A Comparative Study of on and off Grid Tied Integrated Diesel Solar PV Generation System

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Abstract- This paper presents a proposed hybrid system based on diesel generator and solar photovoltaic (PV) as an effective option to power a small remote community. The cost of running diesel generator speedily due to erratic power supply in a small remote community that is not grid connected is highly expensive and not environmentally friendly. A solar PV was used to reduce or augment the continuous diesel generator sets, resulting in reduced cost of operation and maintenance. A proper solar radiation data and sizing based on the specification of the PV system and battery bank was done. In addition, a comparative study was carried out considering two scenarios of the proposed model system. In the first scenario, the diesel generation, solar PV system was treated as autonomous (or standalone). In the second scenario, the proposed model system was connected to the grid system. It is discovered that powering the small remote community with the proposed hybrid system is much more beneficial and encourages competition with other conventional energy sources, because it minimizes both operating costs and pollutants emissions. Furthermore, analysis results obtain from HOMER software shows that is promising to implement the on-grid system.

Keywords- Renewable Energy; HOMER; Grid system; Solar PV; Efficiency; Battery

1. Introduction

The importance of energy system cannot be overemphasized in modern life style. Most often, there is epileptic power supply to maintain the population and economic growth of developing countries. Also diesel generators are the most used type of power generation in these countries, thus, it is imperative to augment the expensive diesel generation of power with renewable energy. Solar energy is one of the most promising of the renewable energy sources in light of unlimited potential energy. The sun's energy radiation is at a rated value of 3.8x1023kW per second [1-4], and a square meter of the platform of the earth can receive up to 1kW of solar power. However, radiation intensity from solar energy is weak compared with the high energy concentration volume of diesel fossil fuel power supply. One of the most common methods of achieving solar PV radiation to power supply is the use of silicon solar cells made in modules that are connected in a base plate electrically [3, 4, 5, 6].

On the other hand, the cost of fossil fuel based electricity generation in the long term is increasing and the costs of production of renewable energy technologies decreasing due to optimized construction and efficiency improvement. Reliability and costs are two different important aspects that must be taken into account when working with standalone-hybrid system for electricity generation. Recently studies shows that, the hybrid standalone system are better in terms of reliability and cost than single source of energy supply [7, 8 and 9]. Due to optimized construction and efficiency improvement, renewable electrical systems in off grid application are economically viable, especially in remote areas [10-13].

In light of the above, this work is proposing a solar photo voltaic (PV) renewable energy integration to an existing expensive constant speed diesel generation powering a small remote community. This will not only help reduce the cost of running the present expensive diesel generation system, but also provide reliability of power supply to the remote community with little or no emission of carbon or other contents, hence improving the greenhouse effect. Furthermore, an analysis of connecting the diesel PV-battery integrated system in a grid was compared with an off grid system. The hybrid optimization model for electric renewable (HOMER) software environment was used in carryout this study.

2. Description of the Model Systems

Figures 1-3 respectively show the model systems of this work. In Fig. 1, the diesel fueled generator of size 50kW was used to power the small remote community alone and in Fig. 2, the solar PV of size 50kW connected to the dc busbar was introduced and the size of the diesel generator was reduced to 30kW. Fig. 3 shows that the diesel generator, solar PV battery system was connected to the grid. All systems were used to power the small remote community whose load profile is shown in Fig. 4 with 265kWh/day and 41kW peak.

