

Optimization of Micro Hydro Electric Power with Solar PV and Diesel Generator Supply System: A case study

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ABSTRACT

Nowadays, energy is one of the most important factors needed in our world. However, some resources to obtain useful energy results are still impracticable because of the exploration cost or pollution generated using these resources, etc. The energy from flowing water and sun is the most readily available, renewable and clean source of electricity. Most of the people in Ethiopia (around 81 % of the population) live in rural areas where energy access is almost negligible. A possible reason is that these areas are far away from the national grid. Micro power electric generation is one of the most valuable answers to the question of how to offer to isolated rural communities to improve the quality of life. The aim of this paper is to analyze the viability and optimization of a micro Hydro power for rural electrification, a case study was conducted at Fantale micro hydro project sites Ethiopia, with solar energy using HOMER software. In this study the necessary data have been collected and analyzed with the respect to anticipated load demand of Inkule village, then after by running the software, the simulation results for different option of power supply systems were recorded and arranged according to their net present cost (NPC). During this study a five different cases were taken for investigation and optimized as per the standard values generated by the software. The optimal results are most economical scenario for the selected site is using 7kw hydropower , PV- 5kw,5kW Diesel Generator,8 Trojan L16p Battery,6KW Convertor, to supply the village loads.

KeyWords: Ultra-low head hydro power, Fantale hydro power project, HOMER, Micro power System, Solar PV, and Renewable energy.

1. INTRODUCTION

Most of the developing countries are suffering from the so called energy crisis, characterized by depletion of locally available energy resources and dependence on imported fuel. In addition, the energy crisis is exacerbating the food crisis by increasing the rate of deforestation and thereby causing degradation of farmlands. So it is important to focus the studies on finding alternatives ways to produce useful energy in an effective way. Hydropower schemes and solar power can contribute with a cheap source, as well as to encourage the development of small industries across a wide range of new technologies. The energy of flowing water and solar is the most readily available, renewable and clean source of electricity. The hydraulic power is one of the oldest energy forms of mankind, namely used for irrigation and industry and also used to grind grain, provide shaft power for textile plants, sawmills and other manufacturing operations. Solar energy was used to drain crop and heat water, but now it start to generate electricity. Due to the limited energy production and transmission, there are places, especially remote areas, where energy is not available /accessed and the people around there are living in darkness. In Ethiopia, the application of water power for grinding is common especially in rural areas, the direct way of utilization of water power. Another way of harnessing the power of water is by direct conversion to electricity called hydroelectric power generation. In this study large hydro, medium hydro, small, mini, micro hydro and even Pico hydro. MHP is defined as the generation of electricity in the range 5 kW to 100 kW. The combination of Micro hydro and solar energy is one of the most valuable answers for the question of how to offer electricity for the isolated rural communities, to improve the quality of life. The Significance of this study is, to apply theoretical background and supplying of

ULH hydro, solar energy and diesel generator which is alternative source combination and delivering such hybrid technology without interruption of power and with minimum cost to the off grid (Enkule village, Ethiopia) to satisfy their basic electric need. This case study is intended to recommend the best combination of micro hydro, solar energy utilization for selected site which has small potential of water and solar energy. By considering cost and reliability of the system, additional of diesel generator is also evaluated.

2. STATEMENT OF THE PROBLEM

Most of the people in Ethiopia around 81 % of the populations live in rural areas where energy access is almost negligible. A possible reason is that these areas are far away from the national grid. But there are accessible resources such as small hydro (mini, micro and Pico) and solar at remote area. These sources need short transmission line and can be installed at load sites. The power generated by Micro hydroelectric at Fantale is one project which answers remote rural electrification, but the constructed power plant from hydro is not enough for the local load. So, other additional power source is required to fulfill all loads (basic electric needs for local community) and to make the site reliable system. The main objective of this case study is to conduct reliability analysis and optimization of micro hydroelectric power on Awash River with Solar PV and Diesel generator supply system. The specific objective is to assess hydro and solar resources potential and collect the required data for Enkule village power generation project, to estimate Local load for selected site, analyze and simulate micro hydropower system, solar PV and diesel generator power using HOMER software, to design & recommend the best combination of solar, hydro and diesel generator for the site with minimum cost.

