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Weather data analysis and optimal design of hybrid PV-wind-diesel power system for a village in Chlef, Algeria

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ABSTRACT

This study considered the ability of a hybrid power system Photovoltaic-Wind-Diesel with storage (batteries) to meet the demand for electric charge of 54 kWh/day in an isolated site of 10 inhabitants, not connected to the electrical grid, within the Chlef region, Algeria. Meteorological data (such as: global solar radiation, Wind speed, Wind direction, air temperature and relative humidity) was measured at Ouled Fares site in Chlef, between 1st January 2015 and 31st December 2015. The monthly average global solar radiation measured at the Ouled Fares site during this period ranged from 2.387 kWh/m^2/d to 7.322 kWh/m^2/d. The monthly average Wind speeds ranged between 1.328 m/s and 3.404 m/s. The objective of this study was the optimization of a hybrid Photovoltaic-Wind-Diesel power system. Simulation software HOMER was used to find out if the hybrid system performed comparably in terms of technical and economic feasibility to a conventional system connected to the grid. The study found that the Photovoltaic-Diesel-Battery system was the most economic power system, it produced 30,472 kWh/y with COE 0.224 $/kWh. The proposed system comprised of 20 kW of PV panels, one Diesel generating 2.5 kW rated power and 36 batteries of nominal capacity 4 kWh. It was noted that 96% (29,144 kWh/y) of energy was produced by the Photovoltaic generator and 4% (1,328 kWh/y) was produced by the generator, which worked 586 h/y with a consumption of 449 L/y. The Diesel price of 0.70 US$ per liter was considered fixed and without fluctuations. The hybrid system was able to meet energy requirements (load of 19,781 kWh/y) of the village with 15.1% energy in excess (4,593 kWh/y). The proposed system avoided over 28.39 kg/y of CO_2 less emissions for the local atmosphere of the site and would save 22.59 barrel/y of fossil fuel. Moreover, the comparison showed that the autonomous hybrid system is the best choice compared to the conventional grid connection with COE 0.047$/kWh when the connection distance exceeds 1.35 km.

Keywords: Sizing; PV/wind/diesel system; Solar radiation; Wind speed; HOMER

1. Introduction

Algeria is a vast country in Africa and there are rural communities located in isolated and mountainous regions; especially in the Sahara where the electrical grid extension to the households is neither economical or feasible. Currently, the diesel generator is the most used technique for the electrification of remote sites. However, the access to these sites is generally difficult, as such the costs of maintenance and fuel supply is very high. The exploitation of renewable energy resources (solar and wind) in combination with a diesel generator to produce electricity proved to be the most cost efficient in isolated regions where the

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extension of a conventional power grid would be technically and financially constrained.

Rapid growth of the world population and industrialization has resulted in increased demand for energy, the depletion of fossil fuels and rapid climate change. Renewable energy is an alternative solution to conventional energy sources and is increasingly sought. Renewable energy sources include wind, solar photovoltaic (PV), geothermal, tidal and biofuels.

A power generating system which combines two or more different sources of energy is called a hybrid system. The hybrid energy generating systems such as wind-diesel, photovoltaic-diesel, wind-photovoltaic-diesel etc. with and without battery storage options are not new technologies or systems, rather they have existed in practice for the last two decades.

Shafiqur et al. [1] designed a hybrid power system using PV-wind-diesel for a village in Saudi Arabia. Their study found that the hybrid system with 35% contribution of renewable energy (26% wind and 9% solar PV) and 65% diesel power contribution was the most economical power system with COE of 0.212 $/kWh at a diesel price of 0.2 $/l. The proposed system was comprised of 3 wind turbines each 600 kW, 1000 kW of PV panels, and four diesel engines each generating 1120 kW of rated power.

A methodology has been developed for calculating the correct size of a PV hybrid system and for optimizing its management by Muselli et al. [2]. The power for the hybrid system comes from PV panels and a diesel generator. The study included the effects of component lifetimes on the economics of PV-hybrid and PV stand-alone systems, it showed that battery size can be reduce by a factor of two in PV-hybrid systems, as compared to PV stand-alone systems.

In the work of Elhadidy [3], hourly wind-speed and solar radiation measurements were made at the solar radiation and meteorological monitoring station in Dhahran Saudi Arabia. This data was analyzed to investigate the feasibility of using hybrid (wind-PV-diesel) energy conversion systems to meet the energy needs of twenty 2-bedroom houses. The author showed that, doubling the wind farm capacity from 100 kW to 200 kW decreased diesel energy generation by 25% and the number of hours of operation of the diesel system decreased by about 18%. The results revealed that, with 100 kW of wind farm capacity, an increase in PV from 100 to 500 m^2 and from 500 to 1000 m^2 decreased the need for diesel-generated energy by 11% and 12.4% respectively.

