Design and Modelling of Hybrid PV-Micro Hydro Power Generation Case Study Jimma Zone

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Abstract: Renewable energy technologies offer clean abundant energy gathered from self-renewing resources such as the sun, micro hydro, etc. Nowadays, due to the ever increasing demand of electricity, renewable energies are becoming the best option for electrification especially for remote area and to meet relatively small load. The standard empirical formula, the collected *sunshine hour* data have been changed to solar radiation. The results obtained in the proposed work based on empirical formulas were compared with expand these words NASA and SWERA data. The selected area has 5.13kWh/m^2/d amount of annual average solar radiation, which shows the area is rich of solar energy. Primary river flow data had been taken for modeling the existing micro-hydro power at MenkoToli River in Ethiopia. The river has an annual average flow rate of 1.131m^2/s. HOMER software had been used for modeling optimized result of the hybrid power generation system. 500 households are considered under studied with a total annual consumption of 31,911 kWh per year. The study included the electrical load of primary school and clinic. From the HOMER software optimization result, 10KW PV, 14KW hydro, 14KW converter and 32 battery string had been selected as an optimized option for electrifying MenkoToli in Ethiopia., with an initial capital cost $55,200, total net present cost of $76,128 and unit cost of $0.045. In the study all combinations of hybrid sources for the HOMER software have been observed for cost effective design.

Keywords: PV, Micro-hydro, HOMER, Optimization

1. Introduction

The development of energy sector is a driving engine for promoting country's economy and the improvement of the living standard of the people. Access to modern energy, especially in rural, remote areas would help significantly to reduce poverty, to get better health care and education, to facilitate modern communication and information systems. Further, (remove color) it will reduce city migration and depletion of fossil fuel resources and deforestation as well as pollutant gas emission to the environment. The development of renewable energy based on locally available resource should play a key role in this regard.

Ethiopia as a long tradition of using water driven mills. These mills are mainly used for grinding of grains in rural areas. More than 1000 of such mills were operational during the last century [1], Most of them were abandoned without leaving any sustainable alternatives.

Ethiopia has a huge renewable energy (micro-hydro power, solar, biomass and wind energy) potential that has are attempted for rural electrification [2], the more noticeable benefits of usable electric power include: improved health care, improved communication system, a higher standard of living and economic stability. Many of the rural areas of Ethiopia attempting to benefited from these uses of electricity in the same proportion as the more populated urban areas of the country. A major motivational plans are required to the develop use electricity for the community at large. Due to the remote location and the low population densities of the rural communities the traditional means of providing power have proven too expensive, undependable, difficult to maintain, and economically unjustifiable. Consequently, many of these communities remain without electricity and may never receive grid power from the utility [3].

The Small town of MenkoToli, a village, is one of those rural areas which have no access to electricity. The community requires electricity for house equipment like TV, Radio player, lighting and other. A hybrid PV and micro Hydro power

generation system is proposed to supply electricity to a model community of more than 2,500 people and 630 households in the base year 2014. The Hybrid Power Generation System (HPGS) is a system aimed at the production and utilization of electrical energy coming from more than one source, provides that at least one of them is renewable such as a system often includes some kinds of storage in order to satisfy the demand during the periods in which the renewable sources are not available and to decrease the time shift between the peak load and the maximum power produced. Power conditioning unit and controller to convert and control one form of energy to another [4].

The hybrid renewable for different regions and locations, climatic conditions, including solar irradiance, temperature and so forth, are always changing. In order to efficiently and economically utilize renewable energy resources of solar and micro hydro energy applications, the optimum much design sizing is very important for solar and micro hydro power generation systems with battery banks. The sizing optimization method can help to guarantee the lowest investment with reasonable and full use of the PV system and micro hydro system and battery bank, so that the system can work at optimum conditions with optimal configuration in terms of optimization techniques of hybrid PV and micro hydro systems sizing have been reported in the literature using the HOMER optimization software. A stand-alone off grid solar and micro hydropower system consists of a charging system, battery storage system [5], and a power conversion system.

