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*Research article*

# Feasibility study for power generation using off- grid energy system from micro hydro-PV-diesel generator-battery for rural area of Ethiopia: The case of Melkey Hera village, Western Ethiopia

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**Abstract:** Electricity supply in Ethiopia is extremely antiquated. Most of the remote rural areas of Ethiopia are not yet electrified. Electrifying these remote areas by extending grid system is difficult and costly. Melkey Hera village is one of a rural community situated in western Ethiopia. In this village, extension of the grid is not yet practical. As the current international trend in rural electrification is to utilize renewable energy resources; solar, wind, biomass, and micro hydro power systems can be seen as alternatives. Therefore, the target of this paper is to investigate the viability of a micro hydro, Photo Voltaic (PV) and Diesel Generator-battery hybrid power system options to come up with the best techno-economic and optimum configuration for supplying electricity to this village. The study was performed by an assessment of the predicted village energy demand, the available renewable energy resources, and then using the software called HOMER. The best hybrid system type was described and the optimization of the system configuration was also done. Furthermore, through the simulation of different configuration of the supply system, the optimal mini-grid hybrid system design was established to combine hydro, solar PV, battery energy storage and diesel generator. This system demonstrated to be more reliable in operation, and the most cost-effective for the required level of service. The role of energy storage in system operation also demonstrated to offer additional operational advantages in-terms of reliability and cost savings. Overall, the design results show that the majority of energy obtained from hydropower, which accounts 79%, the PV module covers 20%, and diesel generator is only 1% of the total load consumption. The obtained hybrid system is cost competitive with $0.133/kWh, which is somewhat good to satisfy the community needs. However, this is more than current energy price in Ethiopia which is $0.06/kWh. If due-merit given to the electricity deficiency of the country, it would play major role in improvement of life quality of community living in rural areas. From environmental standpoint, the renewable fraction of the project is 99%, which shows the system is environmentally friendly. Finally, this study identified that off grid hybrid micro hydro-PV-DG-battery bank energy system is cost effective and environmentally friendly in delivering power for rural areas far from the grid. Moreover, the study provides valuable information to the government and Non-government organization (NGO) about the renewable energy potential of the country for a rural electrification project in Ethiopia.

**Keywords:** hybrid system; renewable energy; HOMER; solar PV; micro hydro and feasibility

**Abbreviations**

| | |
|---|---|
| AC | Alternating current |
| DC | Direct Current |
| DG | Diesel Generator |
| DOD | Depth of discharge |
| EEPCo | Ethiopian Electric Power Corporation |
| ECC | Energy control center |
| GPS | Global Position surface |
| HOMER | Hybrid optimization model for electric renewable |
| HYRESS | Hybrid Renewable Energy Systems for Supplying of Service |
| LF | Load following |
| MHP | Micro Hydro -power |
| MHS | Micro hydropower system |
| MoWIE | Ministry of Water, Irrigation and Energy |
| NASA | National Aeronautics and Space Administration |
| NPC | Net present cost |
| NREL | National Renewable Energy Laboratory |
| PV | Photovoltaic |
| RE | Renewable energy |
| SHP | Small hydro power |
| UEAP | University Education Assistance Program |

## 1. Introduction

Electricity supply in Ethiopia is extremely antiquated. When compared to the African average, overall electric access in Ethiopia is very low. As in most Sub-Saharan Africa countries, urban access and rural access has a huge gap. The electricity consumption of 37 kwh per capita per year, Ethiopia has, one of the lowest consumption rates worldwide. Only approximately, 15% of populations have access to the power grid. About 89.6% of electricity in Ethiopia consumed in urban area [1].

Approximately, 50% is consumed in Addis Ababa city and 20% consumed in Bishoftu town, the second largest town in energy consumption [1].

Even though Ethiopia is rich in renewable energy resources, lack of energy supplies in rural areas in Ethiopia becomes a chronic problem. A possible reason is that, these areas are either far away from the national grid and/or the people living there are sparsely populated. Extending the national grid to these areas is not up to the economic capacity of the country because of the high cost of transmission and the very low load factor in these areas. To satisfy their energy needs, these people are using kerosene, which is becoming difficult to afford because of the high and day-by-day increasing price of the fuel; and firewood, cow dung and other traditional biomass resources, which are causing deforestation and soil degradation. The Ministry of Water, Irrigation and Energy (MoWIE) of Ethiopia is working to change this scenario. In its effort, it has identified that, the use of renewable energy such as micro hydro, Photo Voltaic (PV) and Diesel Generator-battery hybrid power system as an energy source is the solution for the above problem.

Hybrid systems are the most broadly used and cost effective energy sources for rural electrification [2]. Hence supplying energy to the local community from hybrid system will help them improve their life style as well as reduce deforestation. In addition, it will contribute a lot to the achievement of agricultural lead industrialization.

Several researches conducted in hybrid off-grid power generation all over the world and in Ethiopia. Different scholars used different Technology options and approaches to evaluate the various configurations of renewable energy resources, such as solar energy, wind energy, small hydropower and their hybrid configurations. A number of studies results have been published for varieties of applications, some of the papers are reviewed in the following paragraphs.

Simulation of a standalone electricity production for the remote settlements in Cameron was conducted by EM Nfah, et al. [2]. The study presented the energy requirement in the selected rural village were lighting, radio and television entertainments. The magnitude of the energy demand was in the range of 0.2 to 1 kWh/day. They simulated and modeled four different system configurations such as; (hydro-diesel generator-battery), (solar- diesel generator-battery), (micro hydro-diesel generator-battery), (solar- diesel generator -battery). From the simulation result the cost of energy for different renewable energy option was found to be 0.296 €/kWh. The micro hydro hybrid system was generated from a 14 kW micro hydro generator, 15 kW diesel generator and 36 kWh of battery storage. Furthermore, the second simulation for PV hybrid system was accounted for 18 kW PV generator, 15 kW diesel generator and 72 kWh of battery storage, the cost of energy was obtained to be 0.576 €/kWh for remote petrol price of 0.1 €/litter and LPG price of 0.7 €/$m^3$. The author concluded that micro hydro system proved to be the cheapest option for the southern parts of Cameroon at a minimum flow rate of 200litter/second.

Zelalem G. [3], has performed techno economic assessment of solar PV/diesel hybrid power system for a hypothetical rural school by using HOMER software to supply peak load of 11 kw for 24 hours per day. In his study he has compared only diesel power supply system to that of solar PV/diesel hybrid system with battery bank and he showed that the hybrid system is cost effective and environmentally friendly since the solar PV covers around 95% of power demand and the diesel generator is used to cover only 5% of power demand. In addition, he has conducted sensitivity analysis considering uncertainty in two variables: solar radiation and diesel fuel price. Here, the study only considered power supply for the school, teachers' resident, barber and Optimum Design and mobile charging shops for income generation of the school. The study did not consider the nearby community even if the school found in rural area.

Bizuayehu [4] developed hybrid PV/wind/battery power system to replace the existing Diesel power electricity for Kebri Dehar and Degehabur towns of Ethiopia. Both towns are remotely located from the national grid. He identified two power supply options; hybrid (standalone solar/wind/battery) system and extending new transmission line from nearest substation of the national grid to the selected towns. And he designed for both options using the HOMER simulation program as a design tool. The simulation results of hybrid system composed of solar/wind/battery indicated that the best option with the cost of generating energy (COE, US$/kWh) found 0.422 $/kWh and 0.441 $/kWh for Kebri Dehar and Degehabur towns respectively. Whereas the simulation result for the grid extension of energy cost are 1.172 and 0.869 $/kWh for Kebri Dehar and Degehabur towns respectively. According to the software result the grid connected option was found to be not economical feasible solution comparing with hybrid system to supply power for the two towns.

Clint [5] developed Hybrid Energy System for Off-Grid Rural Electrification in Kenya, that aims to design a hybrid energy system comprised of wind turbines, diesel generators and batteries to provide electricity for an off - grid rural community of 500 households, one school, one medical center and an irrigation system. He used HOMER software tool to simulate the hybrid system and analyze the results. At 40 m hub height and 1.2 USD per liter of diesel, excess electricity was generated in the optimal simulations that indicate connecting such energy systems to national electricity grid is economically viable.