An optimal design of a stand-alone hybrid system by Lotfi Trazouei et al. [4] used the imperialist competitive algorithm, particle swarm optimization and ant colony optimization. Their design considered reliable load providing and the LPSP reliability index, for wind- solar-diesel system. The authors showed that the imperialist competitive algorithm was faster and more accurate than the other algorithms and has a more certain design in comparison to PSO and ACO algorithms. The reliability index for imperialist competitive algorithm, particle swarm optimization and ant colony optimization are 3.7%, 4.4% and 4.1%, respectively, these indices are within the normal range.

Recently, Lan et al. [5] proposed a method to determine the optimal size of the PV generation system, a diesel generator and the energy storage system for a stand-alone ship power system that minimized the investment cost, fuel cost and the CO_2 emissions. The authors developed a MOPSO algorithm integrated with NSGA-II to search for the best size for the PV system and ESS and to optimize the outputs of the diesel generator to reduce the total cost and emission. The simulation results showed that the net cost of hybrid PV-diesel-ESS power generation was less than that of PV-diesel power generation.

The loss of power supply probability (LPSP) algorithm with a new proposed techno-economic algorithm for sizing standalone PV-wind system was implemented by Belmili et al. [6]. This cost study took into account different component costs used within the system, their lifetimes, the load profile and the meteorological characteristics of each installation site. This elaborate program enabled the determination of the optimum size of the battery bank and the PV array for a given load, a desired loss of power supply, and took into account the minimum energy cost which depended generally on investment, operation and maintenance costs as well as the depreciation period.

Chellali et al. [7] studied the techno-economical of a stand-alone hybrid system wind-diesel at the site of Hassi-R'mel. Via this study, it has been found that the site of Hassi-R'mel is very adequate for wind energy conversion systems.

Saheb-Koussa et al. [8] developed a complete sizing model in Matlab/Simulink V.6.5 to estimate the appropriate dimension of a stand-alone hybrid PV-wind-diesel with battery storage that guaranteed the energy autonomy of the typical remote consumer with the lowest cost of energy. Their simulation results indicated that the hybrid system is the best option for all sites considered in their study and that the energy cost depended largely on the quality of the renewable energy.

Yang et al. [9] recommended an optimal sizing method to optimize the configurations of a hybrid PV-wind system employing battery banks. The authors developed an optimal sizing method based on a genetic algorithm (GA), to calculate the optimum system configuration that achieved the customers required LPSP with a minimum annualized cost of system (ACS).

In other work, Yang et al. [10] recommend an optimal design model for the design of hybrid PV-wind systems that employed battery banks, by calculating the systems optimal configurations to supply power for telecommunication relay stations along the southeastern coast of China.

Mahmoudi et al. [11] used hourly wind speed and solar radiation data to design a Wind-PV system to meet the energy requirements of seawater greenhouse desalination for arid coastal countries.

Saheb-Koussa et al. [12] simulated different sizes of PV-wind-diesel hybrid system with battery storage for rural electrification in four Algerian sites. From the results, it can be summarized that it would be better to use PV-wind combination for 20 homes instead of a single home system where the unit (kWh) cost of energy varies from 1.49, 2.46, 1.84 and 4.1 $ to 1.19, 2.16, 1.33, and 1.52 $ respectively for: Adrar, Djelfa, Illizi and Djanet.

Ekren et al. [13] developed an optimal sizing procedure for an autonomous PV-wind hybrid system with battery storage and a break-even analysis of this system to satisfy the electricity consumption for mobile communication (GSM) in Turkey.

Dihrab and Sopian [14] proposed a hybrid system as a renewable source of power generation for grid connected applications in three cities in Iraq. The simulation results used MATLAB solver, which showed that it is possible for Iraq to use solar and wind energy to generate enough power for villages both in the desert and rural areas.

A photovoltaic-diesel-battery hybrid system was modelled by Nfah et al. [15] for the electrification of typical rural households and schools in remote areas of the far northern province of Cameroon. The energy produced by the solar modules was been used to model PV-diesel-battery hybrid power system that could meet the energy demand of typical rural households in the range 70–300 kWh/y.

Bernal-Agustın and Dufo-Lopez [16] studied two possible types of optimization of hybrid PV-wind systems for the production of hydrogen by means of an electrolyser. The authors show that in order to recover the initial investment in ten years, the selling price of hydrogen produced in small filling stations depends mainly on the price of spare electrical energy, which was been sold to the grid, on radiation, wind and on the cost of acquisition of the components.

Maleki and Pourfayaz [17] evaluated the performance of different evolutionary algorithms for optimum sizing of a photovoltaic (PV)-wind turbine (WT)-battery hybrid system to satisfy continuously the load demand with the minimal total annual cost (TAC). To optimize the size of the hybrid systems, the authors used three well-known heuristic algorithms (PSO, TS and SA) and four recently invented metaheuristic algorithms (ABSO, IHSBSA, HIS and IPSO). They conclude that ABSO yields promising results in terms of the TAC.

