Feasibility Study and Design of Standalone Hybrid Power Generation System for Rural Area in Ethiopia: Case Study of Minjar-Shenkora Woreda

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Abstract: -Ethiopia is one of the second populated countries in Africa. The highest percentage of the population lives in remote rural areas without having access to clean energy. Energy is one of the power full tools to change the populations' lifestyle. Either extending from the grid or using a standalone system is options to energize the area.

The Dubetu and Rarati Kebeles which are found at Minjar-Shenkora woreda in the Amhara Region of Ethiopia at Latitude: 8.598565, Longitude: 38.433785 with an elevation of 2312. The woreda is located at the southern end of the Semien Shewa Zone, bordered on the east, south, and west by Oromia Region, on the northwest by Hagere Miriamna Kesem, and on the northeast by Berehet. The total number of population and householder respectively is 14088 and 2499. The rural villages are far away from grid (mojo substation of Ethiopia) with a distance of more than 64km. Due to its geographical location and distance from the grid, the area has not been electrified yet, and the population is still living in dark. So, a standalone system is a way to electrify this remote village.

The energy demand of the two towns Residential and Differential load respectively is 5898.605kWh/day and 3611.25KWh/day. In Minjar-Shenkora woreda attractive renewable energy resource are available with a huge potential like good solar insolation, unwanted waste and water. Considering minimum solar insolation of G_{min} 4600 Wh/m^2/day, the Average Biomass input of 8.15t/h, and minimum water flow 3.497m^3/s of a river, a hybrid model has been designed and evaluated using HOMER and MATLAB Simulink Software. The best feasible generation system is determined for the selected site from optimization process; which can supply the whole load in reliable way despite the variation of radiation and water flow. The selected system contains PV, Biogas, Mini Hydro, Battery and Converter with a COE of $0.1718/kWh and a total net present cost (NPC) of $9.203604 million. This system has excess electricity generation of 63.5%, capacity shortage of 1.92%, and unmet electric load 1.92%. The COE of the feasible setups is in the range of 0.1718 to 0.7620 $ per kilowatt-hour, with a relatively low COE than the national tariff.

Key-Words: -Hybrid, PV, Biogas, Mini-Hydro, Primary Load, Deferrable Load, optimization, sensitive, COE, HOMER and MATLAB.

1 Introduction

Energy is one of the power full tools to change the populations' lifestyle all over the world. Mostly social, political, and economic activity is directly or indirectly affected by power source at the local or at the national level, but the current data shows most of the developing nations, their huge number of populations live without harnessing energy. Ethiopia is the second populated nation in Africa and most of people live in the rural area without using electricity, almost all are highly dependent on biomass. Due tothese, the environment is highly threatened. This is one of the critical issues. One way to solve the issue is using environment friendly energy sources **[1].**

An energy source can be non-Renewable and Renewable. Non-Renewable source of energy is a fossil fuel, oil, and so on, kinds of resources are non-terminating once used also, environmentally negative due to a high amount of carbon emission and expansive whereas, Renewable energy source is easily available and terminating types. Among these Hydro, wind, geothermal, solar, biogas energy, are the most promising one's, due to the availability of water, wind, hot spring, good solar irradiation, and waste product and animal, it becomes cost-effective and pollution less in reality **[2].**

One of the cost-effective mechanisms in energy generation is a hybrid power source, in Ethiopia hybrid system is not a new concept. The most common power generation is hydropower, wind and geothermal, and in somewhat solar in communication data revising centre. Since Ethiopia's government highly give attention towards alternative energy source; the power generation capacity increasing now, in the 2011EC energy supply potential of the country grid increased to 58.43% but, not yet satisfy the demand of the nation **[3].**

Hybridization of Energy is a vast concept it involves like, solar photovoltaic, hydro, biogas, geothermal, and with other energy sources to supply consumer loads. Such system encounters complexities arising from the various nature of the renewable electricity sources, low energy densities, and intermittent availability so, energy provide from solar, biogas, and mini-hydro sources can all be represented in terms of deterministic components. Such kinds of power generation integration are done connected with grid or standalone **[4].**

A grid-connected or standalone system might be used to electrify these areas. The grid connection is too expensive but with higher energy capacity. The standalone configuration can supply such villages in more cost-effective way but usually with limited power capacity. The integration of hybrid PV, mini-hydro with a Biogas system to the off-grid is growing due to the enhancement in the electric power technology **[4][5].**

2. Theoretical Background

2.1 Solar System

The sun is the source of life on our planet which is the founder, either directly or indirectly, of most renewable systems. On its surface, the sun emits a radiant power of 63.1 MW / m^2. This means that only one-fifth of a square kilometre of the Sun's surface emits energy equal to the global supply for primary energy on Earth **[6].**

2.1.1 Solar Energy System and Solar Energy Resources

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2.1.2 Photovoltaic's Power System

Photovoltaic (PV) are solid-state, semiconductor type devices that produce electricity when exposed to light. The word photovoltaic means "electricity from light." Many handheld calculators run off power from room light, which would be one example of this phenomenon. Large power applications for this technology are also possible. PV power generation uses solar panels comprising many cells containing a semiconductor material. If the light is shining on the solar cell, it generates electrical power **[7].**

2.1.3 PV cells –modules–strings/Arrays

The fundamental constructing block for PV structures include cells, modules, and arrays. The individual PV cells are connected to make a module (called 'PV module') to make a bigger current and the modules are linked in an array ('PV array'). Depending on modern or voltage requirements, PV arrays are linked with a range of ways, i.e. both in series and parallel. PV cells or modules are commonly linked in sequence strings to construct a voltage whilst string of PV cells or modules can also be connected in parallel to build current **[8].**

Figure1: solar panel in Dubetu health post

Figure.1 show the installed solar panel for Dubetu health post. The energy source used for refrigerator to keep pharmaceutical.

A sun-powered cell which changes over photons in Sun-poweredbeams to direct-current (DC) and voltage. The relatedinnovation is called Sun-powered Photovoltaic (SPV). A commonplace silicon PV cell may be alean wafer comprising of a lean layer of phosphorus-doped (N-type) silicon on the beat of a thicker layer of boron-doped (P-type) silicon. An electrical field is madeclose to the beat surface of the cell where these two materials are in contact (the P-N intersection). When the daylight hits the semiconductor surface, an electron springs up and is pulled in towards the N-type semiconductor fabric. This will cause more negatives within the n-type and more positives within the P-type semiconductors, producinga DC output source. This can be known as the Photovoltaic effect **[9].**

Figure2: Solar module in Rarati

2.2 Biogas Energy

Biogas is a renewable energy source, like solar, wind energy and hydropower which is a fuel gas consisting of a mixture of methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulfide (H_2S), produced through microbial processes under anaerobic conditions from a variety of organic material like manure, sewage, municipal waste, plant material, and crops **[11].**The production of biogas from animal excreta and sewage for the selected site. Methane production is low if the material consists mainly of carbohydrates, such as glucose and other simple sugars and high molecular compounds (polymers) such as cellulose and hemicelluloses. However, if the fat content is high, the production of methane is equally high **[12].**

Table1: Composition of Biogas **[12]**

Gas	**%**
Methane (CH_4)	40-70
Carbon dioxide (CO_2)	30-45
Hydrogen sulfide (H_2S)	1-2
Hydrogen(H_2)	1-2
Ammonia (NH_3)	1-2
Carbon monoxide (CO)	$\angle 1$
Nitrogen (N_2)	$\angle 1$
Oxygen(O2)	$\angle 1$

Methane and additional hydrogen there maybe make up the combustible part of biogas. Methane is a colourless and odourless fuel with a boiling point of 162°C and it burns with a blue flame. At normal temperature and pressure, methane has a density of approximately 0.75 kg/m^3. Due to carbon dioxide being incredibly heavier, biogas has a slightly greater density of 1.15-1.25kg/m^3**[12].**

2.2.1 The Biogas Production Process

Anaerobic digestion (AD) is a biochemical method throughout which complicated organic matter is decomposed in the absence of oxygen, through several anaerobic microorganisms. The result of the AD reaction in the biogas and the digester. Biogas is a flammable gas made up of methane and carbon dioxide. Digestate is a decomposed substrate produced by the production of biogas. If the substrate for AD is a homogeneous combination of two or more types of feedstock (e.g. human and animal excreta, sewage, and agricultural products such as labyrinth and food waste), the process is referred to as "co-digestion" and is frequent to most biogas applications today. The process of biogas formation is a result of linked process steps, in which the initial material is continuously broken down into smaller units. Specific organizations of micro-organisms are involved in every step. The highlight the four major procedure steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The speed of the total decomposition method is decided through the slowest response of the chain. During hydrolysis, very small quantities of biogas are produced. Biogas production reaches its peak all through methanogenesis **[13].**

2.2.2How to secure continuous feedstock supply

The first step in developing a biogas project idea is to make a critical inventory of theavailable types and amounts of feedstock in the region. There are two main categories ofbiomass that can be used as feedstock in a biogas plant. The first category includes farm-based products suchas municipal solid waste, energy crops (e.g. maize, grass silage),vegetable residues, agricultural by-products, and farm-based wastes **etc [15].**

In Dubetu and Rarati Kebele all most they are farmers. They have an attractive resource for biogas production. One of these is the wastage of humans and animals, crops, and so on has found in the village used to secure continuous feedstock for the production of methane, as well as from an economic point of view (e.g. gate fees, collection and transportation costs, seasonality) and this wastage once it used it will be advantageous for farmers as organic fertilizer to increase farm production.