Although the authors described above was used HOMER to actualize their study, the hybrid system setups were studied using different load demands, applications, location of studies as well as climatic data's. Some of the studies employed in areas that have no electricity at all whereas, the others in areas that have electricity access which provided using diesel generator. However, every hybrid power system was designed in a different way based on the available climatic data's, number of households, service centers and consumer load profiles. In most of the study, the electricity to be provided, has to be supplied for large number of households, which has to be applied for lighting, baking, communication, school, health service and small commercial business. In addition, almost all of the above scholar's paper shows the hybrid system either only using PV/wind excluding one of hydro/PV/Wind/Hydro energy. Therefore, enough research work is not available which shows PV with Micro-Hydro-DG. This was considered in this paper to investigate the viability of the project. This system configuration would be best of all due to the Ethiopia have plenty of solar resource and huge amount of Hydro potential in almost many parts of the country. To get continuous supply of electricity mostly to meet the peak load demand, diesel generator is the best solution.

Unlike the previous studies, the main focus of this study was to assess the technical and economic feasibility of standalone Micro Hydro-PV-DG-Battery hybrid energy for Melka Hera village by using HOMER software. This study shall collect, analyze relevant data and information to examine and select the most suitable systems configuration and recommend necessary action, necessary measures that configure a system to accommodate the current and near future electrical energy demand for the selected village.

The original contribution of this study is to provide valuable information to the government and Non government organization (NGO) about the potential of technology in the country for a rural electrification project. As a result the concerned body able to minimize environmental pollution, deforestation and soil degradation. Furthermore, this study can be used as a benchmark to make similar study activities for other sites.

## 2. Description of the Study Area

Melka Hera located in Toke kutaye district, western Ethiopia. One of the selected water resources for hydroelectric generation is, "Indris River" for the communities living in the village called "Melka Hera village". Its geographical coordinates are 08°51.603' North 37°43.927' East and 2379 m elevation. The scheme intends to utilize the natural drop of river elevation to generate hydropower with the available discharge.

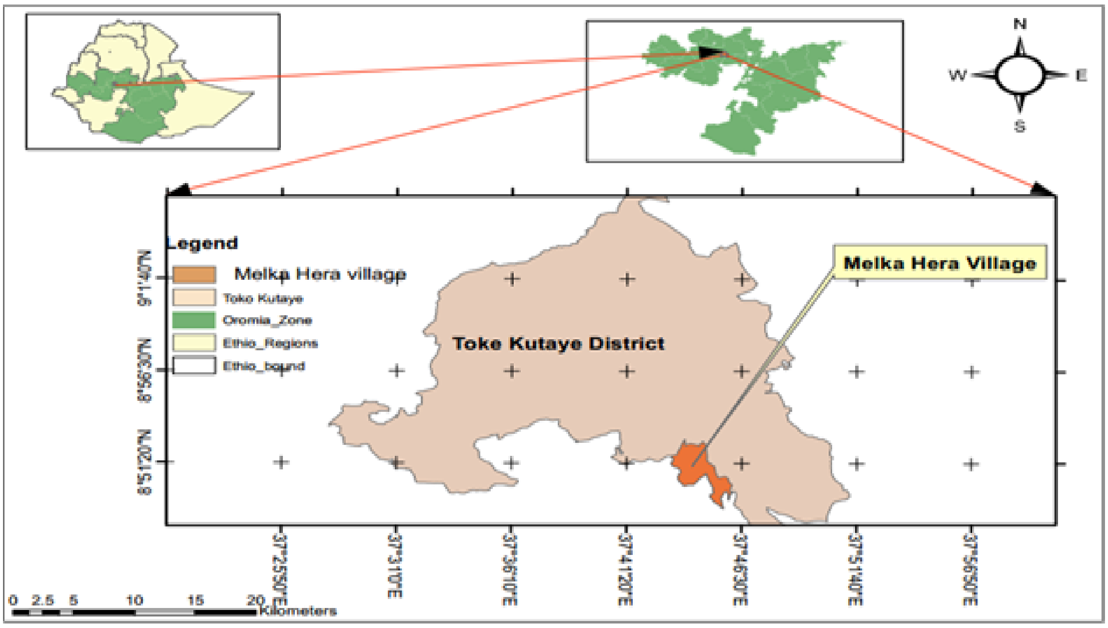


**Figure 1.** Map of the Study Area, From Arc GIS Software.

## 3. Methodology

In order to design micro hydro-PV-DG-battery hybrid power system, one has to provide some inputs such as hourly load profile, Flow data, monthly solar radiation value for a PV system, the initial cost of each component (renewable energy generators, diesel generators, battery, converter), cost of diesel fuel, annual real interest rate project lifetime, etc [5].

Flow rate data of the site was taken from MoWIE. The gross head was measured during field survey using portable GPS. The community services and commercial loads are collected from Toke kutaye district Administration of Ethiopia, and the local people live near to the selected Indris River. The solar radiations data of study area were taken from online data of NASA meteorological department. The capital cost of each equipment taken from solarbuz website and adjusted to local value by including transportation and other costs. The load profile of the village determined by using the wattage and hour of use of the proposed equipment as explained in subsequent section. To get hourly load profile of the village, Excel spreadsheet program were used.

### 3.1. *Estimating load demand of the village*

In the pre-feasibility analysis of the location, it was established that there existed about 505 households within a 1km radius in Melka Hera village. In this paper, the electric load demand of the village community is divided in to the following three major categories like: household/domestic sector, Commercial loads, Community load which consists of (elementary school; health clinic); religious load demand. The total electric load estimated for the listed appliances above were summed up to get the required load to be supplied by the system. Despite of the present situation is below the poverty line, Peak operation hours of the appliances have been proposed. Load estimation was approached based on the electric appliances to be used by each sector. The initial point to know in calculating the load is deciding which appliance has to be used by the rural family households accounting the current and future situation of the local community as well as the countries energy system framework. The three years load projection was done by taking population growth of the community living in the village. The above energy consumption sectors are called primary loads, which is summarized on table 1 below.

**Table 1.** Energy consumption sectors of the village.

| s/n | Energy consumption sectors | Energy(kWh/day) | Power (kw) |
|---|---|---|---|
| 1 | Domestic Load demand | 1088.918 | 516.45 |
| 2 | Commercial electricity Load demand | 239.6 | 28.6 |
| 3 | School Load demand | 1.67 | 0.45 |
| 4 | Health post electrical Load demand | 7.8 | 1.53 |
| 5 | Religious electric load demand | 2.676 | 0.892 |
| 6 | Load projection of the village | 125.77 | 60.02 |
| Total | | 1466.43 | 607.942 |

To import the load data into HOMER hourly load profile for the whole year is required. A load profile of 8,760 hours is created for a year based on hourly estimated load for different months. Therefore, Melka Hera's daily total energy demand is 1466 kWh/day. The total yearly energy demand of the village estimated. Energy kWh/year= 1466 kWh × 365 = 535,090 kWh/year. Simulation result of hourly demand by using HOMER software is given on Fig.2 below.

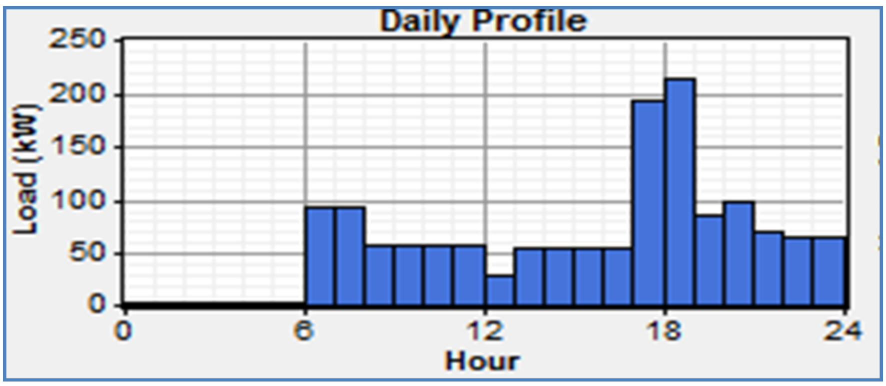


**Figure 2.** Daily load profile of the village, From HOMER.

From analysis, the daily and hourly primary load demand is indicated in Fig.2, as seen from the result, the electricity load profile varies during the day. The load is almost zero from middle of night till morning, between 0:00–6:00 hours, whereas the demand rises during breakfast times from 6:00–8:00 hours, especially at night starting from 18:00–00:00 hour took the maximum power demand than other hours. Therefore, Melka Hera's daily total energy demand is found to be 1466 kWh/day, with a peak load of 213 kW, and daily average of 61.1 kW power.

