International Journal of Sustainable and Green Energy
2015; 4(2): 30-39
Published online March 14, 2015 (http://www.sciencepublishinggroup.com/j/ijrse)
doi: 10.11648/j.ijrse.20150402.12

Cost optimization of hybrid stand-alone power system for cooled store in Kirkuk

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To cite this article:
Sameer Saadoon Al-Juboori, Ali Hlal Mutlag, Ehsan Fadhil Abbas Al-Showany. Cost Optimization of Hybrid Stand-Alone Power System for Cooled Store in Kirkuk. *International Journal of Sustainable and Green Energy.* Vol. 4, No. 2, 2015, pp. 30-39.
doi: 10.11648/j.ijrse.20150402.12

Abstract: However, the design, control, and optimization of the hybrid systems are usually very complex tasks; the stand-alone hybrid solar–diesel power generation system is recognized generally more suitable than systems that only have one energy source for supply of electricity to off-grid applications. A proposed PV system has been designed and optimized using HOMER software computer model to supply a potato cooled store in Kirkuk city in Iraq. The result obtained from the optimization gives the cost of energy (COE) is 0.639 US$/kWh with 2axis trucking system and 0.692 US$/kWh with no trucking system. Energy cost is 0.796 US$/kWh when the load is supplied by the diesel generator alone.

Keywords: Homer, Stand Alone, Hybrid, Kirkuk, Off-Grid, Trucking

1. Introduction

Alternative energy resources such as solar and wind have attracted energy sectors to generate power on a large scale. A drawbacks common to wind and solar options, is their unpredictable nature and dependence on the weather and climatic changes, and the variations of solar and wind energy may not match with the time distribution of demand [1]. One of the major worldwide concerns of the utilities is to reduce the emissions of traditional power plants by using renewable energy and to reduce the high cost of supplying electricity for remote areas. Hybrid power systems can provide a good solution for such problems because they integrate renewable energy along with the traditional power plants. Renewable energy is defined as the energy generated from natural resources such as sunlight, wind, rain, and geothermal heat, which are renewable. Hybrid power systems usually integrate renewable energy sources with fossil fuel based generators to provide electrical power. They are generally independent of large electric grids which are used to feed loads in remote areas. Hybrid systems offer better performance, flexibility of planning and environmental benefits comparing to the diesel generator based stand-alone system. Hybrid systems also give the opportunity for expanding the generating capacity in order to cope with the increasing demand in the future. Remote areas represent a big challenge to electric power utilities. Hybrid power systems provide an excellent solution to this problem as one can use the natural sources available in the area e.g. the wind and/or solar energy and thereby combine multiple sources of energy to generate electricity [2-4]. The optimal design of hybrid renewable power systems is usually defined by economic criteria. But there are also technical and environmental criteria to be taken into an account to improve decision-making. In this paper a discussion on different criteria will introduce the non-economical perspectives in addition to the economic criteria [5,6]. Besides of the shortage supply, the combining power generation with fossil fuels has also harmed environment through the emissions of greenhouse gases (GHG) and other pollutants. Renewable energy can play an essential role in mitigating the ongoing shortage supply and achieving the ultimate goal of replacing fossil fuels with emission free power generation [7, 8].

2. Homer Algorithm Package

HO HOMER is a computer model that simplifies the task of evaluating design options for both off-grid and grid-connected power systems for remote, stand-alone, and distributed-generation (DG) applications.

HO HOMER's optimization and sensitivity analysis algorithms allow one to evaluate the economic and technical feasibility of a large number of technology options and to account for variation in technology costs and energy resource availability for both conventional and renewable-energy technologies [4]. HOMER models a power system's physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. It allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs. [9]

3. Optimal Size of the Proposed System Using HOMER

Potato is one of the most important food crops in Iraq. The objective of the study in [10] is to establish (19×11×6) m cooled store to save 300 tons of potato crop in Kirkuk city in Iraq and to identify cooling load necessary to keep the crop fresh. The daily estimated consumption of potato in this city is 15 tons.

The aim of this paper is to design a hybrid power system to supply the cooled store.

The system consists of; PV modules, diesel generator, batteries, charge controller, inverter, and the necessary wiring and safety devices. The system feasibility analysis was performed using the HOMER software.

4. The Hybrid System Model

In order to design stand-alone renewable hybrid power systems, there are four main aspects to be considered:

- the demand/load characterization,
- the potential of renewable and conventional energy generation,
- the restrictions of the system, and
- the optimization criteria.

The optimization criteria considered are mainly economic aspects: Net Present Cost (NPC) and Cost of Energy (COE) typically. Also technical variables and environmental factors define the configuration of the system and consequently its performance and viability. Various aspects must be taken into account when working with stand-alone hybrid systems for generation of electricity. Reliability and cost are two of these aspects; it is possible to confirm that hybrid stand-alone electricity generation systems are usually more reliable and less costly than systems that rely on a single source of energy [11-14]. It has been proven that hybrid renewable electrical systems in off grid applications are economically viable, especially in remote locations [15-19]. In addition, climate can make one type of hybrid system more profitable than another type. For example, photovoltaic hybrid systems (Photovoltaic–Diesel–Battery) are ideal in areas with warm climates [20].

4.1. Load Profile

The load profile of the cooled store in Kirkuk city is shown in Figure 1. The total daily average load is 667 kWatt-hours [10].

