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HYBRID RENEWABLE ENERGY SYSTEM SOLUTION FOR REMOTE AREAS IN UAE

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Abstract
Today, most remote areas in UAE are fully powered using diesel generators; however, high operating cost and recent concerns from government and activists are rising due to pollution and vibrations from diesel generators, which are affecting the desert's landscape and demography. Therefore, the objective of this study is to provide remote customers with viable hybrid-system (renewable/variable speed diesel generator) solution rather than stand-alone constant speed diesel generator. The study is based on measured load requirements of an existing safari camp in Abu Dhabi over a whole year. HOMER software has been utilized to simulate several alternatives for the case study. The selected solution is based on the system cost and the availability of the renewable energy resource at the location of interest (e.g., wind speed and solar irradiance). The study can be extended to remote farms within UAE.

Keywords: Hybrid systems, renewable energy, variable speed drive, HOMER, and CO_2 emissions.

1.Introduction

Characterized with long hours of sunshine throughout the year and beautiful desert landscape, tourists and residents in the United Arab Emirates enjoy desert safari camps all year long. Dubai alone is expecting more than 10 million tourists in 2011, and desert safari is a popular attraction; therefore hundreds of safari camps are scattered around the country's desert [1]. Some activities in camps are sand skiing, camel riding, barbeques, and dancing. To provide a real sense of the culture, camps are built deep in the desert and away from any civilization. As a result, camps are located far from electric grid lines; thus, stand-alone diesel generators are used. A safari camp is shown in Figure. 1.

Although a diesel generator may seem relatively inexpensive to purchase, it is expensive to operate and maintain, and it has poor efficiency [6,13,15]. They are directly affected by oil price's fluctuation, where prices are forecasted to increase with global demand on the rise [7,12]. The generators in camps are usually installed 30 m to 40 m away due to its noise during operation. The capability of these generators ranges from tens of hundreds of kVA depending on the size of the safari attraction itself. In addition to emitting CO_2 into the air, it has been found that diesel leaking from generators has polluted natural underground water resources that finds path during rainy seasons [2]. Local[1] municipalities have also started to express their concern about long operated generators, where vibrations are changing the landscape of the desert's sand dunes. New regulations are expected to be en-forced by municipalities on generator vibrations in remote desert areas [2,4].

Similar studies have been done in other regions at larger scales and different applications. Some applications, that use similar system, are powering small villages, telecommunications, and water pumps at isolated wells [3,9,10,12-18]. The objective of this study is to propose a hybrid system that utilizes renewable energy and variable speed diesel generatoras an alternative to stand-alone constant speed diesel genera-tor to power desert safari camps. The goal of the system is to produce energy at lower rates and lower generator operation hours resulting in lower CO_2 emissions and oil consumption. For this purpose, the paper presents and compares five different options to power a camp, where three options reflect different hybrid systems and two for standalone generators.

Fig.1: Safari camp in Al-Ain, UAE

2. Background information and load profile

This study has been conducted on a safari camp in Al-Ain city's suburb in UAE (located at 22°11'N and 55°24'E), however, it can be extended to other applications (e.g., remote farms). Like the rest of the UAE, Al-Ain is characterized by long hours of sunshine all year along [12]. The annual average temperature is

29 C° and humidity is 60%. Figure 2 shows the average monthly solar radiation, where the annual average is 5.63kWh/m2.

Safari camps' peak load is from 4pm to 1am daily. Because of its high operational cost, generators are usually turned off during non- peak hours (1am to 4pm).

Table 1. Summary of Safari load profile

	Load Profile # (refer to Fig 3 & 4)	Load kWh/day	Components
Opt1	2	410	35KW Hybrid Diesel Generator (Variable Speed), 35KW PV, 3KW Wind Turbine, 35KW Converter, 120 x 600Ah Battery
Opt2	2	410	35KW Hybrid Diesel Generator (Variable Speed), 35KW PV, 35KW Converter, 115 x 600Ah Battery
Opt3	2	410	35KW Diesel Generator (Constant Speed)
Opt4	1	260	35KW Diesel Generator (Constant Speed)
Opt5	1	260	35KW Hybrid Diesel Generator (Variable Speed), 35KW PV, 35KW Converter, 310 x 600Ah Battery