In this research a comparative analysis and feasibility of solar energy for rural electrification for selected site in Ethiopia is analyzed. Moreover, hybrid design of PV and micro hydro has been modeled with the aid HOMER software so that to reach rural areas which are far from the main grid system.
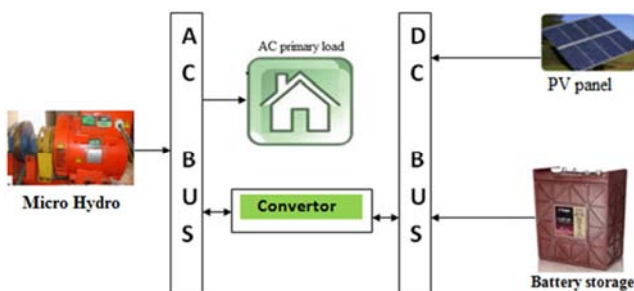
2. Hybrid System

Figure 1. Blocked Diagram of Hybrid PV-Micro Hydro System.

This work present hybrid consists of a solar and micro-hydro renewable combination along a power generator which acts as the supplement. The capability of the electric power generating hybrid systems is to satisfy the power demand on the atmospheric conditions. Such conditions will define different (cited) operation modes of the system. Basically, these operation modes are determined by the energy balance between the total generation and the total demand, the

combination has to be formulated for the efficient investment and operation of the system, figure.1more described that the blocked diagram of hybrid PV-micro hydro System.

This can be characterized as a mixed ac/dc bus hybrid system with some energy sources connected to the dc bus and others connected to the ac bus. Usually the PV array is connected to the dc bus via a battery charge controller, which initially was of the series pulse-width modulation (PWM) type. However ac bus connection of PV is also possible with some systems. Micro hydro power is connected to the AC bus via a transfer switch integrated into the inverter/charger and the inverter/charger controls [6]

The proposed work includes both an AC/DC rectifier and DC/AC inverter. The exciting of PV is DC supply, and the exciting of micro hydro power is AC to make Hybrid. PV and battery after converts the DC to AC to connected AC bus, in block schematic diagram the power conditioner is included in the hydro turbine and PV panel. There are three power options in Figure1 (hydro, solar and storage batteries) PV and micro hydro power are synchronized together with PV and storage battery after converting.

In this section the outcome of the design of a PV-hydro power hybrid power generation system is explained; discussion about the result will presented and at the end, decision for selecting the best situation with the simulation results shall be set forward. The results of the analysis will be presented in the following paragraphs.

3. Optimization Results

The solar energy potential of the site was fed into HOMER and this is depicted in Figure 2. This figure also shows the clearness index, the ratio of the solar radiation striking Earth's surface to the solar radiation striking the top of the atmosphere, which HOMER generated from global solar radiation based on the data input for the analysis. Typical values for the monthly average clearness index range from 0.39 (a very cloudy month) to 0.6 (a very sunny month).
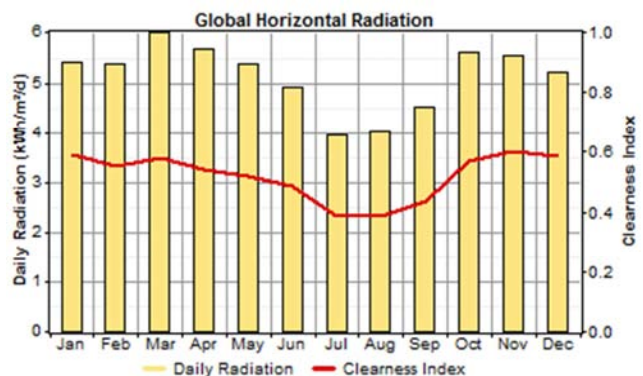

Figure 2. Monthly average solar resources.

The result which HOMER software suggested for MenkoToli site is shown in figure3. The simulation result is also performed. The categorized optimal result and different feasibility relationships are depicted. The PV/hydro/battery

hybrid in the first row of the figure shows a more optimized combination as compared to the Hydro/battery hybrid configuration in the second row.

The first rank overall optimization result (row 1) in figure 3 has 32 lead acid Trojan battery, 14kW convertor, 10 KWPV and 14KW hydro power. For this set-up, the initial capital cost $55,200 the total net present cost (NPC) is $76,128, the cost of energy (COE) is $0.045/kWh, (mathematical calculations are essential)contribution from renewable resources is 100%, and therefore this setup could be a good choice for implementation. Figure 3 shows the monthly average electrical production of this system detail.