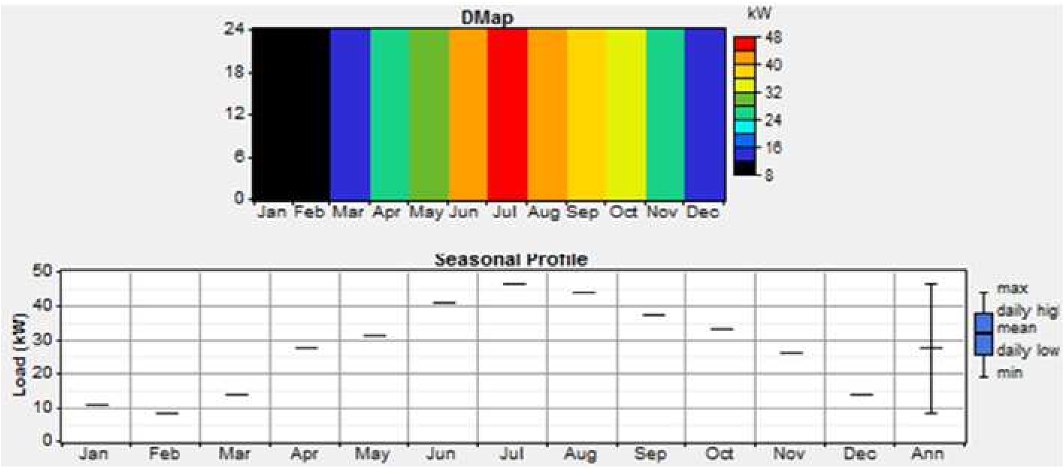


Figure 1. *The Load Profile.*

4.2. System Equipment Configuration

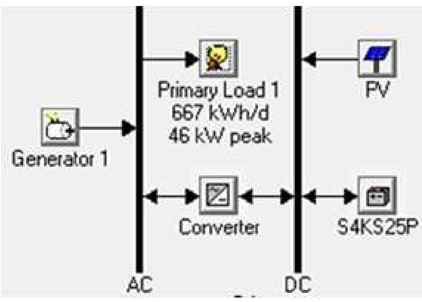


Figure 2. *The equipments considered in the optimization design.*

Figure 2 shows the considered equipments in the optimization. They're photovoltaic solar cells, converter, battery bank and loading system.

4.3. Solar Data

Solar inputs data for HOMER are taken as monthly averaged daily insolation incident on a horizontal surface (kWh/m^2/day) from NASA's Surface Meteorology, NASA gives average values over a 22 year period[21].The solar insolation is taken for 35º 28Nlatitude and44º 23Elongitude of the proposed site in Kirkuk city in Iraq. Figure 3 shows the solar resource profile over one year.

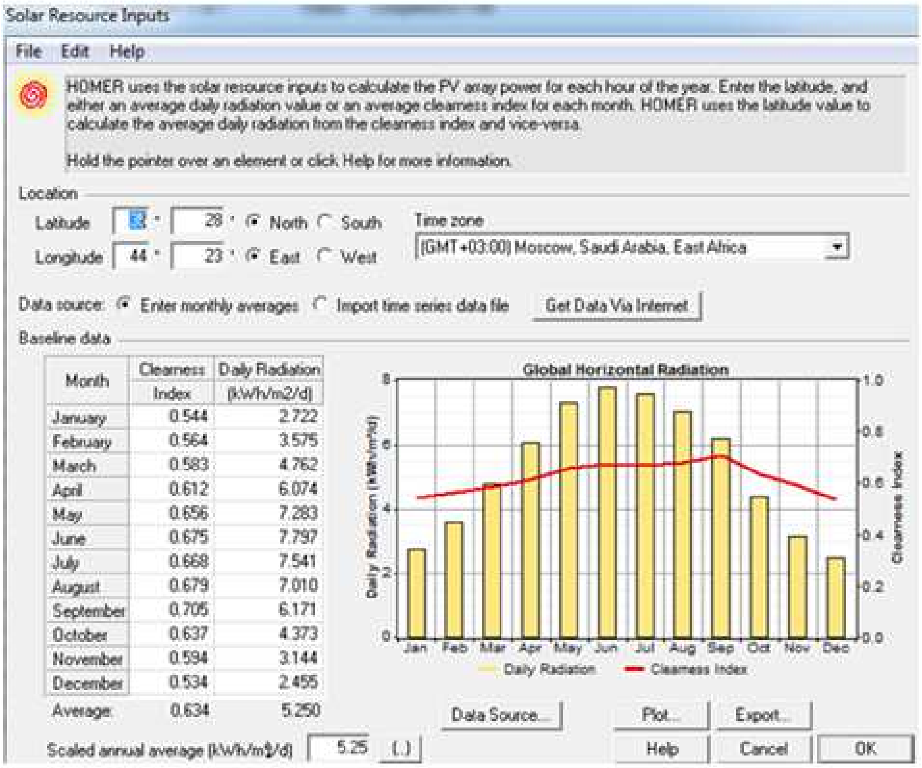


Figure 3. *Solar Resources Profile.*

4.4. PV Array Data

The PV array capital and replacement costs were specified with 16000 US$ and 15000 US$, respectively. Maintenance cost was considered for the panels around 1000 US$/yr. A derating factor of 80% and 20 years lifetime was considered as shown in Figure 4.