2.2.3 Factors Affecting Anaerobic Digestion Process (Methanogens)

The efficiency of anaerobic digestion is influenced by the resource of some parameters; for this reason, excellent prerequisites for anaerobic microorganisms must be provided. The increase and recreation of anaerobic microorganisms are considerably influenced by the aid of prerequisites such as the exclusion of oxygen, regular temperature, pH-value, nutrient supply, stirring intensity as properly as presence, and number of inhibitors (e.g. ammonia)**[14].**

2.2.4 Biogas Plant model

A biogas plant is a complex installation composed of a variety of elements. The layout of such a plant depends on the kinds and quantities of supplied feedstock to a massive extent. As there are several different types of feedstock appropriate for digestion in biogas plants, there are more than a few methods for handling these types of feedstock and different digesters, accordingly. There are different types of biogas plant life in usage to produce biogas **[15]: -**

- Fixed Dome Biogas Plants.
- Floating Drum Plants.
- Low-Cost Polyethylene Tube Digester.
- Balloon Plants.
- Horizontal Plants.
- Earth-pit Plants.
- Ferro-cement Plants.

The most known are:

- The fixed-dome type of biogas plant
- The floating gas holder type of biogas plant

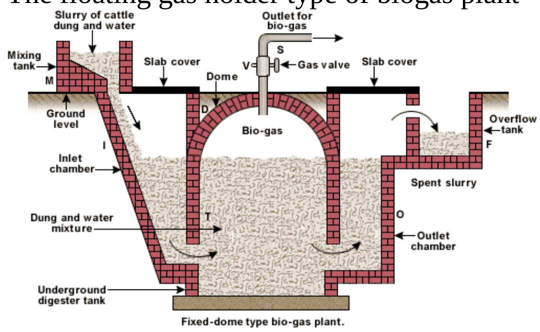


Figure3: fixed dome type biogas plant **[16]**

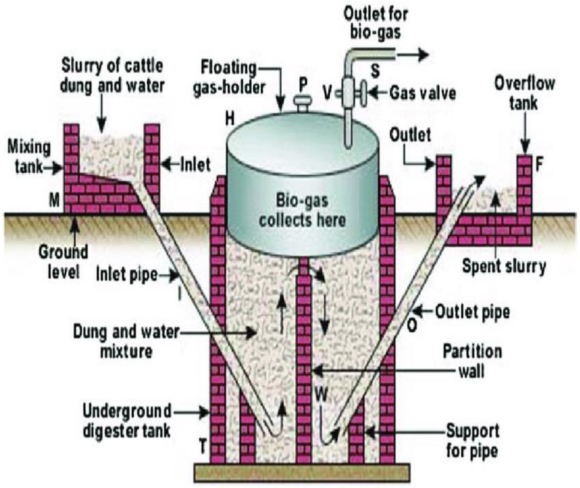


Figure4: Floating gas holder type biogas plant **[17]**

2.2.5 Temperature

The AD process can take place at different temperatures, divided into three temperatureranges: psychrophilic (below 25ºC), mesophilic(25ºC – 45ºC), and thermophilic (45ºC –70ºC). There is a direct relation between the process temperature (Table. 2)**[15].**

Table2: Thermal stage and typical retention times **[15]**

Thermal stage	Process temperatures	Minimum retention time
Psychrophilic	< 20 °C	70 to 80 days
Mesophilic	30 to 42 °C	30 to 40 days
Thermophilic	43 to 55 °C	15 o 20 days

2.2.5 Utilization's of biogas energy

Generally, biogas can be used for heat production by direct combustion, electricity production by fuel cells or micro-turbines, CHP generation or as vehicle fuel.

Direct Combustion and Heat Utilization: these kinds of biogas production used to small family for heat production using pipeline up to the user or directly on the site**[15][18].**

Heat and Power (CHP) Generation: is a standard biogas utilization. The system is used after anaerobic digestion it will have drained and dried. Most gas engines have maximum limits for the content of hydrogen sulphide, halogenated hydrocarbons and siloxanes in biogas. An engine-based CHP power plant has an efficiency of up to 90% and produces 35% electricity and 65% heat **[18].**

Biogas Micro-turbines: in biogas micro-turbines, air is pressed into a combustion chamber at high pressure and mixed with biogas. The air-biogas mixture is burned causing the temperature increase and the expanding of the gas mixture. The hot gases are released through a turbine, which is connected to the electricity generator. The electric capacity of micro-turbines is typically below 200 kW **[18].**

Fuel cells: the fuel cells are electrochemical devices that convert the chemical energy of a reaction directly into electrical energy. The basic physical structure (building block) of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on both sides. In a typical fuel cell, the gaseous fuel (biogas) is fed continuously to the anode (the negative electrode) compartment and an oxidant (i.e. oxygen from air) is fed continuously to the cathode (the positive electrode) compartment. An electrochemical reaction takes place at the electrodes, producing electric current **[18].**

2.3 Hydropower

Hydropower is a renewable energy source of electricity. Those types of energy sources are the world's most popular. This is one of the pathways for greenhouse redaction and power generation. This system aims to stay the system within the predetermined range by controlling the flow through an impact valve at the dam and outflow through the drain valve in any condition for safety in addition to efficient hydroelectricity generation. Controlling reservoirs manually in1 dams is extremely difficult because it's nonlinear or time-varying behaviour like sudden changes in reservoir water level**[19][20][36].**

2.3.1 Water source

Ethiopia has a nation with a massively viable water supply in East Africa. Most sources are lake, river, spring, etc. From this river in Ethiopia the most frequently used for strength technology two. One of the this is kesem river.

Figure 5: Kesem River

Kesem is one of the runs off river in Ethiopia which has been flowing in Afar, Oromia, and Amhara region. The water source has many attributes like Shenkora river, Burka river, kirarge abo river, Bedessa river, Dalati river, Baryawyemotebet River, Jema river, Denkore River, Nifase River, Shola River and Enselale River; due to this kesem has attractive water flow rate throughout a year so, water sources have a huge potential for irrigation and small-scale hydropower generation.

Figure 6: One of the Attributes Shenkora River

Kesem-Kebena embankment types irrigation dam has been bolted, which located middle Awash valley. The region is located between latitudes 8^0 49’ and 14^0 30’ N and longitudes $39^0$34’ and 42^0 38’ E. The annual rainfall ranges from about 561 mm to 225 mm, total reservoir capacity of 500 million cubic meters, the discharge of the spillway will be 6180$m^{3/}$s, a maximum height of 96m and Full Reservoir Level 930.00 meters (asl). These mainly comprise a 90 m high rock fill dam, dam crest width of 10m, 35m high saddle dam, a chute spillway, an irrigation outlet/ intake structure, one diversion tunnel with inlet & outlet portals and a pick-up weir nearly 8 km downstream of the main dam. A dam, built to a crest elevation of 941.0 m **[21].**

The control levels are as indicated below:

- Full Reservoir Level (FRL): - 930.00 meters
- Minimum Draw Down Level:-910.00 meters
- Tile Water Level:- 860.00 meter
- Live Storage:-380.00 million m^3
- Inactive (Dead) Storage:-120 million m^3
- Maximum Water Level:-939.50 meters
- Free Board Above :-1.50 meters
- Top of Dam:-941.00 meters

This water source is more than mini-hydro potential, according to the estimated load and to compromise the cost mini-hydro has been designed.

Figure 7: Kesem Kebena Dam

Figure 8: Kesem Kebena Dam

Figure 9: Kesem Kebena Dam water level view

Figure 10: Kesem Kebena Dam structure view

2.3.2 Powerhouse Components

Powerhouse consists of electro-mechanical equipment such as turbines, generator, and governor. A turbine is a machine that converts energy in the form of falling water (water pressure) into mechanical shaft power, which can be used to power an electric powered generator. The decision of the high-performance turbine for a specific hydro site depends on the design head and flow rate. All turbines have there on characteristics. This means they will operate most effectively at a precise speed, head, and flow combination. The speed of a turbine is on the complete determined through the head which it operates [22][23].

