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Optimal configuration of hybrid PV-generator (diesel/GPL) for a decentralized production of electricity in Algeria

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ABSTRACT

The absence of electricity in rural areas is one of the major challenges faced by many developing countries like Algeria. This work has been devoted to the design of an off-grid renewable hybrid power system for a rural village in the region of Tindouf located in south Algeria. The main objective of this study is to determine the optimum size of the hybrid power system able to fulfill the requirements of 709 kWh/day primary load with 66 kW peak load for a remote area of 230 households. This study is based on simulation and optimization of a (PV-Diesel) and (PV-GPL) hybrid system with a technical-economic analysis. Simulation results showed that electrifying using a PV/GPL generator hybrid system is more advantageous when compared to the PV/diesel generator hybrid system as it has lower operating costs and emissions. The comparison is based on per unit cost of electrical energy production, operating cost of conventional fossil fuel-based energy sources and pollutants gases reduction.

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1. INTRODUCTION

To reduce hydrocarbon dependence by increasingly exploiting renewable energy resources, especially solar power, Algeria has adopted a long-term strategy aimed at producing 40% of electricity from renewable energy. This strategy is based on a true platform for the solar industry coupled with a training program in engineering and project management. Hoping to produce about 22,000 megawatts of renewable energy between 2011 and 2030, it could account for more than 37% of the national product by 2030. This program includes the construction of sixty electric power plants, hybrid PV diesel, thermoelectric diesel, hybrid winds, photovoltaic system farms for their many advantages [1, 2]. The solar potential of Algeria ranks among the highest in the world. The duration of the sun exceeds 2,000 hours per year on all the territory and reaches 3,900 hours in the mountainous areas and the Sahara. The energy received daily on a horizontal surface of 1 m2 is 5 (kW.h) on most of the nation. It is approximately 1,700 (kW.h /m2 year) in the north and 2,263 (kW.h /m2 year) in the south of the country [3-6]. And price augmentation of diesel and gasoline encouraged many generator owners to modify their machines in order to consume LPG. Today in Algeria 1 Litre of diesel costs more than 0.18 $ while the price LPG is about 0.08 $/L [7]. The objective of this paper is to investigate and determine the optimal configuration of renewable energy system in Algeria and to compare the production cost of solar and generator energy with its annual yield relevant to different configurations of a rural area in the region of Tindouf. The article is arranged as follows. In section 2, we briefly describe the different energy sources such as solar energy, generator Diesel/GPL, and define the dimensions of autonomous hybrid solar- diesel/GPL. Section 3 deals with the different components type, capital, replacement, operation and maintenance costs, efficiency and operational life. Section 4 presents simulation results for the optimal configuration of renewable energy hybrid system. Finally, the conclusions are outlined in Section 5.

2. ENERGY SOURCE

The selection of energy resources is very important for the design of an energy system. In our study, the solar energy is sufficient for power generation. The LPG and diesel are used as fuel for the production of electricity from fossil fuels.

2.1. Solar energy resources in tindouf

In this work, RETScreen [8] is employed for simulations. Solar radiation and the clearness index are used as the input data as shown in Table 1. The clearness index which is a measure of the clearness of the atmosphere has an average value of 0.588 and the average solar radiation in Tindouf (Algeria) is 5.88kWh/m2/day according to data accessed from NASA [9].

Table 1. Solar irradiation in Tindouf

Month	Clearness index	Daily radiation (KW/m^2/d)
January	0.379	3.810
February	0.461	4.790
March	0.588	6.180
April	0.706	7.200
May	0.804	7.760
June	0.843	7.840
July	0.809	7.630
August	0.704	6.980
September	0.586	6.050
October	0.477	4.940
November	0.398	4.020
December	0.337	3.340
Annual Average	0.588	5.880

2.2. The liquid petroleum gas (LGP)

The liquefied petroleum gas (LPG) is lower carbon alternative to liquid and solid fossil fuels. Its combustion emits 49% less carbon dioxide than coal and 17% less than oil. LPG also emits almost no black carbon; which scientists now believe is the second biggest contributor to global climate change and is perhaps the single biggest cause of arctic warming [10].

2.3. Fuel price (L/$)

Diesel and GPL generators are generally more durable and cheaper to operate, they provide electrical power form on demand. Their inclusion in a hybrid system not only provides continuity of supply but also can be used to avoid over-sizing the renewable components. Table 2 denotes the different fuel price (L/$) as diesel and liquid petroleum gas (LPG) in Algeria [7, 11].