### *3.2. Village's energy resource estimation and hybrid components*

#### 3.2.1. Micro Hydro Resource Assessment

The only resource needed for a micro hydro power plant is flowing water available at a gradient. Planning for any small hydro plant begins with the (near to) accurate estimation of head and flow available at the proposed site. In the following subsections, various methods for measuring the head and discharge available have been described in detail. The potential of hydropower for the selected village estimated from the available head and flow rate can be calculated. When a site has been identified as topographically suitable for hydropower, the first task is to investigate the availability of an adequate water supply. In order to assess, adequately the minimum continuous power output to be expected from the micro-hydropower system, the minimum quantity of water available throughout the year must be determined.

#### 3.2.2. Calculating Power from micro hydro power plant

The HOMER calculates power output from MHPP from the gross head and flow rate with turbine efficiency values of ($\eta_t$). There are two waterfalls, which are only about 15 meters apart, each other and the flow rate is 70 L/s for each water fall at the driest season of the year. Therefore, to increase the power output from the river, we proposed to combine the first water falls to the second using channel so that we can increase the flow rate of the site to 0.14 $m^3$/s and the gross head remain the same. The flow of water in the selected river is adequately high year round so that the theoretical limit of power production does not limit the proposed project and we assumed the design flow rate to be 0.14 $m^3$/s for the driest season of the year [5]. Homer calculates the actual nominal power from turbine is estimated as equation 1 below:

$$P_n=H_g*\rho_{water}*g*Q_d*\eta_t \tag{1}$$

Pn = nominal power, $\rho_{water}$ = density of water, $\eta_{sys}$ = hydro system efficiency, Hg = gross head and g = acceleration due to gravity. Therefore, by taking turbine efficiency 85%, nominal power can calculated as below. The nominal power would be the power produced by the hydro turbine given the available head and a stream flow equal to the design flow rate of the hydro turbine [2].

Nominal power [kW] = [50 m $\times$1000 kg/$m^3$ $\times$ 9.81 m/$s^2$ $\times$ 140 l/s $\times$ 0.85]/1000 = 58.4 KW

The village's load demand of the village observed is greater than the available supply capacity of 58.4 kW from the design supply of the micro-hydro plant. Thus, other supply configuration has to investigated, to determine the optimal supply system to meet the electricity demand at village.

Therefore, electricity supply for the village is based on available resources of hydro and solar potential. Also included in the design are battery energy storage, and a diesel generator. The capital cost of wind turbine is higher than that of PV Therefore, at our design system, PV is reliable and incur lower costs relative to another RES.

3.2.3. Solar resource assessment of the village

To meet electrical load demand, the next step is investigating solar resource potential of the village.

HOMER runs based on directly imported solar resources from the NASA surfaces Methodology and Solar Energy database by entering the GPS coordinates. This data have been used in order to assess the solar energy potential of the site.

The clearance index and daily radiation the village is obtained from NASA surface metrology at latitude 8.85 °N and longitude of 37.71 °E. For a photovoltaic system, the monthly solar resource can be seen on Fig.3.

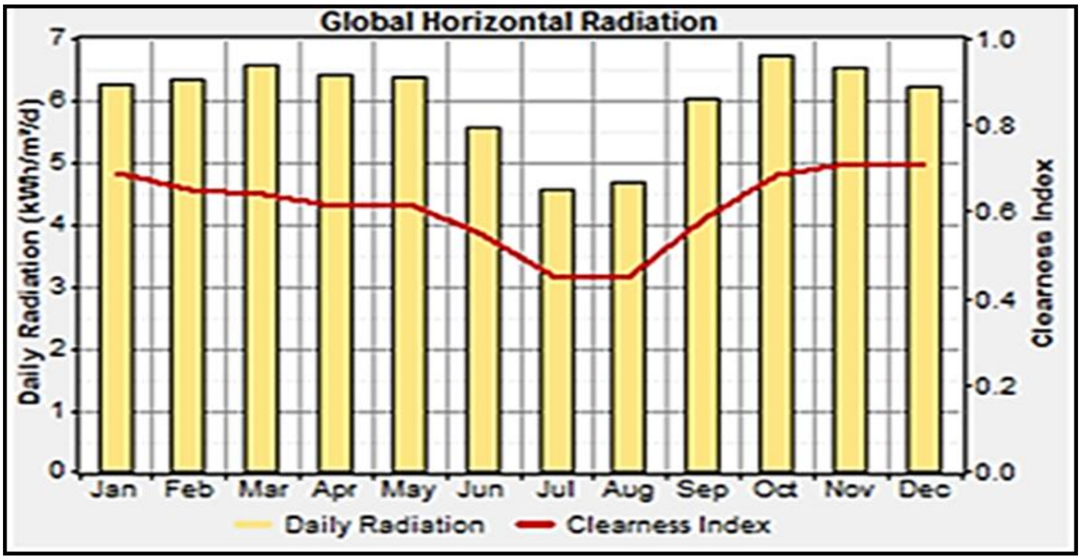


**Figure 3.** Village monthly solar resource [NASA].

The village's average solar radiation is used to determine solar energy potential of the site. The 22 years monthly average solar resource of the village varies from 6.716 kWh/m$^2$/d in October and 4.563 kWh/m$^2$/d in July, which is the summer of Ethiopia, and the clearance index obtained from NASA.

From the analysis, an average solar radiation for the village is obtained to be 6.02 kWh/m$^2$/ day. See Table 2 below.

**Table 2.** Village average solar radiation [NASA].

| Month | Clearness Index | Average Radiation/( kWh/m$^2$/day) |
|---|---|---|
| Jan | 0.693 | 6.263 |
| Feb | 0.654 | 6.331 |
| Mar | 0.641 | 6.583 |
| Apr | 6.412 | 6.412 |
| May | 6.375 | 6.375 |
| Jun | 5.569 | 5.569 |
| Jul | 4.563 | 4.563 |
| Aug | 0.452 | 4.692 |
| Sep | 0.585 | 6.019 |
| Oct | 0.685 | 6.716 |
| Nov | 0.713 | 6.519 |
| Dec | 0.709 | 6.233 |
| | Selected annual average | 6.02kWh/m$^2$/day |

### 3.2.4. Estimating PV output of the village

Broadly, defined, solar radiation is referred to the total frequency spectrum of the electromagnetic radiation originated by the sun. Several factors are used to measure the effective solar radiation, which can be converted into energy. In the solar resource input window we specify, for each time step, the *global horizontal radiation*. That is the total amount of solar radiation striking the horizontal surface on the earth. However, the power output of the PV array depends on the amount of radiation striking the surface of the PV array, which in general is not horizontal. We can describe the orientation of the PV array using two parameters, a slope and an azimuth. The slope is the angle formed between the surface of the panel and the horizontal, so a slope of zero indicates a horizontal orientation, whereas a 90 °slope indicates a vertical orientation. Therefore, to calculate the global radiation incident on the PV array HOMER uses the following equation by ignoring the effect of temperature [6].

$$P_{PV=}\ \gamma_{PV} f_{PV}\left(\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right)[1+\alpha_P(T_C\text{-}T_{C,STC})] \tag{2}$$

Where, $\gamma_{pv}$ is the rated capacity of the PV array, meaning its power output under STC [kW]

$f_{pv}$ = Is the PV derating factor [%]

$\bar{G}T$ = is the solar radiation incident on the PV array in the current time step [kW/m$^2$]
$\bar{G}T, STC$ = is the incident radiation at standard test conditions [1 kW/m$^2$]
$\alpha_p$ is panel temperature coefficient [Vov/k]
$T_C$ is Cell operational temperature [k]
$T_{C,STC}$ is Cell temperature at standard conditions [k]

If the effect of temperature on the PV array ignored, HOMER assumes that the temperature coefficient of power is zero. Therefore, the PV power output can be calculated as equation 3 below.

$$P_{pv} = \gamma_{pv} f_{pv}\left[\frac{\bar{G}_T}{\bar{G}_{T,STC}}\right] \tag{3}$$

### 3.3. *Hybrid system Component's Characteristics and unit Costs*

#### 3.3.1. Micro hydro power plant Unit Cost

Since the cost of micro hydro power plant differs according to various items, in which it is very hard to know the cost of every one because most of the items require a lot of understanding. In this project, we prefer to estimate the cost of micro hydro power plant using deferent researches, which have been demonstrated for the cost per watt of the output power produced.