2.3.2.1 Governor

The combination of mechanical like, hydraulic turbine, penstock, controller, hydraulic servo motor, control valve, and electrical part such as a generator is called Hydro Turbine Governor, which controls the action of the water valve to open and close depends upon the demand. The adjustment in the load side that influences device size, the governor takes steps to control electricity generation. The Governor is in charge of the electricity generation network [24].

2.3.2.2 Turbine

A turbine is a machine that converts water potential energy into mechanical output power.

2.3.3 Turbine Selection Criteria

The turbine 's form, geometry, and dimensions are fundamentally determined by the Features of each given site. Those main requirements are defined as follows:

Net Head: the first criterion that should be considered in the turbine, the selection is the net head. Primarily the Head Calculation determines the selection of an effective turbine. The selection is particularly critical in low-head schemes where the handling of large discharges is required [25].

Range of Flow volume and Discharges through the Turbine: a single flow-value has very little meaning. Knowledge of a site's regime flow is needed. The range of turbine types appropriate to the site and the flow condition is defined by the measured flow and net head. To determine the correct turbine type one solution is to use graphical tools that show the suitability of different turbine designs concerning the head, flow volume, and power output [26].

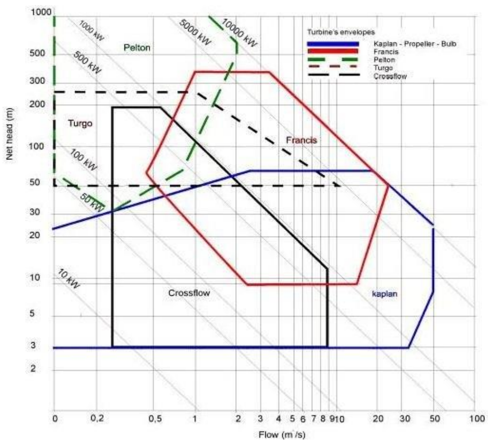


Figure 11: Mini Hydro Turbine Selection Chart [26]

The specific speed constitutes a reliable criterion for the selection of the turbine. They produce electricity in a scheme with H_n (m) net head, using a P (kW) turbine directly coupled to a standard N(rpm) generator it must be by computing the specific speed according to the equation:

$$Ns = N \times \left(\frac{P^{1/2}}{Hn^{1.25}} \right) \ldots\ldots(1)$$

After computing the specific speed, it is possible to choose which turbine type to use or to decide whether to use a speed increase like belts and gears. Using all these tools one can have an appropriate selection of the turbine that is to be used for the site at hand [26].

2.3.3.1 Turbine Efficiency

Their relative efficiencies are an important factor in comparing different turbine types at their design stage every flow. The output of the turbines selected varies with the turbine flow percentage.

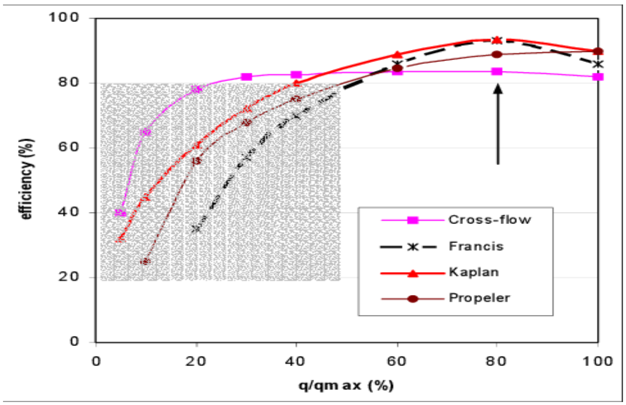


Figure 12: Efficiency of Various Turbines based on Discharge rate [28]

2.3.4 Generator

A generator is an electrical machine that changes mechanical power to electrical power; the combination of turbine and generator is called a generating unit in the hydropower system. There are many kinds of generators such as a synchronous generator, an inductor generator, and DC generators. Synchronous generator the most common in hydropower applications. While induction generator used most frequently with grid-tie systems. DC alternator produces rectified alternating current, and it is easy to service. The turbine, generator, and electrical control containers must all be "housed" in a weatherproof building. The constructing must withstand inclement weather, animals, and unwelcome visitors. Regarding these, a sturdy lock is recommended. So, for this design Synchronous generator used[29].

2.3.4.1 Generator Selection

In most Mini Hydro Power systems, the synchronous generator is used because it can establish its operating voltage and maintain the frequency while operating at a remote location.

Table 3: Selection of Generator Type [30]

Size of the scheme (kW)	Types of Generator	Phase
Up to 10	Synchronous/ Induction	Single or Three-phase
10-15	Synchronous/ Induction	Three phases
More than 15	Synchronous	Three phases

2.3.5 Classification of Hydropower Plants

Hydropower generation systems are mainly classified into the conventional and pumped storage types:

Pumped storage

- pure pumped storage type
- pumped and natural flow storage type

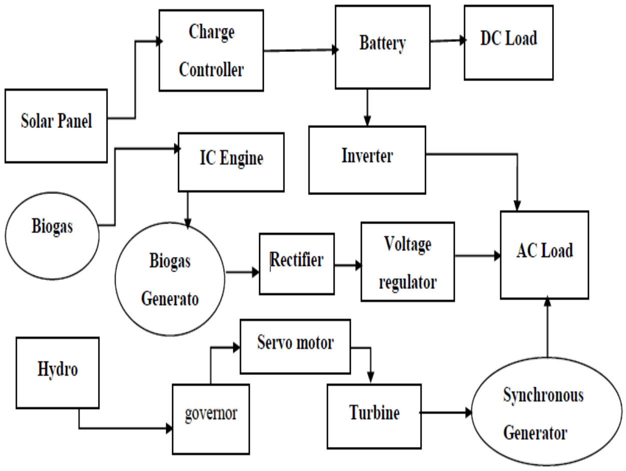
Conventional

- Run-of-river type
- Reservoir type
- Pondage type

2.4 Utilization of energy System

The utility is the company which provides electric energy to the customer at affordable price. In the past time, deiseal generator and power from water have the only source of an electric city in Ethiopia. Now a day the country has additional renewable energy sources like wind, PV, Geothermal power generation system to supply the demand. Even if the nation has massive energy potential, but not yet enough utilization to the consumer because of lack of enough generation station, expansive transmission system infrastructure, and due to geographical location of the rural area has been unelectrified. To overcome the problem, a standalone system is advantages. An off-grid system is one way to supply clean energy when the consumer far away from the national grid [15][31].

2.5 System Description



3 Data Analysis and Design of the Hybrid Energy Source

3.1 Description of Case Study Area

Dubetu and Rarati are kebele which is located in Minjar Shenkora woreda, with a latitude of 8.5986, longitude38. 4338, and off with an elevation of 2312. 23meter. The total population Dubetu (7117) and Rarati (6971) is 14088 with a total householder of (1361+1138) =2499

3.2 Data Gathering

The data used in the design of the hybrid components are collected directly from the site Dubetu and Rarati kebele and Ethiopian Construction Cooperation, Ethiopian Water, Irrigation, and Energy Minister, irrigation Arerti, and form NASA using the latitude and longitude of the site.

Table 4: Solar insolation data of Minjarna Shenkora [2018]

Month	Solar Insolation (kw/m^2)	Month	Solar Insolation (kw/m^2)
Jan	6.15	Aug	4.6
Feb	6.1	Sep	5.94

Mar	6.19	Oct	6.17
Apr	5.55	Nov	5.91
May	5.92	Dec	6.18
Jun	5.22	Ave	5.74
Jul	4.94	-	-

3.2. Electric Load Estimation and Forecasting

3.2.1. Electric Load Estimation

Residential load: is the load that should meet by the energy providing system as it requires immediately; which includes lighting, refrigeration, TV, radio, and others. In load estimation the electricity consumption in each household is considered to be the same and constant throughout the year. The load determination of the village was performed for the total number of population and householder respectively is 14088 and 2499. During load estimation, the nature of load has been thoroughly analysed to come up with sustainable energy demand satisfaction since electric load is vary time to time and seasonal bases. In this energy design system, the selection of appliances was reflected for the low wattage for the affordability of electric energy access. Residential Peak load of Dubetu and Rarati are 356.234kW and 329.146kW with energy demand is 3027.419kWh/day, and 2871.186kWh/day respectively. Residential load is 5898.605 kWh/day.

