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The technical-economic and environmental study of a hybrid photovoltaic liquid petroleum gas energy system for an isolated community in Algeria

***Abstract**. In this work, we have investigated the different configurations employing hybrid PV- LPG system. We have use the HOMER software to evaluate the better price and ideal configuration of hybrid system in Ain el Skhouna village in the city of Saida in Algeria, with reference to price of production of energy and its annual yield suited to diverse configuration. The results prove that the PV-LPG configuration is the best result, with minimum price. energy and ecologically than the others configurations.*

Streszczenie.** W niniejszej pracy zbadaliśmy różne konfiguracje wykorzystujące hybrydowy układ PV-LPG. Za pomocą oprogramowania HOMER oszacowaliśmy lepszą cenę i idealną konfigurację systemu hybrydowego w wiosce Ain el Skhouna w mieście Saida w Algierii, w odniesieniu do ceny produkcji energii i jej rocznej wydajności dostosowanej do zróżnicowanej konfiguracji. Wyniki dowodzą, że konfiguracja PV-LPG jest najlepszym wynikiem, przy minimalnej cenie. energii i ekologicznie niż inne konfiguracje.* (Studium techniczno-ekonomiczne i środowiskowe hybrydowego fotowoltaicznego systemu energetycznego na gaz płynny dla odizolowanej społeczności w Algierii***)

Keywords: Economic; Performance; Solar; LPG; Hybrid System; Homer Software
Słowa kluczowe: hybrydowy system fotowoltaic\zny, płynny gaz, uwarunkowanmia środowiskowe.

Introduction

The world economic and financial crisis has brought new taxes on fossil fuels to Algerian citizens. According to the data from the Algeria Minister of Energy and Mines [1], during the depression (October 2009 - May 2011),. the LPG price rise by about 22% while the price of diesel and gasoline augment more than 45%.The important price growth of diesel and gasoline motivate numerous generator proprietors to use LPG. In Algeria the price of diesel is 0.23 $/L and the price LPG is 0.07 $ / L.

The national company, SONATRACH built the world's biggest LPG plant in the Arzew industrial zone in western Algeria. In 1984, this LPG plant receives the raw material of LPG (gas based on liquefied propane-butane mixture) produced in the gas field Sahara in southern Algeria, 1,400 km from the site [3].

Faced with global warming and energy security, most countries in the world are seeking to replace the fossil energy with renewable sources: geothermal, solar, waves and wind [4]. Algeria has approved a strategy to generate 35% of energy from renewable resources. This plan is founded on a real program for the photovoltaic industry jointed with a training program, which will improve a perfect knowledge in the field of engineering and project management. With a production of 25,000 MW of solar energy capacity between 2015 and 2035 it can represent over 37% of national output by 2030.

This platform contains the building of sixty electrical power plants, and hybrid photovoltaic diesel, thermal photovoltaic diesel and hybrid wind farms photovoltaic diesel systems [5]. My country is among the sunniest areas in the world; the average annual sunlight is 2000 hours, with an average sunlight per day of 6.57 kWh. Comparing the sun with natural gas, the energy capacity of the Algerian sun is equivalent to 37,000 billion cubic meters, 8 times the natural gas reserves in Algeria [6]. The first step to this method is to make a valuation of the existing resources in the region. In the case of Algeria, there are LPG gas, liquid petroleum diesel and solar power.. The second step is to assess the level of demand for electricity that will have to be satisfied. When there is access to electricity, demand always increases, accompanying economic development .The third phase in this method is to design a system that can meet demand by using available resources in the most cost-effective way and at the lowest cost of production.

This can be resolved using simulation software such as HOMER which calculates the optimum generation capacities with regard to the number of entries and the cost of installing and operating different types of generation technologies.

Resources of energy in Algeria

The choice of resources energy is important to design of the energy system. In this work, photovoltaic energy is adequate for power generation and LPG is utilized for the generation of electricity from non-renewable energies.

Solar Potential in Algeria

The Ministry of Energy and Mines says that Algeria can be an exporter of solar energy to Europe.The Ministry of Energy and Mines also shows that within two decades, solar power can deliver an quantity of electricity sufficient to supply almost three times the present population of Algeria [4].

