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Assessment of an independent solar/diesel power generation system for an inaccessible community in Algeria

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ABSTRACT

In general, for isolated regions, the cost of extending the electricity grid is very high. Among the solutions, we can use diesel generators (DG) and photovoltaic systems. In this work, we have studied the two Structures using the hybrid system solar-diesel with AC/AC coupling and AC/DC coupling. With the help of the HOMER program, a technical-economic analysis of the system and comparing the cost and the optimal configuration in a mountainous area isolated from the power grid is made, as well as a comparison between the cost and amount of energy produced annually corresponding to two proposed structures. The results showed that hybrid system AC/AC coupling is the suitable solution that gives technical and economic performance and environmental pollution reduction, with low cost and ecology energy compared to the energy generated by the second structure.

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1. INTRODUCTION

The continuous increase in the population and the constantly increasing demand for energy besides improving living standards of the citizen. Today's main challenge is to meet this mounting request for energy without attrition the reserves intended for future generations. Algeria is based on a long-term policy to create 40% of its energy from photovoltaic (PV) source. This method is built on a real plan for the manufacture of PV panels, which was adopted with a production and training program. The production capacity is approximately 22 Gigawatts of PV energy from 2015 to 2035, it can attain more than 37% of national production by the end of 2035. The design contains the creation of about 50 solar power installations, PV hybrids and photo thermal systems farms [1]-[3]. Algeria is a country which enjoys an enviable position in solar energy. The sun time apparition surpasses 2,100 hours every year throughout the country and touches 3,800 hours in the Saharan regions. Over the country It is around 1,750 to 2,263 (kWh/m^2) during a year in the south and in the north 1,750 (kWh/m^2) during a year of the country. A plane surface of 1 m^2 can receive around 5.2 (kWh) per day on most of the country [4]-[6].

2. HYBRID SYSTEM DESCRIPTION

In this research, the load of the rural city of Naama, located in the southwest of Algeria, was selected to conduct the economic analysis. The daily load of this village isolated from the electrical network is 326 kWh per day.

2.1. Solar radiation

The typical radiation every month is given in the Algerian Meteorological Department. The clarity index has an average rate of 0.508 for Naama. The daily radiation and serenity index data for Naama. The average sun radiation varies from 2.46 kWh per m²/day to 7.72 kWh per m²/day and the average annual solar radiation is 5.18 kWh per m² per day [7]-[10].

2.2. Hybrid system constituent

Table 1 indicates the economical specification of the proposed system. The configuration is composed of at least the following parts [11]-[14]:

a. PV panel: a PV system is made up of cells placed in series and in parallel called a PV panel. These panels are thus associated to satisfy the load request. Numerous reasons can disturb the performance of the PV system such as geographic position, sun heat, and radiance.
b. Battery: used to stock the PV energy.
c. Converter: are used to convert DC power into alternating current. In Table 1 there is detailed information for installation cost, operational cost and lifetime.

Table 1. Economical specification of the system components

		PV			
Cost of capital ($)	Cost of replacement ($/yr)	Cost O.E ($/KWh)	Nominal capacity	Lifetime	
1600 $	1300 $	12 $/year	1Kw	18 years	
		Diesel genertor			
Cost of capital ($)	Cost of replacement ($/yr)	Cost O.E ($/KWh)	Operating hours	Lifetime	
1250	1100	0.2	1500h		
		Converter			
Cost of capital ($)	Cost of replacement ($/yr)	Cost O.E ($/KWh)	inverter	Lifetime	
1100	1100	10$/years	95%	12 years	
		Batteries			
Type of batteries	Nominal voltage	Nominal Capacity	Cost of replacement ($/yr)	Operating hours	Cost of capital ($)
H1000	6 V	1000 h	900	13000	950

Project life time: 25 years

3. COMPLETE SYSTEM MODELING

Mathematical modeling of hybrid energy is the proposed isolated hybrid system includes PVs, batteries storage, PV controllers, diesel generators units, and inverters [15]-[17]. The diagrammatic for the configuration is indicated in Figure 1. The energy production of the PV is given by:

$$E_{PVG} = G(t)AP\eta_{PVG} \tag{1}$$

The energy EDG that can be generated by Diesel generator is determined by (2):

$$E_{DG}(t) = P_{DG}(t)\eta_{DG} \tag{2}$$

The DG generator operates between 84 and 100% of their kW rating. Inverters are largely used as the interface between micro grid components and the load

$$E_{REC-OUT}(t) = E_{REC-IN}(t)\eta_{DEG} \tag{3}$$

$$E_{REC-IN}(t) = E_{SUR-AC}(t) \tag{4}$$

At any time *t*

$$E_{SUR-AC}(t) = E_{DEG}(t) - E_{Load}(t) \tag{5}$$

The load (SOC) of the battery can be computed by (6):

$$E_{BAT}(t) = E_{BAT}(t-1) - E_{CC-OUT}(t)\eta_{CHG} \tag{6}$$

Battery discharge can be expressed by:

$$E_{BAT}(t) = E_{BAT}(t-1) - E_{Needed}(t) \quad (7)$$

Where E_{Needed} is the load demand or the energy required for a given period.