3. METHODOLOGY

The methodologies to accomplish of this case study work are shown in figure 1

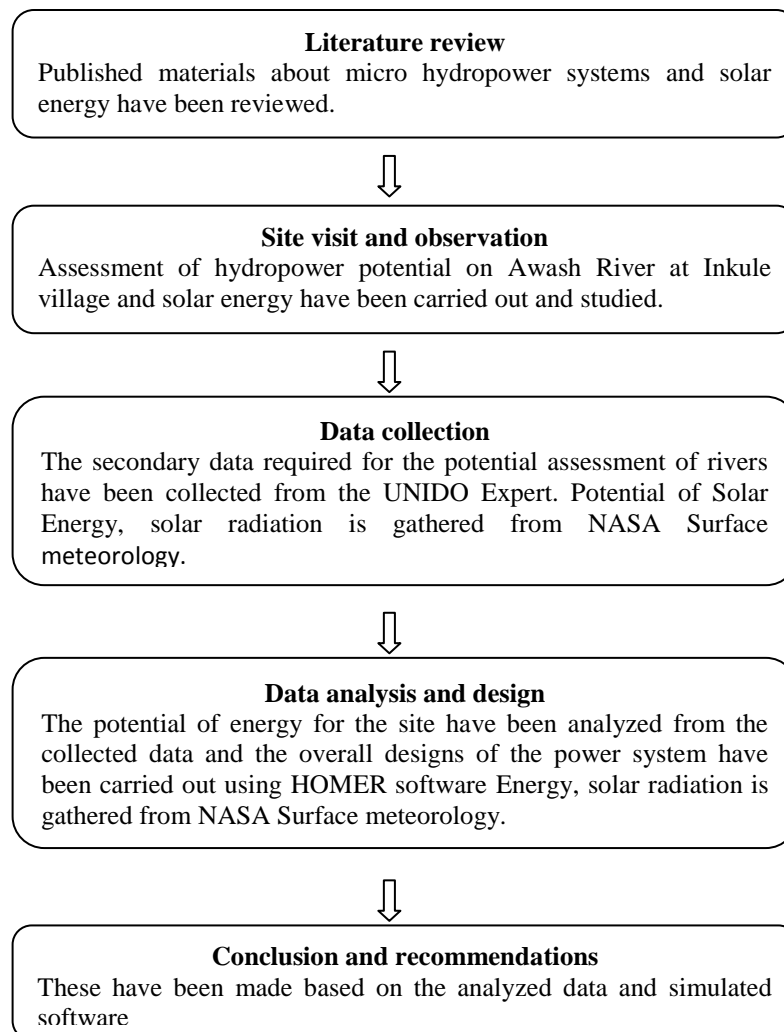


Figure1: Methodology

4. DATE AND ANALYSIS

The Ultra-Low-Head (ULH) hydropower plant usually operates in the “run-of-river” mode, which causes that the prediction of the energy production, and therefore project’s cash flow is a function of probability of hydraulic conditions. Looking more closely at the Flow Duration Curve we notice large variations of the Gross Head: from 50% to 100%. Generally low head turbines are going to be of the reaction type. The water passing through a reaction turbine loses its energy, or pressure, as it passes the turbine blades. The turbine must be encased in a pressurized housing, and fully submerged in water. This is different from an impulse turbine which changes the velocity of the water. Water is directed at the blades of an impulse turbine with a high velocity nozzle.

4.1 Background about Site

This project is Located in Oromia Regional State, East Showa Zone Fantale Woreda, West of Metehare Sugar Factory at Enkule village in Gidara kebele. 10KW ULH-MHP plant and mini-grid will be installed at Dereseden main canal 17+km from head work.

4.1 Hydro and solar Resource for the Selected Site.

For hydro case, water flow and other necessary data are collected from Inkule site is listed are: Generator type; Permanent Magnet Synchronous Generator, Turbine; vertical twin cross flow, Length head 3m, Average Water flow rate (Q) = 0.555m³ /s, Efficiency (η) =61.2%, Power P=10kw. To determine the PV electricity generation potential for a particular site, it is important to assess the average total solar radiation received over the year. Unfortunately in most developing countries there is no properly recorded radiation data. What usually available is sunshine duration data. For this thesis the solar radiation of the Inkule village is taken from NASA's surface solar energy data set.

4.2 Calculation of Inkule Site Load.

Total population of village is= 100 households,

Load estimation for Inkule Village. For 100 house hold total power =16KW (total wattage* 100 HHS)

Total power consumption of lighting for 100 households in one day =60kWh/day

Total power for appliance =6.8KW

Total power consumption for appliance of one day =36.2kWh/day.

Power consumption by above services =4.3KW

Total power consumption for other service of one day =29kWh/day

Total load in one day =load for lighting +load of appliance +other service.

=60KWh/Day+36.2KWh/day+29kWh/day =125.2 KWh/day

By considering the losses of overall system (loss of PV Solar, Converter, battery, Hydro Generator, transmission system, and Controller losses) (30%), Total load =125.2 kwh/day*1.3 =162.76KWh/day. In the future there is additional load because of population number increasing and also may be there is sudden load at that site at one moment. So considering source of energy with reserve capacity (30%) may reduce the village power system interruption. Total energy required from all source =162.76KWh /day*1.3 =211.588KWh/day. The installed capacity of Ultra-low head hydro project of Fantale is 10kw. Average generation (operation) of micro hydro project = 7KW (average)*24h/day =168KWh/day.

Analysis of Power Generation from different Source of Energy

From the above calculation the demand (load) is greater than supply from hydro power generator, so using other source of energy is the better solution. Using solar and hydro to supply site may one solution. But, there is the probability of drought month and cloudy days, so the system isn't secure. To overcome such problem addition of diesel generator is the solution to make system secure & reliable. By using these source of Electricity let us see different cases to deliver power for the total loads. Figure 2 show that Location of Enkule town. The general layout of population of Enkule town as shown in figurer 3.