Deferrable load: is electrical load that must be met within some time period, but the exact timing is not important. Water pumping is a common example. In Dubetu and Rarati kebeles almost all are farmer they use a water pump for irrigation purposes. Differential load in both Dubetu and Rarati is 3611.25 kWh/day.

The total load is 1046.505kW and total energy consumed is 9509.855 kWh/day.

3.2.2 Sizing of a Standalone PV System

PV energy source is interesting to maximum power system in order to supply the load. Using the solar insolation available on the tilted surface, the ambient temperature and the manufacturers data for the PV modules as model inputs, the power output of the PV generator.

3.2.2.1 PV- array sizing

Tracking system	No Tracking
Slope	4 - 23 deg
Azimuth	0 deg
Ground reflectance	20%

Depends on energy source availability in Minjar-Shenkora woreda and the power generation capacity of the resource has been described below in Biogas, and Hydro power design to meet the estimation total load. Due to this huge number of loads is covered by the two renewable energy source and the remain are covered by PV system. Therefore, Solar system are expected to cover 2% of the total load.

Total energy =9509.855kWh/day

2% of the total energy is covered by the solar

$$0.02*9509.855\text{kWh}/\text{day} = 190.1971\text{kWh}/\text{day}$$

$$G_{min} = 4600\text{Wh}/\text{m}^2\text{day}$$, consider summer season

$$P_{PV} = \frac{E_{PV}}{G_{min}} \times 1000\text{w}/\text{m}^2 \text{.......................}(2)$$

$$P_{pv(pick)} = 41.3471956000\text{kW}$$

$$\text{FF} = \frac{\text{Max. power from solar module}}{\text{Isc}*\text{Voc}} \text{............}(3)$$

$$\text{FF} = \frac{145\text{W}}{8.78\text{A} \times 22.3\text{V}} = 0.74$$

$$\text{PV array}(\text{w}) = \text{fill factor} \times \text{PV array}(\text{wp}) \text{........}(4)$$
$$= 30.596925\text{kW}$$

3.2.2.2 Total number of modules

$$N_m = \frac{PV_{\text{array size(w)}}}{\text{Rating per module}} \text{.......................}(5)$$

Maximum power for the selected module is 145w

$$\text{Round up next the whole number} = 212\text{modules}$$

$$\text{Number of modules in the string}, N_s = \frac{\text{Total number of modules}}{\text{nominal module voltage}} \text{..(6)}$$

$$\text{Round up next whole number}, N_s = 9$$

$$N_P = \frac{\text{Total } N_m}{N_s} = \frac{212}{9} = 23.55$$

$$\text{Round up next whole number}, N_P = 23$$

- Total number of modules is207

3.2.2.3 Sizing and Specifying Battery Bank

Battery is a storage device which used to store a DC source. Considering temperature variations of the area and day of autonomy lead acidic battery are selected. In this battery sizing Trojan SSIG 12V, 230Ah lead-acid battery types with depth of discharge for the batteries is 0.7 [32].

- **The storage capacity of a battery**

$$C_{Ah} = \frac{EL * AD}{\eta_{inv} * \eta_{bat} * V_n * DOD} \text{.......................(7)}$$

$$EL = 190.57\text{kWh / day}, \ AD = 2\text{days}$$

$$V_n = 24v, \eta_{inv} = 95\% = 0.95$$

$$\eta_{bat} = 85\% = 0.85 \text{ and } DOD = 70\% = 0.7$$

$$C_{Ah} = \frac{190.57\text{kWh / day} * 2\text{day}}{0.95 * 0.85 * 24 * 0.7} = \frac{381.14\text{kWh}}{13.566} = 28,095.2381\text{Ah}$$

- Number of batteries connected in parallel

$$B_P = \frac{C_{Ah}}{B_c} \text{..(8)}$$

$$B_P = \frac{28,095.2381\text{Ah}}{230\text{Ah}}$$

$$B_P = 122.15 \approx 123$$

- Number of batteries connected in series

$$B_s = \frac{V_n}{V_b} \text{...(9)}$$

B_s=1

Total no of batteries required is 123

3.2.2.4 Sizing and Selecting Charge Controller and Inverter

Charge Controller

The SPS series Solar Regulation System is an advanced electronic control unit for solar power supplies in remote locations. It will prevent overcharging, reduce electrolyte loss and stop over discharge. This will extend battery life and reduce maintenance. State of the art technology has been combined with simple modular construction to create a system with better performance and more features than any other regulator in its class. All control levels are fully adjustable and can be changed by remote control. They are flexible in use, easy to service and are powering telecommunications in some of the most remote parts of the world [33].

Based on the above reason System charge controller has chosen 24V, 75A

The short circuit current (Isc) of the selected PV module times number of a module in parallel

The total current of the charge controller

$$\text{Charge controller}, (I_{tot}) = I_{SC} \times N_P \times \text{oversize factor} \text{..(10)}$$

$$I_{tot} = 234.953\text{A} \approx 235\text{A}$$

$$\text{Number of charge controller} = \frac{\text{Total Current}}{\text{Selected Charge Controller}} \text{...(11)}$$

$$\text{Number of charge controller} = \frac{235\text{A}}{75\text{A}} = 3.133$$

=4

Inverter

The Inverter size should be 25-30% bigger than the total watts of the appliance [10]. Considering 25% of the total watts of the appliance becomes: -

$$30.596925kW + 25\% \times 30.596925kW = 38.2462kW$$

From the standard 40kW by 220V

3.2.2.5 Cable Sizing

The cable size must consider the distance and voltage drop.The rural villages are far away from mojo substation of Ethiopia with a distance of more than 64km. If the system isextended from the grid leads to a high voltage drop, so standalone system is the solution to electrify the remote area with minimum system voltage drop.

The cables must cause less than 3% of voltage drop between PV modules and charge regulator, less than 2% between battery and charge regulator, less than 5% between charge regulator and load. All of these apply at the maximum current condition.

Assuming 3% of voltage drop between PV modules and a charge controller for a maximum short circuit module current, with over size factor of 120% and cable length 10m are considered.

Maximum current =1.20x8.78 = 10.536A

Resistivity of copper = 1.72×10^{-8} ohmmeter

Conductivity of copper = 58×10^{6}s/m

$$\text{Cross sectional area of cable } A\left(mm^2\right) = \frac{2 \times I \times L}{58x10^6 s / m \times V_{drop}}$$

……………………………...…………………….….(12)

3.2.3 Biogas capacity

The row material used for the design of biogas system are unwanted wastes of human being, animal municipal and crops. According to Ararti central administration rural development research (local research), Dubetu and Rarati kebeles has attractive biomass waste with capacity. Considering the temperature of Dubetu and Rarati to produce biogas, it needs 70-80 days. To change biogas content into Energy

$1m3 / day = 2.4kWh, \text{standard } [23]$…....….......(13)

$$\text{Then } 180m3 / day = 432kWh / day$$

$$\text{The power}\left(kW\right) = 432kWh / 24h = 18kW$$

The total demand is 1046.505kW which is assumed to be 100%. So, from the above load estimation and the above information the power generated from the biogas plant (P_{bio} = 18kW) around cover 1.72% of the total demand and,

$$P_{bio} = 18kW, 1.72\% \text{ of the total power}$$

3.2.3.1 Sizing Digester

The size of biogas plant depends on the raw material, quality and the digesting temperature (T) There for, the digester volume (V_d), is determined based on the chosen retention time (RT) and the daily substrate input quantity (S_d)

$$V_d = S_d \times RT \quad \text{………………………….………(14)}$$

$$S_d = M_{biomass} \times m_{water} \quad \text{……………………..….(15)}$$

3.2.4 Hydro Electric Power

Hydropower plan is one of the power sources which enhanced by water using the natural flow of the river or by using artificial preserver. To generate electricity, it needs a resource like water and other mechanical and electrical systems. First, the water potential (kinetic) energy converts to mechanical energy through the turbine and finally converts to electrical output using a generator but, during these processes, there is a loss in both turbine and generator [23][37][38].

3.2.4.1 Hydro Power Design

To design hydropower, there are two options.

- The first options are using the natural flows of the river before interring to the dam. This kind of design system is no guaranty for a constant flow of water which has enough to generate electricity, but it has an advantage which is much closed to the consumers.
- The second option to design hydro power depends on the Kesem-Kebena irrigation project.

Comparing the two options for the design hydroelectric power considering the Kesem-Kebena irrigation dam is very advantageous for regular water flow and to reduce the construction cost of the dam.