4. POWER GENERATION MODEL

The total power of the system is summarized by (8):

$$P(t) = \sum_{1}^{Npv} P_{PVG} + \sum_{1}^{ND} P_{DEG} \quad (8)$$

The mathematical model for the general objective function can be formulated by the annualized cost and the the emissions. The annual investment price of a system element is the total cost by the investment retrieval factor [18]-[25]:

$$C_{Acap} = C_{cap} \,.\, CRF(i \,,\, R_{proj}) \quad (9)$$

Where *CRF(i ,R_proj)*is investment recovery factor and C_{cap} is initial investment cost of the *element.* The investment recovery factor *CFR(i; Rproj*) can be computed by:

$$CFR(i, R_{porj}) = i(1+i)^{Rporj} / i(1+i)^{(R_{porj})} - 1 \quad (10)$$

The complete cost is defined as the addition of:

$$C_{syt} = C_{PV} + C_{GER} + C_{BAT} + C_{CONV} \quad (11)$$

The yearly cost is computed on the charges of all the mounted units.

$$C_O = \{\sum_{t=1}^{365}\{\sum_{t=1}^{24} C_{\mathrm{OPV}}(t) + C_{\mathrm{ODEG}}(t) + C_{\mathrm{OBAT}} + C_{\mathrm{OCONV}}\}\} \quad (12)$$

The total yearly life cycle cost of the system includes both capital and operating charges.

$$C_{\mathrm{An}} = (C_{\mathrm{CRF}} + C_O) \quad (13)$$

Unit cost of energy for hybrid systems is:

$$C_{OE} = \frac{C_{An}}{E} \quad (14)$$

The net present cost (NPC):

$$C_{NPC} = C_{An} / CRF(1, R_{proj}) \quad (15)$$

The functions to be reduced are the total cost and the pollutant emissions of CO_2 kg

5. RESULTS AND DISCUSSION

5.1. Optimal systems

Tables 2 and 3 presents the results obtained after simulation of the two structures. Structure1 (Figure 1(a)): PV-diesel with AC/AC coupling. Structure2 (Figure 1(b)): PV-diesel with AC/DC coupling. Based on the results of the analysis obtained over the estimated life of the project of 25 years. The optimal hybrid system architecture is selected according to its feasibility and installation cost. First for the PV-diesel hybrid system with AC/AC coupling (Figure 1(a)) and based on the simulation results using Homer software. We find that the energy cost is estimated at 0.540 dollars/kilowatt hour and the total cost (NPC) is estimated at 820.802 dollars which is the lowest cost and also the minimum production of carbon dioxide estimated at 56,173 kg/year observed in structure 1, secondly for the Hybrid system PV-diesel with AC/DC coupling we note the highest energy cost of 0.592 dollars/kilowatt hour and total cost (NPC) of 1,051,886 dollars which is the largest. With a maximum CO_2 of 59.144 kg per year observed using the structure 2.

A hybrid solar/diesel-optimized AC/DC coupling structure (Figure 1(b) is more profitable in net current cost (CNP) and cost energy (COE). Table 3 illustrates the architecture for structure1 with AC /DC coupling at 20%. In Table 2 We find that the energy cost is estimated at 0.540 dollars/kilowatt hour and the total cost (NPC) is estimated at 820.802 dollars which is the lowest cost observed in structure 1. In Table 3, we note the highest energy cost of 0.592 dollars/kilowatt hour and total cost (NPC) of 1,051,886 dollars which is the largest observed with in structure 2. Table 3 indicates the optimum solution for structure2 with AC /DC coupling at 20%.