	PV (kW)	Hydro (kW)	Battery	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
	10	14.0	32	14	$ 55,200	1,637	$ 76,128	0.045	1.00	0.00
		14.0	240	14	$ 97,600	3,850	$ 146,818	0.087	1.00	0.00

Figure 3. HOMER categorized simulation results.

From figure 4 one can see that the total electrical production that is produced by all the renewable sources amounts to 166,501 kWh/yr; which encompasses 15,172kWh/yr or 9%from solar, and 151,329kWh/yr from hydro electric production, which covers large amounts of electric production.
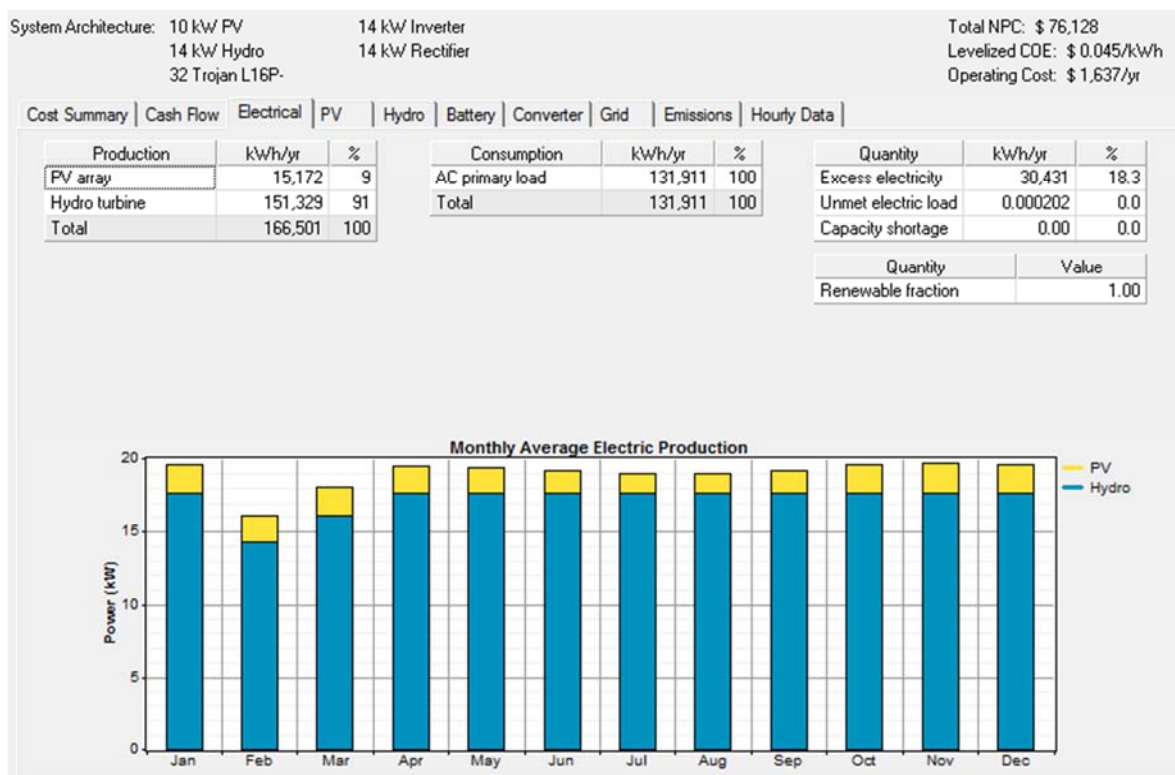
System Architecture: 10 kW PV   14 kW Inverter   Total NPC: $ 76,128
                      14 kW Hydro   14 kW Rectifier   Levelized COE: $ 0.045/kWh
                      32 Trojan L16P-   Operating Cost: $ 1,637/yr

Cost Summary | Cash Flow | Electrical | PV | Hydro | Battery | Converter | Grid | Emissions | Hourly Data