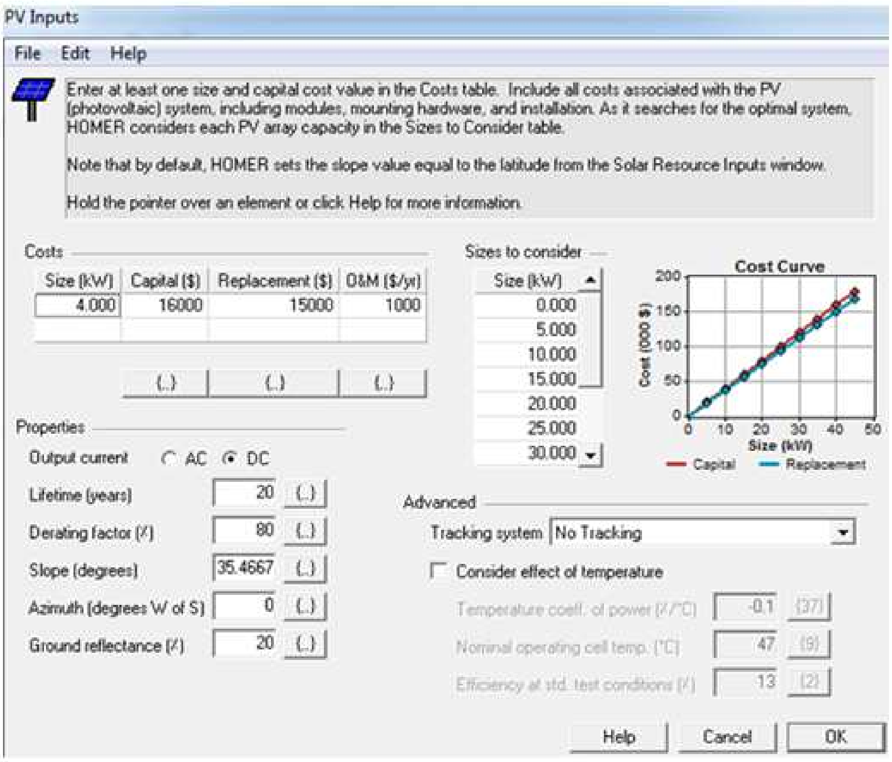


Figure 4. *PV array data.*

4.5. Battery Storage

The battery chosen is the Surrette4ks25p series. It has a nominal voltage of 4V and nominal capacity of 1900Ah (2.4 kWh). Each string consists of 3 batteries in series to get 12V DC. Batteries specifications and data were shown in Figure 5.

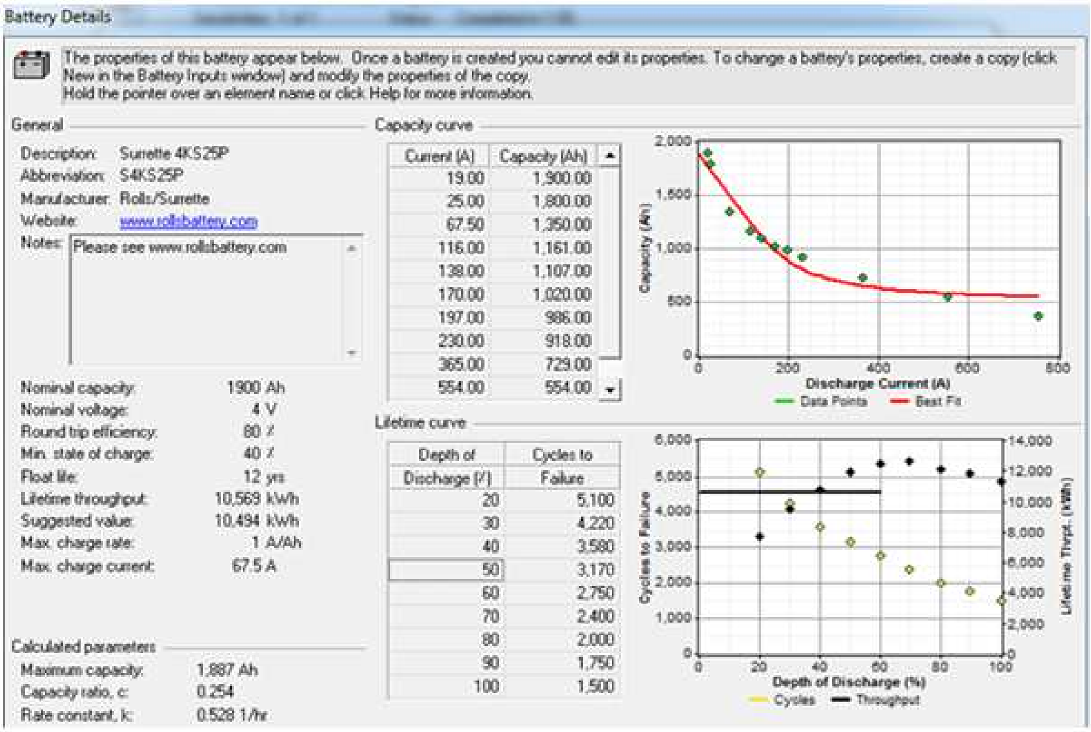


Figure 5. Batteries specifications and data.

4.6. Converter

The inverter and the rectifier efficiencies were assumed to be 90% and 85% respectively for all the considered sizes considered. The considered sizes varied from 0 kW to 50kW. The converter inputs are shown in Figure 6.