A feasibility of hybrid (wind-PV) power systems for Dhahran, Saudi Arabia was investigated by Elhadidy and Shaahid [18]. The hybrid system considered in their analysis consists of two 10 kW wind energy conversion systems (WECS), 120 m^2 of photovoltaic (PV) panels together with a battery storage system and a diesel back-up to meet a specific annual electrical energy demand of 41531 kWh.

An economic analysis of utilization of hybrid PV-diesel-battery power systems to meet the load of a typical residential building (35,120 kWh/y) in different provinces of Saudi Arabia was study by Shaahid et al. [19], using long-term solar radiation data. For this, five geographically distinct sites representing different provinces of Saudi Arabia have been selected. Their simulation results indicate that for a hybrid system composed of 4 kWp PV system together with 10 kW diesel system and a battery storage of 3 h of autonomy, the PV penetration is 22%, 21%, 22%, 20%, and 20% at Abha, Hofuf, Qurayat, Taif and Riyadh respectively.

Shaahid et al. [20] studied the economic feasibility of development of 75 MW wind power plants (wind farms) in the coastal locations of Saudi Arabia by analyzing long-term wind speed data. Hence, four coastal locations (Al-Wajh, Jeddah, Yanbu and Jizan) covering the west coast was chosen. The wind farms consist of different combinations of 600 kW commercial wind turbines was simulated by HOMER software. The authors found that, the annual energy produced by 75 MW Wind farms was 107,196, 81,648, 135,822, and 80,896 MWh at Al-Wajh, Jeddah, Yanbu and Jizan respectively.

HOMER is a time-step simulator using hourly load and environmental data inputs for renewable energy system assessment; it facilitates the optimization of renewable energy systems based on net present cost for a given set of constraints and sensitivity variables [6]. The user must select the components of the model to represent the architecture of his network. For optimization purposes, technical and financial data for each selected component must be entered. It simulates the operation of a system by making energy balance calculations for each of the 8760 h/y, for each hour it compares the electric demand in the hour to the energy that the system can supply in that hour, and calculates the flow of energy to and from each component of the system. The tool also decides for each hour how to operate the generators and whether to charge or discharge the batteries. At the end of the simulation, the different system configurations are classified by their total NPCs (net present cost).

A literature review of the research on the feasibility of autonomous wind farms and solar parks for commercial loads in hot regions was undertaken by Shaahid [21]. Shaahid and Elhadidy [22] investigate in their work optimal sizing of battery storage for stand-alone hybrid (PV-diesel) power systems. Their study shows that for optimum operation of diesel system, storage capacity equivalent to 12–18 h of maximum monthly average hourly demand need to be used. It has been found that in the absence of battery bank, 58% of the load needs to be provided by the diesel system. However, use of 12 h of battery storage (autonomy) reduces diesel energy generation by 49% and the number of hours of operation of the diesel system gets reduced by about 82%.

In the work of Elhadidy and Shaahid [23], the study of hybrid system shows that with thirty 10 kW WECS and 3 days of battery storage, the diesel back-up system has to provide 19% of the load demand. However, in the absence of battery storage, about 40% of the load needs to be provided by the diesel system. Dissemination of off-grid hybrid wind-diesel-battery systems for electrification of isolated settlements in hot regions was investigated by Shaahid et al. [24]. The hybrid systems simulated comprised of various combinations wind farms of 600 kW commercial WECS supplemented with diesel generators and short-term battery storage. The investigation indicates that for a hybrid system consisting of 3.6 MW wind farm capacity together with 4.5 MW diesel system and a battery storage of 30 load minutes, the wind penetration is 24%. Rehman and Sahin [25] proposed wind-PV-battery hybrid system based on 100% renewable source to utilize and tested for water pumping in some of the regions in Saudi Arabia. It is shown that the monthly total water pumping capacity when using a nearly optimal PV-wind water pumping system is fairly uniform throughout the year.

The feasibility of providing electricity by using a hybrid system PV-wind-diesel to a distant hypothetical village, populated by 100 households with an average of five family members per household was study by Saif Ur et al. [26]. The results showed that the proposed hybrid system could be a viable solution for off-grid supply of electric power to remote areas in Pakistan. In other work, Rehman and El-Amin [27], presented a study of a solar PV-wind-diesel hybrid system for a remotely located population near Arar, Saudi Arabia. Four configurations: diesel only, wind-diesel, PV-diesel and wind-PV-diesel power generation systems were designed and compared to select the optimal alternative system by considering the minimum cost of energy and least environmental impact. The performance of both the diesel and solar PV stand-alone power generating systems for underground water pumping purposes was investigated and compared by Shafiqur and Sahin [28]. It was found that the solar PV power generating system not only helped to decrease carbon emissions to the atmosphere but also was comparable in the unit COE with the diesel only system in many sites within Saudi Arabia even though the unit price of diesel fuel is very low.