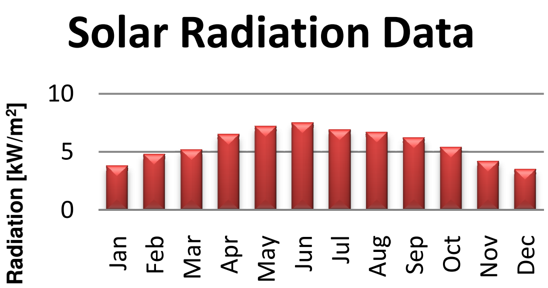

Fig.2: Monthly average solar radiation in Al-Ain

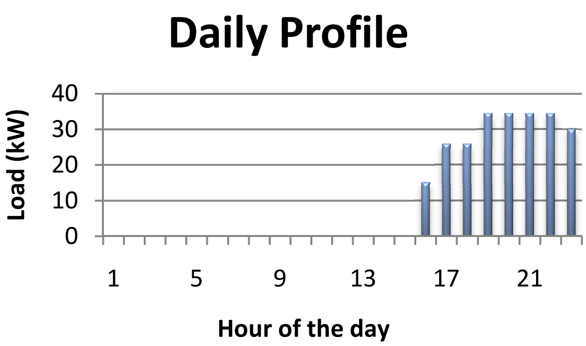

Fig.3: Current load profile of Al-Ain safari camp (Load 1)

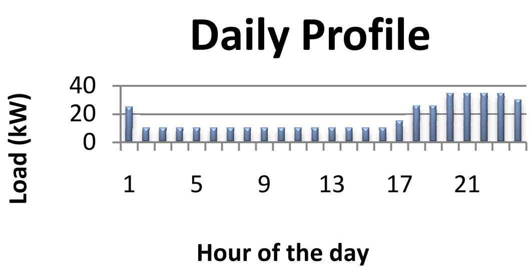

Fig.4: Preferred customer load profile (Load 2)

The annual average wind speed is measured to be 4.81 m/s at 50 m above ground, and the maximum monthly average speed was reported in May at 5.47 m/s

Figure 3 illustrates Al-Ain camp's current load profile. The peak load is 35 kW and the daily consumption is 260kWh/d. This paper will also consider options of powering camps for 24 hrs/day. The proposed load profile is shown in Figure 4. This profile is based on customer preferred load. The profile estimates the non-peak hours (1am to 4pm) load to be 10 kWh, the peak is 35 kW, and a 410 kWh/day load. Table 1 summarizes the different options, loads, and components. In general, the load does not vary significantly during different seasons of the year. However in the month of Ramadan, the average daily load decreases.

3. Proposed renewable energy based solution

Figure 5 shows schematic of the proposed solution in options 1, 2, and 5 for the site of interest. The system employs an innovative variable speed diesel generator [11] connected in parallel with a three phase bidirectional mini grid inverter charger. The only difference in options 2 and 5 is that wind turbine is not considered. Options 3 and 4 are based only on fixed-speed diesel generators. Components and its values are picked based on building an efficient system and taking in consideration the cost of energy and the dependency on diesel generator.

4. Methodology

Simulations were conducted using HOMER software; a product of National Renewable Energy Lab, a division of the U.S. Department of Energy [5,8,13,14,17]. HOMER specializes in modeling and comparing different power generation systems. Based on electric and/or thermal loads, HOMER facilitates finding the optimum solution in terms of a system's installation and recurrent costs over a specific life span. The software executes three major tasks; simulation, optimization, and sensitivity analysis. A model is simulated at every hour of the year to assess its efficiency, viability, and cost effectiveness. Optimization analyzes different system's combination in search for the most cost-effective solution while meeting technical feasibility. Sensitivity analysis analyzes the effect of different input assumptions (such as cost of fuel and average wind speed) on a system [5,19,20].Figure 6 represents HOMER's schematic representation of the hybrid system.