Table 2. Petrol price (L/$) 26-June -2017

Countries	diesel Price ($/L)	LPG Price ($/L)
Algeria	0.18	0.08
USA	0.65	----
Russia	0.65	0.28
Australia	0.95	0.61
Germany	1.19	0.58

3. HYBRID SYSTEM CONFIGURATION

Hybrid system is an integrated system that uses different renewable energy sources such as solar, generator; hybrid system configuration is shown in Figure 1. This configuration is used to design an autonomous hybrid photovoltaic energy system, the converter and the diesel LPG generator are selected on the basis of maximum load demand. The optimum configuration of the system is determined using annual resource data. In this resource, the time period with solar radiation with a standby generator is included in the system configuration to accommodate these real situations. This backup generator provides power to the load in an emergency when the renewable energy and the energy stored in the battery are insufficient to cope with the load demand [12].

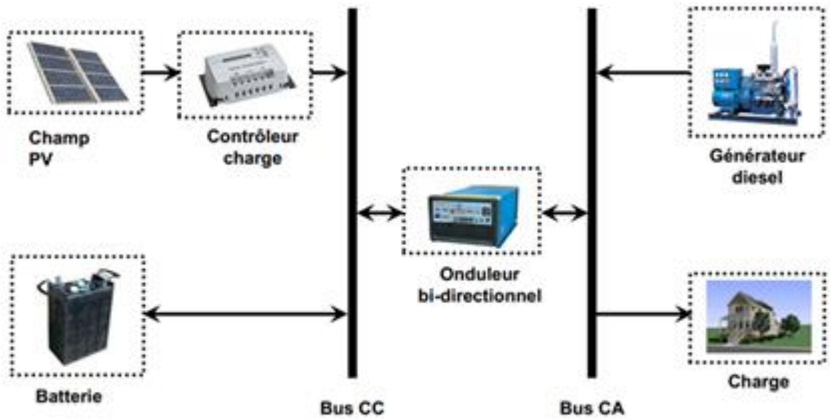

Figure 1. Hybrid system

4. DESCRIPTION OF THE TINDOUF SYSTEM
4.1. Site location

The site we have chosen belongs to the south western of Algeria zone (Tindouf) located at 439 m of latitude and whose geographical coordinates are: latitude: 27 ° 40'6 "N, longitude: and longitude 8° 09 ' 8 "E. The location of this village is illustrated by a red circle in Figure 2 [9, 13].

Figure 2. Google-map position of Tindouf

4.2. Data INPUT
4.2.1.Electrical load

The load profile is based on a rural area with 230 families. Table 3 shows the load profile of selected houses. The simulation process of the chosen hybrid system was analyzed to see if the use of the feed system will be possible or not. It is important to note that these houses presented in the example study are isolated and not connected to the grid, the additional objective was to see the effect of using the hybrid system to supply them with electrical energy.

The daily load of this village is 709 KWh per day, the daily load of a household is 3.027 KWh per day, and therefore the system load built by HOMER simulates the power supply for a sum of houses that can reach 230 households [14, 15, 17].

Table 3. The load consumed by a household.

	Power(W)	Time (h /d)	Consumption (Wh/d)
Adult room	11	4	44
Children's room	22	5	110
living room	22	6	132
corridor	22	2	44
bathroom	22	2	44
toilet	11	1	11
kitchen room	11	7	77
Refrigerator	120	12	1440
Television	75	7	525
fan	100	4	400
various	100	2	200
Total (Wh/d)			3027

4.2.2.PV panel

The PV panels used here cost 1500 $/kW. Most of the PV panels come with a lifetime of 20 years, although they most likely last longer. For energy storage, Hoppecke 100Pzs1000 batteries with nominal capacity of 1000h were used in the analysis [18, 19].

4.2.3.Diesel generators

Diesel generator is used in the study as base load server. In this work, diesel generator Lapel is considered [20, 21]. The initial capital is 1400$, replacement cost 1250$ and O&M cost is 0.30 $/hr. The generator operating lifetime is defined around 11000 hours and the minimum load ratio is 30%. The diesel generator size is considered from 0 kW to 40 kW on 5 kW intervals.

4.2.4.LPG generators

In this work we use the LPG generator with an initial capital of $ 1,200, the replacement cost of $ 1,050 and the cost of O & M of $ 0.20/hr. The generator operating lifetime is defined around 13000 hours and the minimum load ratio is 30%. The LPG generator size is considered from 0 kW to 40 kW on 5 kW intervals [21, 22].

4.2.5.Converter

To generate sufficient power, converters are necessary; the price of the converters is given by the HOMER software. The conversion efficiency of both inverter and rectifier are supposed to be 90% and the lifetime of converter to be 15 years. The sizing of converter is considered from 0 kW to 70 kW at 5kW interval, while the relative conversion ratio of AC and DC is 100% [23, 24].