Algeria is one of the sunniest regions and one of the largest solar parks in the world. The times sunshine all of Algeria exceed 2,100 hours annually and affect 3,800 hours in the Sahara and the mountainous. The energy received of horizontal surface is 5 kWh/m2 on majority of Algeria that is around 2.263 kWh/m2 It is around 2,263 kWh /m2 per year in the south and 1,700 kWh /m2 per year in the north [4], [7], [8].

Solar Energy Resources in Skhouna

The average global radiation per month data is taken from the NASA site (Space Administration and National Aeronautics). The clearness index (the clarity of the atmosphere is measured by this index) has a medium value of 0.490 for Skhouna. Table 1 shows the data of daily radiation and clearness index for Skhouna [7], [8], [9], [10].

The site of this city is shown by a red circle in Figure1 We select a rural city which is not connected to the standard distribution networks and equipped with the largest number of devices for occupant comfort.

Table1: Daily radiation in Skhouna

Month	Clearness index	Daily radiation(KW/m2/d)
January	0.268	2.700
February	0.353	3.670
March	0.445	4.680
April	0.565	5.760
May	0.686	6.610
June	0.783	7.290
July	0.776	7.320
August	0.646	6.410
September	0.493	5.090
October	0.376	3.900
November	0.285	2.880
December	0.244	2.420
Average	0.490	4.900

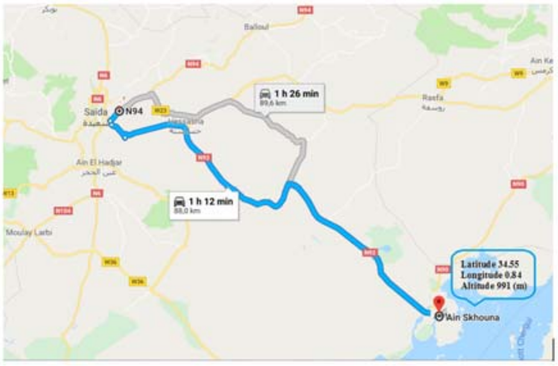

Fig1. Position of Skhouna (Google-Map).

The LGP (Liquid Petroleum Gas)

Liquefied petroleum gas is the best non-renewable source for the production of electricity because it has a lowermost carbon compared to solid and liquid fossil fuels. Indeed Its combustion produces17% less CO2 than oil and 49% than coal.

LPG also produces nearly no black carbon, which researchers today confirm is the second major contributor to global climate variation and is maybe the single main cause of arctic heating [11].

Novel technologies provide the flexibility to flawlessly change between LPG and other fuels such as Diesel, gasoline, permitting power generators to facilely adjust fuel supply based on price and availability. These technologies also offer greater energy efficiency, lower emissions gas carbon dioxide [12].

Fuel price in Algeria ($/L)

Diesel generators are more costly than LPG generators for comparable capacity but are usually more durable and inexpensive to utilize. Whereas generators have important operational costs, they deliver electrical power on demand. The use of LPG generators in a hybrid system not only offers source permanence but can also be used to avert over-sizing of renewable components. Table 2. The different fuel prices.

Table 2: Fuel prices. Dollar per liter in 05-Oct 2020[2].

Country	Gasoline $/L	diesel $/L	LPG $/L
Algeria	0.36	0.23	0.07
USA	0.67	0.63	----
Russia	0.60	0.60	0.31
Canada	0.91	0.74	0.67
Germany	1.47	1.23	0.64
France	1.57	1.44	1.02
japon	1.23	1.05	------

Hybrid system

Our hybrid system works with two different energy sources; such as photovoltaic panels and an LPG generator which are shown in Figure 2. The configuration of Figure2 makes it possible to design an autonomous hybrid energy system; generator and converter are chosen according to the maximum load demand. The optimal system configuration is given on the base of annual resource data. These resources (period of time and solar radiation with a back-up generator) are included in the structure of the system to adapt to these actual situations. This back-up generator powers the load when the energy stored in the battery and photovoltaic energy are insufficient to meet the load demand.