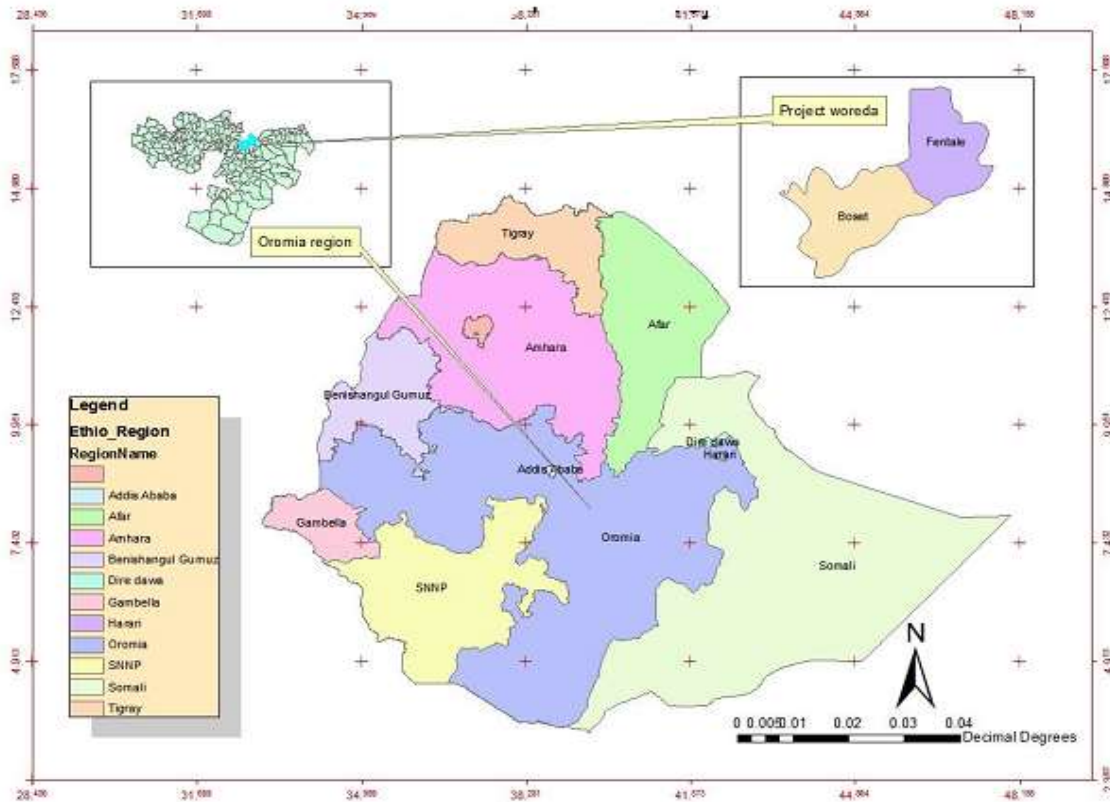


Figure 2: Location of Enkule town

Case 1

Using hydro and solar source

For one day the energy generation capacity (average) of hydro is 168kwh and the total load for the site is 211.588kwh/day. So use solar resource to cover the remaining load,

$$\text{Solar load} = \text{Total load} - \text{hydro generation energy}$$

$$= 211.588 \text{KWh /day} - 168 \text{kwh/day} = 43.588 \text{ KWh/day}$$

Case2. Using diesel generator which generate 10kw for three hour, 30kwh/day.

The other load has to be covered by solar;

$$\text{Solar load} = \text{Total load} - (\text{hydro generation Energy} + \text{diesel generator})$$

$$= 211.588 \text{KWh /day} - (168 \text{KWh/day} + 30 \text{KWh/day}) = 13.588 \text{ KWh/day}$$

5. SIMULATION RESULTS

The analysis and design of micro power systems can be challenging, due to the large number of design options and the uncertainty in key parameters, such as load size and future fuel price. Renewable power sources add further complexity because their power output may be intermittent, seasonal, and non-dispatchable, and the availability of renewable resources may be uncertain. HOMER was designed to overcome these challenges. The HOMER (The Hybrid Optimization Model for Electric Renewable) is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist in the design of micro power systems and to facilitate the comparison of power generation technologies across a wide range of applications. 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. HOMER 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. A micro power system is a system that generates electricity, and possibly heat, to serve a nearby load. Such a system may employ any combination of electrical generation and storage technologies and may be grid-connected or autonomous, meaning separate from any transmission grid. Some examples of micro power systems are a solar–battery system serving a remote load, a wind–diesel system serving an isolated village, and a grid-connected natural gas micro turbine providing electricity and heat to a factory. Power plants that supply electricity to a high-voltage transmission system do not qualify as micro power systems because they are not dedicated to a particular load. HOMER can model grid-connected and off-grid micro power systems serving electric and thermal loads, and comprising any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, reciprocating engine generators, micro turbines, fuel cells, batteries, and hydrogen storage.

