A faisibility Study of a Stand-alone (PV/Diesel) Hybrid System for Power Generation

Electrification of Solar Equipments Development Unit (UDES), Algeria

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***Abstract*—This article presents a study of a PV-Diesel-battery hybrid power system. The idea is to transform the Solar Equipments Development Unit (UDES) from a grid-connected system to a standalone PV-Diesel hybrid system. The system is composed from a PV array, a diesel generator, a battery bank and a (AC-DC, DC-AC) power converter. The Hybrid Optimization Model for Electric Renewables (HOMER) software was used to study the economically feasibility of the system. The daily solar data were provided by the weather station of UDES (Vantage Pro 2). The UDES monthly energy consumption profiles were provided by the accounting service. It was found that (a PV array of 50Kw, a diesel generator of 50 Kw, a battery bank of 170KAh and a 50Kw power converter) system, using HOMER, satisfies the energy demand of UDES with 0.15% excess in electricity and 0% unmet load. The Net Present Cost (NPC) was estimated at about 649360$ such as 44% remains to the PV system, 17% to the diesel generator, 24% to the battery bank and 14% to the converter. The cost of energy (COE) is estimated at about 0.275$/Kwh. The penetration of solar system in electric energy production is 28%, the remaining 72% are produced by the diesel generator. The 28% of solar penetration allowed us to reduce the green house gases emission with about 30% in comparison with a diesel system.**

Keywords PV; Diesel; battery; hybrid system; HOMER, COE, NPC.

I. INTRODUCTION

At the actual hour electrical energy demand is far greater than ever before in developed and developing countries. Conventional sources of electricity (CSOE) are finite and depleting and are responsible of climate warming due to the green house gases emissions [carbons, unburned hydrocarbons sulfur dioxide, nitrogen oxides] [1]. To solve climate problems caused by CSOE, renewable energies (RE) were starting being used all over the world and cover about 15% to 20% of world's total energy demand [2]. Solar energy (SE) is one of the abundant, inexhaustible, free, untaxed, without environmental releases (0% emission of greenhouse gas) and site dependant source of RE [1]. However the drawback of SE is its high cost compared with CSOE. Due to the advantages of SE, photovoltaic (PV) technology knew rapid development and large competition in the past decades conducting to 6.9Gw of photovoltaic cells (PVC) production in 2008 [3] and dropping in costs reaching 2000US$/Kw including installation construction [3]. Nevertheless the cost of PV technology is still high compared with conventional technologies. Towards this status, efforts have been focused on the so called hybrid energy systems (HES) [4] which exhibit reliability and cost effectiveness of generation than systems using only one source of energy. These systems have been being used in remote areas, which are far from the grids, where electric power is provided by diesel generators. The supply of diesel generator by fuel is expensive that makes (PV/diesel) HES competitive with diesel generators [5] [6]. The important feature of HES is to combine one or more renewable power generation technologies to obtain the best operation conditions, and high efficiency than that could be obtained with a single source of energy due to its ability to take the advantage of the complementary, diurnal and seasonal, characteristics [7] and reducing the percentage of greenhouse gases emission in the atmosphere, in [6] an analyzing study of different configurations of a hybrid system was made, the system model in the PV, wind, and grid connected was found to be the most cost effective. In [8] it was found that the PV-wind-diesel hybrid system with battery unit has the lowest cost values. However in [9] and [10] it was found that the integration of a PV array into a diesel –battery stand alone hybrid power system reduces the operating costs and the greenhouse gases and particulate matter emitted to the atmosphere.

The analysis and design of an HES is a challenging task due to the large number of design options and uncertainty in key parameters such as load size and future fuel sizes [9]. Before installing a renewable energy system for power generation economic analysis should be made. Numerous simulation methods have been used by researchers to design HRES in the most cost effective way. Using computer simulation the optimum configuration can be found by comparing the performances and the energy cost of different system configurations [7]. Among softwares used in this domain HOMER finds a large range of application, the time it performs complicated optimization task in an accurate way. In this paper a feasibility study of an autonomous

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PV/Diesel hybrid power system for the solar equipments development unit, using HOMER, is produced. The meteorological data for this site were provided by the UDES Vantage Pro 2 weather station. The proposed hybrid system consists on PV modules, battery storage, diesel generator and a converter. All over this article, are presented the technical characteristics of each component of the system, load profile, simulation software details and finally results and discussions.

