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Cost Analysis and Optimal Sizing of PV-Diesel Hybrid Energy Systems

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Abstract

Renewable energies are the most important solution to a rising universal population demanding reasonable access to electricity while reducing the need for fossil fuels. Egypt possesses an abundance of land and sunny weather, making it a prime location for renewable energy sources; Egypt intends to supply 20% of generated electricity from renewable sources by 2022. This paper discusses the optimization of the renewable energy hybrid system for electrical loads at El-Sheikh Zayd city in Egypt based on the sizing and the economic study of the power system, HOMER software has been used to execute the economic Feasibility of hybrid PV/diesel energy system. The study verified the impact of PV penetration and battery storage on energy production, cost of energy, number of operational hours of diesel generators for given hybrid configurations. The optimization results show that PV-Diesel-battery based power system is economically more practicable with a minimum total NPC of $ 60.160.159 and a minimum COE of $.330/kWh, also results show that the PV-diesel battery energy system is the least energy losses system and environment polluting system.

Keywords

Renewable Energy, Photovoltaic, Diesel Generator, HOMER Software

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1. Introduction

The energy shortage started in 1975 during the civil war in Lebanon [1], the impact of the energy shortage and the political instability led to the increased use of diesel generators that covered a 4 million population area of 10452 km^2. These diesel generators have to cover the electricity shortage when the main grid is down [2].

Solar energy is one of the boundless energy sources existing for the realization of the renewable energy system in isolated areas. It has been pursued by a number of countries with monthly average daily solar radiation in the range of 3-6 kWh/m^2 in an effort to reduce their dependence on fossil fuels [3].

Solar hybrid power systems are systems that combine solar power from a photovoltaic system with another power generating energy source [4]. A common type is a photovoltaic diesel hybrid system [5] combining photovoltaics (PV) and diesel generators, or diesel gensets, as PV has hardly any marginal cost and is treated with priority on the grid [6]. The diesel gensets are used to constantly fill in the gap between the present load and the actual generated power by the PV system [7].

As solar energy is fluctuating, and the generation capacity of the diesel genesets is limited to a certain range, it is often a viable option to include battery storage in order to optimize solar's contribution to the overall generation of the hybrid system [8].

This paper discusses the optimized sizing and the economic analysis for PV –Diesel system at El-Sheikh Zayd city in Egypt, the software used is homer software, for this study, the load is 200 kW AC works 24 hours every day, this has

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scaled up the annual peak load to 216 kW peak. HOMER software is a user-friendly micropower design tool that simulates and optimizes stand-alone and grid-connected power systems. Recently, it is has been used widely in the field of renewable energy [9]. The paper objectives are the sizing of PV–Diesel battery hybrid energy system, the most economic energy system with respect to the net present cost and cost of energy, and also discussing these points with HOMER software taking into account the loss of energy.

2. Site Characteristics

The site chosen is El-Sheikh Zayd city, it is a district of 6th of October City in Giza Governorate in Egypt and part of Greater Cairo urban, El-Sheikh Zayd city is situated about 15 km from Lebanon Square in the Mohandiseen district of Giza. It is bordered to the north by the Cairo-Alexandria desert road, to the south by the 26 July Corridor, and to the west by the neighboring 6th of October [10]. Köppen-Geiger climate classification system classifies its climate as hot desert, it located at latitude 30° 3', north and longitude 30° 58', east [11], so the usage of solar PV technology is suitable for producing electricity in this site.

3. Resource Data for El-Sheikh Zayd

The solar radiation data of El-Sheikh Zayd city is shown in figure 1 as used in HOMER software, figure 1 gives the solar radiation data inputs and the clearness index of the site. As shown from the figure the clearness index ranges between 0.572 and 0.699, the highest solar radiation in june, july and may, annual average value of solar irradiance is estimated to be 5.59 kWh/m^2/day [12].

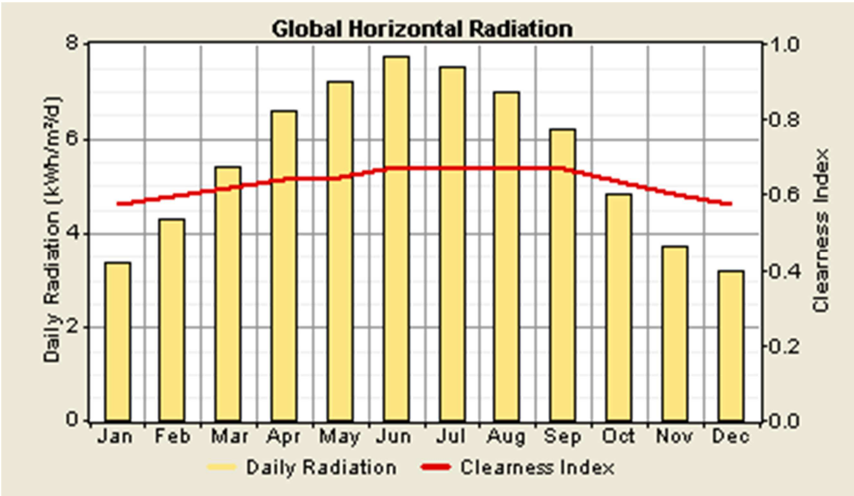


Figure 1. Solar radiation and clearness index data.

4. Electrical Load Data

The load is 200 kW AC works 24 hours every day, figure 2 indicates the load profile monthly over the year, the annual peak load is 216 kW peak, the calculated annual average energy consumption has been measured to size the load to 4.8 (MWh/d).