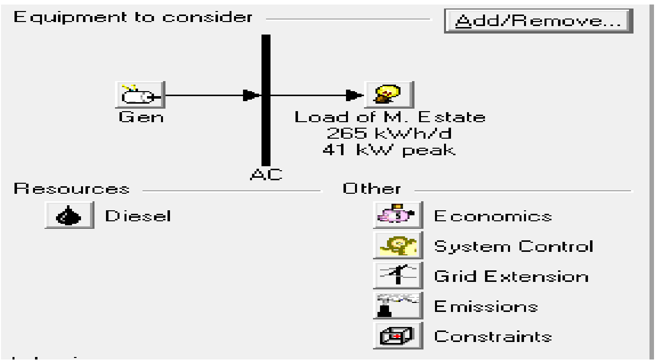


Fig. 1. Model System with only Diesel Generator

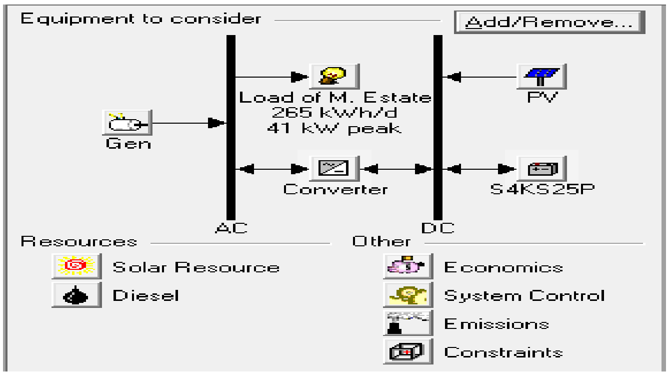


Fig. 2. Model System with Diesel Generator and solar PV

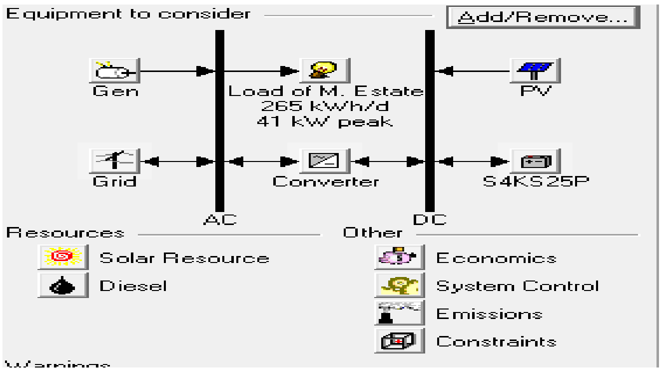


Fig. 3 Model System with Diesel and solar PV Connected to Grid

The combined output power of diesel generation and PV solar system is slightly higher than the demand in the small remote community load profile to accommodate expansion as more buildings may spring up. Details of the parameters of the various components used in the model system are shown in Appendix of this work.

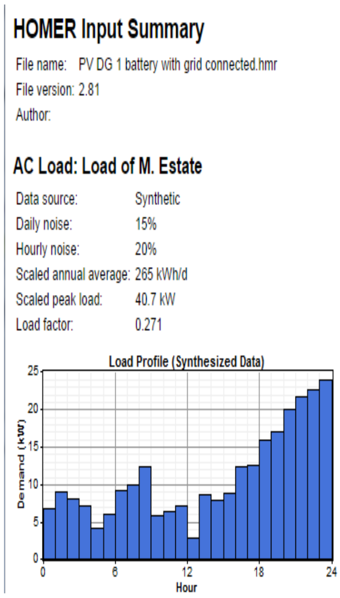


Fig. 4. Load Profile of the Small Remote Community

2.1 The Solar System

The power produced from the solar PV renewable energy source is dc, from the panels which then goes through a grid interactive inverter, thereby converting the dc into ac used by housing utilities in the small remote community. In scenarios where more power or electricity is produced than the small remote community needs; the excess is fed into the grid system as shown in Fig.3. However, during times of low solar radiation with low generation from the solar PV to augment the supply from the diesel generator to the community demand, the small remote community would take power from the grid. Thus, the grid interactive system eliminates the need for a battery backup during low PV output [14, 15], making the grid serves as a battery.