Power from the hydropower is given by

$$P\left(W\right) = \rho gHQ \quad \text{…………………………..(16)}$$

Where:

ρ = water density = 1000 kg/m^3

g = gravitational constant. = 9.81 m/s^2

H = head (m)=53.748m

Q = water flow (m^3/s) = 3.497m^3/s

$= 1841.976209\text{kW}$ theoretical output power

So, to find the real power output from hydro power it should be consider efficiency of turbine and generator.

$\eta_t = 0.603$ and $\eta_g = 0.9$ $P(W) = \rho g H Q \eta_t \eta_g$ ……………………(17)

$= 1841.976209\text{kW} \times 0.603 \times 0.9$

$$= 999.6405\text{kW}$$

Approximately, 1000kW, Hydro Power cover around 95.565% of the total load.

3.2.4.2 Annual Plant Factor

The ratio of annual energy generation to electric energy produced at continuous operation for one year at maximum output is called the:

$$\text{Plant Factor}(\%) = \frac{\text{Annual energy generation}(\text{kWh})}{\text{Maximum output}(\text{kW})8760\text{hr}} \times 100$$
……………………………………………….……(18)

$$\text{Plant Factor}(\%) = \frac{\frac{9105.911025\text{kWh}}{\text{day}} \times 365\text{day}}{1000\text{kW} \times 8760\text{hr}} \times 100$$

$= 0.379$, or 37.9%

3.2.4.3 Regulating Capability Factor of Reservoir (RCF)

The regulating capability of the river flow at a regulating pond or a reservoir is expressed by the following equation.

$$\text{Regulating capability factor}(\%) = \frac{\text{Active storage capacity}(\text{m}^3)}{\text{Annual in flow}(\text{m}^3)} \times 100$$
………………………………………………….(19)

- ✓ Live Storage is 380.00 million m^3 and Inactive (Dead) Storage is 120 million m^3 from the total water capacity of 500*10^{6}m^3

$= 0.208\%$

3.2.4.4 Flow utilization factor

The flow utilization factor is the ratio of the annual plant discharge to the volume of plant discharge at the continuous operation of maximum output for one year. The annual plant factor of the run-of-river kind is usually decreased than the float utilization factor.

$$\text{Flow utilization factor}(\%) = \frac{\text{Annual plant discharge}(\text{m}^3)}{\text{Max.plant discharge}\ \text{m}^3/\text{s} \times 365 \times 86,400\text{sec}} \times 100$$
…………………………………………...…..(20)

$= 0.01653$ or 1.653%

3.2.4.5 Measurement of catchment area

After the intake weir site is determined, confirm the watershed on the topographic map, and measure the catchment area. The catchment area is also known as the drainage area and is expressed in units of km^2. In case water is to be drawn from tributaries, this should be included in the catchment area [21].

Catchment Area= 13341km

3.2.4.6 Head fluctuation rate

The limit of head fluctuation of the Francis turbine is about 0.7 and that of the Kaplan turbine about 0.55. For the Francis turbine, an attempt is made to set the HWL and LWL in the range of the following equation. When the head fluctuation rate cannot be controlled to a value under 0.7,check if it is in the region of the Francis turbine and set the HWL and LWL so that the head the fluctuation rate is close to 0.7 [22][23].

$$\text{Head fluctuation rate} = \frac{\text{LWL - TWL}}{\text{HWL - TWL}}$$ ……....(21)

where,

HWL: High Water Level or Full Reservoir Level (FRL) is 930.00 meters

LWL: Low Water Level or Minimum Draw Down Level is 910.00 meters

TWL: Tail Water Level is 860.00 meter

$$= 0.714$$

Approximately the head fluctuation rate is 0.7 so, Francis turbine is the best turbine for the designed system depends on the head fluctuation rate.

3.2.5 Electric Load Forecasting

Electric load forecasting is the process used to forecast future electric load, given historical load and weather information and current and forecasted weather information. Load forecasting can be divided into three major categories: Long-term electric load forecasting, used to supply electric utility company management with prediction of future needs for expansion, equipment purchases, or staff hiring Medium-term forecasting, used for the purpose of scheduling fuel supplies and unit maintenance Short-term forecasting, used to supply necessary information for the system management of day-to-day operations and unit commitment [32].

Assume 1.5% energy demand growth, forecast for 10 years.

$$\text{Future value} = \text{present value of energy}\left(1 + \%\text{increase}\right)^{k}$$

3.2.6 Controller Design for Servo Motor and Turbine

3.2.6.1 PID

Currently, PID controllers are widely used in industrial use. For this reason, basically, over 85% of controllers are used. Position control systems are usually unstable when implemented in a closed-loop setup. several of PID tuning method are available for system control. Conventional PID tuning method, Ziegler-Nichols, Pole placement, Good-gain method and other soft computing method also present to gets accurate system output. Here two methods are applied first Ziegler-Nichols (Z-N) and second Good-Gain method for PID tuning [33][34][35].

PID controllers tuning for positional control systems is a time-consuming A task, therefore considerable effort was made to analyse the servo systems and to control servo motor and hydraulic turbines using Ziegler Nichols tuned technique the value for the calculating system. Ziegler-Nichols (ZN) is a conventional method for tuning PIDs. This approach is commonly used in controller design. Ziegler-Nichols laid out two methods:

1.Response process step by step and

2.Method for reacting frequently.

In this work, step response method is used for tuning the PID controller [33][34].

$$U(t) = K_p e(t) + K_i \int (t) + K_d \frac{de(t)}{dt} \quad \text{.....(22)}$$

3.3 Input data to the Software

The resource is one of the very important things for electricity generation. A type of source used for electric energy is like hydro, biogas and solar system input are particularly important to find out the feasibility of the system. The solar resource depends strongly on latitude and climate, a hydro resource on local rainfall patterns and topography, and the biomass resource on local biological productivity.

In addition, a renewable resource may show significant seasonal and hour-to-hour variability at any one spot. The renewable energy sources available affect the actions and economics of renewable power systems. Consequently, careful modelling of renewable assets is a required gadget mod problem [36].

Figure 13: Solar resource

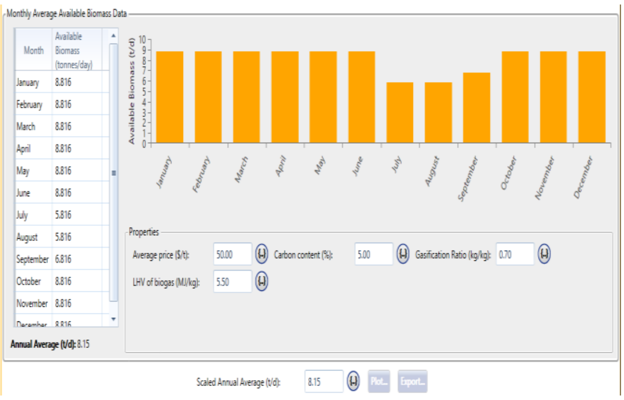


Figure 14: Biogas resource

Figure 15: Hydro flow rate (L/s) resource

Figure 16: temperature

HOMER can be used to model three types of loads: primary load which is electrical demand to be served according to a given timetable, the deferrable load which is electrical demand that can be served at a certain time, the exact timing is not relevant and the thermal load which is a heat demand.

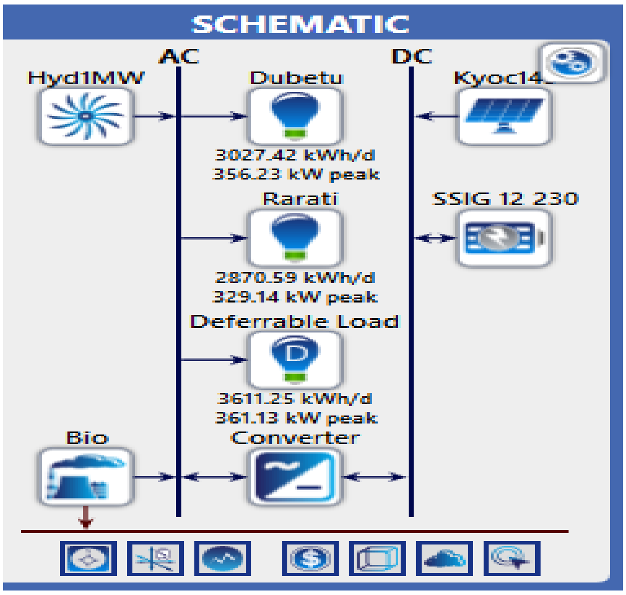


Figure 17schematic configuration of a standalone system

The schematic diagram of the system has contained the Solar Panel, Battery, Converter, Biogas Generator, and Mini-Hydro hybrid power generator System. The hybrid models are configuring the system which has Standalone and with Grid connection to energies the feed Dubetu and Rarati residential load and Deferrable load.