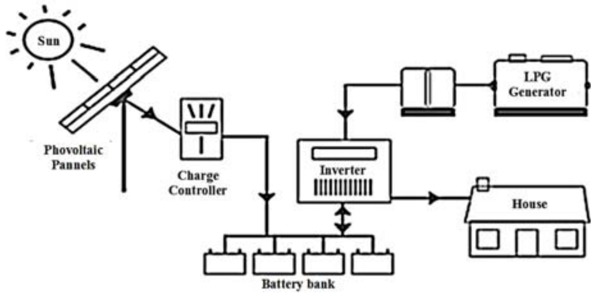

Fig.2. Hybrid system

Description of the Skhouna system

Electrical Load

A rustic area composed of 56 houses is utilized as the load. Table 3 shows the load configuration of chosen houses [13], [15], [20]. The hybrid system chosen was simulated to evaluate the usage of the power supply systemecentralized system shown in the example are not coupled to the grid and isolated. The daily demand for this village is 326 kWh, demand per day for a family of 45 kWh [15], [16], [17].

Table 3: The power consumed by a family

	Power (w)	Watt hour(wh)	Number	Time (h/d)	Consumption (wh/d)
Lamps L1	12	14.2	4	5	284
Lamps L1	25	26.6	2	5	532
Coffee maker	660	67 (6 min)	1	12 min	134
Heating plate	437	303.3 (45 min)	1	1h 30	606.6
Compute r	173	135.5	1	6	813
Refrigera tor	106	89.57	1	24	2149.68
TV	86	87.7	1	13	1140.1
Total (Wh/d)					5658.28

PV panel

The solar panels employed cost around 1500 $/kW. A service life of most of the photovoltaic panels is about 20 years, however they possible last longer. In the period of the night a batteries with capacity of 1000 Ah are used to storage the electricity [18], [19], [20].

LPG generators

The GPL generator is used in this study as a base load server. a price of $ 1400 and a replacement cost is $ 1050 and a maintenance cost is $ 0.20 / hr. The operating life of the generator is 13,000 hours and 35% minimum load. The size of the LPG generator is taken over intervals of 5 kW to 35 kW.]

Converter

To produce necessary power, converters are essential; the converters price is given by the software [12], [18], [19], [20]. The conversion efficacy of the converter are 90% and The operating lifetime of his components is near 12 years and we take from 0 kW to 40kW the sizing of the converter with a relative conversion rate of 95%.

Simulations and analysis

Figure 3 illustrates the hybrid configuration of stand-alone systems using LPG generators and photovoltaic panels to generate electricity. The simulation of different sizes of power converters, photovoltaic panels and batteries utilized and the best economic configuration is chosen after running the simulation numerous times. The search limit for the optimization process is presented in Table 4.There were 4 sizes for photovoltaic panels, 8 for LPG generators, 6 for batteries and 6 for power converters [21], [22], [23].]

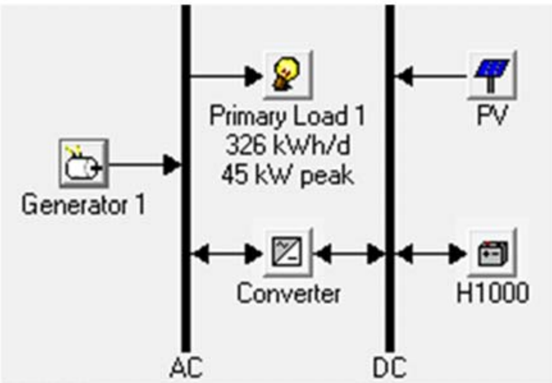

Fig.3. Hybrid generator designed in HOMER software

Table 4: Research area of various components.

PV panels (kW)	PLG generator	Battery	Converter
0	0	0	0
30	5	4	15
60	10	8	20
90	15	12	30
120	20	16	40
	25	20	50
	30	24	60
	35		
	40		

Details of components

This study improves a suitable assembly of parameters such as converter capacity, battery storage and photovoltaic generator power to match the requested load. Replacement cost, maintenance and operating cost and initial capital are taken into account in optimization circumstances.

Table 5: components of system

	Parameters	value	component
PV module	nominal capacity	1	KW
	Capital price	1600	$
	Replacement cost	1300	$
	O&M cost	12	$/year
	Lifetime	18	year
Batteries	Capital price	950	$
	Replacement cost	900	$
	O&M cost	9	$/y
	Minimal battery life	8	Year
	Nominal capacity	1000	h
Converter	Capital price	1100	$
	Replacement cost	1100	$
	O&M cost	10	$/year
	Lifetime	12	Year
	Capacity relative to inverter	95	%
LPG generator	Capital price	1250	$
	Replacement cost	1100	$
	O&M cost	0.2	$/h
	Life time year	1500	h

Results and discussion

The simulation results makes it possible to compare between the technical and economic constraints using the different Configuration of systems

Optimum system

The configurations achieved are chosen according to their feasibility and the cost of the installation. The effectiveness of the method is assessed over the lifespan of the project estimated at 25 years. The simulation results for the two structures are presented in Table 6 (a, b). Table 6a and Figure 4a illustrate the best solution for Hybrid Photovoltaic Liquefied Petroleum Gas (PV-LPG). Table 6b and figure 5a points to the second optimum solution for LPG only.