Production	kWh/yr	%	Consumption	kWh/yr	%	Quantity	kWh/yr	%
PV array	15,172	9	AC primary load	131,911	100	Excess electricity	30,431	18.3
Hydro turbine	151,329	91	Total	131,911	100	Unmet electric load	0.000202	0.0
Total	166,501	100				Capacity shortage	0.00	0.0

Quantity	Value
Renewable fraction	1.00

Figure 4. Monthly Average Electric Production of the selected hybrid system.
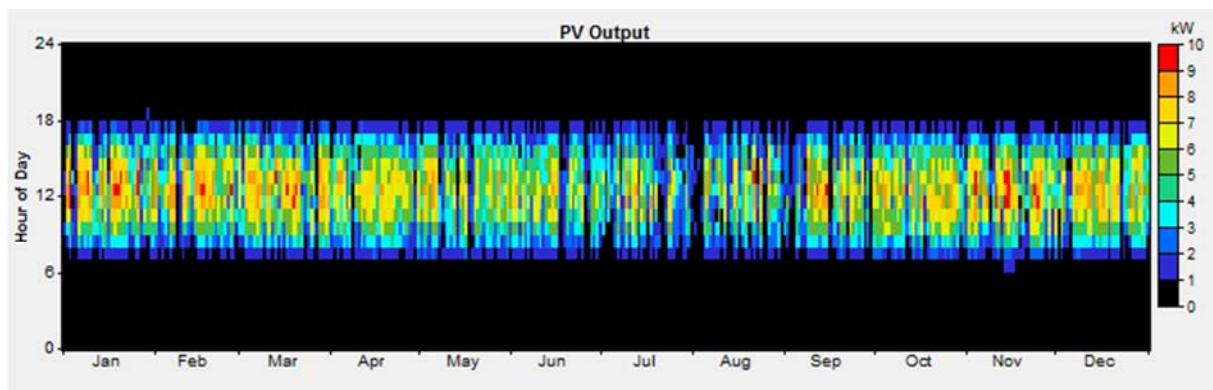

Figure 5. Annual electric energy productions by PV system.

Figure 5 depicts the variation of sunlight available throughout the hours of the day, with the lowest values registered in the first and the last hours of the day and the available peak near midday. It also demonstrates the change in hours of the day throughout the year.
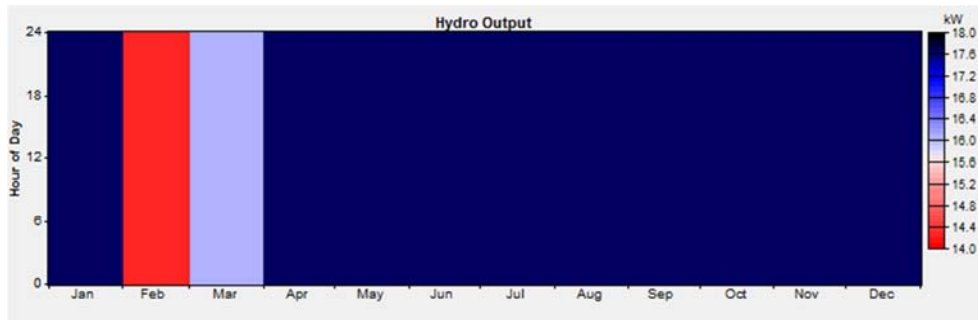

Figure 6. Annual electric energy productions by hydro power system.