The power generated by the solar PV panels is given by [16-18]:

$$P_{PV-out} = P_{N-PV} X (G/G_{ref}) X [1 + K_T (T_c - T_{ref})] \quad (1)$$

Where $P_{pv\text{-}out}$ is the output power generated from the PV panel, $P_{N\text{-}PV}$ is the PV rated power at reference conditions, G is solar radiation (W/m^2), G_{ref} is solar radiation at reference conditions (G_{ref} = 1000 W/m^2), T_{ref} is the cell temperature at reference conditions (T_{ref} = 25°C), K_T is temperature coefficient of the PV panel (K_T = -3.7 x 10^{-3}(1/°C) for mono and poly crystalline silicon. The cell temperature T_c is such that:

$$T_c = T_{amb} + (0.0256 \, X \, G) \quad (2)$$

Where T_{amb} is the ambient temperature in ^oC. The rated power $P_{R\text{-}PV}$ can be calculated using equation 3 as:

$$P_{R-PV} = (E_L\ X\ SF) / (\eta_R X \eta_V X PSH) \quad (3)$$

Where E_L is daily load energy, SF is stacking factor considered to compensate for resistive and PV temperature losses, η_R, η_V, are efficiencies of solar charging regulator and bidirectional inverter respectively and PSH is the peak sun shine hours which is numerically equal to the daily average of solar radiation at the specified location.

2.2 Battery System

The battery considered in the model systems of this work are rated by the amount of current produced over a period of hours (in Ah). The storage capacity of the battery (C_{wh}) is calculated using equation 4 [19];

$$C_{wh} = E_L XAD / (\eta_V X\ \eta_B XDOD) \quad (4)$$

Where DOD is allowable depth of discharge of the battery, AD is number of autonomy days, and η_B is battery efficiency.

2.3 Diesel Generator System

The rated power of the generator and the actual power output affects the fuel consumption of the diesel generator. The fuel consumption of the diesel generator (FC_G) in (1/h) is given by equation 5.

$$FC_G = A_G\ X\ P_G + B_G\ X\ P_{R-G} \quad (5)$$

Where P_G, $P_{R\text{-}G}$ are the output power and the rated power of the generator in kW receptively. A_G and B_G are the coefficients of the consumption curve in (1/kWh), where A_G = 0.246 1/kWh and B_G = 0.08145 for the diesel generation [16, 17].

3. Optimal Design of the PV System Components

PV Solar Array Sizing

The optimal design of the PV solar array sizing, battery sizing, charge controller sizing and inverter sizing can be found in the literature [20].

4. Results of Simulations using HOMER Software

The following are the results obtained using the HOMER software in the course of the study. Simulations were run for three different scenarios using the different model system discussed in section 2 of this paper. The results obtained in the three scenarios are discussed in three different sections. The simulation results using model system in Fig .1 for only diesel fuelled generator off grid system serving the small remote community are shown in section A. In section B, model system in Fig .2 was used where solar PV was introduced including the converter and battery units and the system is still off grid. The grid connected system of the diesel, solar PV and battery system as shown in Fig. 3 was analysed in section C**.**

In section A, Figs 5 and 6 show the optimized and cash flow results for the diesel generation off grid system respectively. It could be seen that the use of the diesel generation incurs very high cost to run with about 2,400 USD net present cost (NPC). The value of the grid extension is also very high of the range of 227km as in Fig. 7, showing that after 227km it would be expensive to use the grid system and the standalone would be cheaper to implement. The emissions of the system in this case is also very high as shown in Table 1, with high carbon, unburned hydrocarbon and nitrogen contents in kg/year.

In section B, in Figs 8 and 9, the optimized results for the diesel, solar PV battery are shown respectively for the off grid system, where it is seen that the NPC of the system dropped drastically compared to the use of only the diesel system, due to the penetration of the solar renewable system. The salvage value of the system for this case is also seen to be appreciative with about 7,000 USD at the end of project life as shown in Fig. 10. The grid extension system dropped drastically from 227km for only diesel system to 139km (Fig. 11) due to the solar PV integration to the system. The emissions of the system are way lower as shown in Table 2 compared to those obtained in section A; this is because a lot of the solar renewable energy technology penetration has made the use of the constant speed diesel power source operation reduced, as compared with when there were no solar PV battery.