5. SYSTEM ANALYSIS AND SIMULATIONS

The Hybrid optimization is used for designing standalone electric power systems that employ some combination of photovoltaic panels, generators (diesel and LPG) to produce electricity Figure 3. The simulation process of different sizes of photovoltaic panels, wind turbines, power converters, and batteries were used and the most economical system was selected after running the simulations several times. The search space for the optimization process is shown in Table 4. There were 8 sizes for PV panels, 8 sizes for wind turbines, 9 sizes for diesel generators, 8 sizes for batteries, and 8 sizes for power converters. Zero is included in the search space of each component for more optimal results [25, 26].

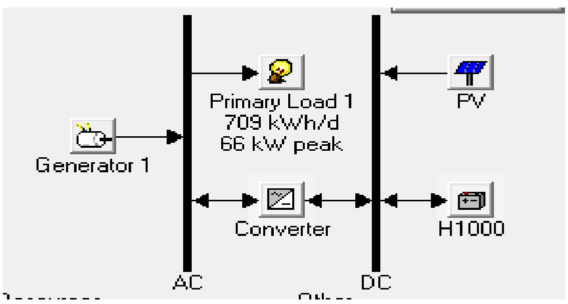

Figure 3. Configuration of hybrid PV/generator system

5.1. Components details

The energy system components are photovoltaic modules, generator, battery, and power converter. This study develops a suitable assembly of the key parameters such as photovoltaic array power, generator power curve, battery storage and converter capacity to match the predefined load. For economic analysis, the cost including the initial capital, replacement cost, and operating and maintenance cost are considered in simulating conditions. All the parameters are shown in Table 4 [25-27].

Table 4. Components details.

	Parameters	value	Unit
PV module	Rated capacity	1	KW
	Capital cost	1500	$
	Replacement cost	1200	$
	Operation and maintenance cost	15	$/year
	Lifetime year	20	year
Batteries	Capital cost	900	$
	Replacement cost	900	$
	Operation and maintenance cost	9	$/y
	Minimum battery life	8	Year
	Nominal capacity	1000	h
Converter	Capital cost	1000	$
	Replacement cost	1000	$
	Operation and maintenance cost	10	$/year
	Lifetime year	15	Year
	Capacity relative to inverter	100	%
Diesel generator	Capital cost	1400	$
	Replacement cost	1250	$
	Operation and maintenance cost	0.3	$/h
	Life time year	11000	H
LPG generator	Capital cost	1200	$
	Replacement cost	1050	$
	Operation and maintenance cost	0.2	$/h
	Life time year	1300	h

5.2. Simulation

The techno-economic study is carried out on the HOMER software; it allows us to compare the financial and technical constraints on the use of different confeguration systems. The software offer comparison with the cost per kilowatt of central grid or utility supply [28, 29]. For this, the initial information including energy resources, economical and technical constraints, energy storage and system control strategies are required. To optimize the system, component type, capital replacement, operation and maintenance costs data must be available. Pour la production et la distribution d'énergie des systèmes autonomes. Il vous permet d'envisager un grand nombre d'options technologiques pour prendre en compte la disponibilité des ressources énergétiques et d'autres variables.

6. RESULTAS AND DISCUSSION

6.1. Optimal system

The study clearly shows that the different configurations of the systems and equipment were analyzed by HOMER software. The configurations obtained are selected according to their feasibility, the cost of installation. The profitability of the operation is evaluated on the life of the project, estimated a priori to 25 years. The simulation results are shown in Table 5 (a, b). The results obtained for two Configurations:

Table 5 (a). Optimum solution for hybrid PV +Diesel

Configuration 2	PV (KW)	Diesel (KW)	Battery H1000	Convert (KW)	Initial Capital$	O$M ($/yr)	Total NPC $	COE ($/KWh)
System 1	190	35	384	60	743.100	60.257	1.513.393	0.458
System 2	240	35	384	70	828.100	55.106	1.432.545	0.463
System 3	260	35	384	60	848.200	54.443	1.544.062	0.467
System 4	240	35	480	60	904.500	51.072	1.557.372	0.471
System 5	00	40	384	30	435.600	165.927	2.556.709	0.773

Table 5 (b). Optimum solution for hybrid PV +GPL

Configuration 1	PV (KW)	GPL (KW)	Battery H1000	Convert (KW)	Initial Capital$	O$M ($/yr)	Total NPC $	COE ($/KWh)
System 1	120	25	288	50	519.200	50.789	1.168.417	0.353
System 2	150	25	288	60	574.200	49.034	1.201.022	0.363
System 3	190	25	192	60	547.800	51.856	1.210.687	0.366
System 4	90	35	192	60	409.800	64.391	1.232.933	0.373
System 5	00	40	192	30	420.850	92.240	1.671.159	0.478

Configuration -1- : The highest energy cost (0.458 $/kWh) with the highest NPC (1.513.393$) was observed with the solar - diesel generator hybrid system. And maximum CO2 (33.008 kg/year) is produced in this system.

