FEASIBILITY STUDY AND DESIGN OF STANDALONE HYBRID POWER GENERATION SYSTEM FOR RURAL AREA IN ETHIOPIA: CASE STUDY OF MINJAR-SHENKORA WOREDA

By:

Woinshet Lera Lachore

A Thesis Submitted to the

School of Electrical Engineering and Computing

Department of Electrical Power and Control Engineering

In Partial Fulfillment of the Requirements for the Degree of Master of Science in

Electrical Power and Control Engineering

(Power Engineering)

Office of Graduate Studies

Adama Science and Technology University

July 2020

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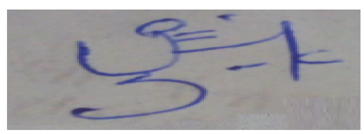
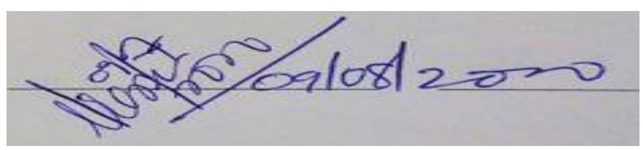
APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Woinshet Lera Lachore have read and evaluated her thesis entitled **"*Feasibility Study and Design of Standalone Hybrid Power Generation System for Rural Area in Ethiopia: Case Study of Minjar-Shenkora Woreda*"** and ex-amined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Electrical Power and Control Engineering (Power Engineering).

Name	Signature	Date
Woinshet Lera Lachore Name of student	________________	________________
Dr.-Ing Getachew Biru Advisor		10/08/2020
Yoseph Mekonnen Abebe (Ph.D.) External Examiner		09/08/2020
Dr. Tefera Terefe Yetayew Internal Examiner		
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DECLARATION

I declare that this MSc thesis has been composed by myself and that the work has not be submitted for any other degree or professional qualification. I confirm that the work submitted is my own, except where work, which has formed part of jointly authored publications, has been included. And all sources of material used for this thesis have been duly acknowledged.

Name:________________________

Signature: _____________________

This MSc Thesis has been submitted for examination with my approval as thesis advisor.

Name:________________________

Signature:______________________

Date of submission: ______________

DEDICATION

To my lovely family

and

my friends (Tsion Tigistu and Mesgana Tulu)

ADVISOR'S APPROVAL SHEET

To: Electrical Power and Control Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled "***Feasibility Study and Design of Standalone Hybrid Power Generation System for Rural Area in Ethiopia: Case Study of Minjar-Shenkora Woreda***" submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Power and Control Engineering (Power Engineering), the Graduate program of the department of Electrical Power and Control Engineering, and has been carried out by Woinshet Lera Lachore, Id number PGR/18393/11, under my supervision. Therefore, I recommend that the student has fulfilled the requirements and hence here by she can submit the thesis to the department.

Dr.-Ing Getachew Biru	__________________	________________
Advisor	Signature	Date
_____________________	__________________	________________
Co-Advisor	Signature	Date

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First and foremost, I would like to take this opportunity to give glory to the almighty **God** and to **Kidanemihiret**, with whom the completion of this work would have been impossible.

I would like to thank my thesis advisor **Dr.-Ing Getachew Biru**. The door to Dr.-Ing Getachew Biru office was always open whenever I run into a trouble spot or had a question about my research writing, for good ideas and discussions regarding in everything. He consistently allowed this paper to be my work and steered me in the right the direction whenever he thought I needed it.

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ACRONYMS

AC	Alternative Current
AD	Anaerobic digestion
AD	Daily Autonomy
Ah	Ampere Hour
ASL	Above Sea Level
BC	Battery Capacity
Bp	Battery Connection in parallel
Bs	Battery Connection in Series
CAh	Storage Capacity of the Battery
CHP	Combined Heat and Power
DC	Direct Current
Dh	Enthalpy Difference
DOD	Depth of Discharge
Dp	Pipe Diameter
ECC	Ethiopian Construction Cooperation
EL	Daily Load Energy
F	Darcy friction factor (obtain from Moody diagrams)
FF	Fill Factor
FRL	Full Reservoir Level
G	Gravitational acceleration
G_{min}	Minimum Solar Radiation
H	Enthalpy of Air
HL	Head loss due to friction is given in units of length
HOMER	Hybrid Optimization Model for Electric Renewable
Hp	Horsepower
HWL	High Water Level(m)
K	Forecasted Number of Year
Km^2	Square Kilo Meter