A. *Photovoltaic (PV)*

Monthly average solar radiation in Al-Ain – Table 3 – has been uploaded into HOMER. Monthly average clearness index has also being used; a ratio of radiation incident on earth's surface to the radiation incident on the top atmosphere. Clearness index is determined by HOMER based on a location's latitude and longitude. The power output of PV arrays is computed using the following equation [20]:

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S} \quad (1)$$

Where: f_{PV} is the PV's derating factor in percentage

Y_{PV} is the rated capacity in KW

I_T is the solar radiation incident on the array in [kW/m2]

I_S is the standard amount of radiation used to test the capacity of the PV array [1 kW/m2]

Table 2. Option Comparison

	Total Net Cost (20 years) ($)	Cost of Energy ($/kWh)	% PV in output	Generator Operation (hr / year)	Fuel (L)	CO_2 Emission (kg/year)	Breakeven Grid Extension (km)
Opt1	572K	0.333	33	3152	35521	94K	1.70
Opt2	562K	0.327	33	3215	36164	95K	1.65
Opt3	590K	0.340	0	8760	63039	166K	1.77
Opt4	308K	0.284	0	3285	32923	87K	0.85
Opt5	456K	0.419	50	1602	18497	49K	1.47

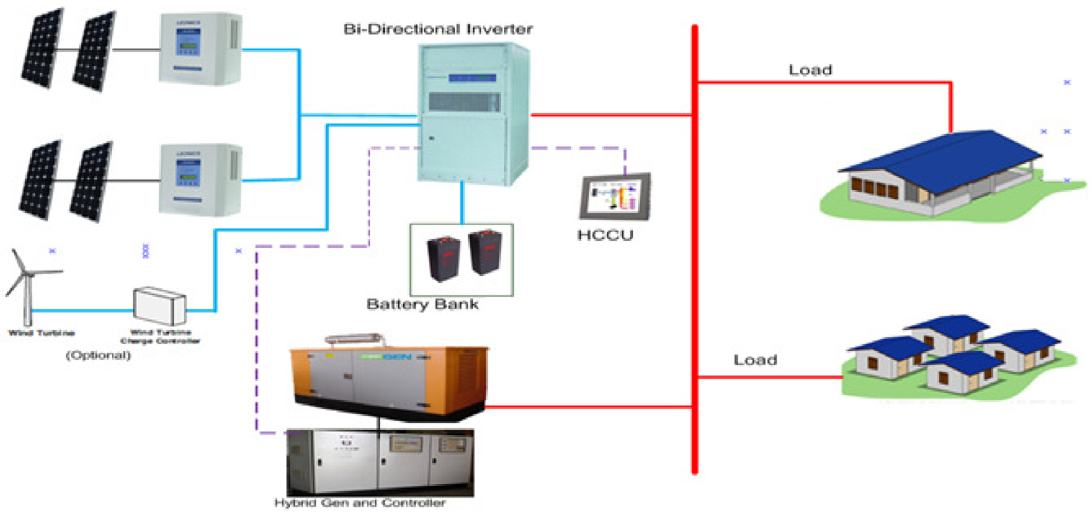

Fig.5: Overall system schematic diagram

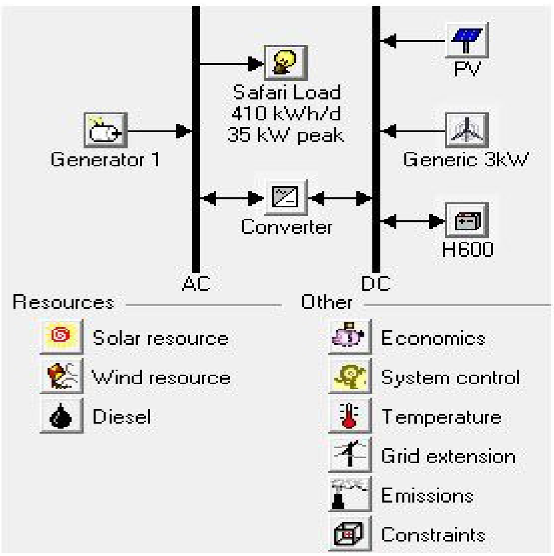

Fig.6: System's Schematic (HOMER)

Table 3. Solar Radiation in Al-Ain

	Daily Radiation ($kWh/m^2/day$)	Clearness Index
January	0.545	3.730
February	0.593	4.710
March	0.561	5.220
April	0.617	6.440
May	0.659	7.270
June	0.665	7.440
July	0.619	6.860
August	0.630	6.680
September	0.638	6.160
October	0.645	5.370
Average	**0.615**	**5.637**