Figure 17 residential loads consists of lightning, radio, tv, refrigerate, and Flour Mill which has found in both Dubetu and Rarati kebele. Listed input data has been the total power listed from living home, Health post, Elementary school, Churches, and mosque which operates at different time of the day.

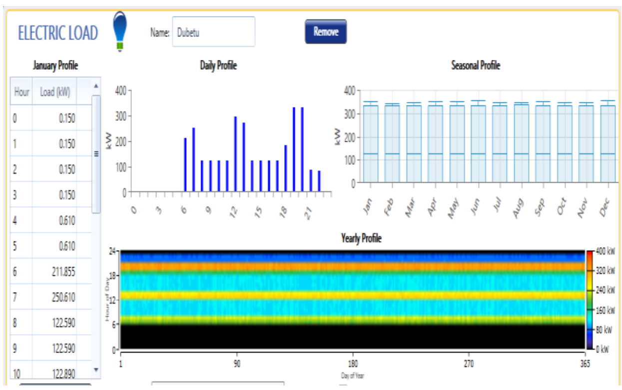


Figure 18: Residential load Profile in Dubetu

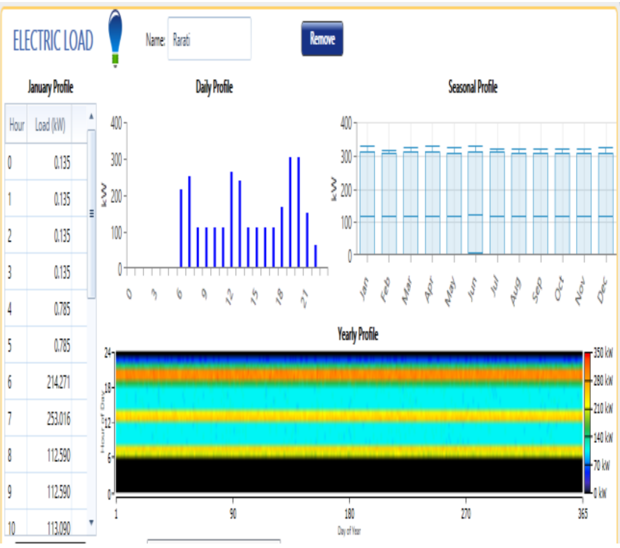


Figure 19: Residential load Profile in Rarati

4.Simulation Result and Discussion

4.1MATLAB Simulink

MATLAB software to offer modelling, simulation, and analysis of dynamical systems under Simulink environment. The overall system consists of a PV, Battery, Converter, Biogas and Hydro Governor. Hydro and Biogas are nonlinear analyses and it display the output of hybrid system. To take care of these system PID controller is used. The maximum output from the hydro, biogas and PV system their individual controllers are also used to extract maximum voltage. The overall generated power output from hybrid model in this mat lab Simulink are 1047kW.

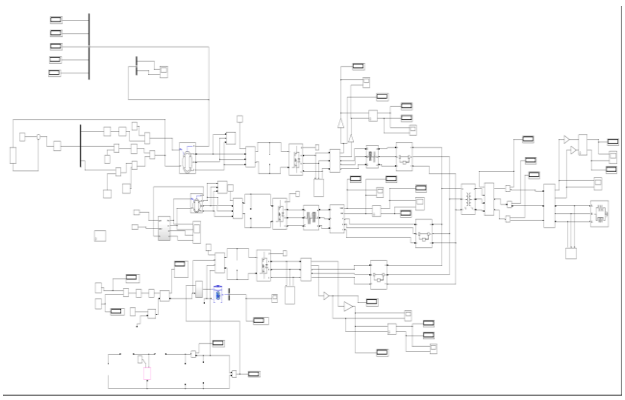


Figure 20: Overall simulation model of a hybrid system

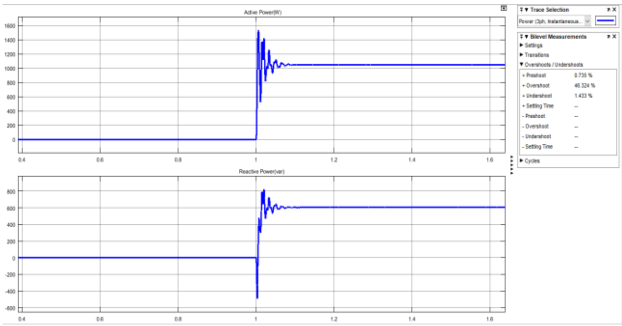


Figure 21: Hybrid active and reactive power out put

The figure 4.2 Shows active and reactive power with output power of 1047kW and reactive power of 604.3kvar, with in pre-shoot 0.735%, overshoot 46.324% and undershoot1.433%.

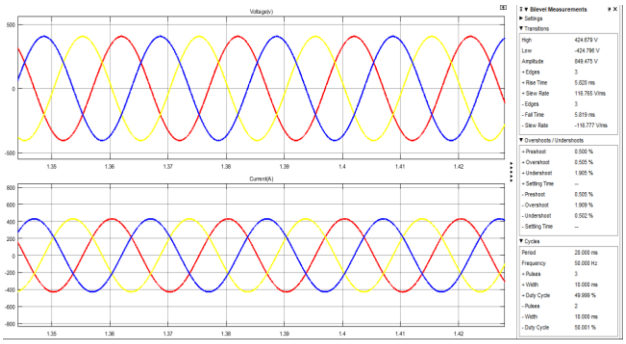


Figure 22: Three phase voltage and current of hybrid system

The figure 22: Shows (y-axis) voltage and current, (x-axis) are represented by time with Vmax 424.679,Vmin -424.679, frequency 50HZ, the time length (period) 20ms, rise time 5.820ms, fall time 5.819ms and for the positive value pre-shoot 0.500%, overshoot 0.505% and undershoot1.905% duty cycle 49.99% also for negative value pre-shoot 0.505%, overshoot 1.909% and undershoot0.502% duty cycle 50.001%.

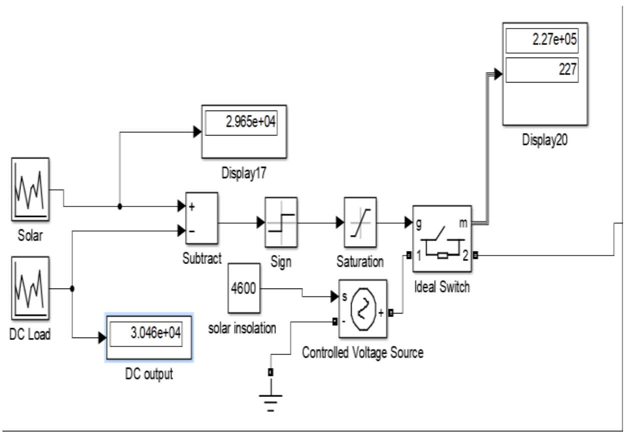


Figure 23:MATLAB Simulink model of solar PV system

The model is showing the solar configuration without battery connection with its DC output level ($3.046*10^4$W). This PV one of the systems in hybrid to satisfy the estimated load in both kebele. In this model expected output.

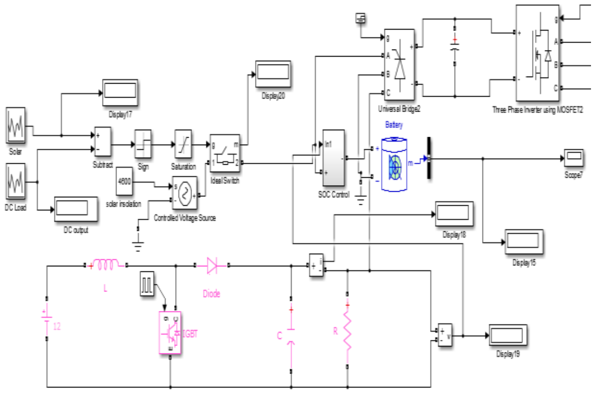


Figure 24: solar system with converter

Above Figure24: The solar system with battery storage and converter. In this model the charge state of the battery is 99.98.