A detailed feasibility and a techno-economic evaluation of the use of hybrid PV-wind-diesel-battery systems to satisfy the electrical energy needs of an environmentally friendly factory in New Borg El Arab city, Egypt and the city surrounding the factory was study by Diab et al. [29]. They found that the hybrid renewable energy system consisting of 60 kW of PV arrays, 100 kW of wind turbines, 40 kW of diesel generators, 50 kW of power converters and 600 batteries was the optimal hybrid configuration in accordance with the system net present cost and cost of energy.

Though the hybrid PV/wind/diesel system is relatively new, several experimental and theoretical studies have focused on improving the technical performance of this technology to meet the demand for different electrical charge. We can note that many promising theoretical enhancements were not practically implemented up till now. Therefore, future research should focus on analyzing those suggested enhancements and implementing the most efficient of performance and cost-effectiveness. For that reason, it is highly recommended to further study the potential of using power hybrid system for electrification isolated remote locations.

This paper proposed the use of a PV-wind-diesel hybrid power system with battery storage in order to electrifying a village in the Ouled Fares area. For this approach the wind speed, the air temperature and solar radiation measurements along with other meteorological parameters were collected in the weather station placed in Chlef University at Ouled Fares. The main aim of our study is to simulate the different power generation and storage options using HOMER (hybrid optimization model for electric renewable) software in the design of hybrid system with storage to power the site. The second aim is to reduce the diesel consumption, minimize CO_2 emissions and at the same time maintain a continuous supply of power to the populations of the village. Finally, a techno-economical study of the standalone hybrid system of the site at Ouled Fares was considered and a comparison was made between the performance of the hybrid system and grid connection.

2. Site and data collection methodology

The geographical coordinates of the data collection site at Ouled Fares were 36°23′N Latitude, 23°1′W Longitude and 143 m altitudes above mean sea level (Fig. 1). The meteorological data: air temperature, relative humidity, surface station pressure, global solar radiation, wind speeds and wind direction, were collected from the weather station “Vantage Pro 2” at Ouled Fares city from 1 January 2015 to 31 December 2015. These values were recorded every 15 min. The weather station is 20 m from the ground and is shown in Fig. 2. Data has been recorded every 15 min on a removable data logger. This recorder is used to finely operate on collected data by the weather station “Vantage Pro2”; these kits include a data recorder and a “Weather Link” operating system. The data logger was either connected to a PC or in disconnected mode, and the climate data could be viewed in real-time. The recorder could collect data at an interval of 1, 5, 10, 15, 30, 60 or 120 min.

Fig. 1. Ouled Fares site location.

Fig. 2. Photo of the weather station “Vantage Pro 2” in Chlef University at Ouled Fares.

2.1. Wind resource

The hourly wind speed was measured in the site of Ouled Fares, Chlef, during 2015. The monthly mean wind speed was above 3 m/s at 20 m except between October and January and in March. The annual mean wind speed did not exceed 3 m/s as shown in Fig. 3.

The Weibull distribution is the most used in the literature related to wind speed fitting and it is practically the only method recommended in books on wind energy [30]. The Weibull distribution with two parameters is given by the following equation [31]:

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{1}$$

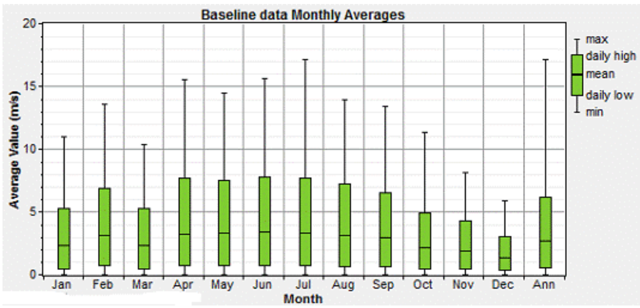

Fig. 3. Monthly mean wind speed at 20 m above the ground at Ouled Fares.

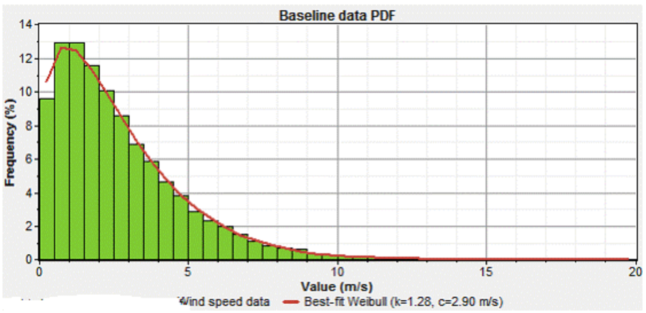

Fig. 4. Histogram of wind speed compared to Weibull distribution for the site of Ouled Fares.

where k is the shape parameter (dimensionless) and c is the scale parameter having the dimension of speed. The distributions take different shapes with different values of k.

The histogram in Fig. 4 was evaluated using the monthly wind speed average during 2015. The maximum daily average of wind speed was 18 m/s. From the daily average result it was shown that the site has fast wind speeds. We found that the wind speed, which indicates monthly variation was not relevant, it was also noted that the wind speeds were in the range of 0.5 m/s to 3.5 m/s and less likely to be higher.