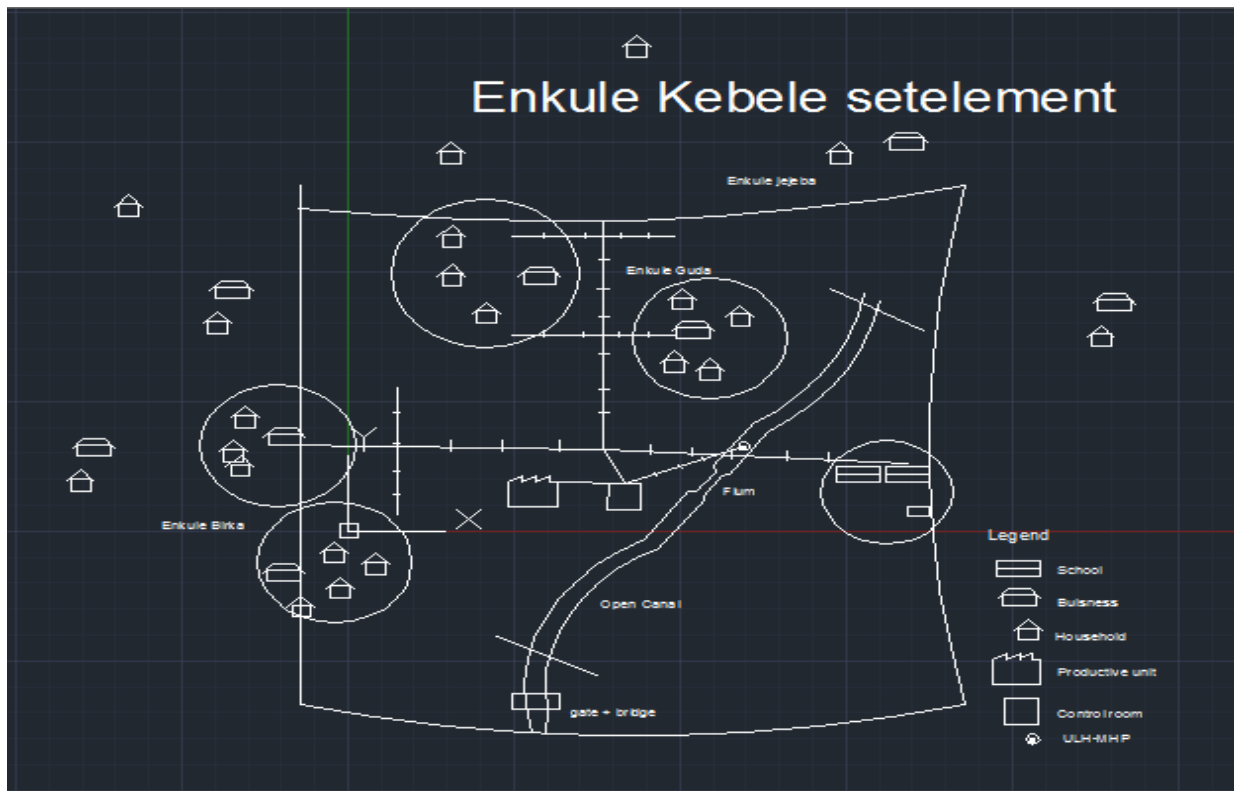


Figure 3: General layout of population settlement of Enkule town [UNIDO]

5.1. Simulation Approach

The system simulation is performed by considering the system reliability as 100%, so no interruption is assumed during operation of the system. The developed optimization software enables to change the variables of the hybrid system model in terms of sizing and operation. In such a way the life cycle cost of the hybrid systems respecting the demand requirements are minimized. In this approach the renewable energy sources (Hydro & PV) plus the energy stored in the battery are used to cover the demand. But the diesel generator is switched on at peak load. The following cases are considered with the illustrated priority while developing the simulation software.

- **Case 1** : Generating electricity by renewable sources, hydro only. The load is greater than generated power.
- **Case 2** : Generating electricity using hydro and battery, charging battery during base load and use. Two of them at peak load time. Here, it may need many batteries to satisfy load.
- **Case 3** : The generated energy by the hydro may not sufficient to supply the load and charge Battery; using additional source of PV may answer the question of security.
- **Case 4** : The generated energy by those renewable sources may not answer the reliability of the selected site, hydro source may be affected by drought and solar source also may be decrease by cloudy days. To overcome such problem addition of diesel generator is suitable solution. In this case the diesel generator is switched on only at peak load, and other source is operating at appropriate time

5.2 Software Inputs and Outputs Parameters

The input variables and parameters to the simulation program are:

Load demand, measured solar radiation averaged on daily basis over a year, Average of water flow, the effective head water, Component costs and economic factors.

5.3 The outputs from the simulation program

Hydro generator rated power, Battery storage capacity, PV modules, and diesel generator, Operating hours of diesel generator, Diesel fuel consumption, Emission gas generated as a result of operation of diesel generator, Cost of energy production, and Net present value. In addition to numerical results, graphs of different variables can be obtained. Figure 4 Illustrated the different case while developing the simulation software.