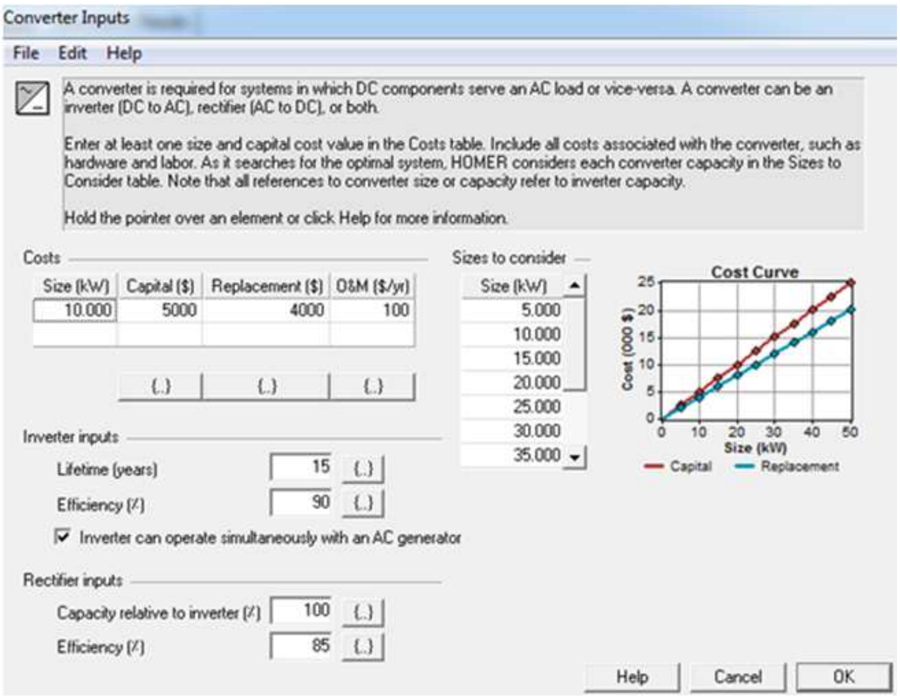


Figure 6. The converter input data.

5. Hybrid System Controller

Using homer software which was gives three study cases which were implemented considering trucking system type effects.

5.1 Case One: No Tracking System

The simulation overall results in case of no tracking system is shown in Table 1.The optimum total net present cost NPC and the cost of energy unit COE are 2,154,920$ and 0.692 $/kWh respectively. Categories can be shown by system components, cost types and in details. Figure 7 shows the optimal simulation results by components.