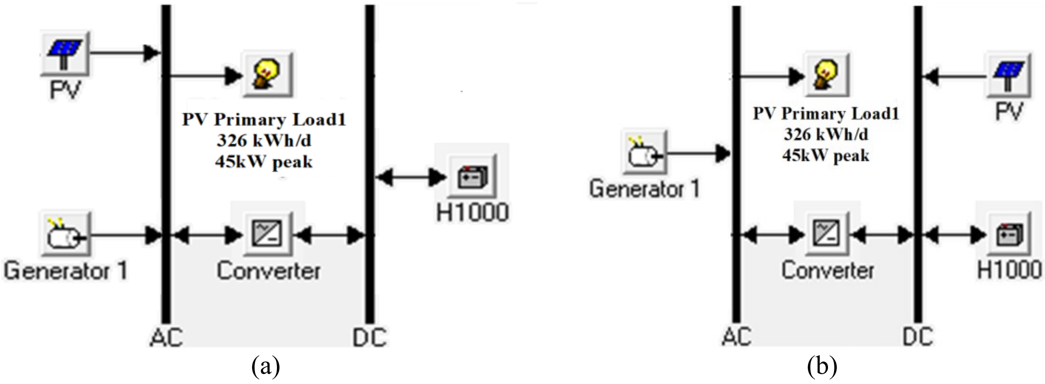

Figure 1. PV-diesel configuration (a) AC/AC coupling and (b) AC/DC coupling

Table 2. Hybrid architecture and optimum solution PV- diesel with AC/AC coupling at 20%

Structure 1	PV (KW)	Generator (KW)	Battery	Converter (KW)	Cost of capital ($)	Cost of replacement ($/yr)	Total NPC $	Cost O.E ($/KWh)
Architecture 1	100	35	96	15	293.400	41.257	820.802	0.540
Architecture 2	00	20	192	20	216.800	47.985	830.207	0.546
Architecture 3	00	40	00	00	48.000	106.676	1.411.679	0.928
Architecture 4	30	40	00	00	93.000	107.363	1.465.457	0.964

Table 3. Hybrid architecture and optimum solution PV-diesel with AC/DC coupling at 20%

Structure 2	PV (KW)	Generator (KW)	Battery	Converter (KW)	Cost of capital ($)	Cost of replacement ($/yr)	Total NPC $	Cost O.E ($/KWh)
Architecture 1	95	35	96	20	290.900	59.925	1.051.886	0.592
Architecture 2	00	35	96	15	143.400	74.798	1.099.566	0.723
Architecture 3	00	40	00	00	48.000	139.288	1.828.572	1.202
Architecture 4	30	40	00	15	108.000	140.162	1.899.738	1.249

5.2. Technical evaluation of the system

As shown in Table 4, analysis of the data obtained after the simulation of the two architectures shows that the AC/AC coupled system has advantages over the AC/DC coupled system. The PV system with a generator for the production of electricity makes it possible to: i) reduce fuel consumption; ii) reduce the emission of greenhouse gases; iii) reduce the running time of the generator set.

Table 4. Technical evaluation of the system

Parameters	Structure1 with AC/DC coupling	Structure 2 with AC AC coupling
PV power	33.970	35.758
DG power [kW]	101.932	96.297
Total energy produced [kWh/year]	135.902	132.055
Group consumption [L/year]	23.534	22.352
Number of hours of operation of the diesel group [h/year]	3.223	3.078
CO_2 emission [kg/year]	59.144	56.173

5.3. Economic evaluation

The aim of study is to obtain a configuration at the lowest cost while ensuring uninterrupted power to the load. Table 5 present the investment cost, the cost over the life cycle of the systems and the discounted cost per kilowatt hour of the various systems considered.Table 5 illustrates economic evaluation of the system.

Table 5. Economic evaluation of the system

Parameters	Initial investment	The annual cost of operating and maintaining	Net present cost (NPC)	Cost per kilowatt hour
Hybrid system PV-diesel with AC/AC coupling	652399	209098	820803	0.540
Hybrid system PV-diesel with AC/DC coupling	851776	231550	1051887	0.592

5.4. Quantity of polluting emissions, in tones, avoided each year

Table 6 summarizes the total pollutant emissions in the two structures examined. In structure 1, we have found that a minimum of CO_2 (56.173 kg/year) is created. The most CO_2 (59.144 kg/year) is created in the hybrid solar-diesel AC/DC coupling system. In Figure 2, the different curves determine the margin of achievable savings, when choosing an AC/AC coupled or mixed-coupling (AC/DC) system instead of a diesel generator system are demonstrated. The two Figures 3 and 4 represent the evolution of fuel consumption and CO_2 emissions according to the share of energy produced by the PV part of the system. The evolution of the fuel system consumption is a decreasing function of the minimum energy share produced by the PV generator.