Configuration -2- : we found that the lowest cost of energy (0.353 $/kWh) with the lowest NPC (1.168.417 $) was observed with the hybrid system solar- LPG generator, and minimum CO2 (8.306 kg/year) is produced in this system.
The optimized PV-GPL generator hybrid system is more cost effective in terms of Net Present Cost (CNP) and Energy Cost (COE).

6.2. Electric power generation

Energy production in a year is detailed in Table 6. The production systems involving the following fractions described in the table and which show a significant participation of the photovoltaic source which reaches 68% for configuration 1, and 61% for configuration 2.

Table 6**.** Annual energy produced.

Configuration	Configuration 1.		Configuration 2.	
Production kWh/year %	kWh/year	%	kWh/year	%
Photovoltaic	236.127	68	205.975	61
Generator	107.113	32	130.058	39
Excess electricity	67.146	18	53.722	16
Unmet electric load	24.4	00	31.7	00

6.3. Environmental analysis

The annual pollutant emissions of above two studied systems are shown in figure 4. It is possible to significantly reduce emissions of pollutants by the integration of a generator running on butane gas. According to the results, the emissions of pollutants can be reduced by approximately 60% compared to the use of a diesel generator in the hybrid system, especially emissions of CO2 and CO responsible for the air pollutant and environment.

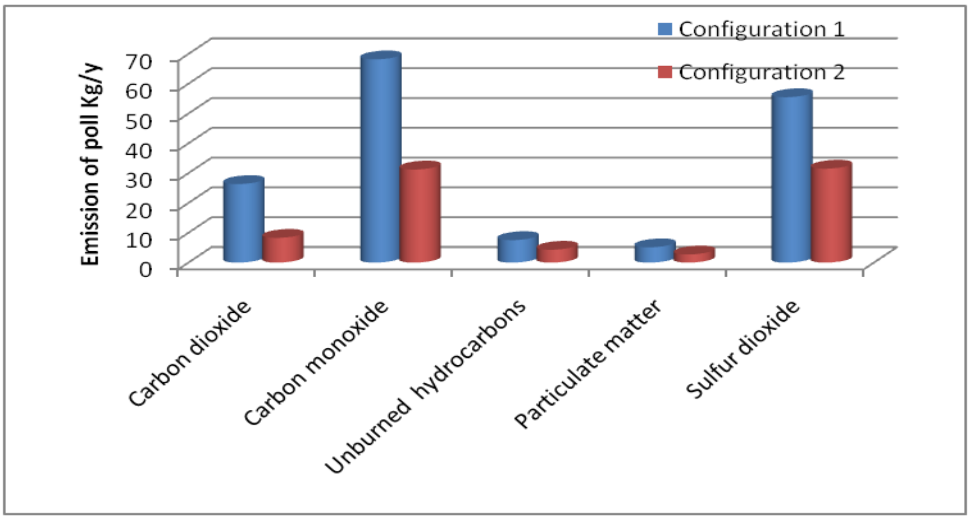

Figure 4. Emission of air pollutants

7. CONCLUSION

This article is a simulation study of the PV-Diesel and the PV-GPL hybrid power system optimization with a technical - economic comparison analysis. Its main objective is to determine the optimum size of the best hybrid power system able to fulfill the requirements of a 230 households' remote area in the Tindouf region in the south of Algeria. Simulation results showed that a PV/GPL-generator hybrid system is more advantageous when compared to the PV/diesel-generator hybrid system as it has lower operating costs and pollution gases. Results indicate the lowest cost of energy (0.353 $/kWh) with the lowest NPC (1.168.417$) was observed with the solar- LPG generator system. The highest energy cost (0.485 $/kWh) with the highest NPC (1.513.393$) was observed with the solar- diesel generator system. There is an increase in the CO2 production rate of (33.008 kg/year) with the solar-diesel generator system, and a minimum CO2 production of (8.306 kg/year) with the solar-LPG generator system. With regard to CO2 production and future load demand, the optimized PV-LPG generator hybrid system is more cost effective in terms of Net Present Cost (CNP) and Energy Cost (COE). Based on analysis and environmental friendliness comparison results, it has been found that the PV-GPL hybrid system would be a feasible solution for distribution of electric power to remote locations and villages are far away from the main grid.

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