Micro hydro installation in Ethiopia costs about US$1,200 per installed kW, or about half of the cost of most other plants being built in eastern Africa [22]. In addition, the information from [17] saying that, the investment cost for a micro hydro power plant can be estimated as $1136 per kW, replacement cost is 50% of capital cost and O&M cost is 10% of capital cost. Moreover, internationally an initial capital cost estimated for micro hydro power plants, with new technologies, is estimated in between US$1500 to $2500/kW. Where this cost is composed with around 75% of the development cost, it is decided by the location conditions, and the remaining 25% is the cost of purchasing engineering components (the turbine, generator, electronic load control, manual shunt-off valve, and other components). Thus in this development, the cost is taken as an average at $1200/kW by considering the remote area, and thus complicated position of the village and neighboring areas. The capital cost, replacement cost and O&M worth of the micro-hydropower system were estimated at $46,200, 23100 and $4620/year respectively.

#### 3.3.2. Solar PV module types and cost

For this study PV module produced by Sun Power with model X21-345 is selected because universities and independent research laboratories around the world compared the performance of solar panels from Sun Power against other technologies and in each case Sun Power solar panels were the clear leader [18].

The price Sun of Power with model X21-345 with efficiency 21.5% is $2/Watt. In addition, other costs such as labor, installation, structure costs, civil work also contributes a significant portion of the capital costs (Soft costs or other cost) account for 22% of total module costs [19]. Generally, PV capital cost is given as: PV capital cost (KW) = PVsyst + Soft costs or other cost.

#### 3.3.3. Converter size

The power conditioning units are electronic devices and grouped into DC-DC/AC, AC/DC. The DC/DC converters are electronic devices used to change DC voltage or current in to needed voltage and frequency outputs. The DC/AC converter uses to switch the DC voltage or current produced by the hybrid system to the AC type voltage output. This type of power converter is called power inverter. The AC/DC power converter functions as an inverse of the inverter and it is called rectifier. Inverters for solar electric system are also divided into four types depending with its application: Stand-alone inverter or off-grid inverter, Grid connected inverter, hybrid power Grid interactive inverter. With this project, we will use the Hybrid power inverters, are good for the combination solar, hydro power and diesel generator. Costs of inverters and control chargers vary based on their sizes. In this case, we select the Sunny Island, which is a bidirectional inverter for stand-alone systems. The Sunny Island can also deactivate loads automatically if the battery does not provide sufficient electrical energy. The lifetime of converter is 20 years and efficiency of 96% [16].

#### 3.3.4. Storage Batteries

A battery is a device that stores Direct Current (DC) electrical energy in electrochemical form for later use. The type of storage battery chosen is Surrette 6CS25P from the manufacturer Rolls/Surrette, which is a very high capacity battery with New Generation series 5000 advantages and features. Dual case replaceable cells small footprint and an expected life of over 10 years (depending on maintenance and application). This battery is given in HOMER tool library. The selected battery has the following characteristics obtained from HOMER modeling tool. The nominal capacity of this battery is 1156 Ah (6.94 kWh) ,maximum charge current is 41 A, lifetime throughput of 9645 kWh was considered, minimum state of charge is accounted for 40%, round-trip battery efficiency is taken as 80. By estimating the transportation and tax, the capital cost comes to $1212. In this project the approximation of replacement and O&M cost has been taken as $1212 [22].

#### 3.3.5. Diesel Generator

Diesel generator initial costs vary with size, model and design. According to their rated power and manufacturer, price of each one, and the cost in ($/kW) for each, there are different types of diesel generators. For the range of power taken in this case study analysis, this cost can be considered about 550 $/kW. The generator is used as a standby application only. As there is a variety of generator available from various manufacturers and distributors, it is difficult to compare all the different information. Here we select *Perkin* diesel generator, generator heads are all direct drive using maintenance free single bearing designs. They are completely maintenance free and automatic voltage regulated. The replacement cost is considered as 80% of capital cost and operation and maintenance cost of $0.15/hr. The lifetime of diesel generator is taken as 25000 hr [11]. The costs include the costs of installation, logistics and dealer mark-ups. The minimum load ratio is taken to be 30% of the capacity; moreover, HOMER requires the partial load efficiency to simulate this component. HOMER calculates the total operating cost of the generator based on the amount of time it has to be used in a year [19].

### *3.4. Mathematical methods and software tools for designing of hybrid energy system*

The design of hybrid energy system (HES) must be optimal in order to supply electricity reliably and economically. At present, there is no simple method to determine the best combination of HES that is well suited for a particular application due to the complexity and diversity of hybrid energy systems. The only way to seek solution to this problem is by modeling the HES. This permits to have a good idea of the performances of the system at the least possible cost of generation. There are two main approaches in designing HES: the conventional methods and the software based approach [20].

### 3.4.1. Conventional approach

This approach provides pragmatic guidelines on best practices involved in the sizing and operation of hybrid systems based on experiences with installed systems. These approaches are rule of thumb method and Ampere hour method. However, they have their limitations. It is not accurate and may not be suitable for huge project. It can only give wide intuitive or “rough” estimations and recommendations, which might still be open to improvement by a computer based technique and the method is time consuming compared to the computer based approach.

### 3.4.2. Software based hybrid energy system modeling

The utilization of computer software for the design and analysis of hybrid energy system is the natural progression of the mathematical models describing hybrid energy system and corresponding step-by-step procedural algorithm that becomes adopted and implemented in a given computer software. Most of these software tools simulate a predefined hybrid system based on a mathematical description of the component characteristic operation and system energy flow and often incorporate financial costing of the system configuration. These packages are valuable to assess a certain hybrid system design and enable to view the effects of changing component sizes and settings manually. However, many of these software tools required a hybrid system having being predesigned by other means such as the rule-of-the methods. There are some software tools available for hybrid system design and analysis. Such as Hybrid2, HOMER, RET Screen and In My Back Yard (IMBY) [20].

The strength and the weakness of the software are obtained from different literature and are classified in term of software availability (free or commercial), accuracy, and capability for economic analysis and suitability for hybrid design optimization. Thus, HOMER is the best method to model off grid hybrid energy system (Micro hydro-Solar PV-Diesel generator-Battery storage) [20]. It is the best method providing an efficient and methodological way of making informed decision about designing and constructing a hybrid energy system. The software tool has the capability to determine the system configuration, system components and sizing, cost and availability of resources and the large number of technology options available. It main advantage over many other hybrid energy system design software is that it can easily help simplify complex hybrid energy design and make an inform decision on difficult situations. HOMER simulated the operation of the system by making energy balance calculations for each of the 8,760 hours in a year. For each hour, HOMER compared the electric and thermal demand in the hour to the energy that the system can supply in that hour, and calculated the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators, HOMER will be used to decide for each hour how to operate the generators and whether to charge or discharge the batteries. For each system configuration under consideration, HOMER will perform these energy balance calculations and then determines whether a configuration is feasible, i.e., whether it can meet the electric demand under the conditions that is specified, and estimates the cost of installing and operating the system over the lifetime of the project. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest. The software has the capability to perform system optimization. The optimization process determined the best possible system configuration from a range of options [13,22]. Another interesting capability of the software program is its ability to perform sensitivity analysis. The sensitivity analysis will allow one to see how results obtained from simulation and optimization varies with changes in unpredictable inputs, such as fuel costs and solar radiation.

### *3.5. System Architecture*

In the design of a mini-grid system, the choice and sizing of the components, and the most adequate control and management strategy must be obtained. Numerous configurations of hybrid energy systems have been installed in a variety of countries over the last three decades. This has provided the necessary experience to identify the strengths and weaknesses of different configurations. Thus good performance models have been developed, that are able to prioritize the functionality of the power supply systems in such a way as to achieve cost reductions and improve system reliability. Hybrid power systems can be categorized according to their configurations: Series configuration, Switched Configuration and Parallel Configuration [13].