II. DATA DESCRIPTION

The initial data in the implementation of a production renewable energy system like all power systems is the energy demand which will be determined relatively to the load that may be supplied. The UDES energy demand data were provided by the accounting service for each month of the year 2012. On Figure. 1 are represented the daily consumption profiles used in this study, for 24 hours a day for all months from January to December.

If we take a look at the UDES consumption profiles, we can see that the hours of high demand are the same for all months of the year. The highest consumption coincides with work hours [between 08h: 30 and 16h: 30].

The UDES energy demand of the year 2012 has been estimated at about 509Kwh/day and it's divided between the following blocks (Administration, Renewable Energy Equipments Division, Cold and Water Treatment by Renewable Energy Division, mechanical workshop) the energy is distributed between lighting, heating, air conditioning, laboratories and electronic machines.

III. GEOGRAPHICAL AND SOLAR DATA

The solar equipments Development unit is a research unit located at Bou-Ismail wilaya of Tipaza at about 45 km from the west of Algiers the capital of Algeria. The geographical data of the implantation site are summarized in the Table1.

Solar radiation data Figure. 2 were collected from the weather station of UDES. These data were taken every five minutes. The Weather Station is a wireless Vantage Pro 2 station (reference 6153FR).

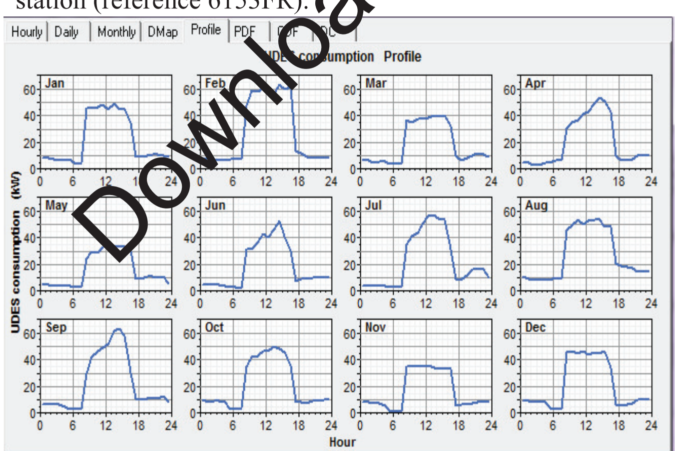

Figure 1. UDES daily consumption profiles

TABLE I. Geographical data of UDES site

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	Longitude [°]	Latitude [°]	Altitude [m]	Location
Characteristics	2°42'	36°39'	5	Bou- Ismail (tipaza, Algeria)

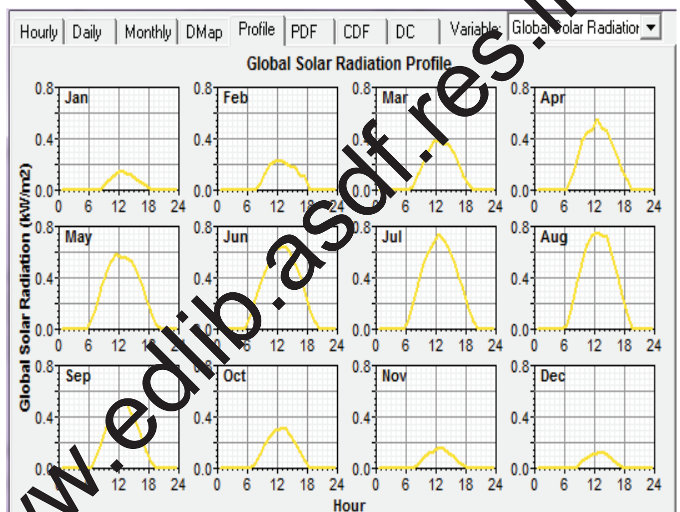


Figure 2. UDES Solar radiation data

IV. HOMER SIMULATION

The HOMER software (**H**ybrid **O**ptimization **M**odel for **E**lectric **R**enewables) is a software developed by NREL (National Renewable Energy Laboratory) in the United States (USA). It simplifies the task of evaluating the design of off-grid and grid-connected electrical power systems.

HOMER runs simulations with different energy production systems (PV modules, wind turbines, hydroelectric dams, biomass generators, power systems, fuel cells…….) and also offers a wide range of energy storage devices (batteries bank, hydrogen…).

The HOMER software simulates the system based on potential data of different energy sources (solar, wind, diesel, etc) and based on energy demand (energy needs) of the system. Thereafter, it is possible to analyze several different configurations for the same system in order to obtain an optimal level of cost system. The software simulates all the required configurations and gives the best solution, the cheapest solution, among them.