The optimized results and the cash flow summary for the on grid tied scenario for the diesel generator and solar PV battery system are shown in Fig. 12, and Fig. 13, respectively in section C. It could be observed that the values of the net present cost (NPC), levelized cost of electricity (COE), and total operating cost were lower than the results obtained in sections A and B. Also, based on Fig. 14, the fuel cost was very low, with reduced and evenly distributed operating and replacement costs, for the on grid system, though the salvage value is lower in this case. Fig. 15 shows the solar radiation used to generate electricity in the solar PV system for all the model systems considered in this study. The global solar and the solar altitude scatter diagram is displayed based on the location where the PV system was sited. Table 3 shows the amount of energy purchased, sold from the grid system and the net purchases in kWh for the year of operation. The peak demand and energy charge for the grid system is also shown in Table 3.

Section A (Only Diesel Generator off Grid System)

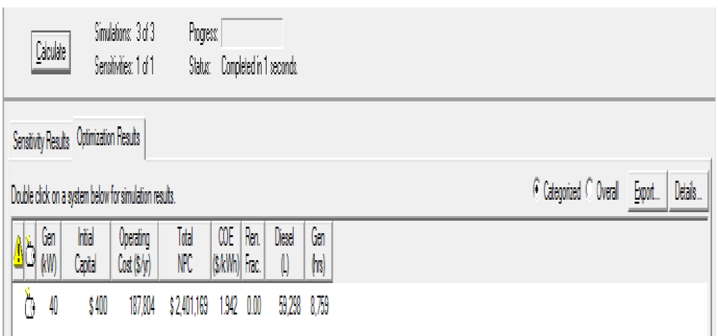


Fig. 5. Optimized Results using only Diesel Generator

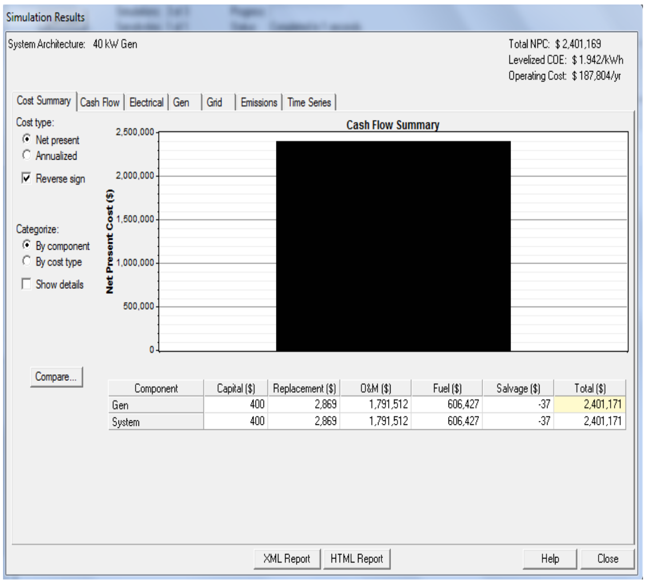


Fig. 6. Cash Flow summary using only Diesel Generator

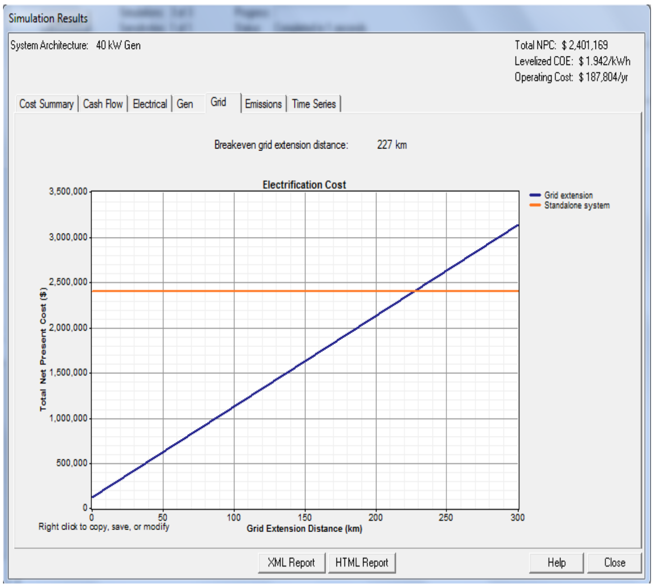


Fig. 7 Grid Extension using only Diesel Generator

Table 1. Emissions of using Diesel Generator

Pollutant	Emission(kg/yr)
Carbon dioxide	156, 152
Carbon monoxide	385
Unburned hydrocarbons	42,7
Particulate matter	29.1
Sulphur dioxide	314
Nitrogen oxides	3,439