Among the above system configuration, we can use parallel Configuration; Current hybrid energy system software simulations and designs are based on this model design as shown in figure 4. The parallel configuration allows all energy sources to supply the loads separately depending on the demand, as well as meeting an increased level of demand by combining the various energy sources. The bi-directional inverter charges the battery (acting as a rectifier) when excess energy is available from the other generators, as well as act as DC-AC converter (inverter) under normal operation. The main advantage of this system is improved system efficiency and reliability through optimal operation and sizing of the generation components to meet the demand. While the main disadvantages to this system are, its complexity, and thus the need to automate the different controls; and also specialized training to operate the system [13].

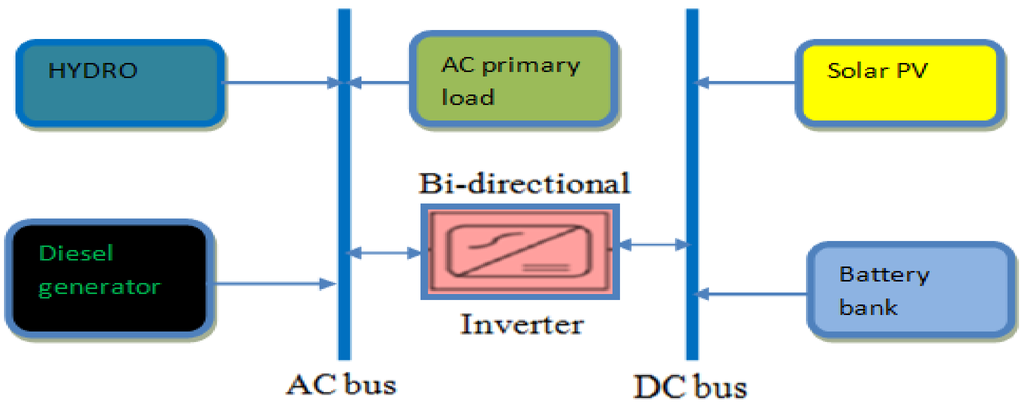


**Figure 4.** Parallel configuration hybrid systems as simulated in homer [15].

There are some approaches like substation, control center and both in this a centralized architecture. Substations are key parts of electrical generation, transmission, and distribution systems. Substations transform voltage from high to low or from low to high as necessary. However, in mini grid energy system, substation is expensive due to high installation cost, it needs maintenance and repairs for each substation, and it needs additional human power (operators) for each substation. Generally using substation to the system is not economically feasible and not affordable.

The energy control center (ECC) has traditionally been the decision center for the electric transmission and interconnected system in mini grid. The ECC provides the functions necessary for monitoring and coordinating the minute-by-minute physical and operation of the power system. The proposed architecture consists of sub-components of load demand prediction, renewable generation resource integration, electrical power-load balancing, and responsive load demand. EMSs are operating for micro grid (MG) by considering the problem constraints, power set-points of generation resources, and possible shortage or surplus of power generation in the MGs. Various parameters such as load demand and renewable power generation are treated as uncertainties in the proposed structure. In order to handle the uncertainties, central control (Bi directional inverter) is utilized [21].

## 4. Hybrid System Designing

A hybrid power system for Melka Hera village is designed where micro-hydro has been combined with photovoltaic array, battery, and diesel generator as a backup unit. The section presents the modeling of hybrid system using the optimization software called HOMER. The section starts by describing the important inputs that demonstrate the technical specifications, resources data and the costs which are relevant for modeling the system in HOMER.

### *4.1. System inputs*

System analysis with HOMER requires information on the resources, economic constraints, and control methods. Input information will includes design variables like PV array size, convertor size, quantity of battery, dispatch strategy, available head (m), flow data (water head and flow rate) and average solar radiation (KWh/m$^{2/}$day). The village load demand, component technical details and costs, constraints, controls, and type of dispatch strategy is important in the system designing. The Hydro+ Solar+ battery storage +Diesel configuration shown as Fig. 5 below:

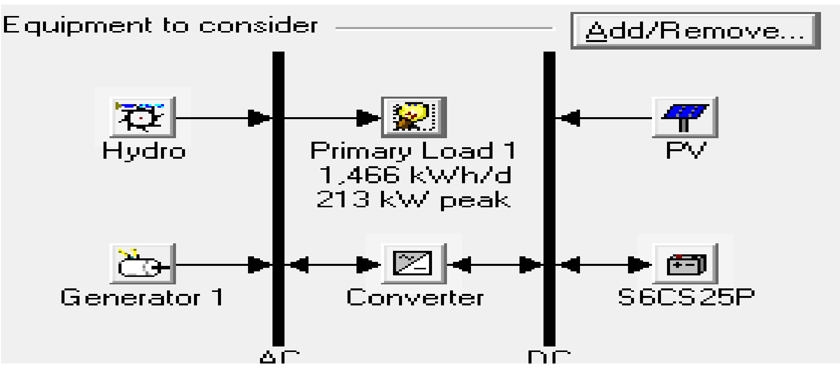


**Figure 5.** Hybrid PV-micro hydro-Diesel generator- battery micro grid topology.

In order to enable the parallel operation of the AC coupled voltage source without involving any communication the so called droop mode is used. This method uses active and reactive power statics as a basis for coordinating the performance of the various coupled converters.

## 5. Result and Discussion

This chapter would give the details of the optimization results for the selected hybrid power system of a typical 505 households and discussed toughly. After introducing all of the input variables in to the modeling tool, the software is run repeatedly to get feasible results. Optimization results are displayed in the form of overall and categorized showing the most feasible power systems architecture, which meets the load and the input constraints made by the modeler. The feasible solutions are presented in an increasing order of the net present cost from top to down. The categorized table presented the least cost effective combination from among all components setup, whereas, the overall optimization results displayed all of the affordable system combinations based on their NPC. Power systems are selected after simulation based on primarily minimum net present cost. On top of these parameters less cost of energy, high renewable fraction, low excess electricity generation, and less diesel fuel consumption could be used for comparison of power generating schemes in order to check their technical feasibility and the obtained results are discussed.

### *5.1. Simulations result and the system outputs*

The output simulation is a list of feasible combinations of micro hydro, PV, generator converter, and battery hybrid system set-up. The optimization results are generated in either of two forms; an overall orb in which the top-ranked system configurations are listed according to the least- coast system configuration is considered for each system type. Table 5.1 represents optimization results in categorized from. The tables are generated based on a particular set of inputs and the solar and micro hydro resource data for sit. The best energy system were selected with less net present coast (NPC), less cost of energy (COE), high renewable fraction, less excess electricity and less fuel consumption. The maximum annual capacity shortage and minimum renewable fraction are the worst constraints case.

**Table 3.** Categorized Simulation Result, from HOMER.

| PV (kW) | Hydro (kW) | DG (kW) | S6CS25P | Conv. (kW) | Disp. Strgy | Initial Capital | Operating Cost($/yr) | Total NPC | COE ($/kWh) | Ren. Frac. | Capacity Shortage | Diesel (L) | DG (hrs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 58.4 | 12 | 160 | 140 | LF | $591,680 | 28,782 | $997,334 | 0.133 | 0.99 | 0.01 | 3,063 | 888 |
| 70 | 58.4 | | 320 | 150 | CC | $791,140 | 32,635 | $1,251,091 | 0.167 | 1.00 | 0.01 | | |
| | 58.4 | 20 | 160 | 130 | CC | $408,940 | 83,395 | $1,584,308 | 0.211 | 0.80 | 0.01 | 45,423 | 8,743 |

### *5.2. Micro hydro output*

Nominal capacity 58.4 kW, Capacity factor 97.2%, total electric production is 497,075 kWh/yr Hydro. Penetration 92.2%, Levelized cost 0.0159$/ kWh shown in table 3 and Fig.6