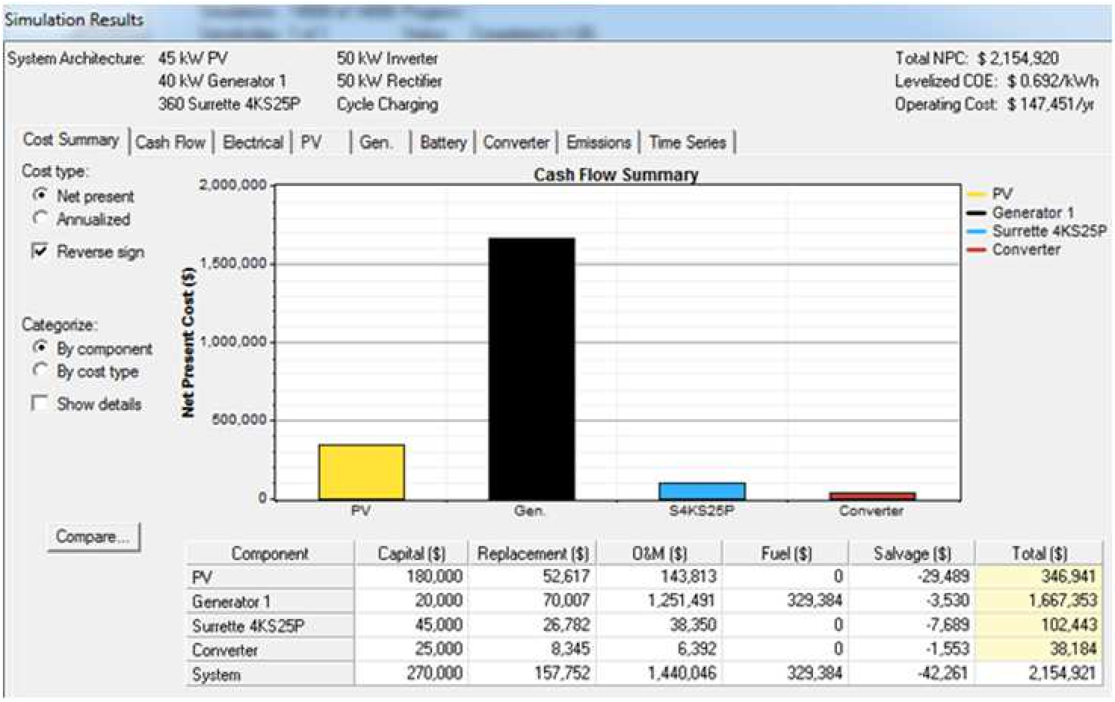


Figure 7. *The optimal simulation results by components.*

Table 1. *The simulation overall results in case of no tracking system.*

PV	Gen. [kW]	Batteries	Conv. [kW]	Initial Capital	Operating Cost[$/yr]	Total NPC	COE [$/kWh]	Ren. Frac.	Diesel [L]	Gen. [hrs]
45	40	360	50	270.00	147.451	2154920	0.692	0.20	64416	4895
45	40	360	50	267.5	149.051	2172876	9.688	0.20	64530	4973
40	40	360	50	250.0	151.052	2180954	0.701	0.17	67060	5083
40	40	360	50	247.5	152.385	2195497	0.705	0.17	67201	5148
35	40	360	50	230.0	155.047	2212023	0.711	0.13	69800	5288
35	40	360	50	227.5	155.434	2214466	0.711	0.13	69805	5311
45	45	126	50	243.25	154.957	2224347	0.715	0.18	66912	4751
30	40	360	50	207.5	157.919	2226232	0.715	0.10	72005	5455
45	45	360	50	272.5	153.109	2229749	0.716	0.18	66397	4559
40	45	126	50	223.25	157.219	2233033	0.717	0.15	69461	4863
30	40	360	50	210.00	158.261	2233105	0.717	0.10	72124	5464
45	45	117	50	242.125	156.299	2240146	0.720	0.18	67164	4807
40	45	117	50	222.125	158.257	2245177	0.721	0.15	69585	4909
35	45	126	50	203.25	159.882	2247078	0.722	0.11	72033	4992

The production percentage from PV array and diesel generator is 28% and 72% respectively. Figure 8 shows the production details. Daily generator output is shown in Figure 9.