Section B (Diesel Generator and Solar PV Battery off Grid System)

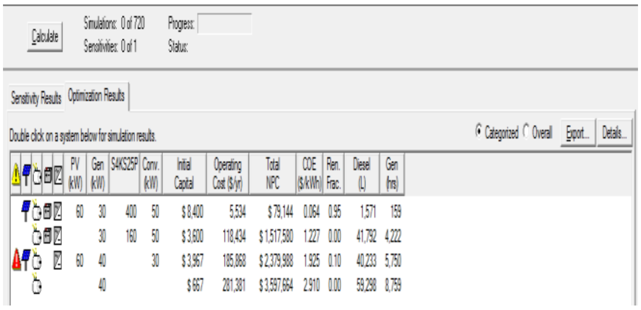


Fig. 8. Optimized Results using Diesel Generator, Solar PV

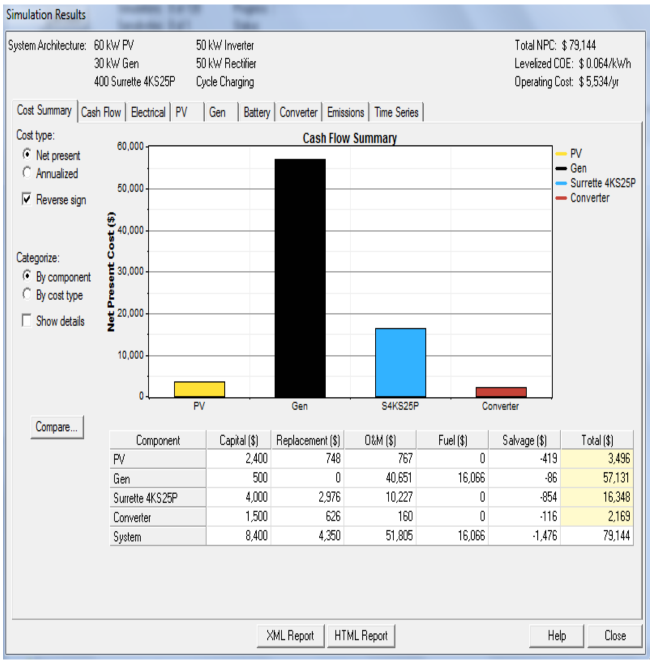


Fig. 9 Cash Flow Summary using Diesel Generator, Solar PV

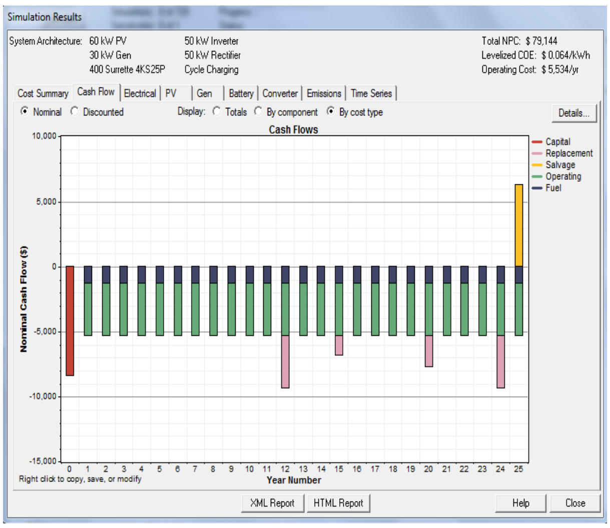


Fig. 10. Cost Analyses using Diesel Generator, Solar PV

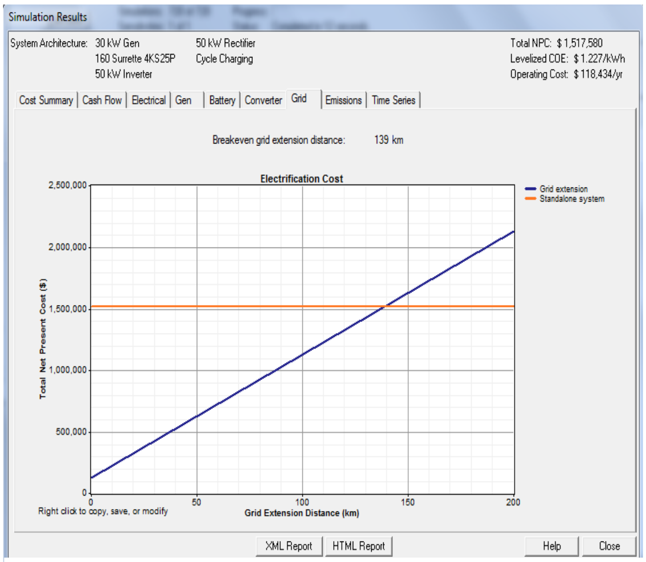
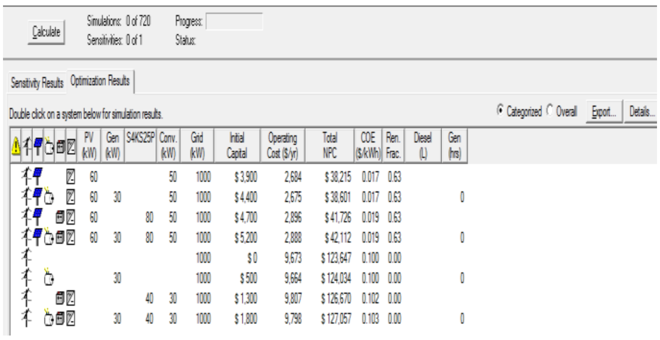


Fig. 11. Grid Extension using Diesel Generator, Solar PV

Table 2. Emissions for Diesel, Solar PV off Grid

Pollutant	Emission(kg/yr)
Carbon dioxide	4,137
Carbon monoxide	10,2
Unburned hydrocarbons	1,13
Particulate matter	0,77
Sulphur dioxide	8,31
Nitrogen oxides	91,1

Section C (Diesel Generator, Solar PV Battery System on Grid Connected)



PV (kW)	Gen (kW)	S4KS25P	Conv. (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Gen (hrs)
60			50	1000	$ 3,900	2,684	$ 38,215	0.017	0.63		
60	30		50	1000	$ 4,400	2,675	$ 38,601	0.017	0.63		0
60		80	50	1000	$ 4,700	2,896	$ 41,726	0.019	0.63		
60	30	80	50	1000	$ 5,200	2,888	$ 42,112	0.019	0.63		0
				1000	$ 0	9,673	$ 123,647	0.100	0.00		
	30			1000	$ 500	9,664	$ 124,034	0.100	0.00		0
		40	30	1000	$ 1,300	9,807	$ 126,670	0.102	0.00		
	30	40	30	1000	$ 1,800	9,798	$ 127,057	0.103	0.00		0