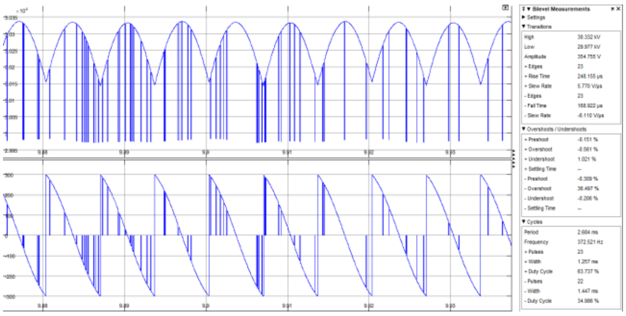


Figure 25: solar system output after converter

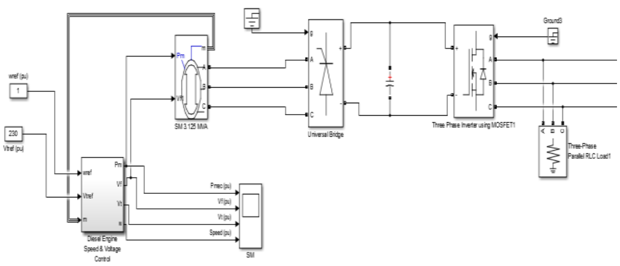


Figure 25: Biogas system

Figure 25: shows the model of Biogas energy source configuration model with controller and biogas.

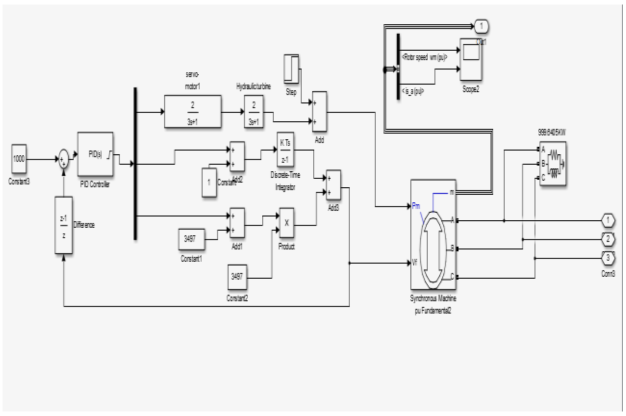


Figure 26: Hydropower system

Figure26: illustrates hydro power configuration model with Governor (servo motor, turbine) and synchronous generator. In this system, the Governor controls the water intake to generate the required power considering the frequency variation at the consumer side.

In standalone system there are three optimized option as seen in figure 27:

First Case: in these categories almost, all sources are existed

SecondCase: in this option Biogas, Hydro, Converter and Battery are there.

Third Case: in this option PV, Biogas, Converter and Battery are there.

Last Case: in this option PV, Biogas, Hydro, and Converter are there.

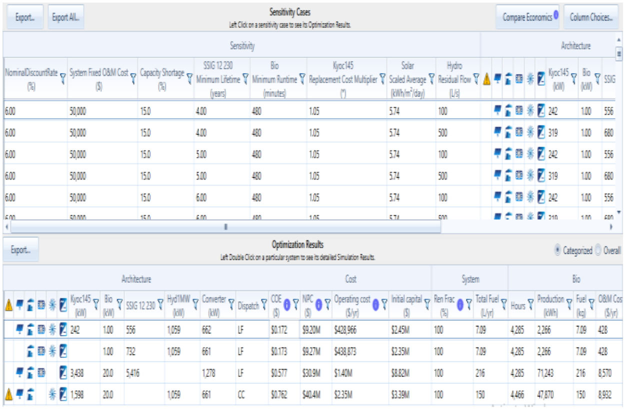


Figure 27: Overall optimization result of standalone

First Case: in these categories all of the sources are existed. The optimization result is with COE $0.1718/kWh, NPC 9.20M, Operating Cost per year $428,966, O and M cost per year $428, Total Fuel per year 7.09L, Fuel Cost per year $354, Battery Autonomy 3.12hr, Excess Electricity 63.5, a capacity shortage 1.92, unmet electrical load 1.92, mean output power 1021kW and the model is 100% renewable. The COE and NPC are relatively the best compare to the other option.

Figure 28: Standalone system of the component with a nominal value 1st case

The above chart which shows the off-grid system component without a discount of its cash flow

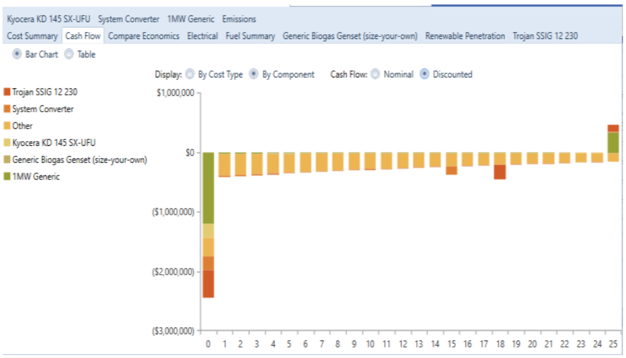


Figure 28: Standalone with discounted from the 1st option

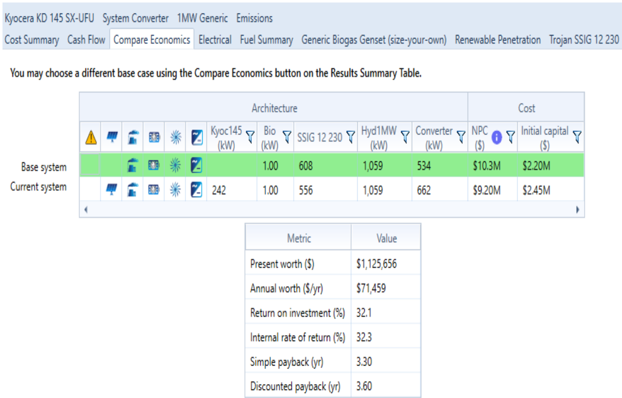


Figure 29: Economical comparison of standalone hybrid configuration from the 1stcase

In the Economical comparison the base system with current system of standalone hybrid configuration Present Worth ($1,125,656), Annual Worth ($71,459/year), Return on investment (32.1%), Internal rate of return (32.3%), Simple payback year (3.30), Discounted payback year (3.60)

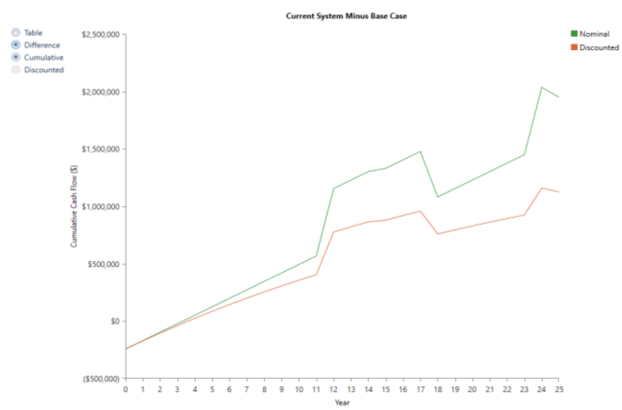


Figure 30: Current system mines base case standalone hybrid configuration from the 1stcase

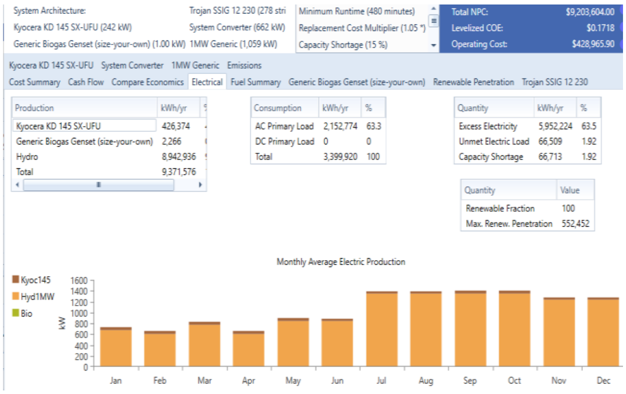


Figure 31: Electrical properties of standalone hybrid system from the 1st case

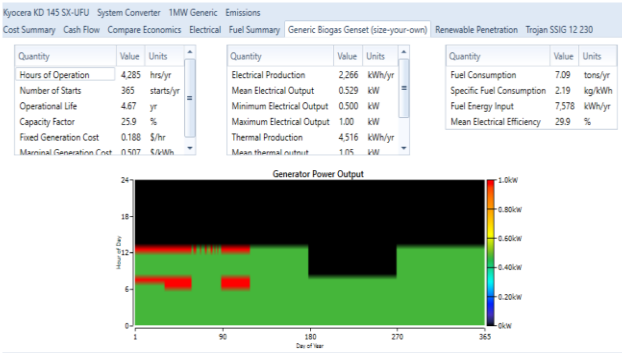


Figure 32: Biogas generator of standalone hybrid from the 1st case

In this result the minimum Run-time of biogas generator are 480 minutes.