2.2. Solar resource

The global solar radiation was measured on a horizontal surface at Ouled Fares during 2015. The average daily radiation value on a horizontal surface was 4.75 kWh/m^2/d.

The monthly mean daily global solar radiation is illustrated in Fig. 5. We can show that more solar radiance can be expected from the month of March to September while less solar radiance is expected from October to February. In addition the diurnal variation of global solar radiation during the different months of 2015 was measured. It can be seen that the solar radiation values were observed only during the interval from 08:00 to 18:00, where the peak intensity was around 13:00 in each month of the year, and it was almost null during the night. This coincides with the load requirements which will be further discussed in section 2.3. The HOMER software can generate the clearness index from the solar radiation data.

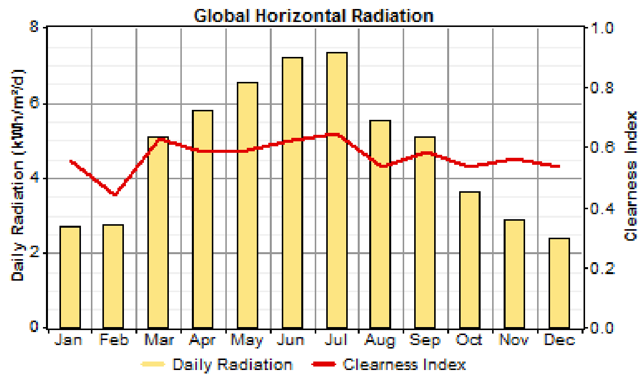

Fig. 5. Monthly mean daily global solar radiation at Ouled Fares in 2015.

2.3. Village load assessment

In a remote rural village, the demand for electricity is not high in comparison to urban areas. Electricity is needed in domestic use for appliances such as the television, radio, lamps, fans and the refrigerator. In this study, the village energy load requirement is carefully estimated and the daily load profile was considered according to the data measured from one house and multiplied tenfold. The daily profiles reflect the consumption of residences in the village for 24 h/d for December, February, March, June, July and August as represented in Fig. 6, which assumed that the same profile would be followed through the year. The average demand for the day was approximately 54 kW. The maximum value of the load logged was 3.8 kW and occurred on 5th July 2015 at 21:00 h. The 8760 hourly electrical load values for a whole year 2015 were synthesized by HOMER software, using the hourly loads profile and adding random variability factors, known as day-to-day variability and time-step-to-time step variability [32]. In our study taken 15% and 3% respectively. The annual load factor for this area was 0.596.

Fig. 7 shows the hourly variation of load during different months of the year 2015. We can show that the consumption load is high in summer and low in winter.

The monthly profile is shown in Fig. 8. We found that the average power demand is relatively constant over all the year (2.26 kW).

2.4. Input data and technical details

HOMER software uses the ambient temperature to calculate the PV cell temperature. The monthly mean air ambient temperature measured at the site considered is presented in Fig. 9. This showed that the air temperature was high in the summer, which influenced negatively on the PV modules production power, and was low in winter.

In addition, some other factors have been set as additional specifications. To highlight the importance of the stand-alone system, the cost of connecting to the grid is set to be 33,110 $/km. while the price of purchasing a kWh is fixed at 0.047 $/kWh [33]. The emissions are not taken into account in the optimization process. Tables 1–5 give the summary of the costs and the technical details of the wind

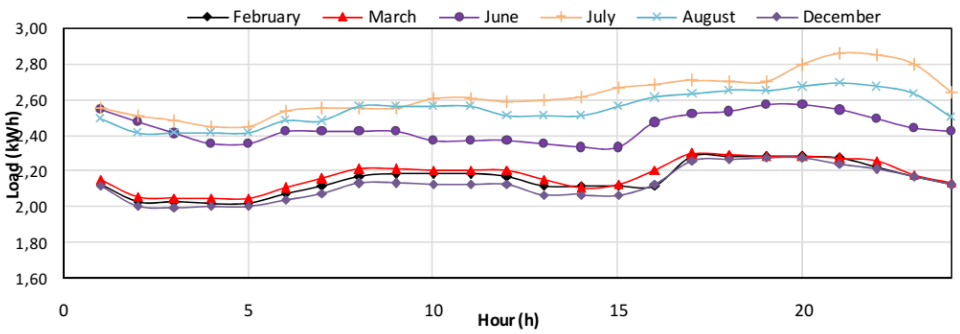

Fig. 6. Typical summer and winter day load demand for the village in 2015.