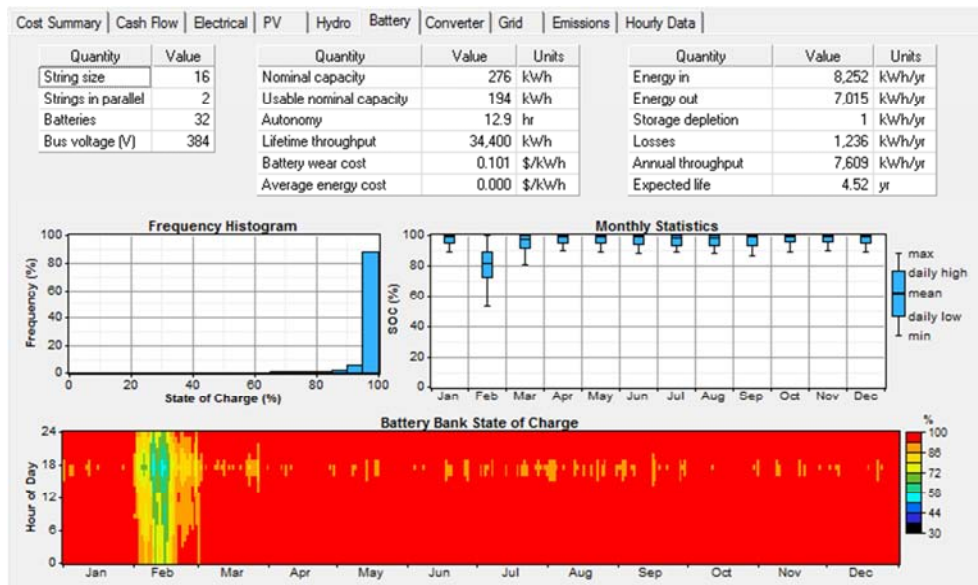From Figure 6 one can learn that the potential electric generation over various months of the year with the lowest amount expected to be near February.

Figure 7. Annual Statistical result of battery system.

As indicated in Figure 7, the battery is fully discharged in due of delivering power to loads because of the minimum generation capacity in hydro-electric component of the system during the same month. It's also evident here that the battery becomes operational during 12:00-18:00pm hours of the day to compensate the unavailability of sunshine.
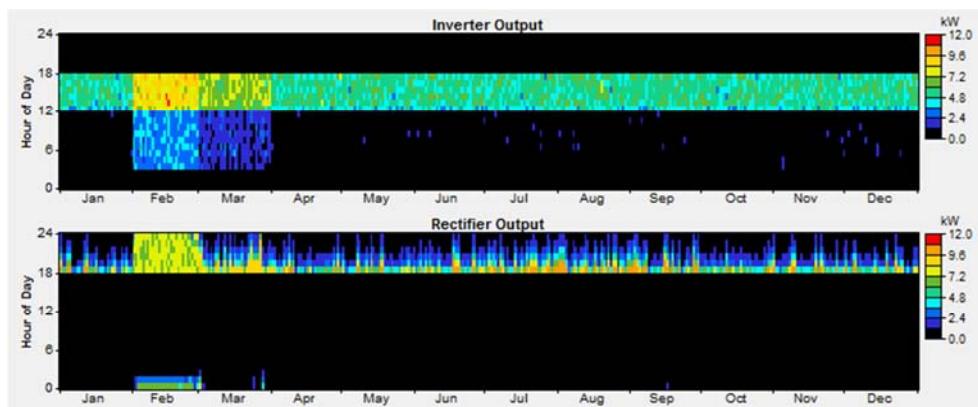

Figure 8. Annual Statistical result of convertor system.

As indicated in Figure 8 the convertor is fully functional in due of delivering power to loads from 12-18pm during the pick load, also from February to march convertor is fully functional due to of decreasing of flow of water highly using PV and battery.