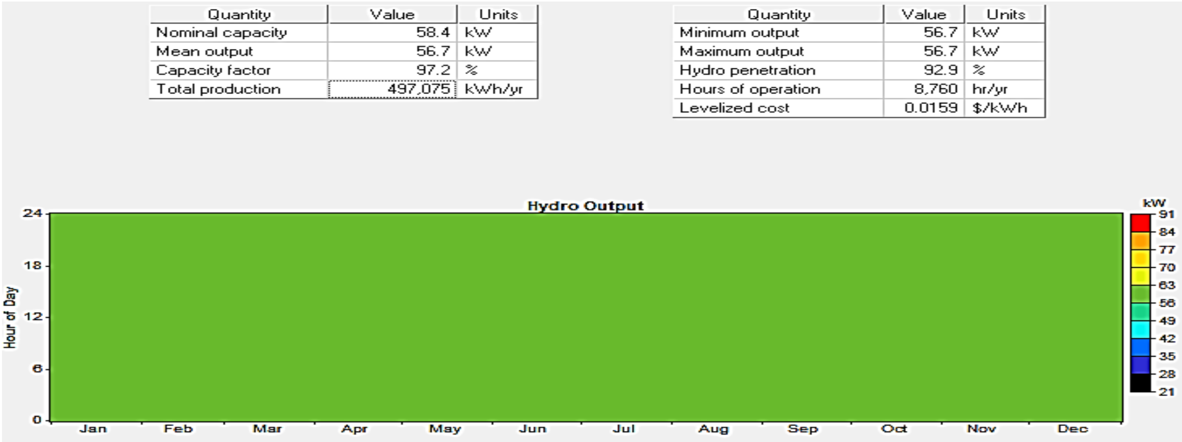


**Figure 6.** Hydropower output of the system.

### *5.3. Solar PV Output*

As result shows in the rated capacity PV is 70.0 Kw, mean output 65.6 Kw, capacity factor is 20.7%, total production 127,016 KWh/yr, Hour of operation 4,473 and levelized cost 0.09785 $KWh.

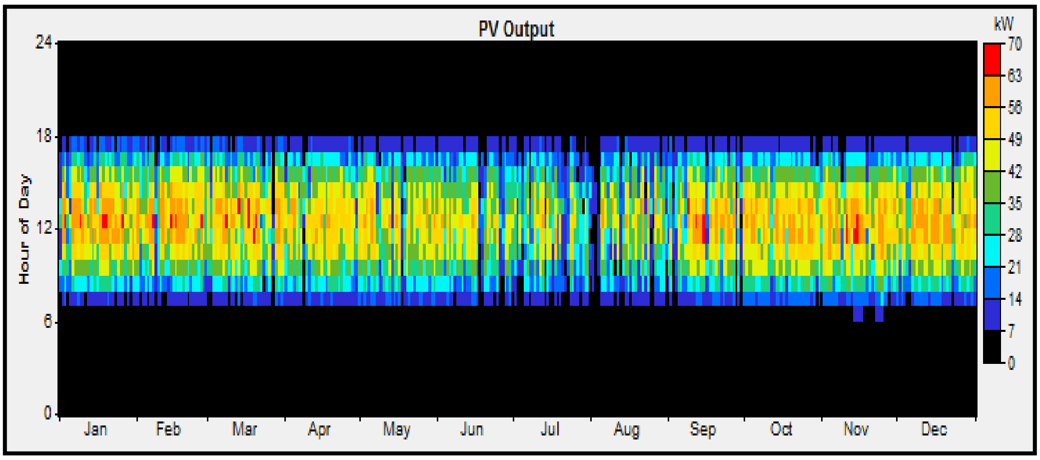


**Figure 7.** Monthly Solar PV output of the system, from HOMER.

As noticed from the Fig. 7, electricity generation is higher at the times of high solar radiation striking the earth's surface, of which October is the month that gets the largest amount of irradiation. Starting from May until end of Sept PV power generation is lower than the other months, which are below 20 kW due to cloud coverage of the sky. Mean power output is about 65.5 kW. The rated power output is 70 kW when sky is clear enough, and during no sun time the minimum power output is 0 kW. Daily high power output above 70 kW is registered in five months such as; January, February, March, October and December. Solar PV total hours of operation is 4,473 hours per annum, thus it shows that almost more than 10 hours per day is working. Levelized cost of electricity only for this system case is about 0.0978$/kWh.

### 5.4. Generator output

The following Fig.8 shows generator power output and power share of the system.

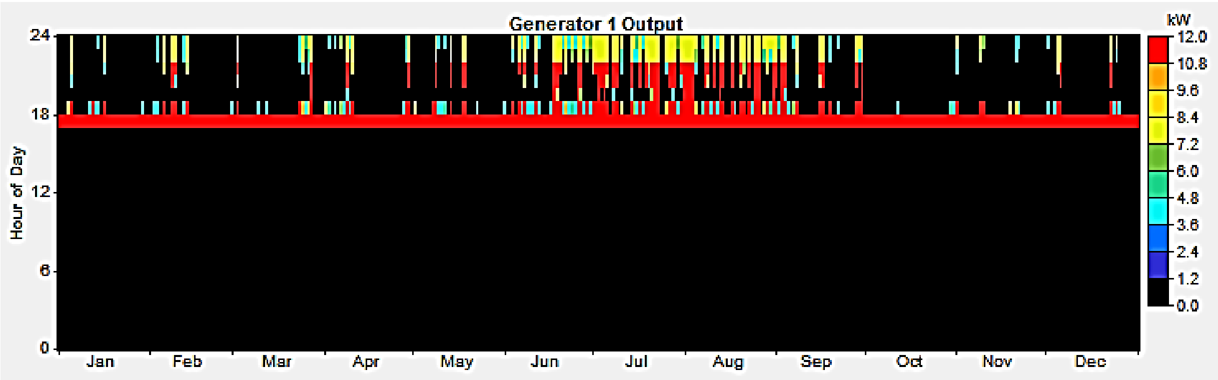


**Figure 8.** Generator output of the system.

Diesel generator power production distribution is presented in Fig. 8. Hence, the power production is relatively high during summer season of June until September because PV power generation is minimum during this period. Largely diesel power production is in the evening time (17:00–00:00) generator participating in this hybrid power system generates mean power output of 9.96 kW, minimum electrical output of 3.6 kW. The generator total operational hours and life is being 888hour per annum and 16.9 years respectively. The amount of diesel fuel consumed is around 3,063 liter per annum. The main disadvantage of the inclusion of diesel generator in power systems is environmental pollution, high running cost and noise. Use of renewable sources of energy declines emission pollutants, CO2, CO, $SO_2$, Nox and particulate matters from emitting to the atmosphere.

### 5.5. Optimization Analysis of the Selected Scenario

After simulation the following characters would be resulted such as; annual electrical energy production, initial capital cost, excess electricity, renewable fraction, unmet electric load, capacity shortage, annual fuel consumption, and operation hours of generator, etc. In table 3 is the truncated overall optimization result of all the promising configurations of feasible power scheme. There was no any requirement for pre-selection of the truncated power systems listed in the table but only the ones from top ranked cost effective scheme architectures are displayed here. The result is for the selected scenario A based on current diesel price of $0.72/liter, primary load demand of 1466 kWh/year, maximum annual capacity shortage of 1%, and minimum renewable fraction of 60%. The system set-up in the first row of table 3 is the cost efficient system composed of Micro hydropower with 58.4 kW, 70 kW photovoltaic panel. To compensate for the potential uncertainty, raised by variation in climatic conditions, back-up power is often essential. Here, these issues are taken care of by using a hybrid system of PV-Hydro, along with back-up sources of Battery bank and Diesel generator supported by a Bidirectional inverter and Charge controller, 12 kW diesel generator, 160 unit batteries, and 140 kW converter, where the diesel generator runs in load following (LF) strategy. The trend of monthly power generation in kW obtained after simulation shown in Fig.9. All of the power schemes producing electricity throughout the year, no power unit is producing peak load. However, diesel generator runs regularly the whole year due to the reason that large nighttime load sought because renewable energy sources stored in the battery is not enough to meet the load.