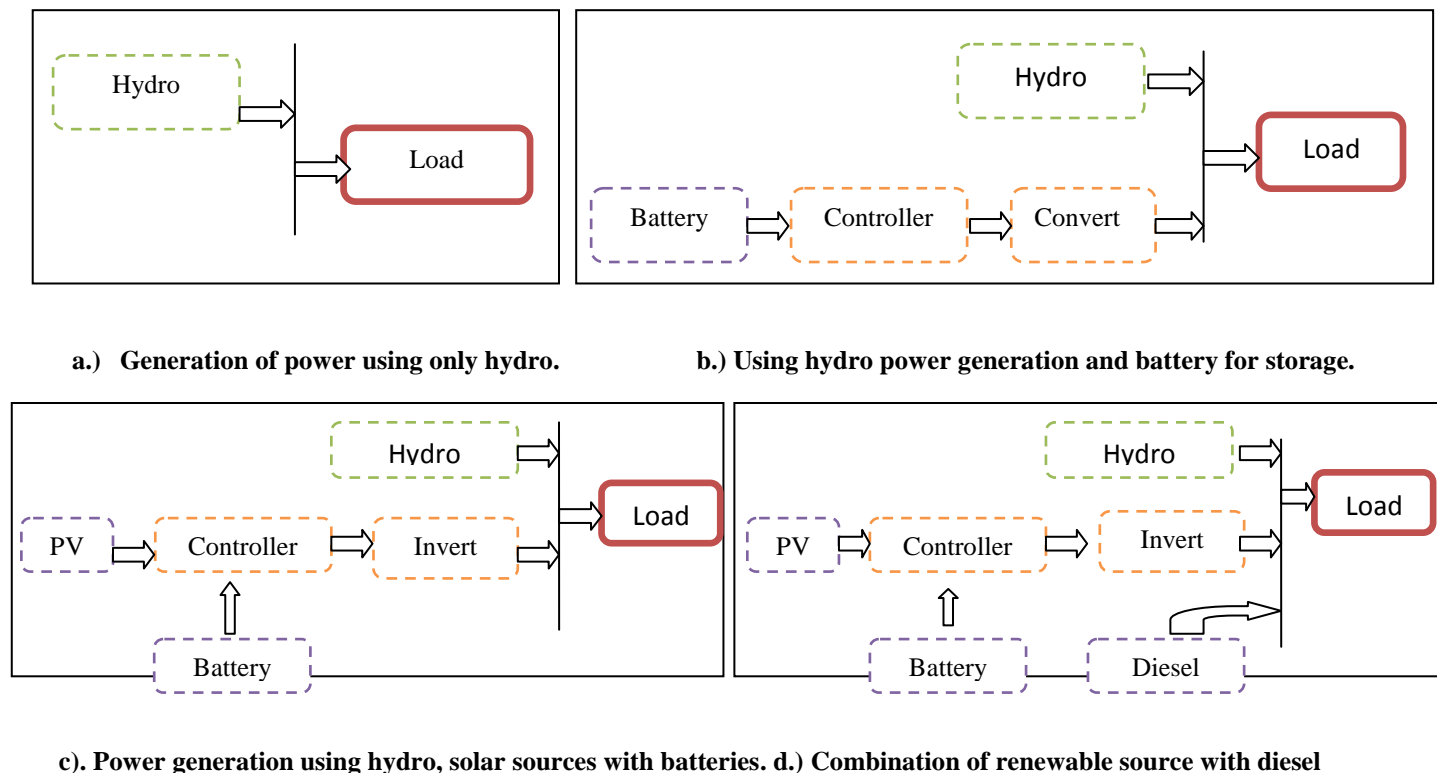


Figure 4. Illustrated priority while developing the simulation software

6. RESULT AND DISCUSSION

The design of hybrid system, which supplies electricity to model for a Fantale project, was introduced previously. The results of the investigation will be discussed in the following paragraphs. The solar energy potential of the site was fed into HOMER and this is depicted in Figure 5, also in figure 6 mention the water flow rate below. It 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 for the analysis. Typical values for the monthly average Clearness index range from 0.25(a very cloudy month) to 0.75 (a very sunny month).

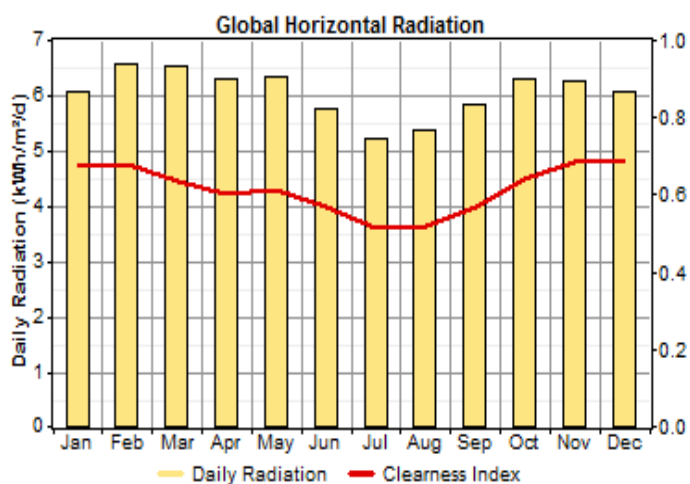


Figure 5. Monthly average solar resources

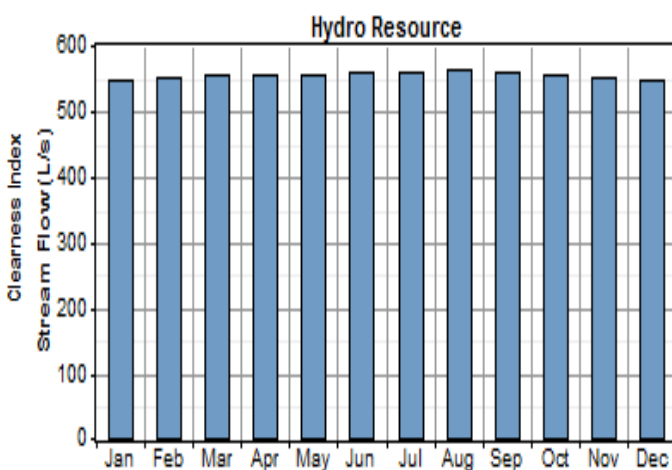


Figure 6: Water flow rate (L/s) of sites

After entering the hydro and solar resource data into software, to find the optimum solutions, HOMER is run repeatedly by varying parameters that have a controlling effect over the output. The output of the simulation is a list of feasible combinations of solar PV, hydro, diesel generator, converter, and battery hybrid system set-up. The optimization results are generated in either of two forms; an overall form in which the top-ranked system configurations are listed according to their net present cost (NPC) and in a categorized form where only the least-cost system configuration is considered for each system type. The tables are generated based on a particular set of inputs selected from the input summary of table 1 and the solar and hydro resource data for site. By

considering the above costs the following analysis and its output is done using HOMER software as follows. The following tables shows different case for the revalent dates are shown in the tables.