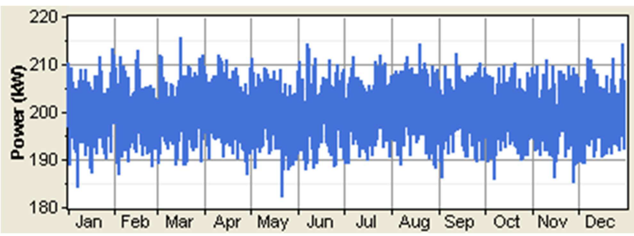


Figure 2. Load profile data.

5. System Components Specification

The PV-Diesel energy system is 25 years lifetime with annual interest rate 8%. The first component in the system is PV, a derating factor of 90% means that the PV production decreases by 10% to take in consideration the temperature and dust changeable effects on the panels. The PV module technical and cost specifications are shown in Table 1 [12]. The power output of the PV module, considering the effects of ambient temperature, can be obtained using the following formula [13]:

$$p_{pv} = Ps..\ D_{pv}\ (GT/Gs)[1+\alpha_{pv}(Tc\text{-}Ts)]$$

where:

D_{pv}, PV derating factor;

G_T, solar radiation incident on the PV module at the current time (kW/m^2);

Gs, solar radiation at standard test conditions (1 kW/m^2);

Ps, power output of the PV module under standard test conditions (kW);

Tc, temperature of the PV module at the current time (°C);

Ts, temperature of the PV module under standard test conditions (25°C);

α_{pv}, temperature coefficient of the PV module (%/°C).

Table 1. PV module Parameters.

Size (kW)	1
Total capital cost/kW ($)	3,000
Replacement cost ($)	2,500
Annual maintenance cost ($)	10
Lifetime (yrs.)	25
Derating factor	90%
Ground reflection	20%
Nominal cell temperature °C	47

The second component in the proposed energy system is diesel generator**,** table 2 highlights the summary of the diesel generator technical and cost data [14], fuel price of .2$/l.

Table 2. Diesel Generator costs.

Size (kW)	1
Total capital cost/kW ($)	400
Replacement cost ($)	300
Annual maintenance cost ($)	.25/h
Lifetime (yrs.)	15000h
The fuel price	.2 $/l

The type of the battery that used for the system is Hoppecke 24OPzS 3000 model. Table 3 presents the battery parameters [15], the nominal voltage of the battery is 12 V, two battery per string, nominal and maximum efficiency is 3000and 3.65 Ah respectively.

A power electronic converter is used to keep the flow of energy among Ac and Dc components. The parameters of the converter are shown in Table 4 [16]. The efficiency with which the inverter converts DC electricity to AC electricity is 90%, the rated capacity of the rectifier relative to that of the inverteris 100% and the efficiency with which the rectifier converts AC electricity to DC electricity is 85%.

Table 3. Battery parameters.

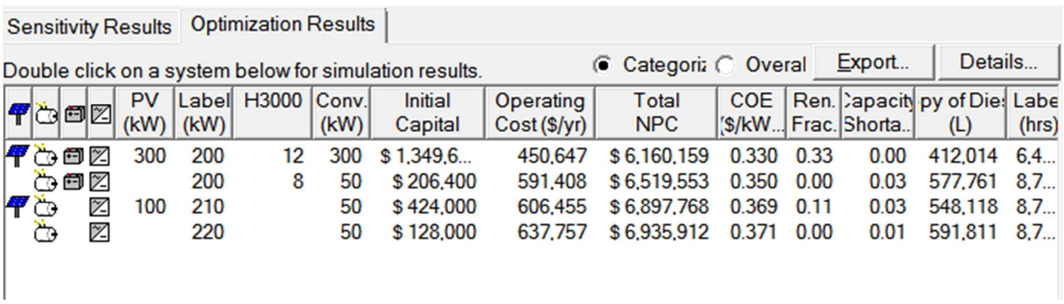
Nominal capacity (Ah)	3000 Ah
Nominal voltage (V)	12 V
Maximum Capacity (Ah)	3.65Ah
Round tip efficiency (%)	86%
Min. state of charge (%)	30%
Max. charge rate	1A/Ah
Total capital cost ($)	10800
Replacement cost ($)	9000
Annual maintenance cost ($)	360
Lifetime (yrs)	5

Table 4. Converter parameters.

Size (kW)	**1.000**
Total capital cost ($)	800
Replacement cost ($)	600
Annual maintenance cost ($)	5
Lifetime (yrs)	15

6. Results and Discussions

Once the previously described specifications have been input to HOMER, the software has been used to perform the technoeconomic feasibility of hybrid PV/diesel energy system, The investigation demonstrated the impact of PV penetration and battery storage on energy production, cost of energy, number of operational hours of diesel generators for a given hybrid configurations. This software performs calculations to determine the best combination that technically and economically meets our demand. The results are summarized in Figure 3. Where the optimal systems are ranked according to their technical and economic feasibility. As shown in figure 3, the optimized systems are PV-diesel-battery system, diesel-battery system, PV-diesel system and diesel system.



PV (kW)	Label (kW)	H3000	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Capacity Shorta..	py of Die: (L)	Labe (hrs)
300	200	12	300	$ 1,349,6...	450,647	$ 6,160,159	0.330	0.33	0.00	412,014	6,4...
	200	8	50	$ 206,400	591,408	$ 6,519,553	0.350	0.00	0.03	577,761	8,7...
100	210		50	$ 424,000	606,455	$ 6,897,768	0.369	0.11	0.03	548,118	8,7...
	220		50	$ 128,000	637,757	$ 6,935,912	0.371	0.00	0.01	591,811	8,7...

Figure 3. Homer simulation results.