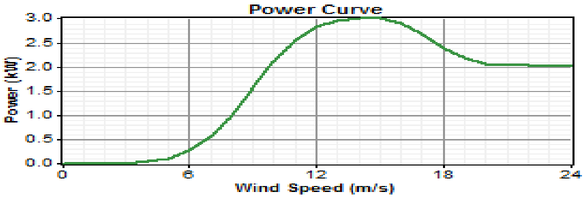

Fig.7:Wind Turbine's Power Curve (HOMER)

Table 4. PV Array Parameters in HOMER

Parameters	Value (per 1kW)
Capital Cost ($)	2500
Replacement Cost ($)	0
Operation and Maintenance Cost ($/yr)	10
Lifetime (years)	25
Derating Factor (%)	80

The derating factor takes in consideration elements that would degrade the power output; elements such as dust and temperature. HOMER considers a PV array size based on its rated capacity rather than its physical size. Rated capacity is the amount of power a panel would produce under ideal conditions (1 kW/m2 irradiance and 25°C). Table 4 lists parameters used in this simulation [19,20].

B. Wind Turbine

Table 6 shows the average monthly wind speed in Al-Ain. Based on that, HOMER generates hourly date using different statistical parameters; Diurnal Pattern Strength, Weibull Shape, Autocorrelation Factor, and the hour when wind speed is at its peak. The Diurnal Pattern Strength uses the hour of peak wind speed to determine the magnitude and phase of the average daily pattern of wind speed. Weibull Shape is the distribution of wind speeds over a year. Autocorrelation Factor relates to how much is wind speed at a specific hour dependant on the previous hour. Table 5 lists the parameters used in the simulation [20]. HOMER simulates wind turbine based on a specific power curve, depending on the type of turbine. Figure7 shows the power curve used in this simulation. The simulation involves four steps; computing average wind speed at a specific hour at the anemometer height, translate that wind speed to the speed at the turbine's height (using power or logarithmic laws), convert the kinetic energy into power using the power curve, and taking in consideration the air density [20].

Table 5. Parameters used in Turbine Simulation

Parameters	Value per turbine
Capital Cost ($)	12000
Replacement Cost ($)	0
Operation and Maintenance Cost ($/yr)	180
Lifetime (years)	20
Hub Height (m)	25
Anemometer Height (m)	50
Weidbull	2
1-hr Autocorrelation Factor	0.85
Diurnal Pattern Strength	0.25
Hour of Peak Wind speed	15

Table 6. Monthly Average Wind Speeds in Al-Ain

Month	Wind Speed(m/s)
January	4.530
February	5.210
March	4.930
April	4.870
May	5.470
June	5.420
July	5.150
August	4.920
September	4.700
October	4.260
November	3.890
December	4.450
Average	**4.814**

C. Diesel Generator

HOMER uses the following equation to determine a generator's fuel consumption:

$$F = F_0 Y_{\text{gen}} + F_1 P_{\text{gen}} \qquad (2)$$

Where,

F0 is the fuel curve intercept coefficient

F1 is the fuel curve slope

Ygen is the Rated Capacity inkW

Pgen is the electric output in kW

Table 7 shows parameters used to determine cost. Homer uses the following equation to determine a generator's fixed cost of energy:

$$C_{\text{fixed}} = C_{\text{O\&M}} + \frac{C_{\text{replace cost}}}{\text{lifetime (hrs)}} + F_0 Y_{\text{gen}} C_{\text{fuel}} \qquad (3)$$

Where:

$C_{O\&M}$, and C_{fuel} are the operation and maintenance cost and fuel price in U.S. Dollars, respectively

F0 is the fuel curve intercept coefficient

Ygen is the Rated Capacity in kW

And the following to determine a generator's marginal cost; additional costs for every KWh a generator produces:

$$C_{\text{marginal}} = F_1 C_{\text{fuel}} \qquad (4)$$

Figure 8 illustrates the simulation results of all five options. Results shown are based on a project life time of 20 years. Thus, the most cost effective system is represented in its total Net-Present-Cost (NPC). Table 2 summarizes the simulation results of all five options. Note that all currencies are in USD and diesel cost is 0.75$/L. Grid extension is $234K/km. Temperature's effect on PV is considered [20].

5. Results

Two load profiles were taken into account in simulation. Load 1 is the current load profile of the safari camp in Al-Ain's suburb. Load 2 is the customer preferred load that takes into account a load of 10 kWh between 1am and 4pm and keeps the same load during peak hours. The results shown compare powering both loads using a hybrid system and a stand-alone diesel generator.