4. Sensitivity Result for Meneko Toil Site

Figure 9 shows the results of a sensitivity analysis over a range of load sizes and annual average solar radiation. The model assumes seven values for the average size of the electric load and five values for the annual average global solar radiation. The axes of the graph correspond to these two sensitivity variables. Both colors in the graph indicate these sensitivity cases, and the color of each diamond indicates the optimal system type for that sensitivity case. At an average load of 361kWh/day and an average solar radiation of 5.3kWh/day the optimal cost is $76,128 using the optimal system type of hydro/PV/battery. At an average load of 360kWh/day and the same stream flow rate, the optimal system type is found to be hydro/PV/battery. HOMER uses two-dimensional linear interpolation to determine the optimal system type at all points between the diamonds. The graph in Figure 8 shows that for the assumptions used in this analysis, hydro–battery systems are optimal for very small systems, as the load size increases the optimal system type changes to hydro/PV/battery used.
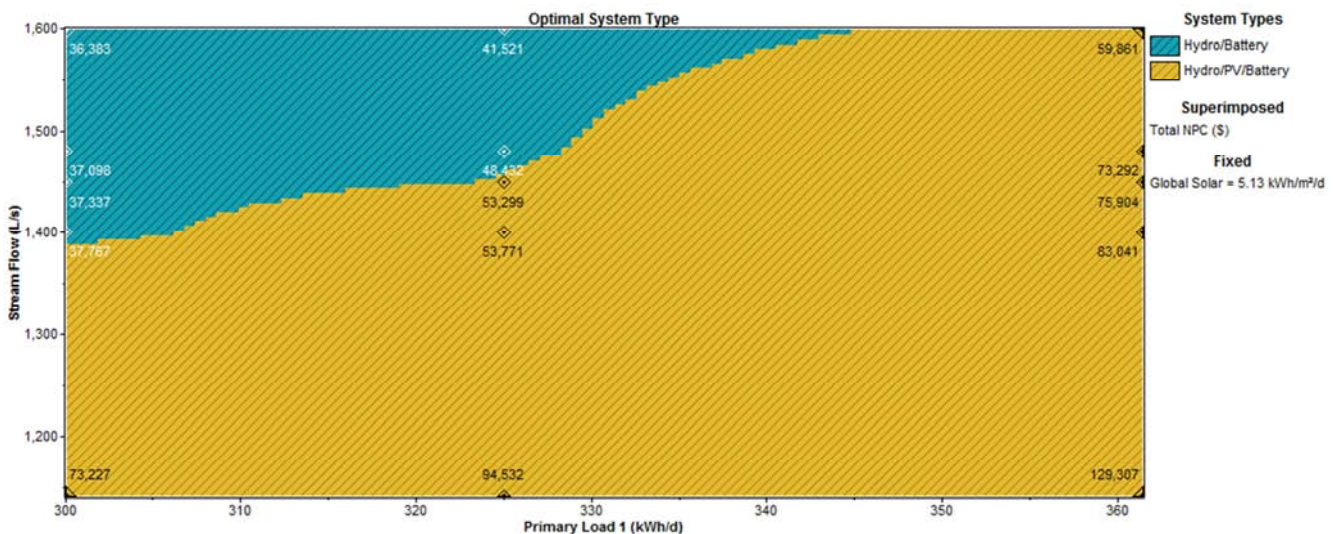

Figure 9. Sensitivity result to show the NPC for variable primary load and stream flow.

The solutions present in the optimization space of Figure 8 are shown Obviously, the higher costs correspond to systems based on steam flow increasing if it is used hydro/battery and lower costs correspond to the solutions associated with higher primary load is decreasing if it using Hydro/PV/battery not optimum. In the intermediate region, the costs are distributed in horizontal bands, so depending on the stream flow more than the primary load.
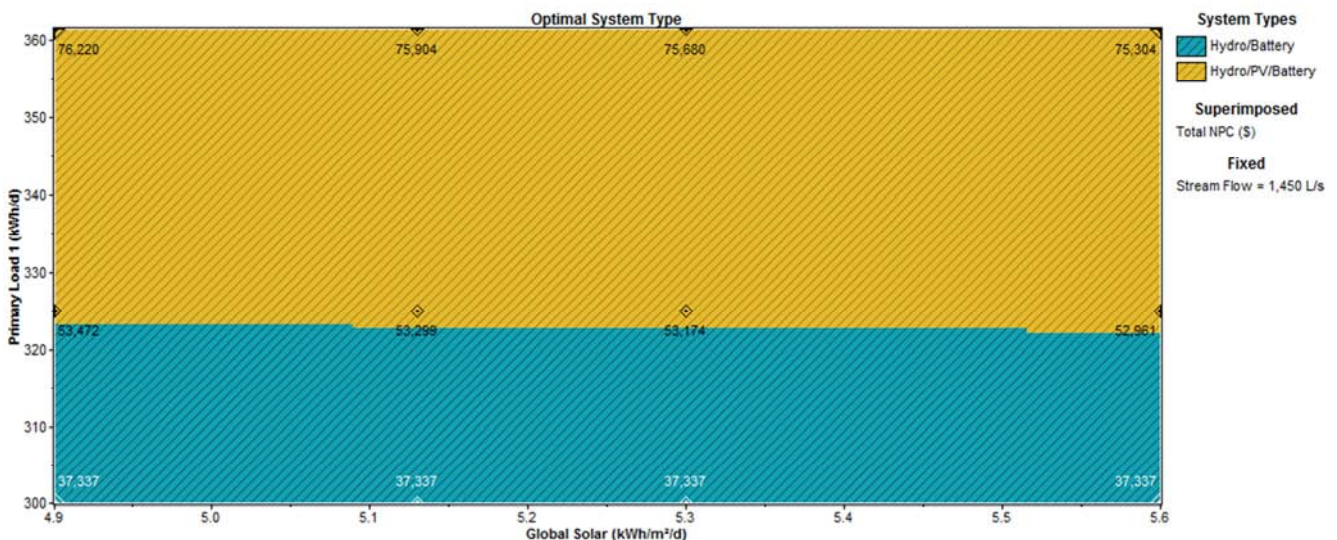