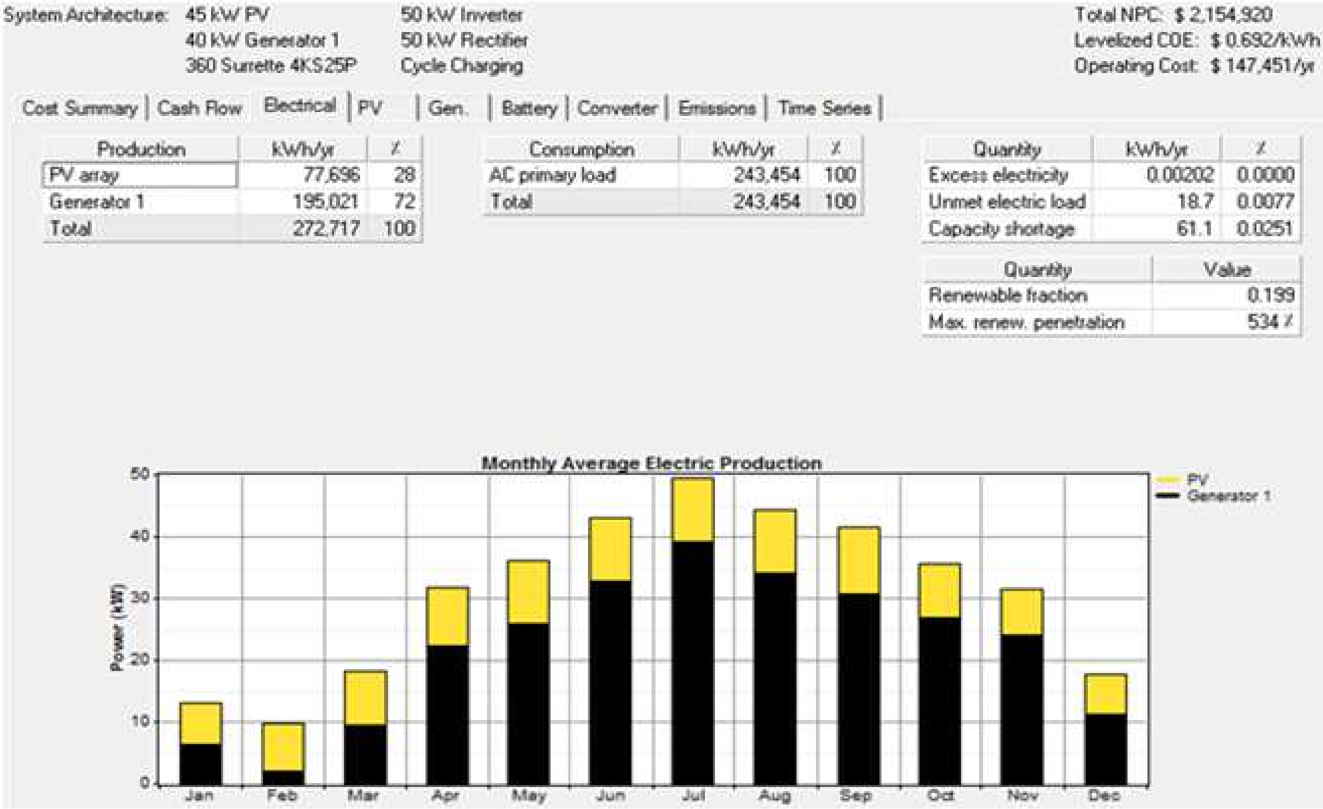


Figure 8. *Case study1 production details.*

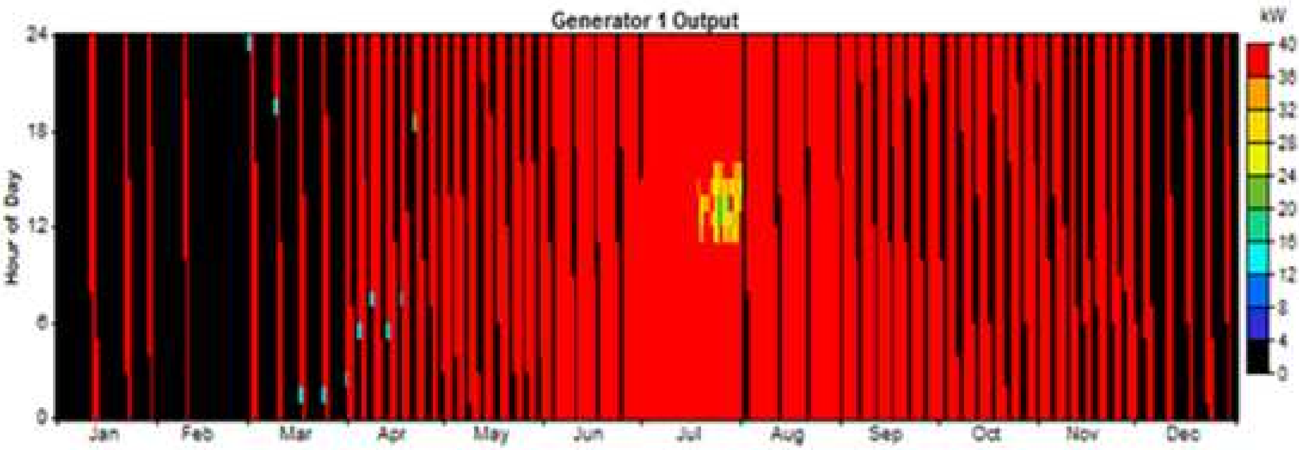


Figure 9. *daily generator output.*

Daily convertor output and batteries state of charge are shown in Figure 10.

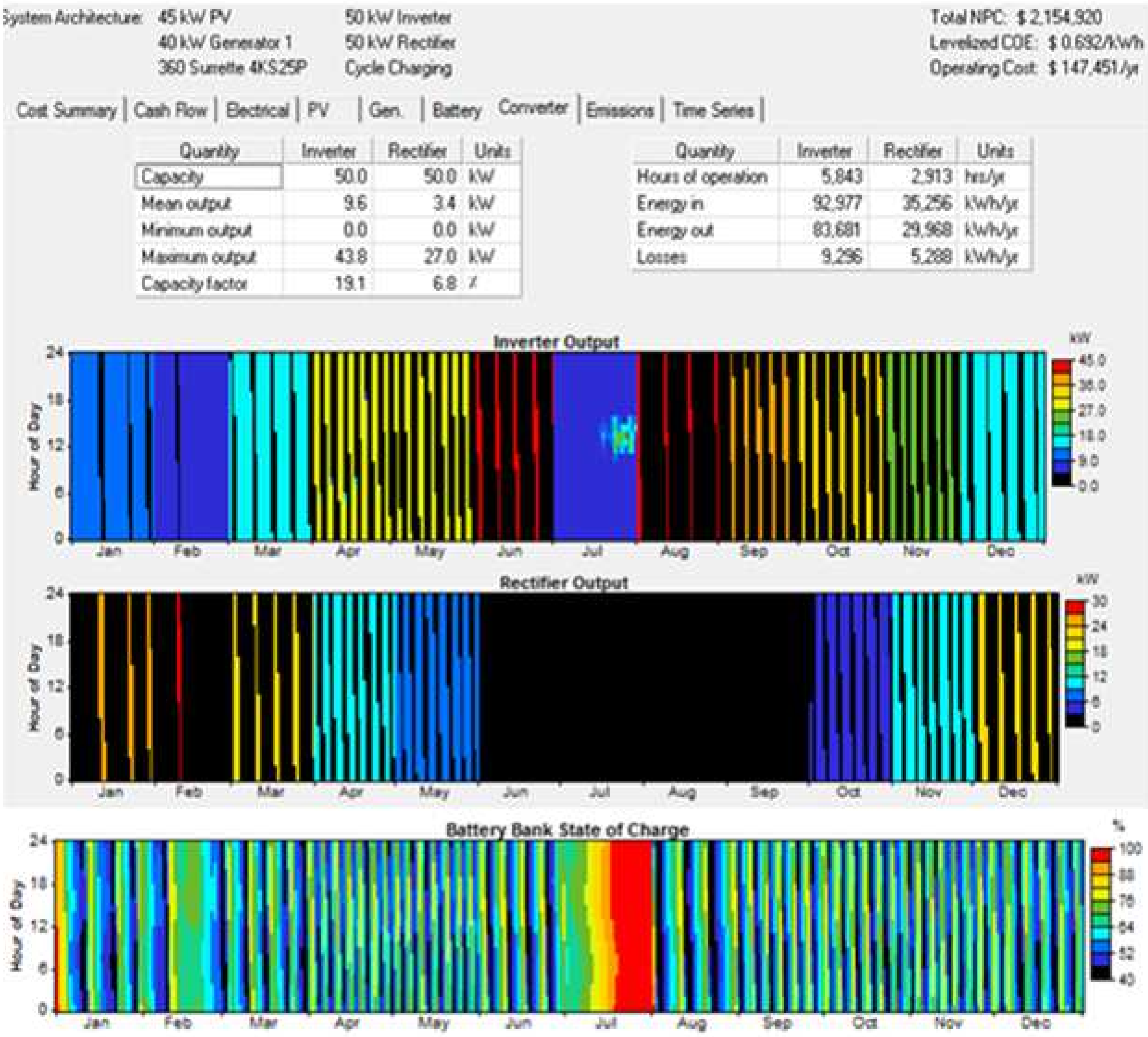


Figure 10. *Convertor daily output and batteries state of charge.*

To understand how friendly environment is our system in case study 1, the important pollutants were calculated. The emissions in kg/yr are shown in Table 2.