Load 1 (Fig3), using a standalone constant speed generator as seen in option 4 (Table 4)has a total net cost, over 20 years, of $308K. Using a hybrid system (option 5) that includes a hybrid variable speed generator, photovoltaic, converter, and batteries will cost $456K. However, option 5's diesel hybrid generator works for 53% fewer hours than option 4's. Figure 10 illustrates the generator's activity in this option, where the generator turns on only between 5pm to 11pm.In addition, option 5 consumes 41% less fuel and CO_2 emission. Figure 9 shows that 50% of the output power is produced from clean energy source, photovoltaic. For load profile 2 (Fig4), two options are proposed. Option 1 consists of a hybrid variable speed generator, photovoltaic, wind turbine, converter, and batteries. Option 2 is similar to option 1 except with no wind turbine.

6. Discussions

Option 2 is recommended because wind turbines are visible from distance; therefore, it may have a negative impact on the desert's landscape. In addition, the region's wind profile may be modest for good efficiency from wind turbine [12]. The cost of powering a camp using a stand-alone constant speed diesel generator costs $590K over 20 years (option3). Using option 2's hybrid system will cost 5% less; $562K. Furthermore as seen in figure 12, option 2's generator works 63% less hours compared to option 3 and consumes 42% less fuel and CO_2. Figure 13 demonstrates batteries' activity during a day, and figure 11 shows that 33% of the output power is produced from clean energy source, PV. Unlike [3], using renewable energy sources is more affordable than using stand-alone diesel generator. This is due to the difference in diesel cost, where the cost in Saudi Arabia is 0.1$/L [3].

6. Future Work

The selected option is being built at UAE university at a lower scale of 5KW. The remote load is being emulated by an off-grid shed. The shed load consists of an Air condition, data acquisition system and lights. Future work is planned to be able to monitor, detect and predict faults within the renewable energy system. A further stage is planned where another renewable energy system will be added. Software management system is planned to distribute load among both systems based on load requirements, renewable energy system capability and battery storage levels.

7. Conclusion

In this paper, three hybrid systems using renewable energy have been proposed to replace stand-alone diesel generators used in desert safari camps in UAE. A camp in Al-Ain city was used as a research sample. The hybrid system takes to its advantage the long sunshine hours in UAE. The study has proposed more efficient systems for two different load profiles. Load 1 current load in Al-Ain's camp operates only for 9 hours a day. Camps operators are facing challenges powering the camps because of expensive operational cost of diesel generators and increasing criticism because of generators' pollution and vibrations that is altering UAE's sand dunes demography. Another load (load 2) was considered in this study;a customer preferred load that operates for 24 hours a day.

For load 1, option 1's hybrid system is proposed as the optimum solution consisting of 35 kW hybrid variable speed generator, 35 kW PV, 35 kW converter, and 310 600Ah batteries. The total net cost of the system and output power over 20 years is $456K, compared to $308K for stand-alone constant speed diesel generator. The hybrid system will diminish the working hours of the generator by more than 50% compared to the conventional system. CO_2 emission and fuel consumption also decreases by more than 40%.

For load 2, option 3's hybrid system is proposed as the optimum solution. The system contains a 35 kW hybrid variable speed generator, 35 kW PV, 35 kW converter, and 115 600Ah batteries. The total net cost of the system over 20 years is $562K, com-pared to 590K for stand-alone constant speed diesel genera-tor. The hybrid system will diminish the working hours of the generator by more than 60% compared to the conventional system. CO_2 emission and fuel consumption also decreases by more than 40%.

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	PV (kW)	G3	Gen1 (kW)	H600	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
	35		35	115	35	$ 197,217	31,763	$ 561,532	0.327	0.33	36,164	3,215
	35	1	35	120	35	$ 210,817	31,449	$ 571,535	0.333	0.35	35,521	3,152

	PV (kW)	Gen1 (kW)	H600	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen1 (hrs)
	35	35	310	35	$ 259,617	17,153	$ 456,355	0.419	0.50	18,497	1,602

	Gen1 (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
	35	$ 15,000	25,624	$ 308,900	0.284	0.00	0.05	32,923	3,285

	Gen1 (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Gen1 (hrs)
	35	$ 15,000	50,170	$ 590,443	0.340	0.00	0.03	63,039	8,760