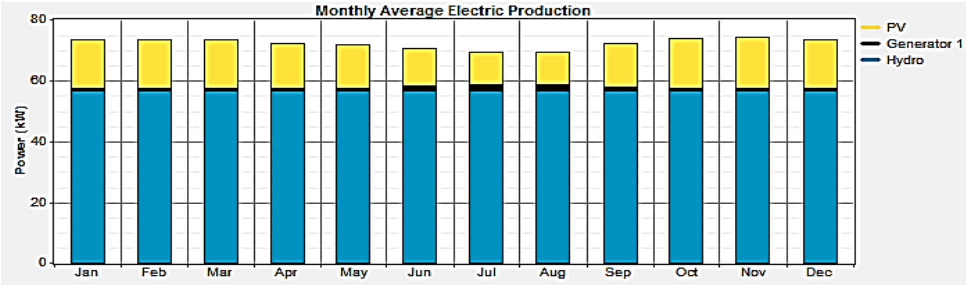


**Figure 9.** Hydro-PV-diesel system electrical supply properties.

The electricity generation by individual power units of the hybrid system and consumptions by primary AC are given in Fig.10. PV array power production accounts for 20% whereas Hydro accounts for 79%, and diesel generator accounts for 1% of total electricity produced by the hybrid scheme. As generation of electricity from Hydro sources is higher than any other scheme incorporating in the hybrid structure, hence it is considered as the base load of the hybrid assembly.

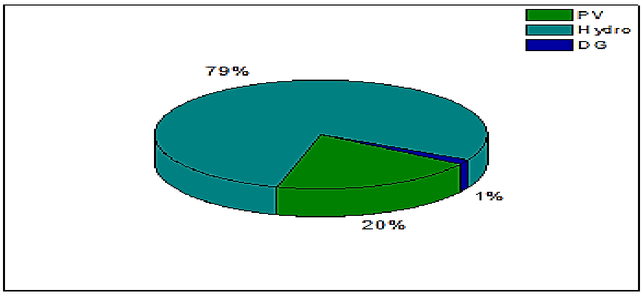


**Figure 10.** Power Generation 99% RF, from Math lab.

According to the above observations, we can see that PV system produce more power than micro-hydro turbine with less system output percentage (20%). Because when the photovoltaic array produces more energy than being consumed, the energy is used to charge the battery bank if the battery is in a low state of charge otherwise it increases the bus frequency and automatically reduces the power feed from a photovoltaic array to the buss. If, on the other hand, the photovoltaic array generates less energy than being used, the batteries provide the needed margin. Most load profile indicate peak load in the evening time, but solar energy is available only during daytime particularly at peak sun hour. Even though the micro-hydro produced rated power is less than PV, this system can meet the load with an availability of around 100% resulting in only around 0 hours of power outage during a year.

The hybrid system, which uses both renewable sources and diesel generator, is more economical than the system with only renewable energy sources. However, the important matter is the sizing of the hybrid components in a right way to reduce the energy cost or net present cost of the project. If sizing is not done properly then we may end up with a system having larger NPC than the base system was in concern.

*5.6. Sensitivity analysis*

Two sensitivity variables have been chosen to take in to accounts show the variation of these variables in the future. The chosen variables are amount of solar radiation of the site and the price of diesel fuel. It is assumed that these two a variable highly affect the cost of the system. The output of sensitivity analysis is shown as graph as shown in Fig. 11.

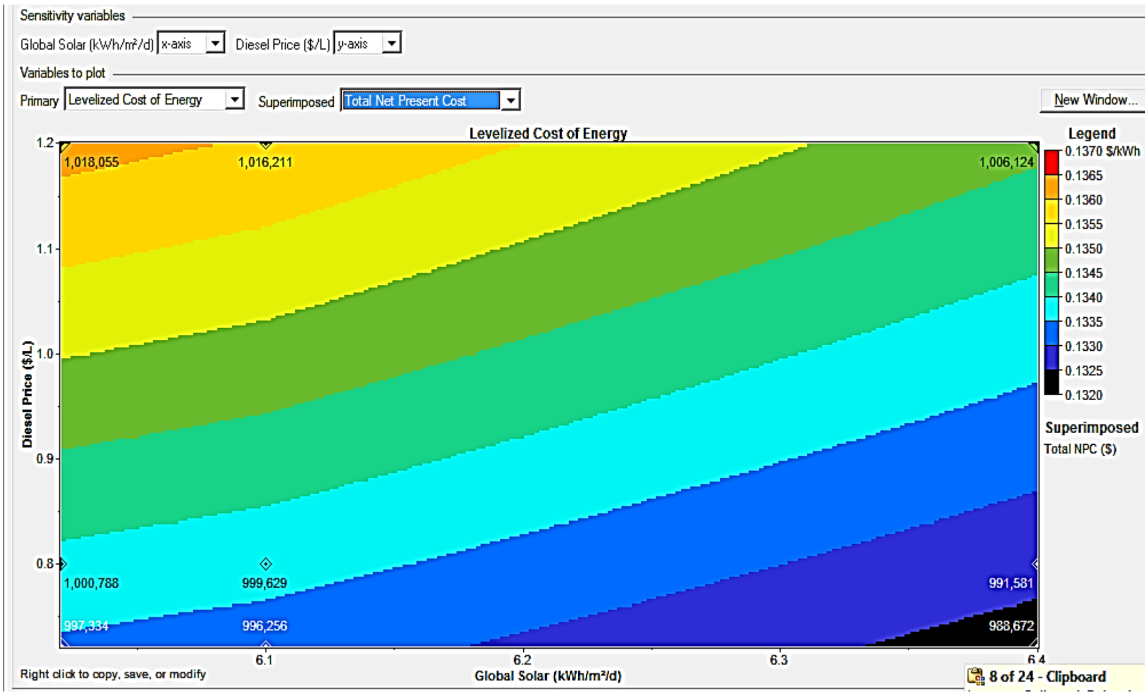


**Figure 11.** Diesel price **and** global solar radiation Variations on COE and NPC.

As seen from figure, PV-micro hydro DG-battery system is optimal unit the solar radiation will reach 6.02 KWh/M$^2$/day and less sensitive to the price change of the fuel. The current diesel fuel price in Ethiopia is around 0.72 $/liter. When the diesel price sore beyond 1.2 $/litter micro hydro-PV-DG-battery hybrid system is more economical. Since the optimal system incorporates all the subsystems, it is feasible to install generator as back up and use solar energy and battery to cover base loads.

*5.7. Engineering economical analysis*

Once the technical requirements of a hybrid system application have been stated and a Hybrid system design completed, the economic analysis can be carried out. The economic assessment includes both costs and benefits of the system. The replacement and O&M costs are further illustrated in Fig.12 as a nominal cash flow of the project throughout 25 years. Here we can see, after 9 and 18 years battery replacement occurs, the same case for the converters, the letter will be replaced after 19 years. Yearly, the O&M cost for hydro, DG and battery will be occurred. Due to PV lifetime is equals to the project lifetime, it has t no replacement and it has no O&M cost. The lifetime of the selected DG for the case study is more than project lifetime, it has no replacement cost.

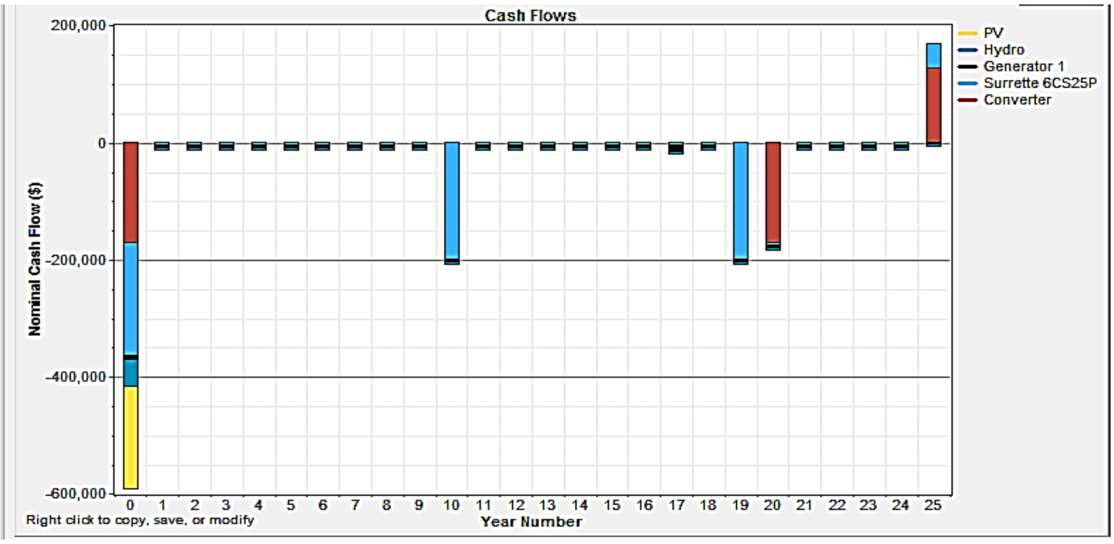


**Figure 12.** Nominal cash flow of the project throughout 25 years.

Net present cost (NPC): The present value of the cost of installing and operating the system over the lifetime of the project (also referred to as lifecycle cost). Project lifetime in this study considered as 25 years. The total net present cost is HOMER's main economic output. All systems ranked according to net present cost, and all other economic outputs calculated for finding the net present cost. The net present cost calculated according to the following equation [8]. The lower the net present Cost, the more attractive the proposed project.

$$NPC = \frac{PC_{ann,tot}}{\text{CRF (i, Rproj)}} \tag{5}$$

Where, $PC_{ann,\ tot}$ is total annualized present cost [$/year]. The CRF () - capital recovery factor

For present (P) given annual value (A) (P/A, i, n), P= A*$\left[\frac{i*(i+1)^n}{(1+i)^n-1}\right]$.