Table 6. Quantity of polluting emissions avoided each year

Emission of air pollutants (kg/year)	Structure 2	Structure 1
Carbon dioxide	59.144	56.173
Carbon monoxide	153	145
Unburnt hydrocarbons	16.9	16.1
Particulate matter	11.5	11
Sulfur dioxide	124	118
Nitrogen oxides	1.365	1.296

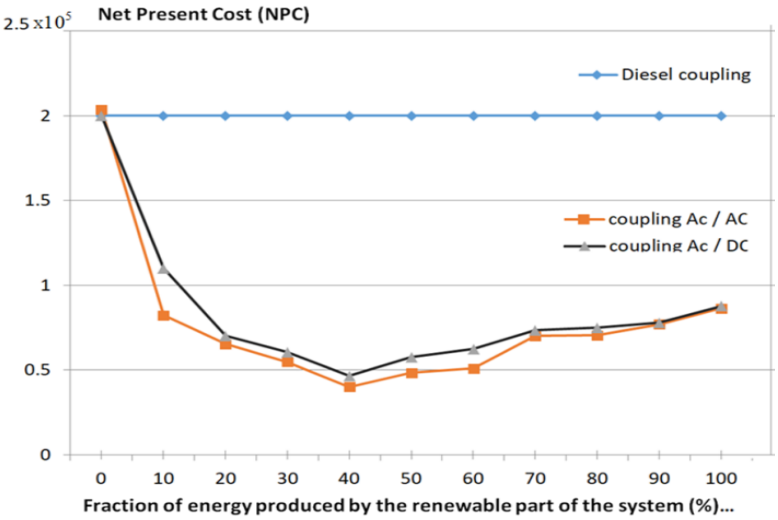

Figure 2. Current net cost of different hybrid systems

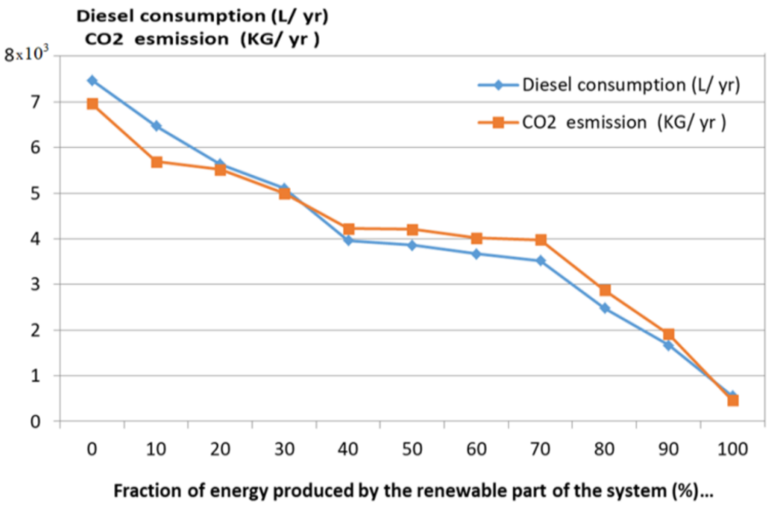

Figure 3. Evolution of the consumption and emission curve of system coupling AC/DC

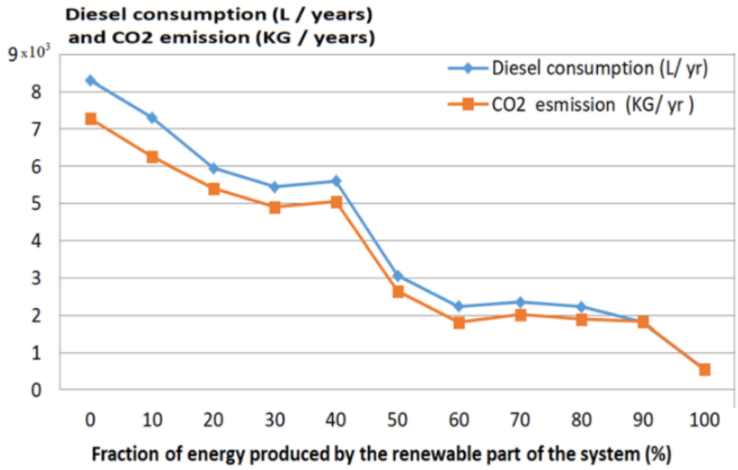

Figure 4. Evolution of the consumption and emission curve of system coupling AC/AC

6. CONCLUSION

The general objective of this document is to show the technical, economical, and ecological feasibility of a hybrid energy production unit intended for a small village of 130 households in Naama. More specifically, this work aims to simulate different configurations of hybrid systems, in order to derive an ideal combination ratio of the structure for the demand considered and participate in reducing the environmental impact linked to greenhouse gas emissions. After study and simulation of the different structures of the systems, We find that the energy cost is estimated at 0.545 dollars/kilowatt hour and the total cost (NPC) is estimated at 820.802 dollars which is the lowest cost and also the minimum creation of carbon dioxide evaluated at 56,173 kg/year observed in structure 1, secondly for the system Hybrid PV-diesel with AC/AC coupling we note the highest energy cost of 0.592 dollars/kilowatt hour and total cost (NPC) of 1,051,886 dollars which is the largest with a maximum CO_2 of 59.144 kg per year observed using the structure 2.

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