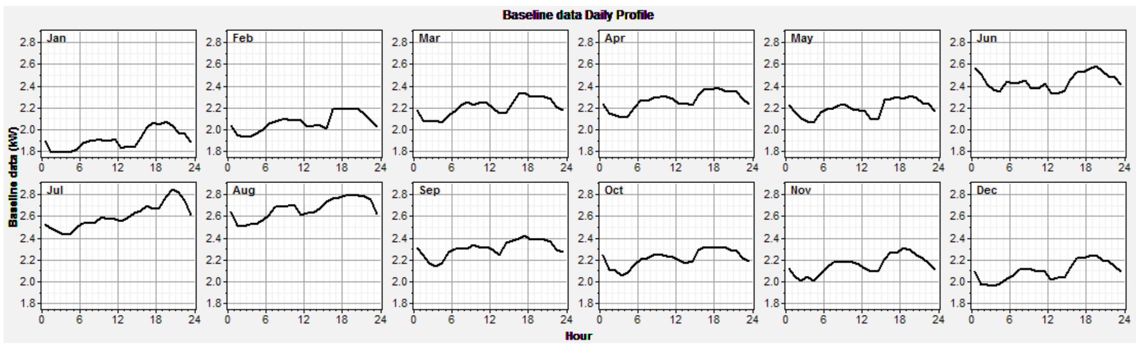

Fig. 7. Diurnal variation of load during different months of the year 2015.

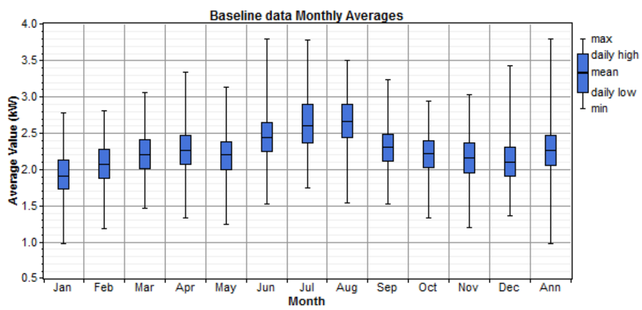

Fig. 8. Monthly profiles of load village during the year 2015.

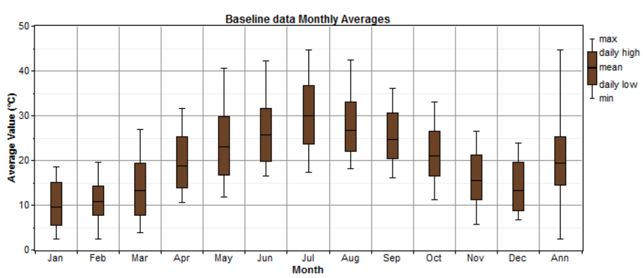

Fig. 9. Monthly mean air temperature at Ouled Fares in 2015.

turbine, the power converter, the batteries [34], the diesel generator [35] and the PV module [36] respectively and to run the HOMER software for 25 years of the project's lifetime with a 6% annual interest rate.

Table 1
The costs and the technical details of the wind turbine [34]

Wind turbine	
Model name	SW Whisper 100
Rated power, kW	0.9
Hub height, m	10
Capital cost, $	2145
Replacement cost, $	2145
O&M cost, $/y	51
Life time, y	20

3. Hybrid power system modelling

The essential functionality of HRES (hybrid renewable energy system) is the summation of two or more renewable power generation technologies to develop their operating characteristics and to increase efficiency higher than the efficiency of a single power source. This feature resulted from the ability of HRES to take advantage of the complementary seasonal and diurnal (night/day) characteristics of the available renewable energy resources data given. Fig. 10 shows the configuration of the hybrid PV-wind-diesel-battery system using HOMER software based on the user inputs of loads, components costs, components technical details, Solar and Wind resources availability.

Table 2
The costs and the technical details of the PV modules [36]

PV modules	
Model name	CEM100M-36
Peak power, kW	1
Derating factor, %	80
Slope	36
Ground reflection, %	20
Operating temperature, °C	47
Efficiency, %	13
Capital cost, $	1176
Replacement cost, $	1176
O&M cost, $/y	0
Life time, y	20

Table 3
The costs and the technical details of the power converters [34]

Converter bidirectionnel	
Rated power, kW	1.6
Capital cost, $	546
Replacement cost, $	546
O&M cost, $/y	7
Efficiency, %	82
Life time, y	25

Table 4
The costs and the technical details of the batteries [34]

Battery	
Model name	Hoppecke 16 OPzS 200
Nominal capacity, Ah	2000
Nominal capacity, kWh	4
Roundtrip efficiency, %	86
Min. state of charge, %	30
Float life, y	20
Max. charge rate, A/Ah	1
Max. charge current, A	406
Capital cost, $	276
Replacement cost, $	276
O&M cost, $/y	20
Life time throughput,kWh	6.801

4. Results and evaluation

HOMER performs calculations to determine the best combination for a hybrid power system that meets the technical and economical specifications required by the site. Based on the above input, 4160 simulation runs were made. The results are shown in Fig. 11 where the optimal systems are ranked according to their technical and economic feasibility. HOMER suggested an optimal PV-diesel-battery hybrid power system for the village with 20 kWp PV panels; one generator with a rated power of 2.5 kW, 4 kW sized power converter and 36 batteries with 4 kWh of nominal capacity, followed by the combination PV arrays with wind turbine, diesel generator and battery bank. It should be noted that the first system overtook the wind-based system because the mean speed considered of 3 m/s used in this study is a too conservative.

