of discharge of 50% is set, the capacity of the storage system should be 7.91 kWh; this induces to a quantitative number of three storage batteries during this deficit day.

The calculation program finds the best configurations of the power generation system that will generate enough or all energy for the apartment. The results of these configurations are shown in Table 5.

Table 5. Optimum configurations

Parameters	Optimum Configurations	
	Configuration A	Configuration B
Photovoltaic system(KW)	1,7	1,4
Number of panels PV	34	28
Number of wind turbines	0	1
Number of batteries	3	3
Number of convertors	1	1
Total cost (€)	4125	5735

Table 5 displays the two best selected configurations. Configuration (A) contains a purely photovoltaic system with a power of 1.7 kW and consists of 34 photovoltaic panels, 3 storage batteries, a converter, and contains no wind generator. The surface of the photovoltaic panels represents 12.7 m². The net present cost of this configuration is estimated at 4125 Euros.

The second configuration (B) contains a hybrid photovoltaic/wind system. There are fewer photovoltaic panels than in configuration (A) and counts 28 panels with a surface of 9.6 m² generating a power of 1.4 kW. The number of storage batteries and converters is the same as in configuration (A). Concerning the net present cost of this configuration, it is higher and is estimated at 5735 Euros.

5.2. Production result and electricity consumption

This section shows more details about the two configurations by comparing the energy produced and consumed annually by each configuration (kWh/year). Figures 10, 11 show the average hourly electricity production for each day of the months of the year in both configurations.

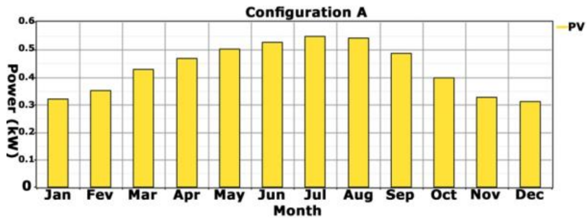

Figure 10. Average hourly electricity production for each day of the months of the configuration (A)

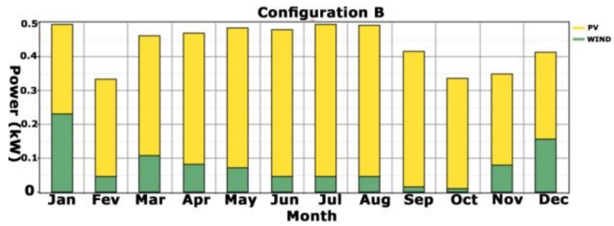

Figure 11. Average hourly electricity production for each day of the months of the configuration (B)

According to Figure 10, it has been found that the production of electrical energy comes only from the photovoltaic system estimated at 3803 kWh/year. The average hourly production is less than 0.4 kW/h from November to February, unlike the other months of the year when this average is greater than or equal to 0.5 kW/h. The electrical energy consumed directly from the (AC) bus represents 1756 kWh/year, the rest of the energy produced is stored in batteries so that it can be used at night or during the period when there is a lack of solar radiation and represents 1606 kWh/year or 42.2% of the production of the pure photovoltaic system.

Figure 11 shows that the production of electric energy from the photovoltaic/wind hybrid system is estimated at 3822 kWh/year where 82% is generated by photovoltaic panels and 18% by the wind system, i.e. 3132 kWh/year and 690 kWh/year respectively.

The energy generated by the photovoltaic panels is much higher than that of the wind system during all the months of the year. The average hourly production in February, October and November is less than 0.4 kW/h. The electric energy consumed directly from the AC bus represents 1755 kWh/year, the rest is stored in the batteries in order to be used at night or during the deficit period of the two energy sources and represents 1730 kWh/year or 45.3% of the production of the hybrid system.

5.3. Other results of configuration 'A'

This part will discuss the behaviour of photovoltaic panels with storage during all days of the year. The annual energy produced by the photovoltaic system per day and over the whole year is represented in Figure 12.

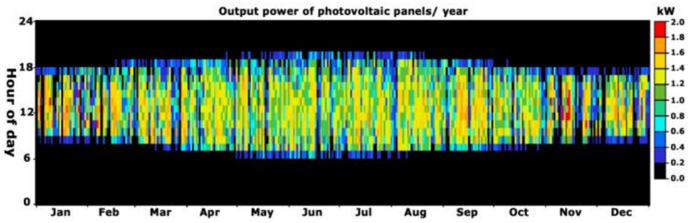

Figure 12. Daily energy produced by PV throughout the year

As shown in Figure 12 the production is stable during all the days of the year and this between 6 am and 7 pm. hourly production is around 0.4 kW up to 1.2 kW continuously and can even reach 1.8 kW and very rarely 2kW during the day. The operating hours of photovoltaic panels are estimated at 4387 hours per year.