Fig. 12. Optimized Results for Diesel Generator, Solar PV on Grid System

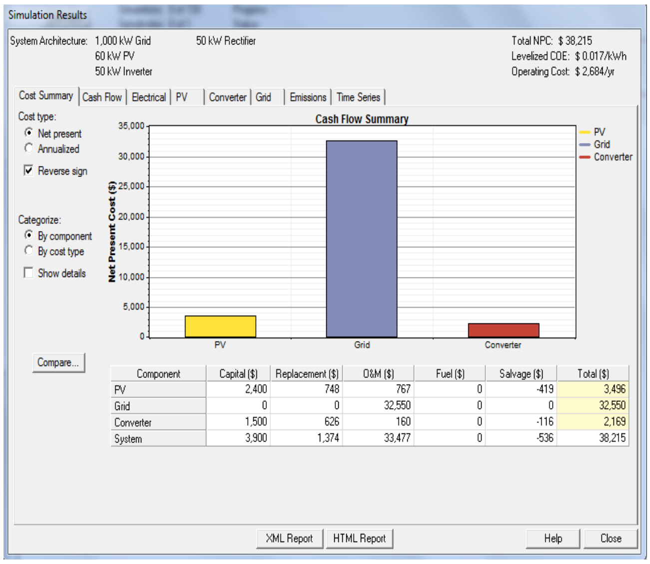


Fig. 13. Cash Flow Summary using Diesel Generator, Solar PV on Grid System

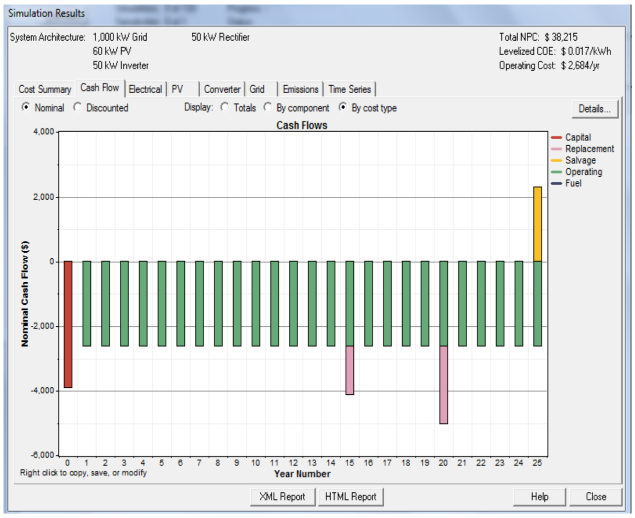


Fig. 14. Cost Analyses using Diesel Generator, Solar PV on Grid System

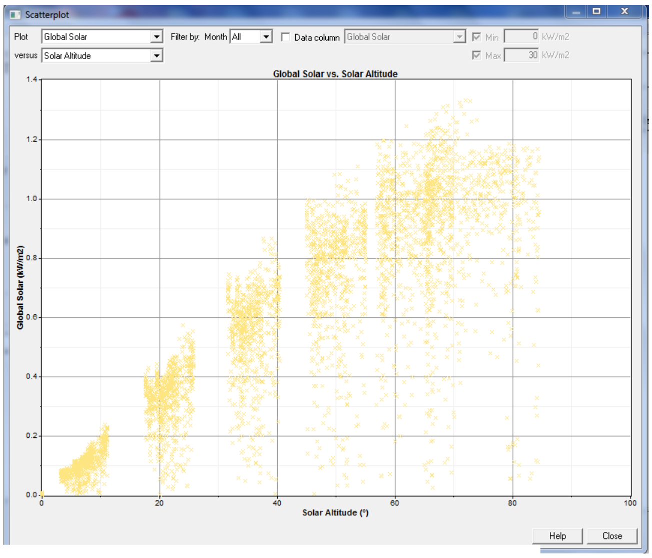


Fig. 15. Solar Radiation for all Model Systems

Table 3. Diesel Generator and Solar PV on Grid System

Month	Energy Purchased (kWh)	Energy Sold (kWh)	Net Purchases (kWh)	Peak Demand (kW)	Energy Charge ($)	Demand Charge ($)
Jan	5,611	5,726	-116	36	275	0
Feb	4,710	6,667	-1,957	37	138	0
Mar	5,650	6,617	-966	34	234	0
Apr	5,272	7,747	-2,475	36	140	0
May	5,394	6,036	-642	34	238	0
Jun	5,437	5,446	-8	37	271	0
Jul	5,277	8,311	-3,034	37	112	0
Aug	5,768	6,050	-282	41	274	0
Sep	5,791	3,766	2,024	37	391	0
Oct	5,305	7,734	-2,429	34	144	0
Nov	5,066	8,642	-3,576	35	75	0
Dec	5,527	5,951	-424	35	255	0
Annual	64,810	78,694	-13,884	41	2,546	0