To use HOMER, we provide the model with inputs, which describe technology options, component costs, and resource availability. HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that we can view as a list of feasible configurations classified by Net Present Cost (NPC).

The net present cost is given by the equation (1):

$$NPC=TAC/CRF \quad (1)$$

Where TAC is the Total Annualized Cost ($). The Capital Recovery Factor (CRF) is given by equation (2):

$$CRF= [i*(1+i)^N/ (i+1)^N-1] \quad (2)$$

'N' is the number of years and 'i' is the annual real interest rate.

The standalone hybrid (PV-diesel) system was simulated in HOMER taking into account the parameters defined in paragraphs above. It consists on PV modules; diesel generator, battery bank and a power converter (convert AC-DC or DC-AC). The details of solar radiation and load profile are given above in Fig.1 and Fig.2. The other components of the system are described in the following paragraphs:

Photovoltaic modules:
Technology: REC Solar
Photovoltaic considered sizes (Kw): 47, 49 and 50.
Capital cost of photovoltaic array (US$/Kw): 5678.
Replacement cost of photovoltaic array (US$/Kw): 5678.
Operation and maintenance cost of photovoltaic array ($/year): 10
The PV modules are considered fixe with a 25 years working life

Diesel generator
Generator considered sizes (Kw): 45, 47 and 50
Capital cost of diesel generator (US$/Kw):313
Replacement cost of diesel Generator (US$/Kw):313
Operation and maintenance cost of diesel Generator (US$/hr): 0.001

Batteries
Technology: Hoppecke-1-10 OPzS 1000
Nominal voltage of each battery: 2 volt
Nominal capacity of each battery: 500Ah
Considered sizes: 80, 90,100, 135, 170 and 190.

Power converter
Technology: EFFECTA
Capital cost of power converter (US$/Kw): 734,
Replacement cost of power converter (US$/Kw):734.
Operation and maintenance cost of power converter (US$/yr): 2
Considered sizes: 50Kw.

The architecture of the system is described in Figure. 3. The system works as follows: in normal operation, PV modules feed the load demand. The excess of energy [energy above load demand] from the PV is stored in the battery bank until full capacity is reached. The diesel generator is used when PV system fails to satisfy the load and when the battery storage is depleted.

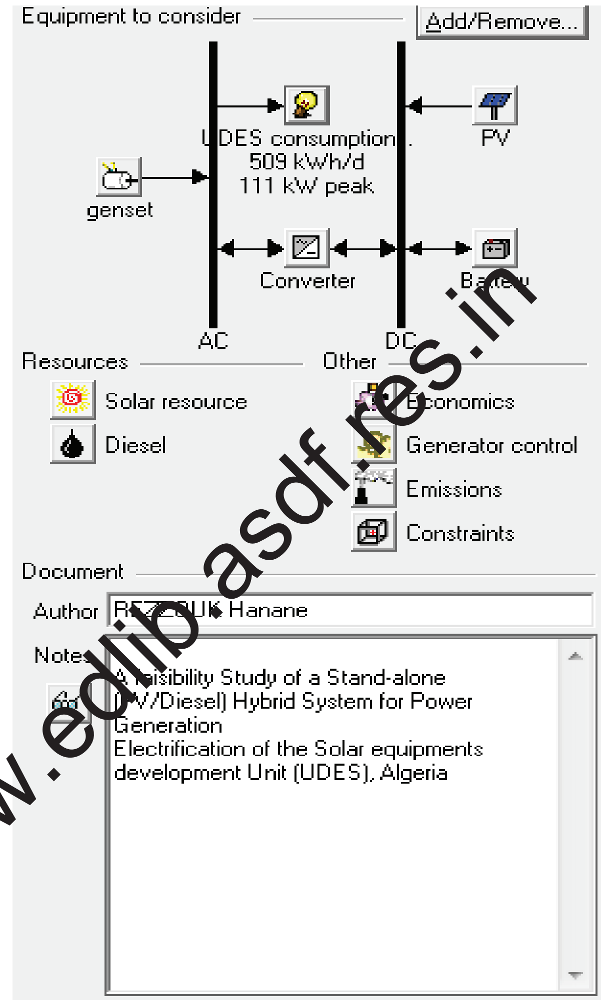
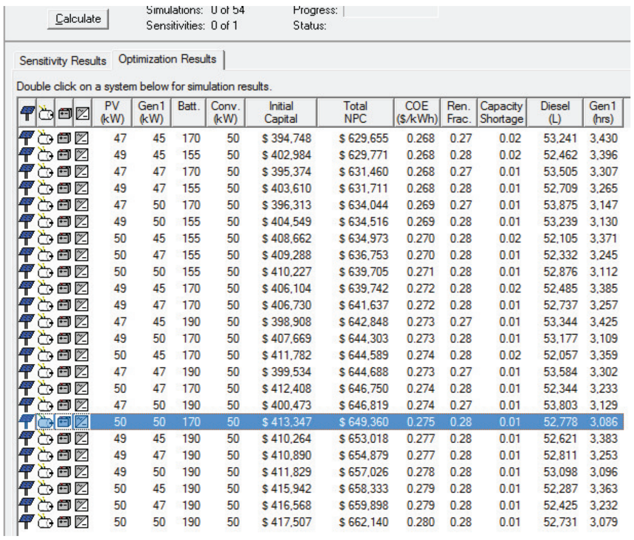