Figure 10. Sensitivity result to show the NPC for variable primary load and global solar radiation.

Figure 10 shows that the solutions corresponding to primary load is increased and solar radiation is decreased, the recommended combination to be used is hydro/PV/battery because of the fact that the optimal cost is least. However the primary load is decreasing and solar radiation is increasing the green color region slightly larger is better to use recommend Hydro/battery because net present cost is less.
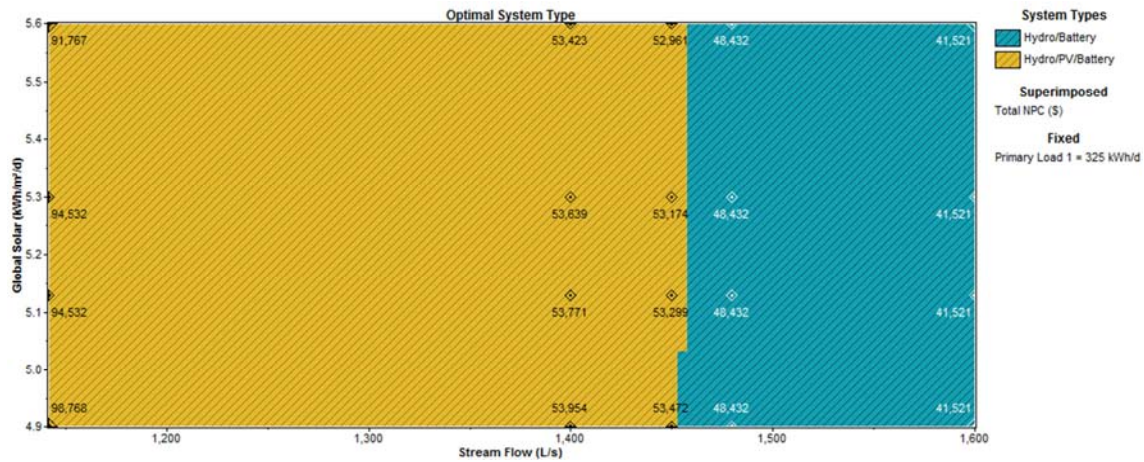