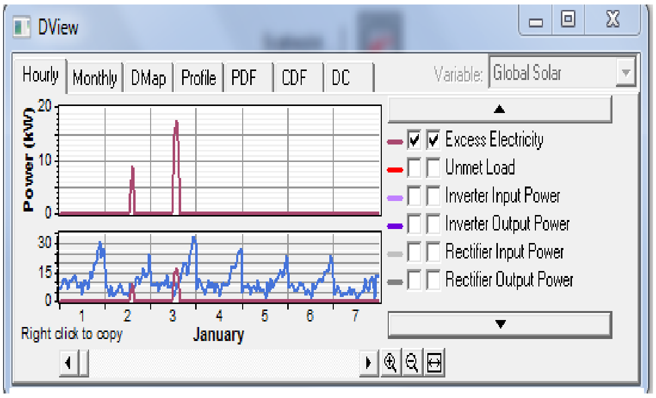


Fig. 16. AC load and Excess Electricity (without grid)

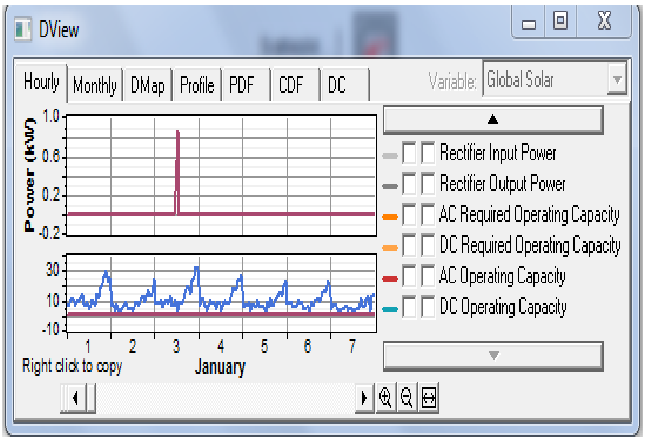


Fig. 17. AC load and Excess Electricity (with grid)

5. Economic Analysis of the System

The economic analysis of the proposed system was carried out. The responses of the AC primary load and excess electricity produced for without grid and with grid modeled system for this system are shown in Figs. 16 and 17 respectively for the month of January. When the grid was not considered, the excess electricity produced was as high as 18.2kW as against 0.8kW with the grid modeled into the proposed system. A summary of the economic analysis for the scenarios of the proposed diesel solar PV battery system with and without grid is given in Table 4. From the table, it could be seen that when the grid is modeled in the proposed system, the results are more favorable.

Table 4. Economic Analysis of Diesel, Solar PV without and with Grid System

Scenarios	NPC ($)	LCOE ($/kWh)	Operating Cost ($/yr)	Excess Electricity (kW)	Renewable Fraction
Without Grid Modeled	79,144	0.064	5,534	18.2	0.95
With Grid Modeled	38, 215	0.0017	2,684	0.8	0.63

6. Conclusions

Solar photovoltaic (PV) power system has a great potential in future as one of the renewable energy technologies for power generation. This work has presented an off grid connected diesel, solar PV system to power a small remote community. Some of the benefits of the proposed system are reduced cost, reliable and secured power generation for the small remote community, reduced carbon and pollutant emissions because of minimal use of the diesel plant. A comparative analysis was also done for both the off grid and on grid connected system. The simulated results show potential results for favoring on-grid system, thus the long term planning towards on grid diesel hybrid PV systems to power a small remote community would be encouraging. An economic analysis of the proposed system in terms of cost was further carried out for a grid connected and off grid connected scenarios. However, the cost of the proposed system may be high, but commercial use with more customers of the remote community can mitigate the cost of technology and this would be economical for the occupants.

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