Fig.8: Simulation Results (HOMER); Options 2, 1, 5, 4, and 3 respectively

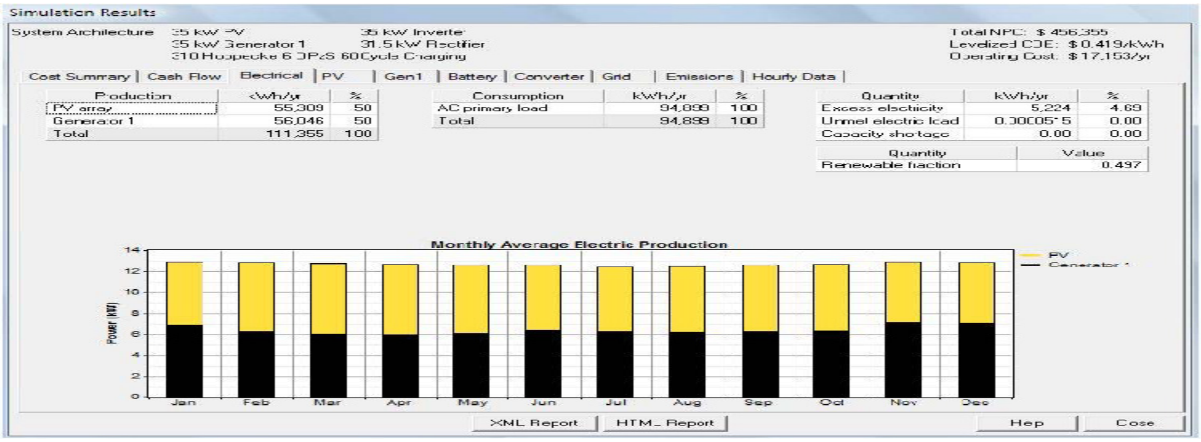

Fig.9: Option 5 electrical characteristics

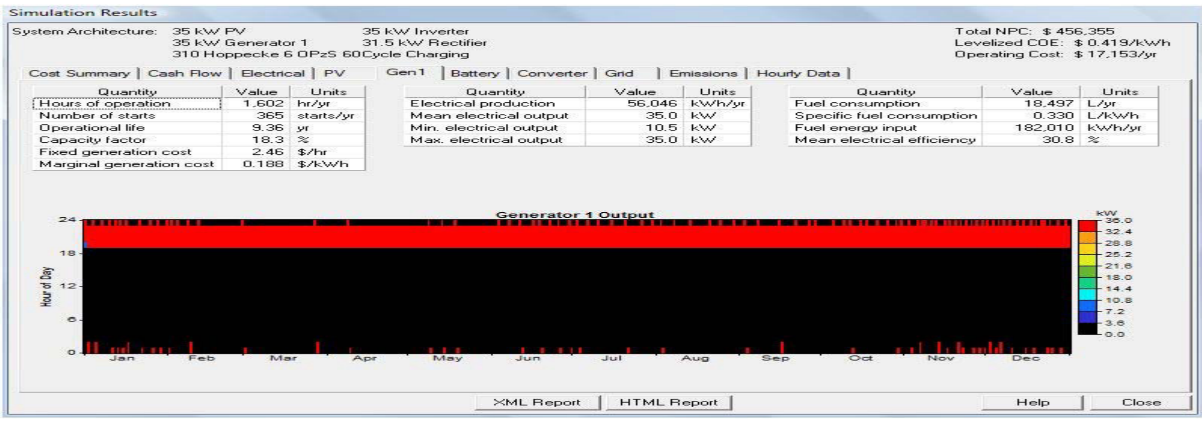

Fig.10: Option 5 electrical characteristics