Figure 3. Architecture of the hybrid system

V. RESULT AND DISCUSSIONS

Based on data entered into Homer (solar data, load profile, hybrid PV/Diesel system description) a fifty four (54) system configurations were proposed by HOMER, classified according to the NPC. HOMER displays simulation results in a wide variety of tables and graphs that help to compare configurations and evaluate them on their economic and technical merits.

Simulations have been carried carefully in HOMER. The results of simulation are presented in Figure. 4. It can be noticed that a system configuration [47Kw PV modules, 45Kw generator and 170 units of batteries] economically feasible with a total present cost of 577028US$ and a minimum cost of energy COE of 0.246$/Kwh. The contribution of the renewable energy in electricity production is important (about 27%) with 0.30% excess in electricity, however this configuration doesn't satisfy about 2119 Kwh of the load demand (1% unmet load).



PV (kW)	Gen1 (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
47	45	170	50	$ 394,748	$ 629,655	0.268	0.27	0.02	53,241	3,430
49	45	155	50	$ 402,984	$ 629,771	0.268	0.28	0.02	52,462	3,396
47	47	170	50	$ 395,374	$ 631,460	0.268	0.27	0.01	53,505	3,307
49	47	155	50	$ 403,610	$ 631,711	0.268	0.28	0.01	52,709	3,265
47	50	170	50	$ 396,313	$ 634,044	0.269	0.27	0.01	53,875	3,147
49	50	155	50	$ 404,549	$ 634,516	0.269	0.28	0.01	53,239	3,130
50	45	155	50	$ 408,662	$ 634,973	0.270	0.28	0.02	52,105	3,371
50	47	155	50	$ 409,288	$ 636,753	0.270	0.28	0.01	52,332	3,245
50	50	155	50	$ 410,227	$ 639,705	0.271	0.28	0.01	52,876	3,112
49	45	170	50	$ 406,104	$ 639,742	0.272	0.28	0.02	52,485	3,385
49	47	170	50	$ 406,730	$ 641,637	0.272	0.28	0.01	52,737	3,257
47	45	190	50	$ 398,908	$ 642,848	0.273	0.27	0.01	53,344	3,425
49	50	170	50	$ 407,669	$ 644,303	0.273	0.28	0.01	53,177	3,109
50	45	170	50	$ 411,782	$ 644,589	0.274	0.28	0.02	52,057	3,359
47	47	190	50	$ 399,534	$ 644,688	0.273	0.27	0.01	53,584	3,302
50	47	170	50	$ 412,408	$ 646,750	0.274	0.28	0.01	52,344	3,233
47	50	190	50	$ 400,473	$ 646,819	0.274	0.27	0.01	53,803	3,129
50	50	170	50	$ 413,347	$ 649,360	0.275	0.28	0.01	52,778	3,086
49	45	190	50	$ 410,264	$ 653,018	0.277	0.28	0.01	52,621	3,383
49	47	190	50	$ 410,890	$ 654,879	0.277	0.28	0.01	52,811	3,253
49	50	190	50	$ 411,829	$ 657,026	0.278	0.28	0.01	53,098	3,096
50	45	190	50	$ 415,942	$ 658,333	0.279	0.28	0.01	52,287	3,363
50	47	190	50	$ 416,568	$ 659,898	0.279	0.28	0.01	52,425	3,232
50	50	190	50	$ 417,507	$ 662,140	0.280	0.28	0.01	52,731	3,079

Figure 4. Optimal PV-diesel hybrid system configurations

On the other side the energy demand of UDES is met with 28% [50Kw PV modules, 50Kw generator and 170 battery elements] PV power system penetration which was found optimal in terms of excess in energy only 304Kwh (0.15%) of the energy produced by the PV system was in excess with 0% unmet load, the other percentage of energy requirements is provided by the diesel generator.