In PV-diesel-battery system, PV and diesel generator are the electric power producing sources and the battery is the storage unit. Figure 4 shows the monthly average electric energy generation, the PV produces 601,514kWh/yr and the diesel turbine produces 1,238,134 kWh/year. Diesel generator contributed 67% and the PV array participates only 30% of the total energy production., the cash flow summary is represented in Figure 5, as shown diesel generator is the most component cost in the system includes the capital cost, the cost of replacement, o&m cost, fuel cost and salvage value, The PV-Diesel-battery system satisfy the electrical load with zero capacity shortage and low excess energy just 14.249kwh/yr.

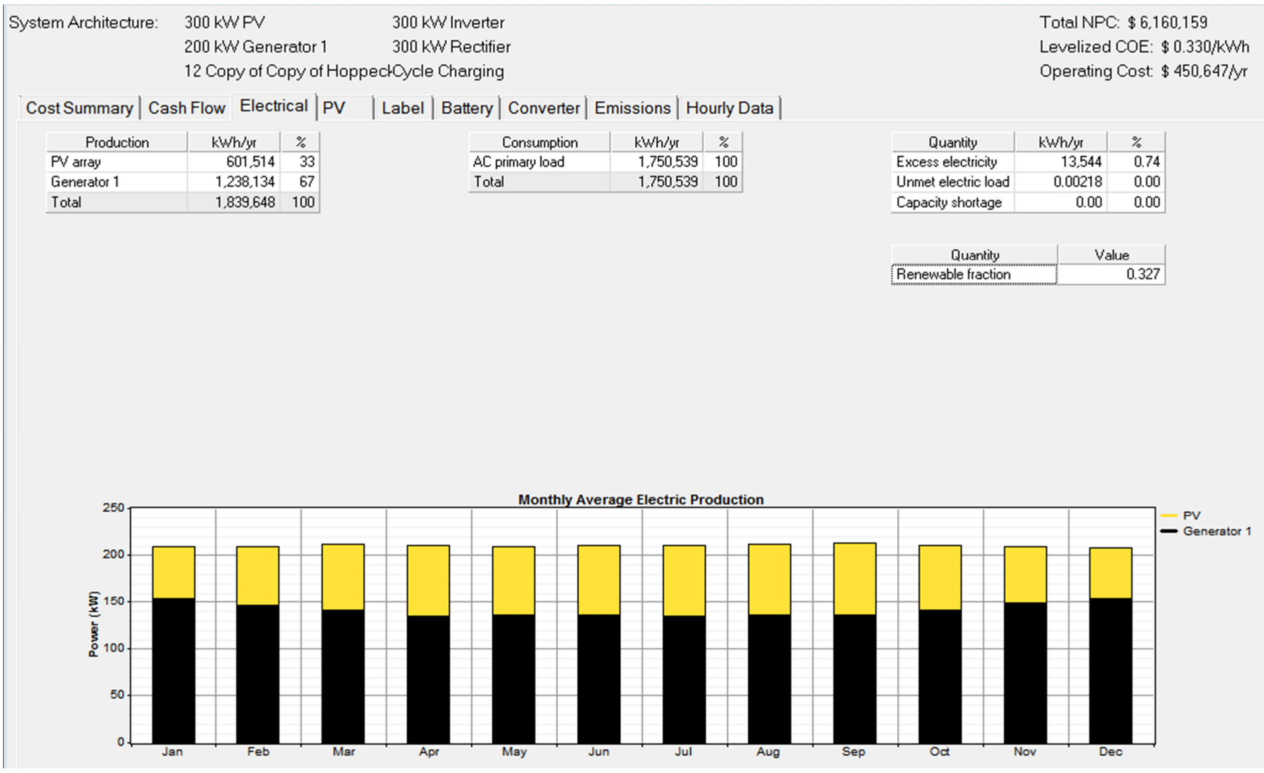


Figure 4. Monthly average electric energy production.