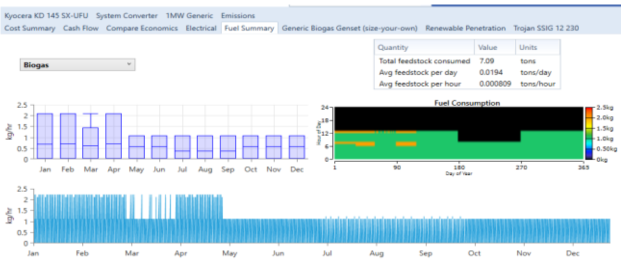


Figure 33: Fuel summary of a standalone hybrid system from the 1st case

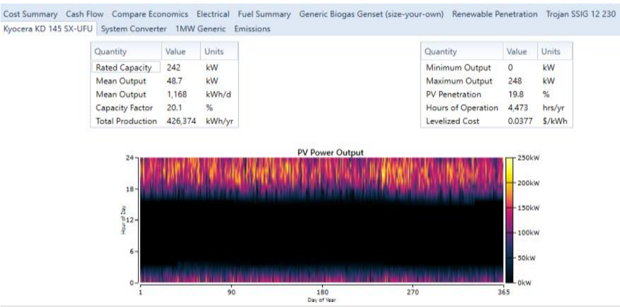


Figure 34: Solar result of a standalone hybrid system from the 1st case

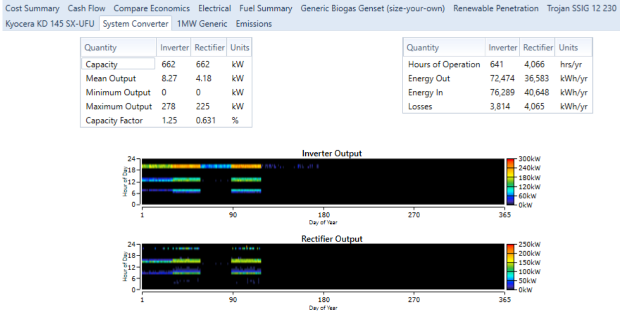


Figure 35: System Converter result of a standalone hybrid system from the 1st case

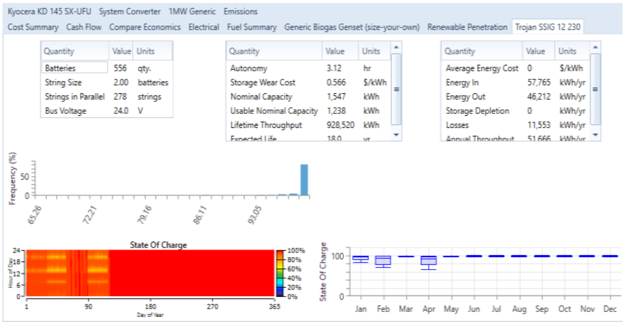


Figure 36: Battery result in standalone hybrid system from the 1st case

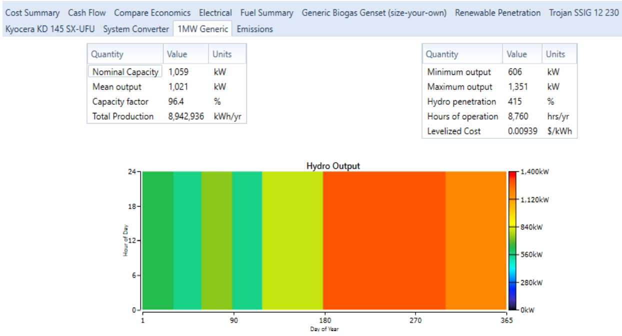


Figure 37: Hydro result in standalone hybrid system from the 1st case

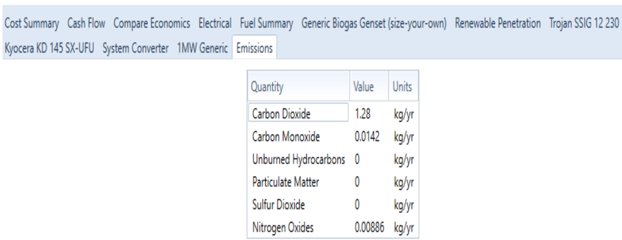


Figure 38:Emission result in standalone hybrid system from the 1st case

Standalone hybrid system configuration for the 1st case, Emission result are excellent, the gas is produced due to methane formation. These gases are a little effect on the environment according to the result.

Second Case: in this option biogas, hydro, converter and battery are there. The optimization result is with COE $0.1730/kWh, NPC 9.27M, Operating Cost per year $438,873, O and M cost per year $428, Total Fuel per year 7.09L, Fuel Cost per year $354, Battery Autonomy 4.11hr, Excess Electricity 61.6, a capacity shortage 1.92, unmet electrical load 1.92, mean output power 1021kW and the model is 100% renewable. The contribution of Biogas is very small almost all load highly depends on Hydro source. The COE and NPC are relatively increased but the battery life time is good compare to the first option.

Third Case: in this option PV, Biogas, Converter and Battery are there. The optimization result is with COE $0.5773/kWh, NPC 30.91687M, Operating Cost per year $1.40M, O and M cost per year $8570, Total Fuel per year 216L, Fuel Cost per year $10,790, Battery Autonomy 30.4hr, Excess Electricity 33.9%, a capacity shortage 1.93%, unmet electrical load 1.92%, and the model is 100% renewable. The contribution of Biogas is insignificant, almost all load

highly depends on solar source. The COE and NPC are much variation but, the battery life time is better compared to the first and second option.

Last Case in this option PV, Biogas, Hydro, and Converter are there. The optimization result is with COE $0.762/kWh, NPC 40.4M, Operating Cost per year $2.35M, O and M cost per year $8932, Total Fuel per year 150L, Fuel Cost per year $7477, Excess Electricity 71.5%, a capacity shortage 12.9%, unmet electrical load 2.94%, and the model is 100% renewable. The contribution of Biogas is insignificant, the load is depending on solar source (%23.9) and hydro (%75.7). The COE and NPC are a huge variation compare to the first, second and third case without battery.

4.2 Return on investment

The **1st case**return the invested money with return on investment 32.1%, the system must be simple payback in 3.3 year, and discount payback 3.6 within the year.

The **2nd case**return the invested money with return on investment 47.9%, the system must be simple payback in 2 years, and discount payback 2.13 within the year.

The **3rd case**returns the invested money with return on investment -17.5%, the system has unachievable.

Last Case return the invested money with return on investment -158.6% the system has not advisable.

The **1st case** and the **2nd case** arethe best compare to **3rd case** and **Last Case** for the consumer and for investor on the hybrid system

The **3rd case** and the **Last Case** are not recommended due to expansivity, it is impossible buying energy to and to return the total investment cost. Such system is not advisable for both consumer and investor.

4.2.1 Cost Compartion of standalone system with national grid of Ethiopia

Table 0.1Cost Compartion of standalone with grid

Range of energy(kWh)	Designed standalone COE	Grid connected COE in 2012EC
>500	0.1718	1.5870

According Table 4.1 cost compartion of standalone system with grid, offgrid system are best to electrify the remote village, so grid connected system isn't recommended as option.

5. Conclusion

The research was conducted on feasibility study and design of standalone PV/ Mini-Hydro / Biogas hybrid power generation systems with a battery bank for rural areas in Dubetu and Rarati kebele of Minjar Shenkora Wereda in Ethiopia to electrify 2499 households.

In this study, the potential assessments of the sources, its feasibility and also cost comparison of the standalone system with the grid-connected one have been done using the commercial HOMER and

MATLAB Simulink software to show an optimized power flow for the hybrid model. Additionally, the load was Forecasted for both kebeles in the range of ten years.

Considering minimum solar Radiation of G_{min} 4600 Wh/m^2day, the Average Biomass input of 8.15t/h, and Minimum Water Discharge for hydro $3.497m^3/s$ ware taken for the designed system. Due to this, different system configuration is found to be feasible options for the specific load. One feasible system from the site can be taken to make up the overall system capable of supplying the whole load even if they are sensitive to both Radiation, Biogas Input, Hydro Discharge, and Cost variations. One sample overall system containing the PV-Biogas-Mini Hydro-Battery-Converter setup shows a COE of $0.1718/kWh and a total net present cost (NPC) of $9.203604M. This system has excess electricity generation of 63.5%, capacity shortage 1.92%, and unmet electric load 1.92%. The COE for feasible option has the range between 0.1718 to 0.7620$ per kilowatt-hour Although the designed system has a relatively low COE than the national tariff and return the invested money with return on investment 32.1% , the system must be simple payback in 3.3 year, and discount payback 3.6 within the year.

Finally, comparing grid connected with a standalone system was done. National grid is costlier than compared with the designed system as per the COE and NPC. So standalone system to energize those rural community under the case study is the best solution.

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Woinshet Lera Lachore carried out the data collection, design, simulation and paper organization.
Dr.-Ing Getachew Biru was responsible to advise the me.

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