Table 5
The costs and the technical details of the diesel generators [35]

Diesel generator	
Model name	1 kW GMI
Rated power, kW	1
Life time, h	3650
Min. load ratio, %	30
Fuel	Diesel
Capital cost, $	342
Replacement cost, $	342
O &M cost, $/h	0.05
Fuel cost, $/L	$0.7 [37]

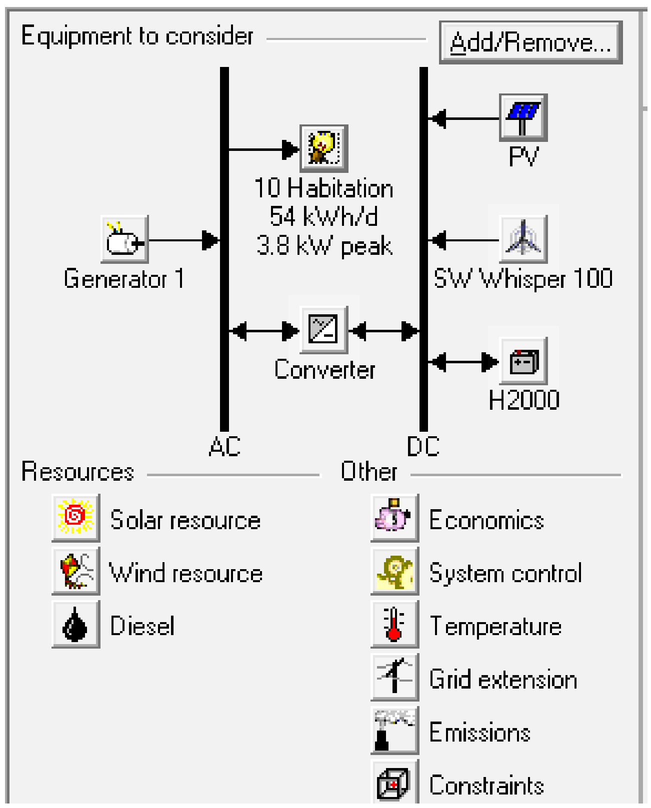

Fig. 10. The configuration of the hybrid PV-wind-diesel-battery system using HOMER software.

PV (kW)	W100	Ge (kW)	H2000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Ge (hrs)	Batt. Lf. (yr)
20		2.5	36	4	$ 35,341	1,658	$ 56,536	0.224	0.96	449	586	17.5
20	1	2.5	36	4	$ 37,486	1,722	$ 59,500	0.235	0.96	442	575	17.5
40			48	4	$ 61,318	1,625	$ 82,096	0.325	1.00			20.0
40	1		48	4	$ 63,463	1,699	$ 85,187	0.337	1.00			20.0
		3.0	12	4	$ 5,368	8,388	$ 112,591	0.445	0.00	7,109	7,181	18.8
	1	3.0	12	4	$ 7,513	8,430	$ 115,271	0.456	0.00	7,080	7,151	18.6

Fig. 11. The optimization results with the optimum systems ranked.

Fig. 12 shows the monthly electricity production from the different system components in the optimum hybrid system, we can say that the total annual electricity production from the optimized system is 30,472 kWh/y. From this total annual electricity production 29,144 kWh/y (96%) of the electricity comes from the PV panels, and 1,328 kWh/y (4%) of the electricity comes from the diesel generator. Moreover, the capacity shortage of the optimal system is lower than 0.1% and the excess electricity is 4,593 kWh/y (15.1%).

The total costs of each component of the hybrid power systems, including mainly PV panels, generator, batteries and power converter are shown in Fig. 13. The division of capital, replacement, O&M, fuel, salvage and total costs are given in Table 6. The capital cost of the proposed hybrid power system was worked out to be $35,341 with replacement, O&M, and fuel cost of $12,417, $10.383, and $4,021 respectively. The optimization results show that the optimal PV-diesel-battery hybrid system has lowest NPC ($56,536) with COE 0.224 $/kWh.

Fig. 14 previews the profile of the battery bank monthly state of charge and the designation of hours/day profile of the batteries. We could say that the energy output from the batteries is 12,986 kWh/y while the energy input to the batteries is 14,980 kWh/y with losses of 1,901 kWh/y and storage depletion of 93 kWh/y. Moreover, we can note that the state of charge of the batteries is about 100% year round and the estimated lifetime of the batteries is 17.5 y.

The amount of greenhouse gases (carbon dioxide, carbon monoxide, unburned hydrocarbons, particulate matter, sulfur dioxide and nitrogen oxides) are given in Table 7, which were emitted from the PV-diesel-batteries hybrid system. After the simulation, it calculated the annual emissions of the pollutant by multiplying the emissions factor by the total annual fuel consumption. It is clear that a great reduction in the amount of greenhouse gas emissions could be obtained throughout the lifetime of the optimal hybrid renewable energy system, in comparison with other systems configurations specifically the diesel only system. The proposed system avoids over 28.39 kg/y of CO_2 equivalent emissions for the local atmosphere of the site and save 22.59 barrel/y of fossil fuel.