***Figure 11.** Sensitivity result to show the NPC for variable global solar radiation and stream flow.*

Figure 11 shows that for Sensitivity result to show the NPC for variable global solar radiation and stream flow the assumptions used in this analysis, hydro–battery systems are optimal for green reign, as the load size increases the optimal system type changes to hydro/PV/battery used
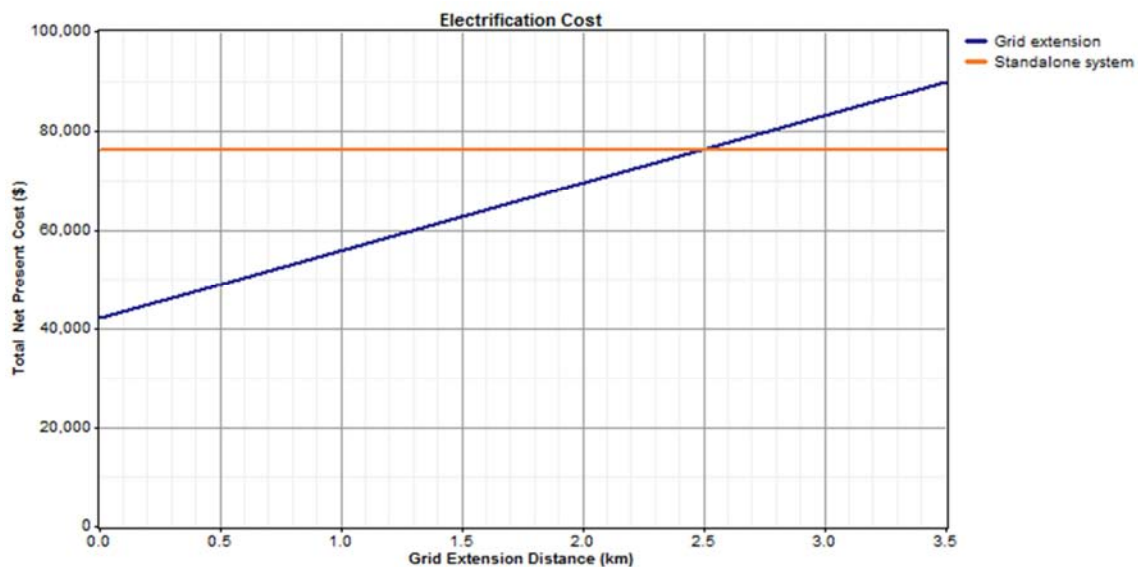

***Figure 12.** Breakeven grid extension distance in the first optimal system.*

From above figure 12 showing that the evaluation costs of the PV and micro hydro hybrid system with the grid extension in terms of breakeven grid extension distance certain at 2.49 km meeting point between the grid extension cost in blue and the stand-alone cost in red. For the selected site, the shortest distance from the grid to the load centre is about 8km consequently the hybrid system is more economical than a grid extension

***Table 1.** Summarized system report of the first optimal system.*

SystemArchitecture		Annual electric production			Types ofLoa	Annual electricconsumption(kWh/yr)	
Hydropower	14kw	Type	kWh/yr	%	ACprimaryload	31,911	100%
PV	10kw	Hydropower	151,329	91	Total	131,911	100%
Battery	32 Trojan	PV	15,172	9			
Inverter	14kW	Excesselectricity	30,431	18.3	Cost Summary		
Rectifier	14kw	Unmetload	0.000202	0	Total NPC	$76,128	
					COE	$0.045Kwh	

This research uses first iteration of overall optimization results, however if the demand load is increased in the future then by using the appendix table 1 data of iteration it is possible to find the appropriate values of component's based on the load.

5. Conclusion

This paper discussed the optimization and operational strategy of hybrid renewable energy system. The main target of this thesis is to show that renewable energy can play a satisfying role in providing electricity to rural communities. Integrating available renewable energy and designing as a hybrid power system minimizes the cost of the system and energy per kWh in the long term.

The hybrid system devised in this research work gives an insight into the advantage of off-grid electric power generation as compared to its counterpart, the grid system. Based on actual parameters of the area, MenkoToli and the surroundings, the analytical procedures undertaken provided conclusive and promising results in terms of capital and other related costs with the comparable supply ratings. For a load distance of greater than 2.49km, a grid supply is not feasible to employ. For the selected site (8km away from the grid) the proposed hybrid supply option, composed of 10kW PV and 14kW micro-hydro has a COE of $0.045 per kWh, which is much less than the capital cost for grid system. For this specific site, for a load distance of greater than 2.49km, a grid supply is not feasible to employ. For the selected site (8km away from the grid) furthermore the renewable energy source potential of the site amounts to 15,172 kWh per year from PV and 152,329 kWh per year from Hydro. This is an essential and environmental friendly energy source that needs to be exploited at an optimum cost. For instance, the net present cost (NPC) that needs to be expended to realize this project is $76,128, which is much less than the grid cost (refer to figure 3).

In conclusion, this study shows that developing a hybrid power system is more cost effective and suitable for rural communities where renewable energies are available; the result of this study encourages private investors and local community members, especially in Ethiopia, to take advantage of renewable energy and be convinced that there is sustainability in investing in hybrid power systems

Acknowledgment

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