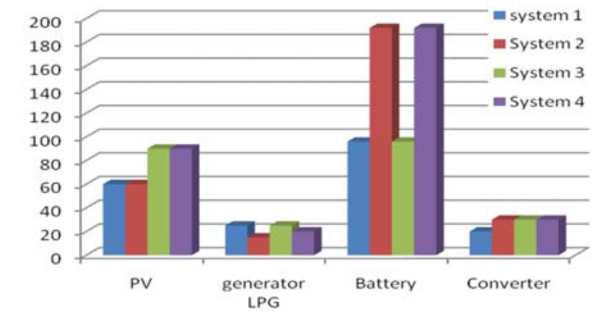

Fig 4a the best solution for configuration 1

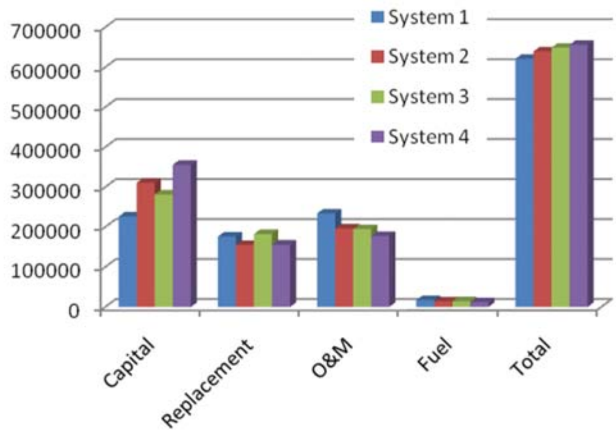

Fig.4b. Cost of system configuration 1

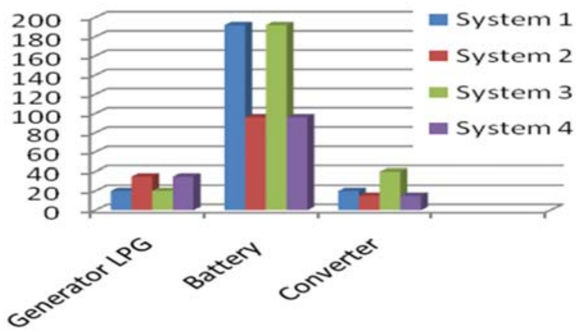

Fig. 5a the best solution for configuration 2

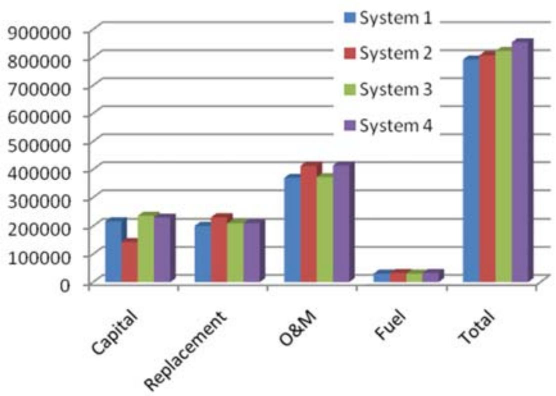

Fig.5 b. Cost of system configuration 2

The energy generation is elaborated in table 7. The generation systems designated in the table 7 illustrates a significant production of photovoltaic energy which delivers (54%) and an LPG generator delivers (46%) of load demand for structure 1 and total production for the LPG generator for structure 2.

Economic analysis

The designed system is examined according to the cost of electricity (COE) of the system. Figure (4b, 5b) shows the Capital cost, Replacement cost, Operation and maintenance cost and fuel for different system configurations.