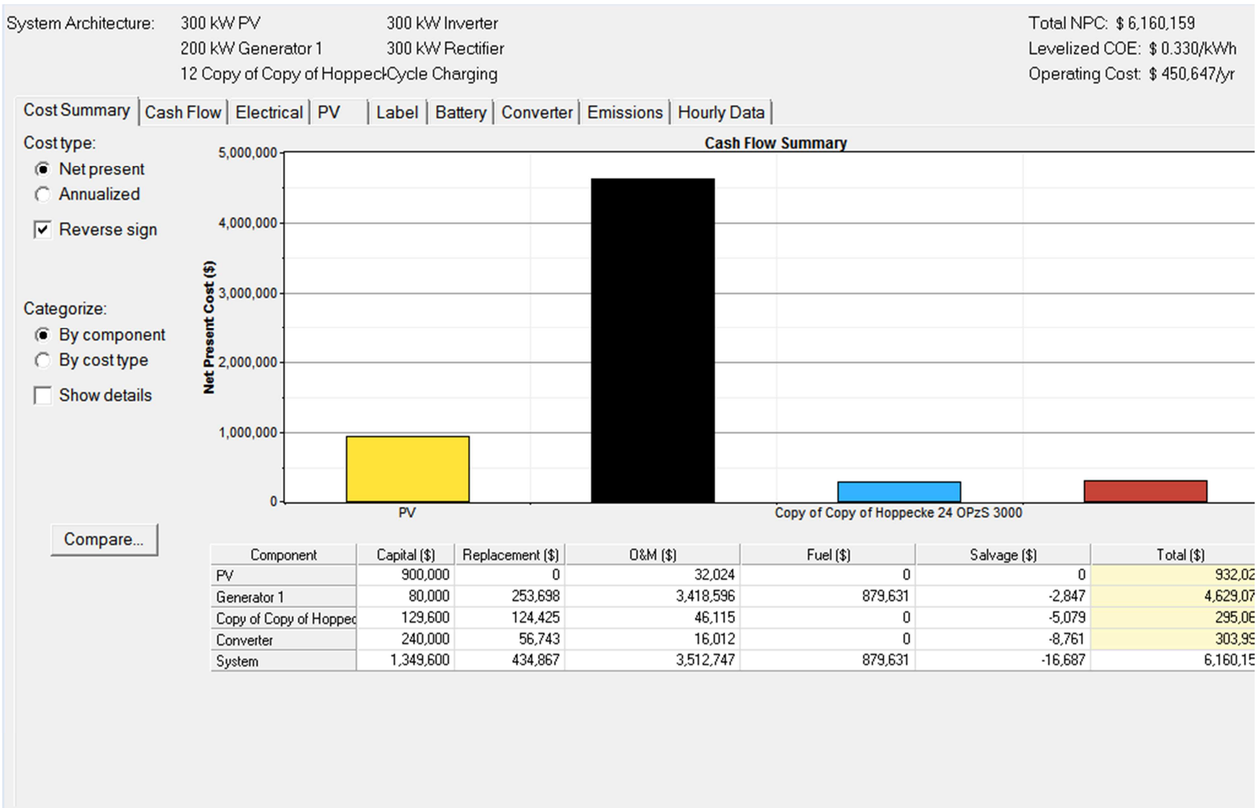


Figure 5. Cash Flow Summary of PV-Diesel-Battery System.

In diesel-battery system, the diesel generator is the only source for producing power and the battery is storage unit. The system architecture and cost analysis are illustrated in figure 6 and Figure 7, the system not produces excess electricity but has capacity shortage 3.01% this means a 52.625 deficit to meet the electrical load. The cash flow figure shows that diesel generator operating cost is very high; the cost of batteries is lower than the previous system as the quantity decreases as it consumes high maintenance and replacement costs.

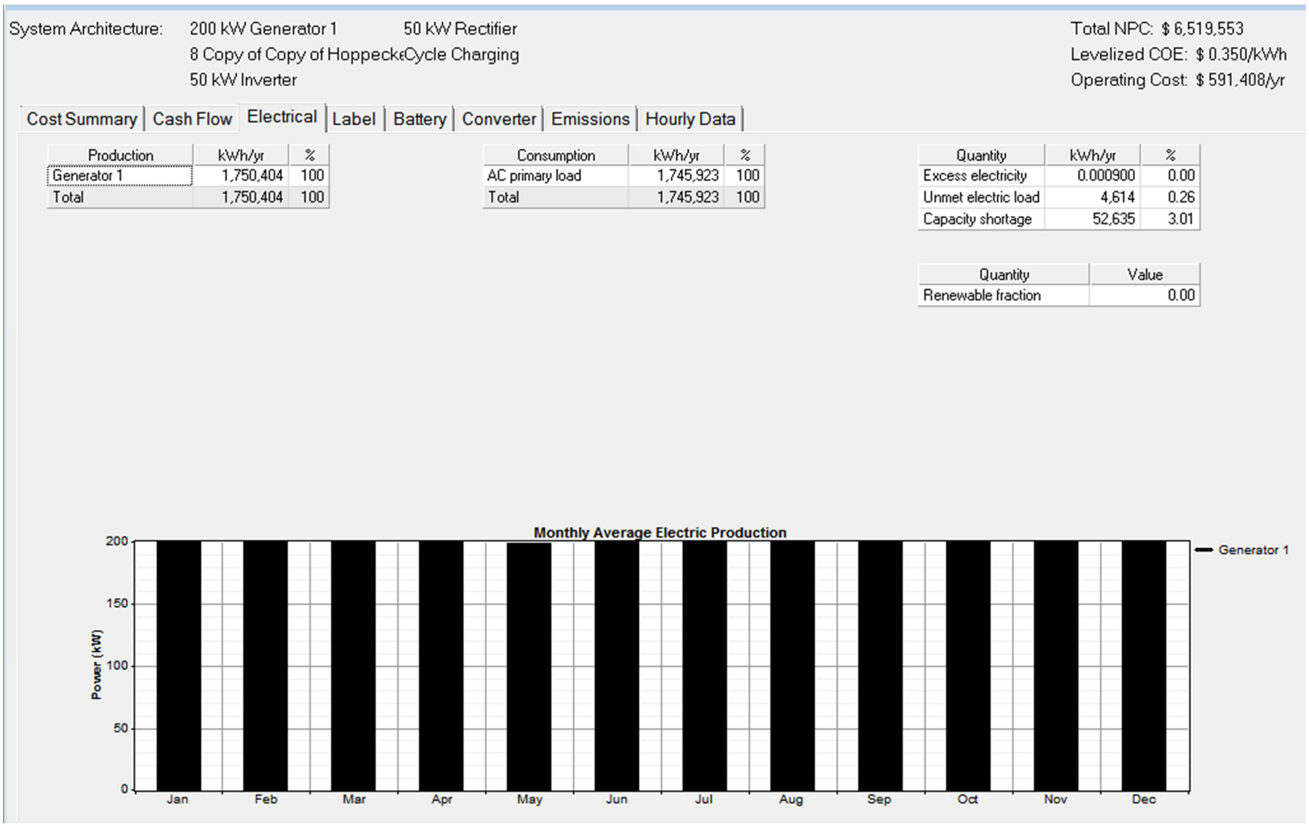


Figure 6. Monthly average electric energy production.