Figure 13 shows the daily charging and discharging status of batteries throughout the year. Figure 13 shows that the batteries are always almost fulfilled during the year except during the summer period which lasts from June until August when it can reach an estimated depth of discharge of 90% to 65%. In mid-July the battery discharge will reach its maximum of 50% for a few hours at night.

The energy converter operates fully throughout the year.

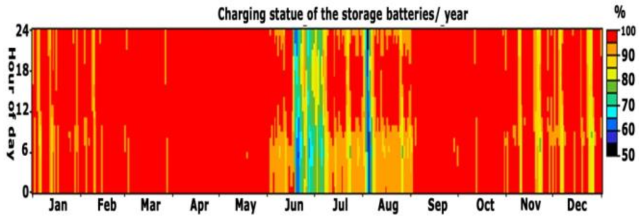

Figure 13. Daily energy produced by PV throughout the year

5.4. Other results of configuration 'B'

This section will discuss the behavior of the photovoltaic/wind hybrid system during all days of the year. The annual energy produced by the photovoltaic and wind systems each day of the year is shown in Figure 14 and 15 respectively.

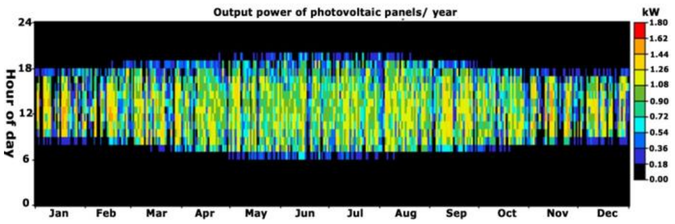

Figure 14. Daily energy produced by PVs during the year

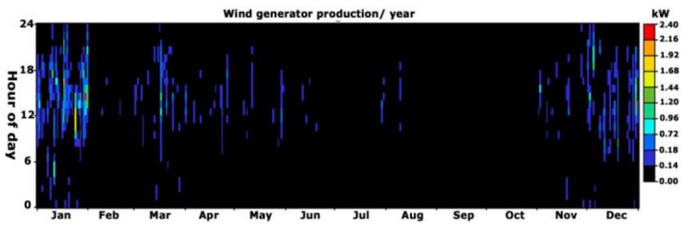

Figure 15. Daily energy produced by wind turbine during the year

From Figure 14 and 15 it was noticed that the production of the photovoltaic system is dominant during the year while it is reduced during the months of January, November and December.

This phenomenon is due to the presence of the wind generator which is associated with the photovoltaic system. Nevertheless, the wind production is essentially valid only the months of December and January. It is estimated very low between 0.14 and 0.72 kW hourly. It reaches its maximum value of 2.23 kW during two hours of production in mid-January. Wind turbine operating hours are low. The batteries will have the same behaviour as in the ‘A' configuration and the converter will operate fully during the year.

Consequently, the ‘A’ configuration is better than the 'B' configuration, on account of the total net cost of the investment, which is respectively 4125 Euros against 5735 Euros.

6. Conclusion

This study focused on the use of two sources of energy wind and solar to identify a system of electrical energy production coupled or separated based on these two sources and which aims to develop the electrical energy required daily by a house. The study conducted in this article leads to deduce the optimal configuration for supplying a continuous availability of electrical energy at any time of the day to a residential apartment autonomous and away from the conventional power network in Tlemcen, Algeria. However, the methodology presented can be used for identifying optimum energy production system for any location in the world and especially for small power sites. Based on the results, the following conclusions are drawn:

-Solar resource assessment for the region shows the possibility of adequate power generation potential from pure photovoltaic systems. The wind resource analysis shows the inefficiency of the wind energy generation due to the very low wind speed of this non windy site. So this region can only be considered for solar power generation as opposed to wind energy.

-The optimum practicable configurations of electrical power system for energy demand of 3,26 kWh/day in the winter season and 9,15 kWh/ day in the summer season are determined.

-Two configurations that distinguish this study are highlighted, the first is purely photovoltaic and consists of 34 panels, 3 storage batteries and 1 converter with a total cost of 4125 Euros, and the second represents a hybrid photovoltaic/wind system, and consists of 28 panels, 1 wind turbine, 3 storage batteries and 1 converter with a total cost of 5735 Euros.

The main obstacle in the production of energy for hybrid systems is the lack or failure of a source either solar or wind. Hence the latter must be strong and constant for a better energetic profit.

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