Table 1: Summary of input components with their values and costs

Component	Rating (KW)	Capital (\$)	Replacement (\$)	O & M (\$ /yr)
PV	1	1200	0	10
Generator	10	2000	1600	2.3
Hydro	10	1526360	0	3663.234
Battery	1	200	200	2
Converter	1	100	100	10

Table 2: Cost and energy production using Hydro & battery

Component	Capital (\$)	Replacement (\$)	O & M (\$ /yr)	Fuel (\$)	Salvage (\$)	Total (\$)
Hydro	1,526,360	0	46,829	0	0	1,573,189
Battery	5,200	13,015	1,662	0	-251	19,626
Converter	900	0	1,151	0	0	2,051
system	1,532,460	13,01520	49,641	0	-251	1,594,866

Table 3: Cost and energy production using Hydro PV & battery

Component	Capital (\$)	Replacement (\$)	O & M (\$ /yr)	Fuel (\$)	Salvage (\$)	Total (\$)
PV	9,060	0	965	0	0	10,025
Hydro	1,526,360	0	46,829	0	0	1,573,189
Battery	5,200	13,015	1,662	0	-251	19,626
Converter	900	0	1,151	0	0	2,051
system	1,532,460	13,01520	49,641	0	-251	1,594,866

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Table 4: Cost and energy production using Hydro PV , diesel generator(10KW) & battery

Component	Capital (\$)	Replacement (\$)	O & M (\$ /yr)	Fuel (\$)	Salvage (\$)	Total (\$)
PV	9,060	0	965	0	0	10,025
Hydro	1,526,360	0	46,829	0	0	1,573,189
Generator 1	2,000	720	32,195	32,335	-65	67,185
Battery	5,200	13,015	1,662	0	-251	19,626
Converter	900	0	1,151	0	0	2,051
system	1,532,460	13,01520	49,641	0	-251	1,594,866

6.1. Cost Analysis

From the above discussion the peak load of Inkule site is 13kw, the power generated from Hydro 7kw, 5kw Diesel Generator is operate at peak load and 5kw Solar PV has to be installed to make the site effective system. By selecting the appropriate values of other components with HOMER software, Using PV, hydro, diesel generator (5KW), and battery is the best combination for this project. At world standard, average investment costs for large hydropower plants with storage typically range from as low as USD 1050/kW to as high as USD 7650/kW while the range for small hydropower projects is between USD 1300/kW and USD 8000/kW. The figure 7 shows that the cash flow summary for all the components.

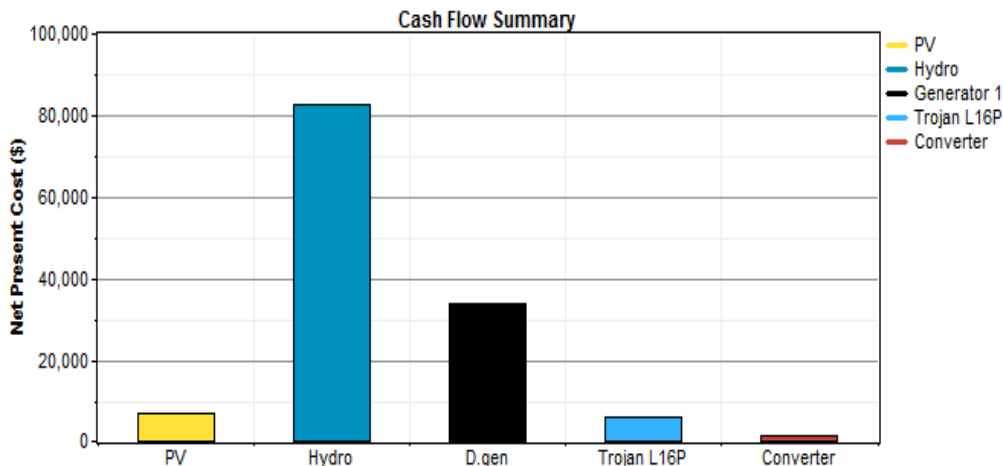
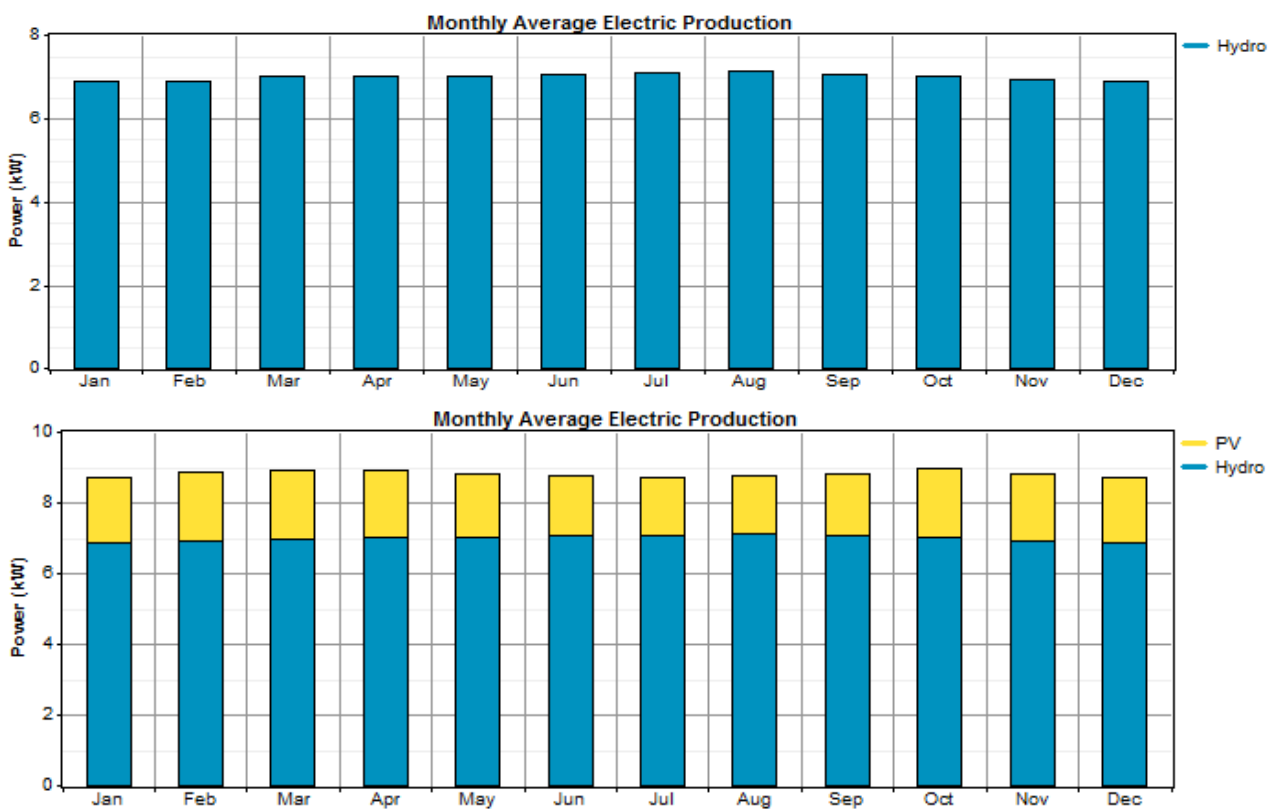