Energy Production

Table 6a: Best solution for the configuration 1

Configuration 1	PV (K)	LPG (KW)	Battery H1000	Convert(KW)	Initial Capital$	OM ($/yr)	Total NPC $
System 1	60	25	96	20	226.400	30.871	621.034
System 2	60	15	192	30	310.800	25.700	639.330
System 3	90	25	96	30	281.400	28.748	648.339
System 4	90	20	192	30	355.800	23.494	656.135

Table 6b: Best solution for the configuration 2

Configuration 2	LPG (KW)	Battery H1000	Converter (KW)	Initial Capital$	OM ($/yr)	Total NPC $
System 1	20	192	20	216.800	45.015	792.249
System 2	35	96	15	143.400	51.940	807.367
System 3	20	192	40	236.800	45.825	822.599
System 4	35	96	15	229.800	48.810	853.760

Table 7: Yearly energy produced

Production kWh/ year	PV (KW)/yr	GPL (KW)/yr	Total production	Excess electricity (KW)/yr	Unmet electric load (KW)/yr	LPG (L/yr)
PV +LPG	85.819	72.747	158.566	25.951	0	16.920
LPG	0	134.960	134.960	0	14.5	29.693

Analysis of the Environmental

Table 8 shows the total emission of air pollutants in two cases of the examined configurations estimated by HOMER. From this table, notice a reduction in pollutant emissions by the solar-LPG generator system running on liquefied petroleum gas. Depending on the results, pollutant emissions can be reduced by approximately 56% compared to the system's LPG generator. The air pollutant emissions for the two optimal systems are detailed in Table 8 and Figure 6.

Table 8: Emission of air pollutants

Emission of air pollutants(kg/year)	Configuration 1	Configuration 2
Carbon dioxide CO_2	180	316
Carbon monoxide CO	110	193
Unburned hydrocarbons	12.2	21.4
Particulate matter PM	8.29	14.5
Sulfur dioxide SO_2	0.0214	0.0376
Nitrogen oxides NOX	981	1.722

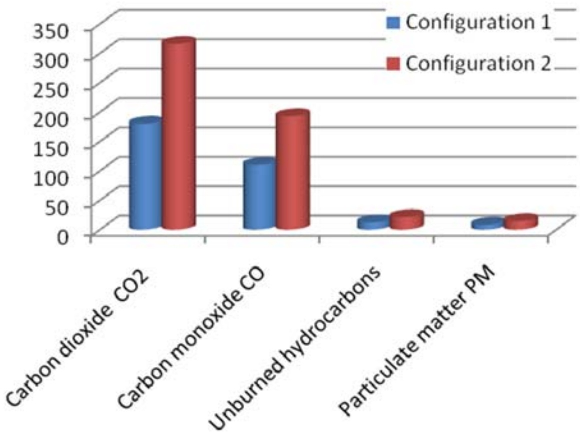

Fig 6. Emission of air pollutants

Conclusion

Electrifying rural areas in the Algeria operate on diesel or GPL generators, resulting in higher operating costs and pollution gases that can be reduced through more nature-suitable electricity production. This work was devoted to the optimization and the design of an off-grid renewable hybrid energy system for a community of 56 households in the rural village of Ain el Skhouna located in western Algeria in the town of Saida.

Results showed that a PV/GPL-generator configuration is more advantageous when compared to the GPL generator configuration as it has lower operating costs and pollution gases. The comparison is based on the cost of 1KWh of the production of electrical energy, and the pollutants gases reduction. We found that the low cost of energy is $ 0.408 / kWh with the low NPC of $ 621.034 and a minimum CO2 production of (180 kg/year) was achieved with the LPG solar generator. The highest energy cost is $ 0.521 / kWh with the highest NPC of $ 792.249 and maximum CO2 production of (316 kg/year) was achieved with the LPG generator. Based on comparison results, the hybrid Photovoltaic-LPG generator is more efficacious in terms of cost energy and quantity of polluting gases reduced.

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Notation

The notation used throughout the paper is stated below.

PV	*Photo-voltaic*
Wh	*Load hours*
WHD	*Load per day*
LPG	*LIQUID PETROLEUM GAS*
KWh	*Kilowatt Hours*
kWh/m2	*Kilowatt Hours/m2*
kWh/m2/d	*Kilowatt Hours/m2/day*
L/ $	*Price*
COE	*Cost of Energy*
NPC	*Net Present Cost*
$/L	*Euro/Litre*
h/d	*Hour/day*
OM($/yr)	*Operating maintenance(Euro/Year)*
wh/d	*Watt hour/day*
CO2	*Carbon Dioxide*
CO	*Carbon Monoxide*

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