In this study, the distance of the proposed site is not known but the breakeven grid extension distance can be determined. If the site is less than this distance from the existing distribution grid, it is more cost-effective to extend the grid, but if it is more than this distance from the grid then the stand-alone system is economically preferable. The Fig. 15 compares the costs of these two options and shows the breakeven grid extension is 1.35 km, where, the NPC of grid extension is $33,110/km.

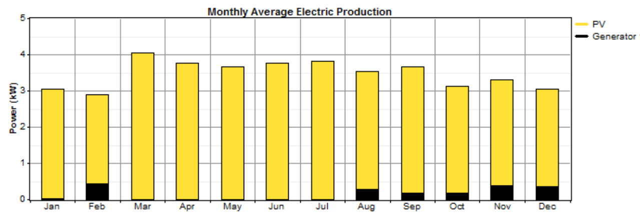

Fig. 12. The monthly electricity production from different system components.

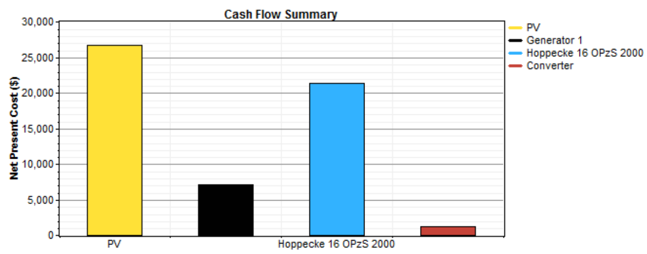

Fig. 13. Cash flow summary of various components of the hybrid power system.

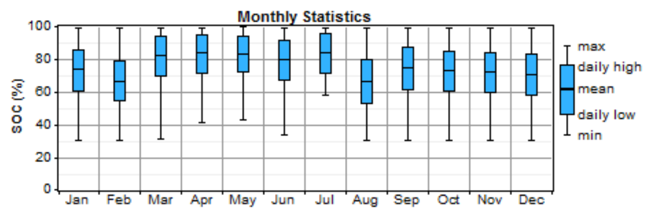

Fig. 14. The profile of the battery bank monthly state of charge.

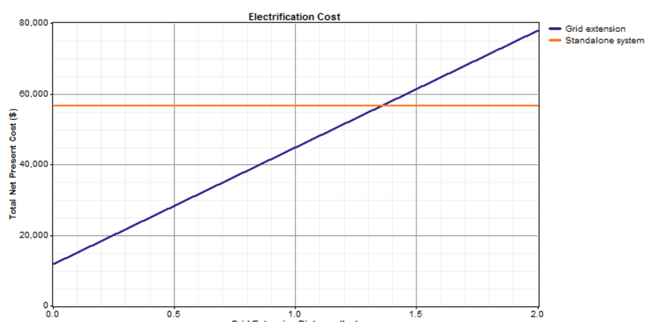

Fig. 15. A comparison between stand alone and grid connection alternatives.

Table 6
Summary of annualized cost of the hybrid power system

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	23,520	7,334	0	0	–4,110	26,744
Generator 1	855	1,497	936	4,021	–196	7,112
Hoppecke 16 OPz S 200	9,936	3,587	9,204	0	–1,320	21,407
Converter	1,030	0	243	0	0	1,273
System	35,341	12,417	10.383	4,021	–5.627	56,536

Table 7
The amount of greenhouse gases emitted from the hybrid PV-Wind-Diesel system.

Pollutant	Emissions (kg/y)
Carbone dioxide	1,183
Carbone monoxide	2.92
Unburned hydrocarbons	0.324
Particulate matter	0.22
Sulfur dioxide	2.38
Nitrogen oxides	26.1

5. Conclusion

In this study, an attempt was made to explore the possibility of utilizing the power of the wind and the sun for a hybrid standalone energy system. The meteorological data: global solar radiation, wind speeds, wind direction, air temperature and relative humidity, and the village load were measured at Ouled Fares site in Chlef, Algeria, during 2015. The optimization was carried out using HOMER software that determined the optimal technical and economical system. This showed that the most economical power system with COE 0.224 \$/kWh at a diesel price of 0.7\$/l was a PV/diesel/batteries hybrid system that used 20 kWp PV panels; one generator with rated power of 2.5 kW, 4 kW sized power converter and 36 batteries with 4 kWh of nominal capacity.

We can note that, the first system overtook the wind-based system because the mean speed considered of 3 m/s used in this study is a too conservative.

Moreover, the optimal configuration of hybrid system is able to decrease a significant amount of greenhouse gases emissions, which are known to have negative effects on the environment and people. Finally, a separate techno-economic analysis of each component (PV arrays, diesel generator, converters and batteries) in the optimum hybrid system was described.

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