Table 2. *The most important pollutants in kg/yr.*

	Emission [kg/yr]
Carbon dioxide	169630
Carbon monoxide	419
Unburned hydrocarbons	46.4
Particulate matter	31.6
Sulfur dioxide	341
Nitrogen oxides	3736

5.2 Case Two: Two Axis Tracking System

Sun tracking is one of the methods which can boost the total collected energy from sun by 10-100%. Sun tracking systems move the solar panel based on hourly and seasonal movement of the sun in order to absorb the highest possible amount of energy [22].Table 3 shows the simulation overall results in case of two axis tracking system effects. The optimum total net present cost NPC and the cost of energy unit COE are 1,9888,411$ and 0.639 $/kWh respectively. Using two axis tracking system increased PV percentage electric production from 28% to 35%as shown in Figure 11.This result will reduce CO_2 emission.

Table 3. *The simulation overall results in case of two axis tracking system.*

PV	Gen. [kW]	Batteries	Conv. [kW]	Initial Capital	Operating Cost[$/yr]	Total NPC	COE [$/kWh]	Ren. Frac.	Diesel [L]	Gen. [hrs]
40	40	126	50	220750	138278	1988411	0.639	0.26	60221	4748
	50	117	50	64625	188778	2477842	0.796	0.00	92760	5660

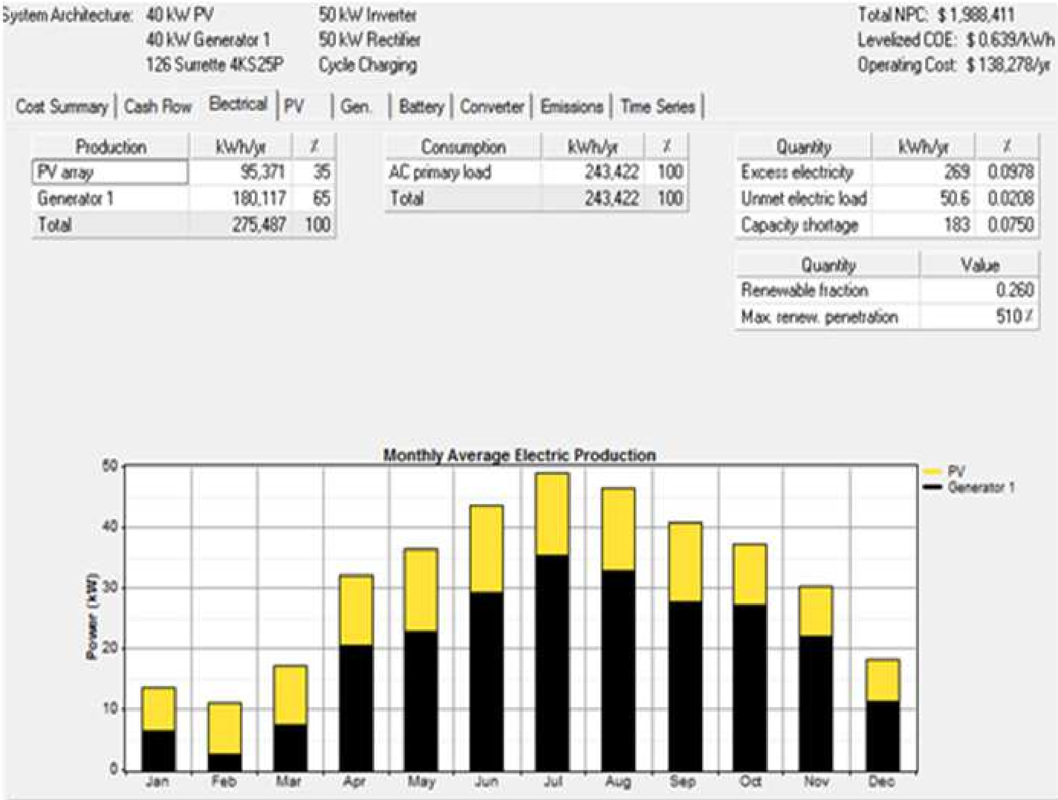


Figure 11. Case study2 production details.

5.3. Case Study Three: Power supplied by Diesel Generator

The optimum total net present cost NPC and the cost of energy unit COE are 2,477,843$ and 0.796 $/kWh respectively. Figure 12 and 13 show the monthly electric generation and the optimal simulation results by components respectively.