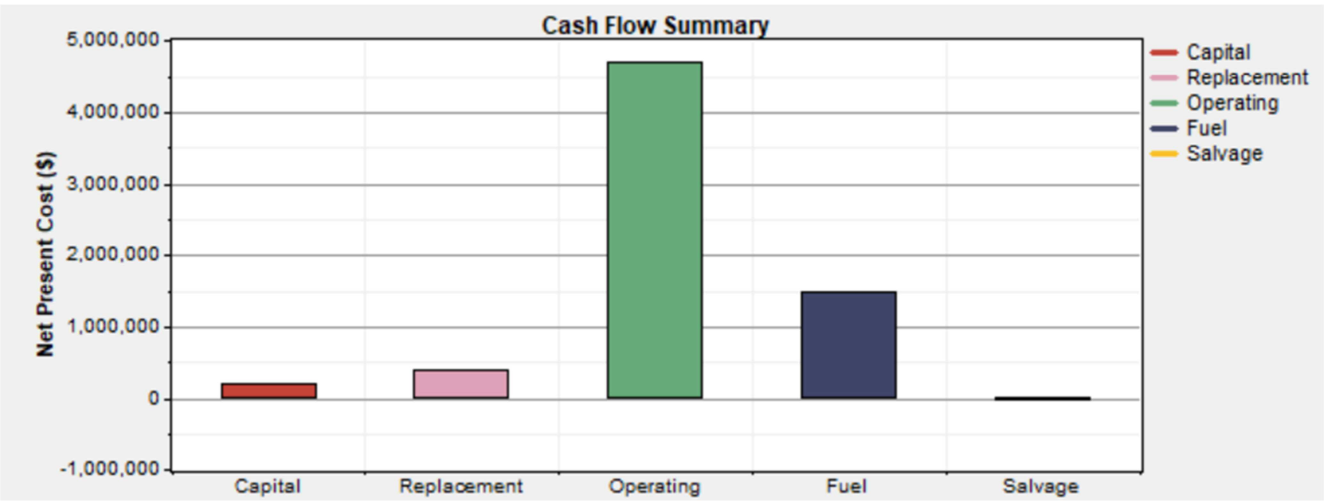


Figure 7. Cash Flow Summary of Diesel-Battery System.

In PV-Diesel system, PV and diesel generator is the electric power producing sources. As shown from figure 8, the monthly average electric energy production is presented, PV participates only 11% from load demand but diesel generator contributes 89%, there is an excess energy 37.525 kWh/yr. and capacity shortage 48.514 kWh/yr.

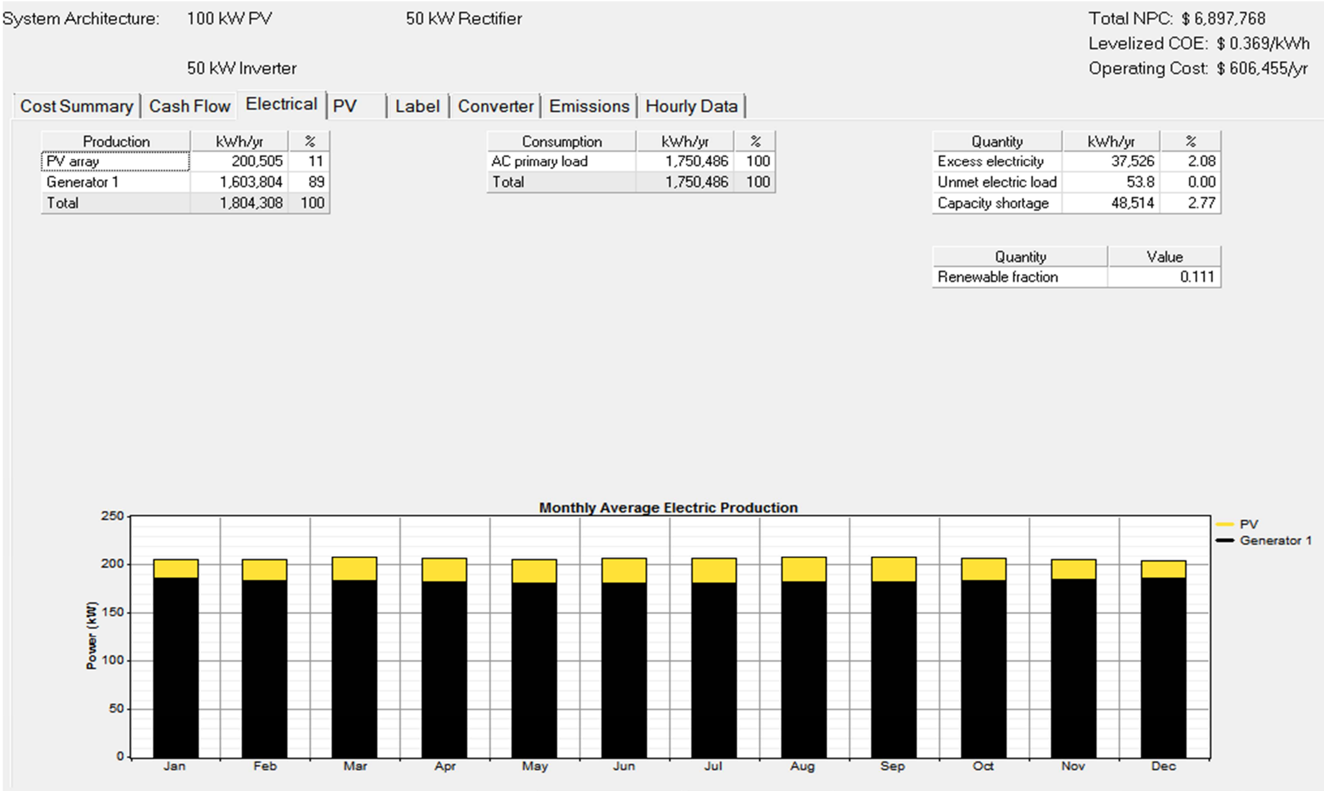


Figure 8. Monthly average electric energy production.