Fig. 11: Option 2 electrical characteristics

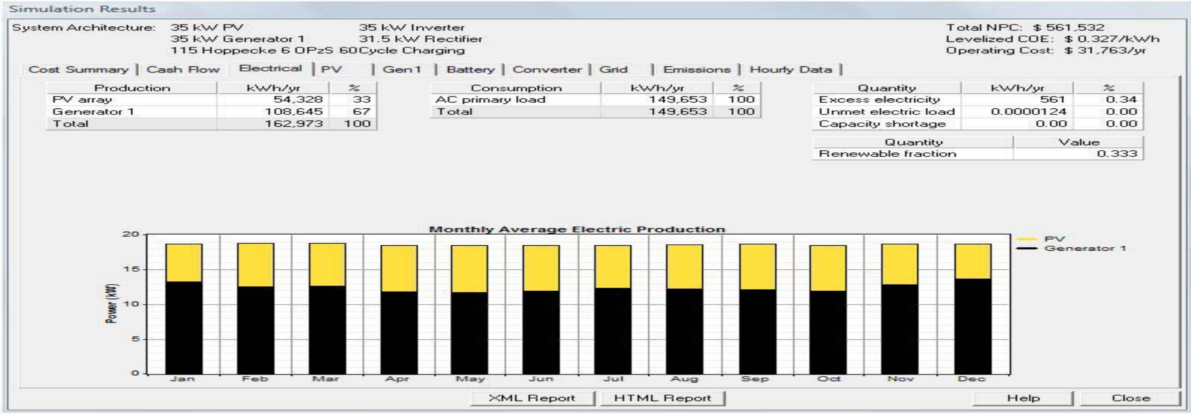

Fig. 11: Option 2 electrical characteristics

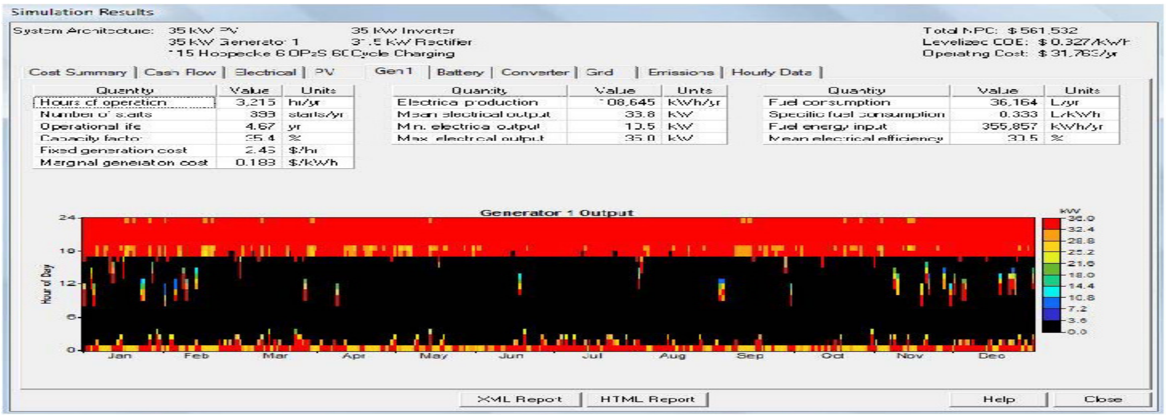

Fig.12: Option 2 generator activity

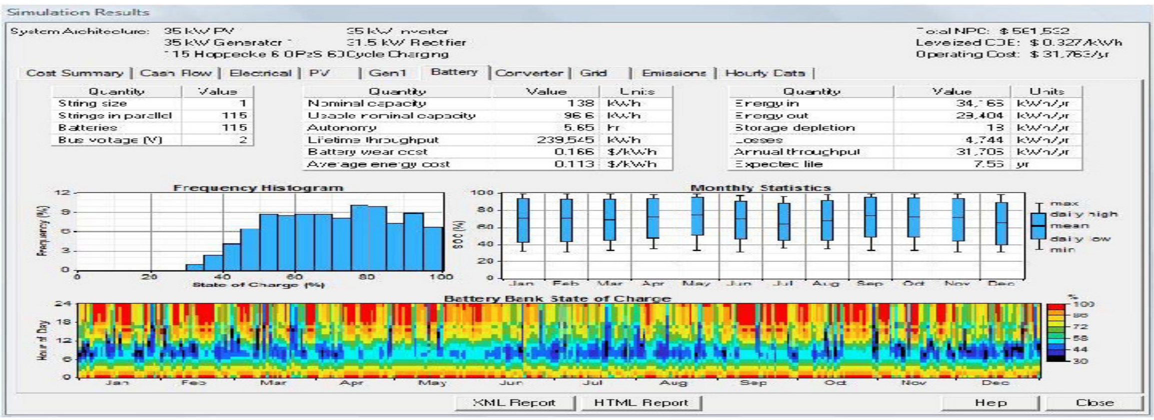

Fig.13: Option 2 generator activity