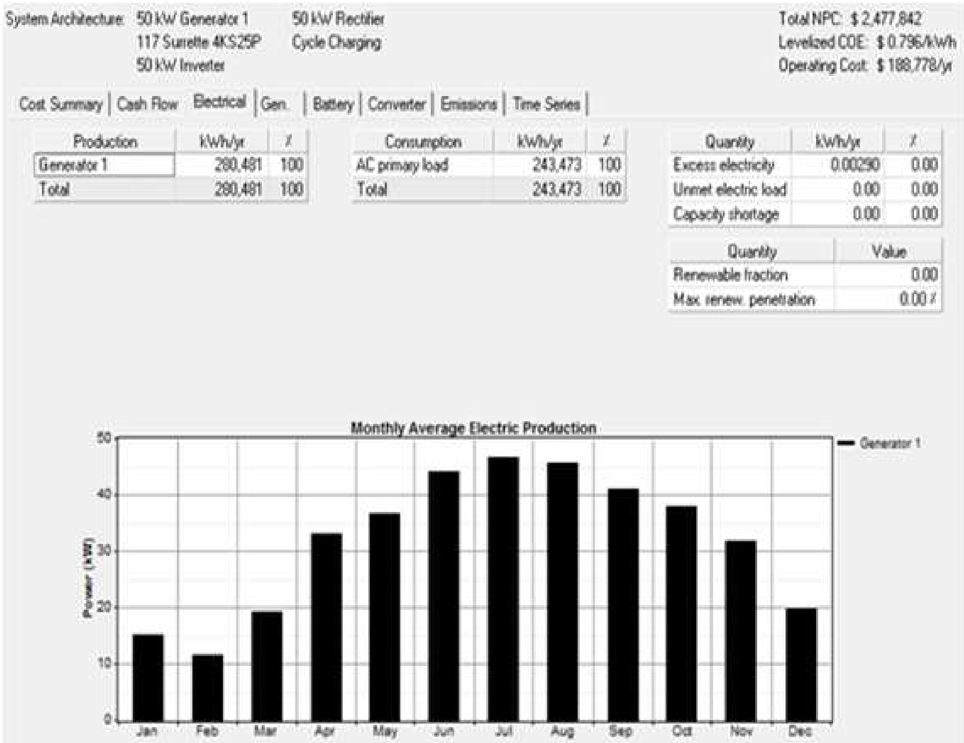


Figure 12. the monthly electric generation

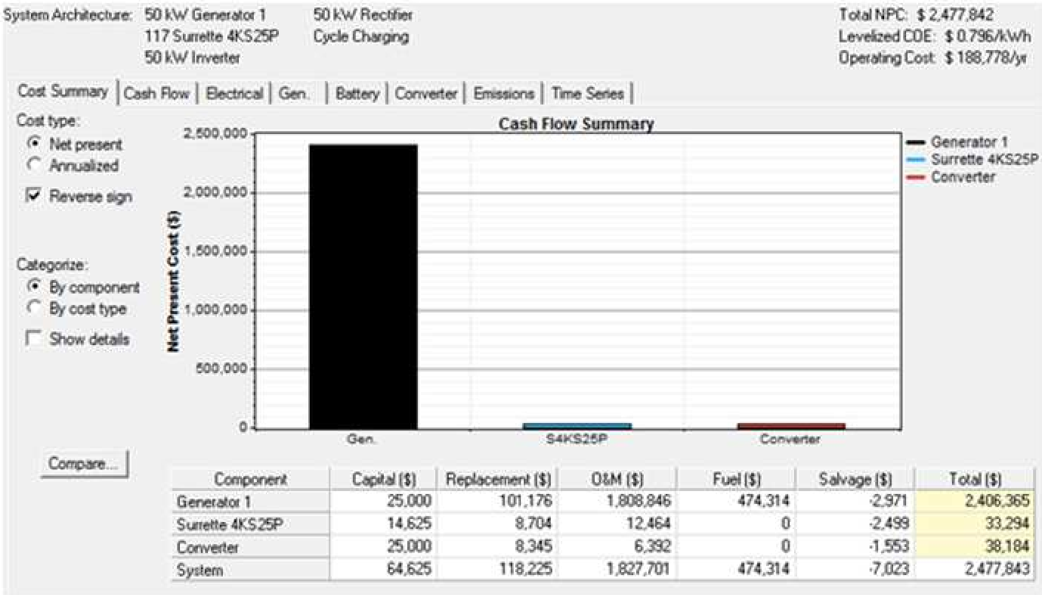
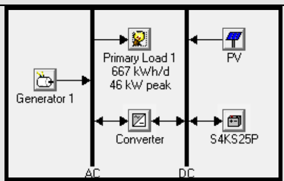
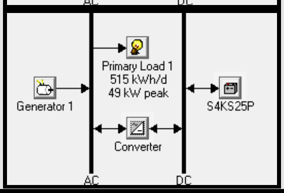


Figure 13. *Case study 3 optimal simulation results by components.*

Total net present cost, cost of energy unit, CO2 emission and percentage of electric production for all studied cases are summarized in Table 4.

Table 4. *Total net present cost, energy unit cost and CO2 emission for all studied Cases.*

Case	Description	Power System Diagram	Total Net Present Cost[$]	Cost of Energy COE [$/kWh]	CO_2 Emission [kg/y]	Production Percentage PV%	Generator %
1	Power supply: Hybrid. Tracking sun: No trucking system.		2,154,920	0.692	169,630	28	72
2	Power Supply: Hybrid. Tracking sun: Two axis trucking system.		1,988,411	0.639	158,580	35	65
3	Power Supply: Diesel Generator.		2,477,842	0.796	244,268	0.0	100

6. Conclusions

The stand-alone hybrid solar power generation system is recognized as a viable alternative to conventional fuel-based remote area power supplies. It is generally more suitable than systems that only have one source of energy for supply of electricity to off-grid applications. All the optimization systems are ranked according to net present cost. All other economic outputs are calculated for the purpose of powering the store and finding the best net present cost.

Results shows that the initial capital cost depends on the size of the PV panel, the number of the batteries used and the size of the converter.

Sun tracking is one of the methods which can boost the total collected energy from sun.

In Table 4, case studies 1&2 show that PV electric production increased by 7% and CO2 emissions decreased by 6% when using 2 axis sun tracking system.

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