The total annualized electrical energy production of the system is about 199571Kwh/yr with, as it was said above, 28% (56352Kwh/yr) of the electricity produced remains to the PV system and about 143218Kwh to the diesel generator. The annual UDES served electric load is about 184864Kwh.

In table are summarized the technical and economical characteristics of the hybrid power system.

The net present cost of the system has been evaluated by HOMER at about 649360$ with an annualized cost of 50797$. The annualized costs and annualized energy production for each component of the hybrid system are summarized in TABLE II.

On Figure. 5 and Figure. 6 are represented respectively the monthly average electric power of the PV array (in yellow) and the diesel generator (in black) and the annualized costs of the system and

The hybrid system greenhouse gases emission is estimated by HOMER at about 139418Kg/yr of carbon dioxide, about 1214Kg/yr of monoxide and 1056 Kg/yr of unburned Hydrocarbons. The emission of greenhouse gases is reduced by about 30% in comparison with a diesel power system.

TABLE II. Energy and economical characteristics of the hybrid system

System	Production Kwh/yr	%	Costs $/yr	%
PV array	56352	28	22709	44
diesel	143218	72	8716	17
Battery	----	----	12296	24
Converter	----	----	7077	14
total	199571	100	50797	100

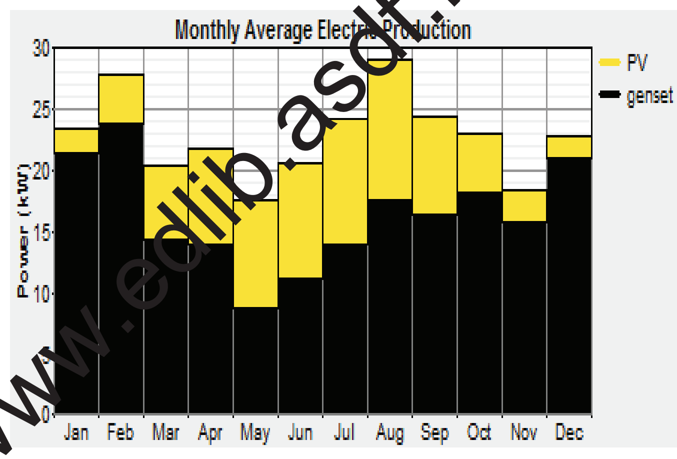


Figure 5. The monthly average electric power production of the hybrid system

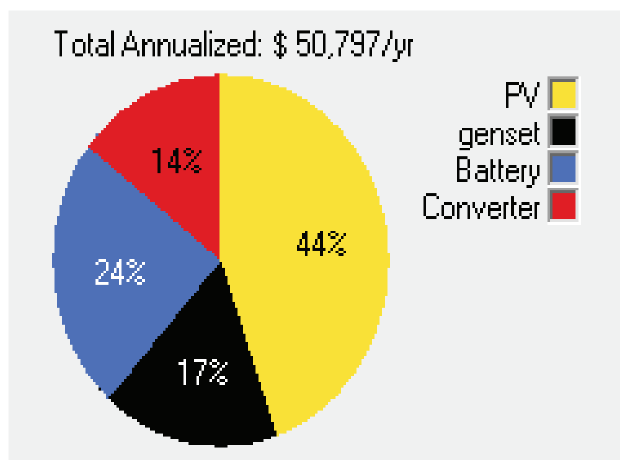


Figure 6. Annualized costs of the hybrid system

VI. CONCLUSION

A feasibility study of a hybrid PV-Diesel power system for supplying the solar equipments development unit with electric energy was conducted in this study. The system is composed of a PV system, a diesel generator, a battery bank and a converter. The penetration of the solar system was found equal to 28% of the energy production, 72% remains to the diesel generator. The total cost of the system has been evaluated using HOMER at about 649360$ with an annualized cost of 50797$. The annualized cost of the PV system is 22709$/yr (44% of the total annualized cost of the system) while that of the diesel generator is about 8716$/yr (17%), for the battery bank and the converter annualized the costs were estimated at about 12296$ (24%) and 7077$ (14%) respectively. The cost of energy was found equal to 0.275$/Kwh. The use of the solar energy in this system has allowed us to reduce the emission rate of green house gas to about 70% comparing with a diesel system.

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