Figure 7: Cash flow summary for all components

Adding additional capacity at existing hydropower schemes or existing dams that don't have a hydropower plant can be significantly cheaper, and can cost as little as USD 500/kW. Annual operations and maintenance costs (O&M) are often quoted as a percentage of the investment cost per kW. Typical values range from 1% to 4%. Large hydropower projects will typically average around 2% to 2.5%. Small hydropower projects don't have the same economies of scale and can have O&M costs of between 1% and 6%, or in some cases even higher. The cost of electricity generated by hydropower is generally low although the costs are very site-specific. By comparing the cost operation of the Inkule power generation system with the standard cost, it is very expensive to generate 1kwh (2.778\$/kWh). The reason of cost increment is the designed total cost of hydro power for Inkule project; it is exaggerated, if it is related with world standard. Using the above standard values; to generate micro hydro power of 10KW, Investment cost is 80000\$(taking the maximum values of the standard), and O&M of Hydro power is 192 \$/yr (6%) of capital costs. Using this cost let analyze by using the standard cost for hydro power project and by setting other values for all component the same with the previous Using PV, hydro, diesel generator (5KW), and battery.



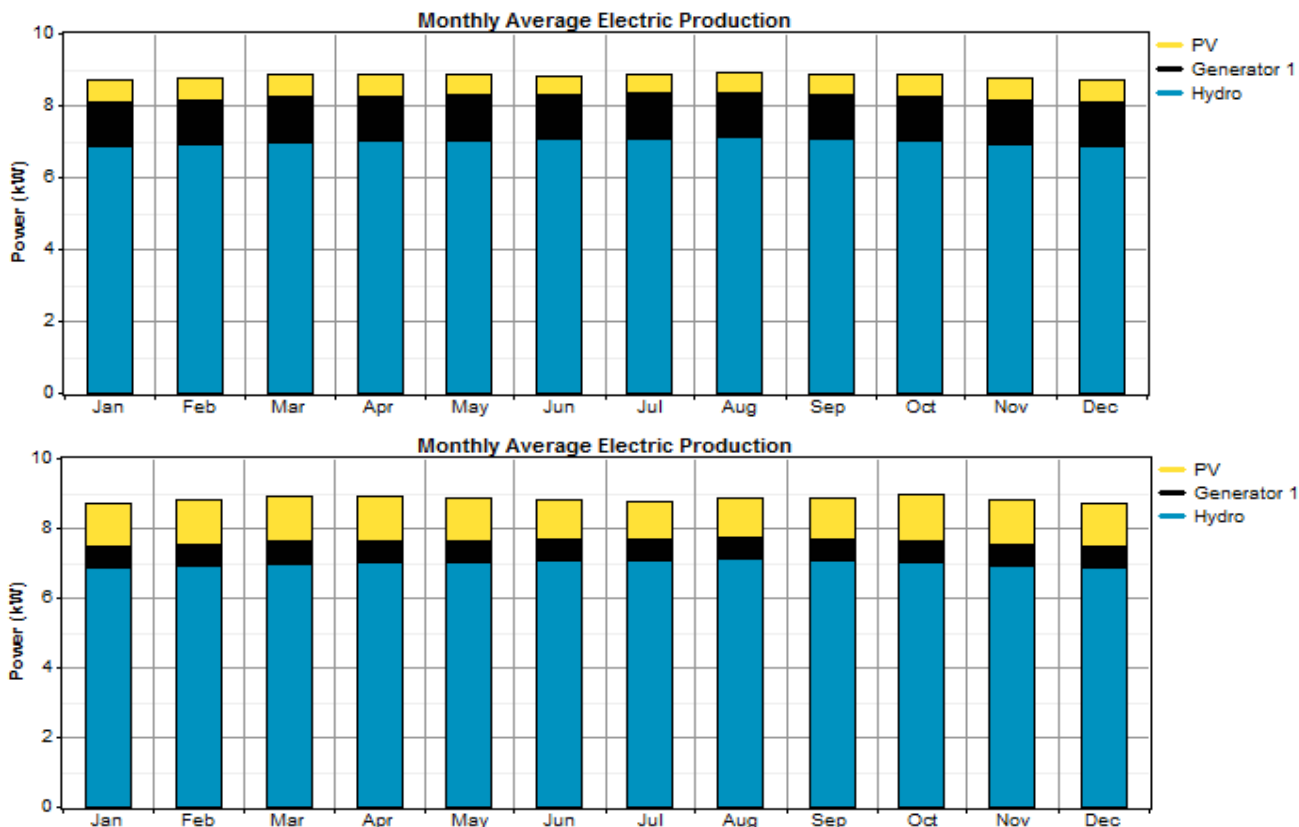


Figure 8: Monthly average electric production for the different case

From the above analysis the total NPC of the system is 129,800\$, levelized cost of energy is 0.223\$/kWh which is feasible to generate and supply energy to customer, operating cost of the system in one year is also 3,176\$/kW that found in the range of standards. By comparing the two costs; cost of Fantale project that proposed by UNIDO and approved by authorized