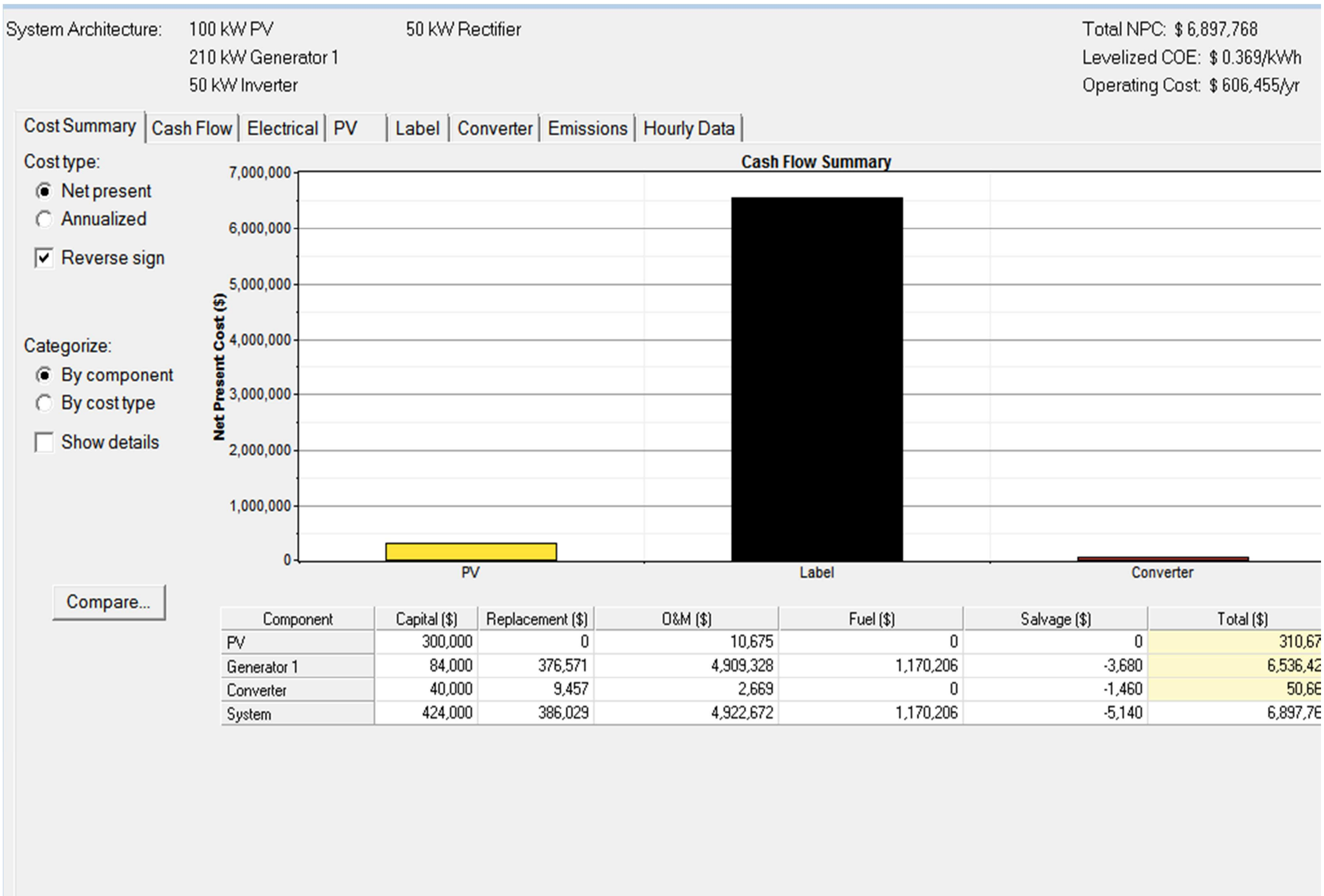


Figure 9. Cash Flow Summary of PV-Diesel System.

Figure 9 introduces cost summary of the PV-Diesel system, the cost of diesel generator is very high as it has high replacement and maintenance cost, the system is shown to be more expensive than the others systems above.

The last optimized system from the software is Diesel system, the diesel generator is the only source for producing power without battery storage. The electric and cost analysis is illuminated in figure 10 and figure 11; diesel generator has the most costly system compared to the others.