By using equation. 5, the tot annual present capital cost is given as:

CRF (i, Rproj) = $\left[\frac{i*(i+1)^n}{(1+i)^n-1}\right] = \left[\frac{0.05*(0.05+1)^{25}}{(1+0.05)^{26}-1}\right] = 0.0709$

$PC_{\ ann,tot} = PC_{cap,tot} * \left[\frac{i*(i+1)^n}{(1+i)^n-1}\right] = \$997{,}334 * [0.0709] = \$70{,}763$

NPC=70,763/[0.0709] = $997,334

Levelized cost of energy (LCOE**)**: HOMER defines the levelized cost of energy (COE) as the average cost/kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity by the total useful electric energy production.

$$LCOE = \frac{PC_{ann,tot}}{E_{prim,AC}} \tag{6}$$

$E_{prim,\ AC}$ is AC primary load served [kWh/year] and $PC_{ann,\ tot}$ is annualized present cost

$COE = \frac{70763}{530{,}381} = \$0.133/kWh$

*Simple Payback period:* The payback method determines the number of years required for the invested capital to be offset by resulting benefits. The number of years required for the investment to be recovered is called as payback period.

$$Simple\ payback\ period = \frac{\text{Initial Investment}}{\text{Annual, Cash Inflow}} \quad (7)$$

$payback\ period\ (P_B)$, Calculated for a proposal compared with some predetermined target period (scenario B and C). By this method, HOMER compares $P_B$ of scenario A with (Scenario B and C). Therefore, $P_B$ of scenario A is $3.42 \approx 4yrs$ which is the lowest. Hence, the project is profitable.

## 6. Conclusion

This paper work has been devoted to feasibility of micro hydro-PV-DG-battery hybrid off grid energy system, to answer the question technically feasible and cost effective system configuration system for Melka Hera village, western Ethiopia. The hybrid system designed to supply electricity to the village to improve live quality as well as infrastructure in the village where they are detached from the central grid. The study of renewable energy potentials of the site is based on the recently recorded data of twenty-two years average solar radiation optioned from surface metrology [NASA] and the flow data is obtained from MoWIE. The average monthly profile and hourly data for both sources were analyzed using HOMER software. From potential determination of the site is not sufficient supplying the village's in the current and near feature energy demand. Alternatively, when batteries capacity decreases, and thus, facilities face no supply interruption.

The result optioned from the software gave numerous alternatives of feasible hybrid systems with different levels of renewable resource penetration, which their choice sorted by changing the net present cost of each set up. From technical point of view, micro hydro/PV/GD Battery hybrid system is proposed in this study. From simulation result, the majority of energy is optioned from hydropower, which accounts 79%, the PV module covers only 20%, and DG is only 1% of total load consumption. From economic point of view, it is found hat for the village under study, which is characterized by average stream flow140 l/s and solar radiation 6.02 kWh/m$^2$/day. The hybrid system is cost competitive with $0.133/kWh, is somehow good. However, it is more than the current grid price of Ethiopia $0.06/kWh. Because the main source of energy in the country is hydropower. However, hydropower potential is not exploited fully to cover the electricity demand of the country. If due- merit is given to the electricity, it would play a major role in the improvement of life quality of the country living in rural areas. At the same time it will also improve the quality of education, reduce fire wood cultivation, and environmental pollution, taking this all into consideration, this higher cost should not be given concern. From environmental standpoint, the renewable energy fraction of the project is 99%, which implies the total energy almost obtained from renewable energy sources. Due to this study, promoting clean energy and its contribution to reduction of pollutant emission released to the environment.

Finally, we can conclude that this hybrid power system is an excellent option solution due to economical and attractive for electrification of the selected rural village under the condition of involving local trained people for maintaining the system and receiving some funds or donation from the government or non-governmental organizations. This energy system, minimize environmental pollution and deforestation due to environmentally friendly**.** Moreover, provide valuable information to the government and Non-government organization (NGO) about the potential of technology in the country for a rural electrification project in Ethiopia. Furthermore, this study can be used as a benchmark to make similar study activities for other sites.

**Acknowledgments**

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**Conflict of Interest**

The authors declare there is no conflict of interest.

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**Appendix: Summary for the village's energy demand**

| Period | Domestic load(kWh/d) 25% HH | School load (kWh/d) | Health post load (kWh/d) | Churches load (kWh/d) | Commercial (kWh/d) | Total load |
|---|---|---|---|---|---|---|
| **00:00-1:00** | 0 | 0 | 0.06 | 0 | 3.6 | 3.66 |
| **1:00-2:00** | 0 | 0 | 0.06 | 0 | 3.6 | 3.66 |
| **2:00-3:00** | 0 | 0 | 0.06 | 0 | 3.6 | 3.66 |
| **3:00-4:00** | 0 | 0 | 0.06 | 0 | 3.6 | 3.66 |
| **4:00-5:00** | 0 | 0 | 0.06 | 0 | 3.6 | 3.66 |
| **5:00-6:00** | 0 | 0 | 0.06 | 0 | 3.6 | 3.66 |
| **6:00-7:00** | 92.119 | 0 | 0.06 | 0 | 0 | 92.179 |
| **7:00-8:00** | 92.119 | 0 | 0.06 | 0 | 0 | 92.179 |
| **8:00-9:00** | 29.44 | 0.1 | 1.27 | 0.1 | 25 | 55.91 |
| **9:00-10:00** | 29.44 | 0.1 | 1.27 | 0.16 | 25 | 55.97 |
| **10:00-11:00** | 29.44 | 0.1 | 1.27 | 0.16 | 25 | 55.97 |
| **11:00-12:00** | 29.44 | 0.1 | 1.27 | 0.12 | 25 | 55.93 |
| **12:00-13:00** | 29.44 | 0 | 0.06 | 0 | 0 | 29.5 |
| **13:00-14:00** | 29.44 | 0.1 | 0.25 | 0 | 25 | 54.79 |
| **14:00-15:00** | 29.44 | 0.1 | 0.25 | 0 | 25 | 54.79 |

| Period | Domestic load(kWh/d) 25% HH | School load (kWh/d) | Health post load (kWh/d) | Churches load (kWh/d) | Commercial (kWh/d) | Total load |
|---|---|---|---|---|---|---|
| **15:00-16:00** | 29.44 | 0.16 | 0.27 | 0 | 25 | 54.87 |
| **16:00-17:00** | 29.44 | 0.16 | 0.25 | 0 | 25 | 54.85 |
| **17:00-18:00** | 192.775 | o.25 | 0.27 | 0.73 | 0 | 194.025 |
| **18:00-19:00** | 213.22 | 0 | 0.06 | 0 | 0 | 213.28 |
| **19:00-20:00** | 79.94 | 0.25 | 0.27 | 0.73 | 3.6 | 84.79 |
| **20:00-21:00** | 92.35 | 0.25 | 0.14 | 0.67 | 3.6 | 97.01 |
| **21:00-22:00** | 66.195 | 0 | 0.14 | 0 | 3.6 | 69.935 |
| **22:00-23:00** | 60.505 | 0 | 0.14 | 0 | 3.6 | 64.245 |
| **23:00-00:00** | 60.505 | 0 | 0.14 | 0 | 3.6 | 64.245 |
| **total** | **1214.68** | **1.67** | **7.8** | **2.67** | **239.6** | **1466.428** |

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