government sector with the standard cost, the approved cost is very expensive. Using this Investment capital, more than 12 projects that can generate the same amount of power with Fantale power generation project can be constructed. Figure 9 show the output of the diesel generator power daily.

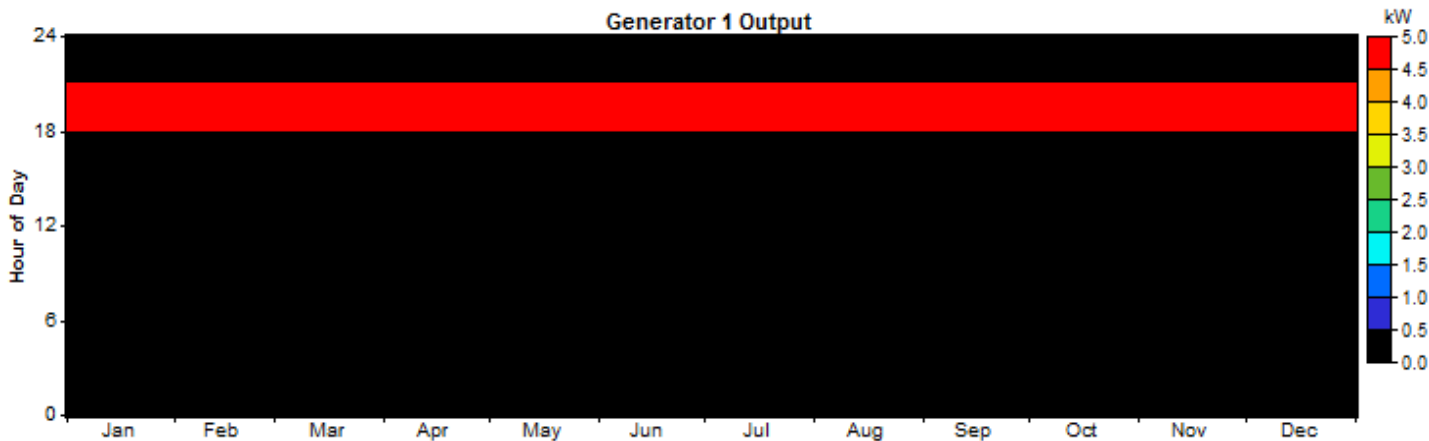


Figure 9: Diesel generator daily power output.

7. CONCLUSIONS

In this case study, reliability analysis and optimization has been done depending on the resource that found at the selected site, where the power generated from micro hydro power cannot supply all demands of Inkule village.

A micro power generation system which comprises of PV arrays, hydro and diesel generator with battery banks and power conditioning units has been discussed. In this case study to achieve a cost effective system configuration which is supposed to supply electricity to Enkule town. Before the design of the micro power system was started, the hydro energy potentials of the area had been studied. The potential Hydro power resource is evaluated from site visit and some data is taken from UNIDO experts and regarding of solar energy potential, the necessary data for the site is taken from NASA database which is recorded for many year (average solar radiation). The analysis of those energy resources data has been carried out by HOMER software. After

many simulations, depending on net present cost the optimized combination of power component has been selected by considering security and reliability of site power system and also cost of the project is analyzed by comparing with international standards. The optimal results are obtained for the selected site is using 7kw hydropower , PV- 5kw,5kW Diesel Generator,8 Trojan L16p Battery,6KW Convertor, to supply the village loads.

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