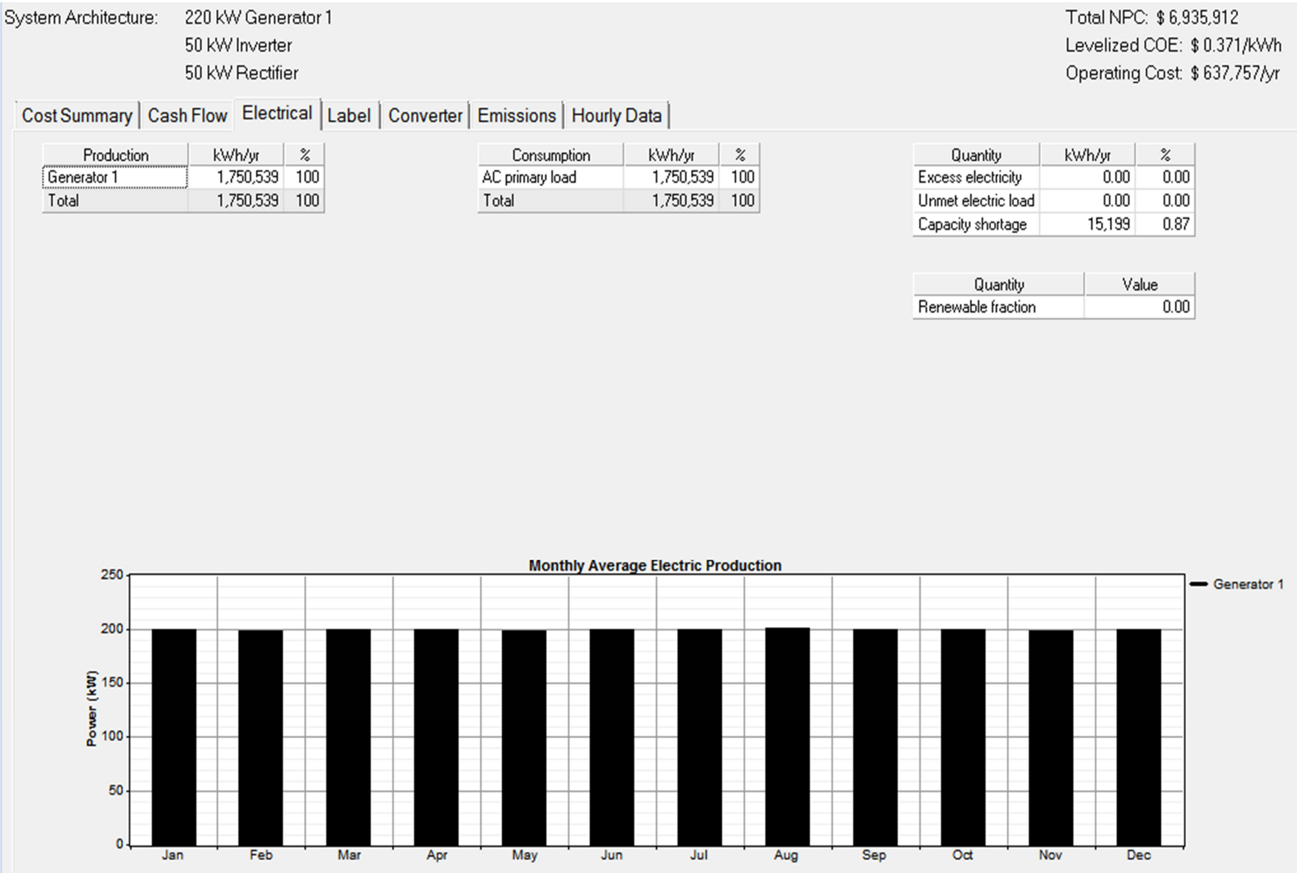


Figure 10. Monthly average electric energy production.

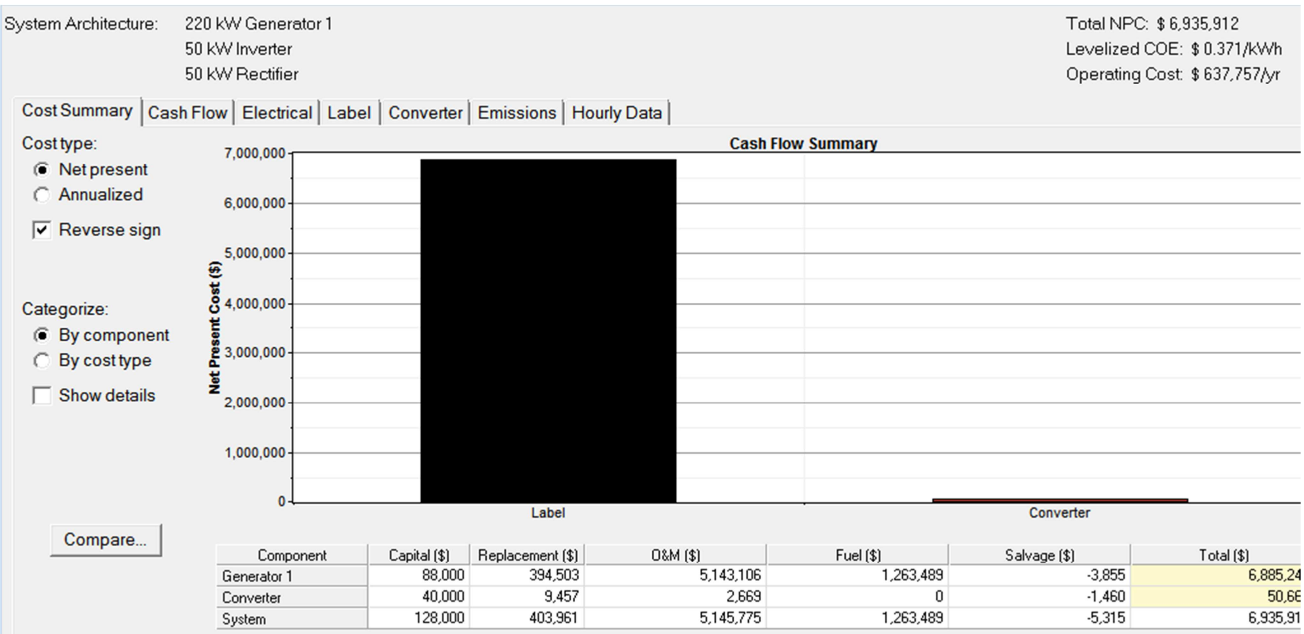


Figure 11. Cash Flow Summary of Diesel System.

7. Optimization Results

A PV-Diesel-battery based power system is economically more practicable with a minimum total NPC of $ 60.160.159 and a minimum COE of $.330/kWh. The simulation for the (PV /Diesel/battery) hybrid power system has been discussed. From results, this system can give good profit with a reasonable investment due to the amount of renewable energy generated. It utilizes almost all renewable energy with a 0.33 renewable fraction. The solar PV and diesel generator contributes 33% and 67% respectively to electricity generation. The hybrid power system solution for off-grid electricity supply to Sheikh Zayd City resulted in a least-cost combination of solar (PV/Diesel) generator and batteries. The results also show the excess energy and capacity shortage for each system, for PV-diesel battery system the excess energy contributes 13.544 kWh/y and there is no excess energy, the diesel battery system has .0039kWh/y but has a high shoratage in energy 52.625 kWh/y, in case of PV diesel system has high capacity shortage 48.512kWh/y and also high excess energy 37.525kWh/y, in case of diesel system, there is no excess energy but has a shortage 15.199 kWh/y. As obvious the PV-diesel battery system is the most fitting system from the economic point of view and also for energy savings.

8. Emissions

Table 5 show the total amount of each pollutant produced annually by the power system. Pollutants originate from the consumption of fuel. The total emissions were 1,078,221 kg/year; this has shown a considerable reduction in emission with the others systems.

Table 5. Annual Pollutants.

Pollutant	Emissions (kg/yr)
Carbon dioxide	1,084,968
Carbon monoxide	2,678
Unburned hydrocarbons	297
Particulate matter	202
Sulfur dioxide	2,179
Nitrogen oxides	23,897

9. Conclusion

This paper offered the utilization of the hybrid optimization model for electric renewable (HOMER) for designing renewable system bearing in mind energy efficiency. An arrangement of different energy technologies was simulated by the HOMER system and a combination of different configurations were achieved, with the best result which gives the least net present cost selected as the most optimized conclusion of the diverse technologies. The results showed that A PV-Diesel-battery based power system is economically more practicable with a minimum total NPC of $ 60.160.159 and a minimum COE of $.330/kWh. The annual amount of each pollutant of the system is discussed; it shows that the PV-diesel battery system is the least environment polluting system. The results also show the excess energy and capacity shortage for each system, as discussed above PV-diesel battery energy system is the least energy losses system. Finally, PV-diesel battery system is the most optimized system. Efforts must be done to reduce excess energy more and more for the PV-diesel battery system, also hybrid energy system must be the most used systems for remote areas that have a shortage in fossil fuels and have abundance in renewable energy.

References

[1] S. Alayan, "Design of a PV-Diesel Hybrid System with Unreliable Grid Connection in Lebanon", Master Level Thesis European Solar Engineering School, 2016.

[2] Sophia Alayan, "Design of a PV-Diesel Hybrid System with Unreliable Grid Connection in Lebanon", Master thesis, 2016.

[3] K. Y. Lau, M. F. M. Youssef, S. N. M. AR shad, M. Anwari. A. H. M. Yatim, "Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions", Energy journal, PP. 3245-3255, Vol. 35.

[4] M. Usman, M. T. Khan, A. S. Rana, S. Ali, "Techno-economic analysis of hybrid solar-diesel-grid connected power generation system", Journal of Electrical Systems and Information Technology, 2017, PP. 1-10.

[5] Thomas Hillig, 2016, Hybrid Power Plants. Th-energy.net.

[6] S. Mandal, H. Yasmin, M R I Sarker and M R A Beg, "Prospect of Solar-PV/Biogas/Diesel Generator Hybrid Energy System of an Off-Grid Area in Bangladesh", AIP Conference Proceedings 1919, 2017, PP. 1-8.

[7] Hybrid power plants (wind- or solar-diesel, 2015), https://www.th-energy.net/english/platform-renewable-energy-and-mining/hybrid -power-plants/.

[8] Mustafa E. Amiryar and Keith R. Pullen, "A Review of Flywheel Energy Storage System Technologies and Their Applications", Applied Sciences Journal, 2017, PP. 1- 21.

[9] T. Tahri, A. Bettahar, and M. Douani, "Optimization of a Hybrid Wind-Pv-Diesel Standalone System: Case Chief Algeria", International Journal of Mathematical, Computational, Physical, Electrical and Computer Engineering, 2013, PP. 108-111, Vol. 7.

[10] https://en.wikipedia.org/wiki/Sheikh_Zayed_City,2018.

[11] NASA, Surface Meteorology and Solar Energy, (2016). file:///D:/New%20folder/dr%20mostafa%20exam/NASA%20 Surface%20meteorology%20and%20Solar%20Energy%20-%20Available%20Tables.htm.

[12] Feldman D, Barbose G, James T, Weaver S, Fu R, Davidson C. (2014). Photovoltaic system pricing trends. http://www.nrel.gov/docs/fy14osti/62558.

[13] F. Diab, "An Environmentally-Friendly Tourist Village in Egypt Based on a Hybrid Renewable Energy System—Part One: What Is the Optimum City?", energies journal, 2015, PP 6926-6944.

[14] World Petrol Prices. China. (2015). http://www.mytravelcost.com/pet roll-prices/.

[15] Alibaba. Alibaba Group, 2015, http://wwwalibabacom/.

[16] I. Mrčela, D. Sumina, F. Šašić, T. Bariša, "A wind turbine two level back-to-back converter power loss study", 2016 IEEE International Power Electronics and Motion Control Conference (PEMC), 2016, pp. 308-314.