kWh/m^2	KiloWatt Hour Per Square Meter
LCC	life-cycle cost
LHV	Lower Heating Value
Lp	Pipe Length
LWL	Low Water Level(m)
L	Length
m^3	Meter Cube
m_{air}	Mass of Air
m_{water}	Mass of water
$M_{biomass}$	Mass of biomass
MHP	Mini Hydro Power
NASA	National Aeronautics and Space Administration
Nm	Number of Modules
N_p	Coefficient of the penstock material type.
L_p	Penstock length in (m)
H_g	Gross head in (m)
Np	Number of Parallels
NREL	National Renewable Energy Laboratory
Ns	Number of Series
N_s	Turbine specific speed
N	Running speed of the turbine (RPM)
H	net head (m) and
P	the power to be generated (kW)
PV	Photovoltaics
Q	Discharge of water (m_3/sec)
RES	Renewable Energy Source
RES	Renewable Energy Source
RPM	Revolution Per Minute
RT	Retention time
Sd	Daily substrate input
T	Peak duration hours (hour)

T_1	mechanical time constant
T_2	electrical time constant of motor
TWL	Tail Water Level(m)
V	Flow velocity
V_d	Volume of the digester
Ve	The storage capacity of re-regulating reservoir
VFA	Volatile fatty acids
Vn	Nominal Battery Voltage
w	Width
X	Gas Content
η_{Bat}	Battery Efficiency
η_{Inv}	Inverter Efficiency
β	Specific Fuel Conception
ηg	Efficiency of Generator
ηt	Efficiency of Turbine

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.

Keyword: Hybrid, PV, Biogas, Mini-Hydro, Primary Load, Deferrable Load, optimization, sensitive,COE, HOMER and MATLA.

CHAPTER ONE

1 INTRODUCTION

1.1 Background

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 to these, 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 center. 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].

1.2 Statement of the Problem

Most rural areas have been un-electrified in Ethiopia. To electrify the remote area either extending power source from the existing national grids or developing standalone power generation systems must be used. The problem is common in Mingar-Shenkora Woreda (Dubetu and Rarati kebele) since a huge number of the population is living there and they need electricity. This thesis aims at identifying and evaluating a feasible way of electrifying such rural villages.

1.3 Objectives

1.3.1 General Objective

The main objective of this thesis is the feasibility study and design of standalone PV/ Mini-Hydro / Biogas hybrid power generation systems for rural areas at Minjar-Shenkora Woreda, Ethiopia.

1.3.2 Specific Objectives

To achieve the main goals, the study has the following specific objective:

- To study the solar, mini-hydro, and biogas energy potential of the area.
- To estimate and forecast the energy demand of Dubetu and Rarati by considering the basic needs of the people.
- To select appropriate solar modules, battery, biogas generator, and mini-hydro depending on the energy demand.
- To compare the investment cost of the hybrid system against the cost required to electrify the areas by extending the national grid.
- To estimate the year of recovery of the investment.

- Analyze the performance of the designed system using HOMER and MATLAB software.

1.4 Scope and Limitation of the Study

The scope of the study is limited to identifying and designing a renewable energy based power generation system for Dubetu and Rarati rural village. The sizing of stand-alone hybrid components like PV module, batteries, inverter, charge controller, and generator is accomplished.

1.5 Significance of the Study

The combination of photovoltaic, biogas and mini-hydro has the advantage that the three sources complement each other since the peak working times for each system happen at diverse times of the day and year. The hybrid system reduces interruption time. As a result the system can provide a high level of energy security. It helps the remote village to start a modern life, and to re-use the biomass for their agriculture.

1.6 Case Study Area Description

The Dubetu and Rarati have a kebele which is found at Minjarna Shenkora woreda in the Amhara Region of Ethiopia at Latitude: 8.598565, Longitude: 38.433785.

Figure 1.1 Map of Ethiopia [7]

Figure1.2 shows the woreda is located at the southern end of the Semien Shewa Zone, bordered on the east, south, and west of the Oromia Region, on the northwest by Hagere Miriamna Kesem, and on the northeast by Berehet; the Gemama (Kesem) river forms the boundary between this woreda and Hagere Miriamna Kesem and Berehet with the area of 1510km^2. The administrative center is Arerti [6].

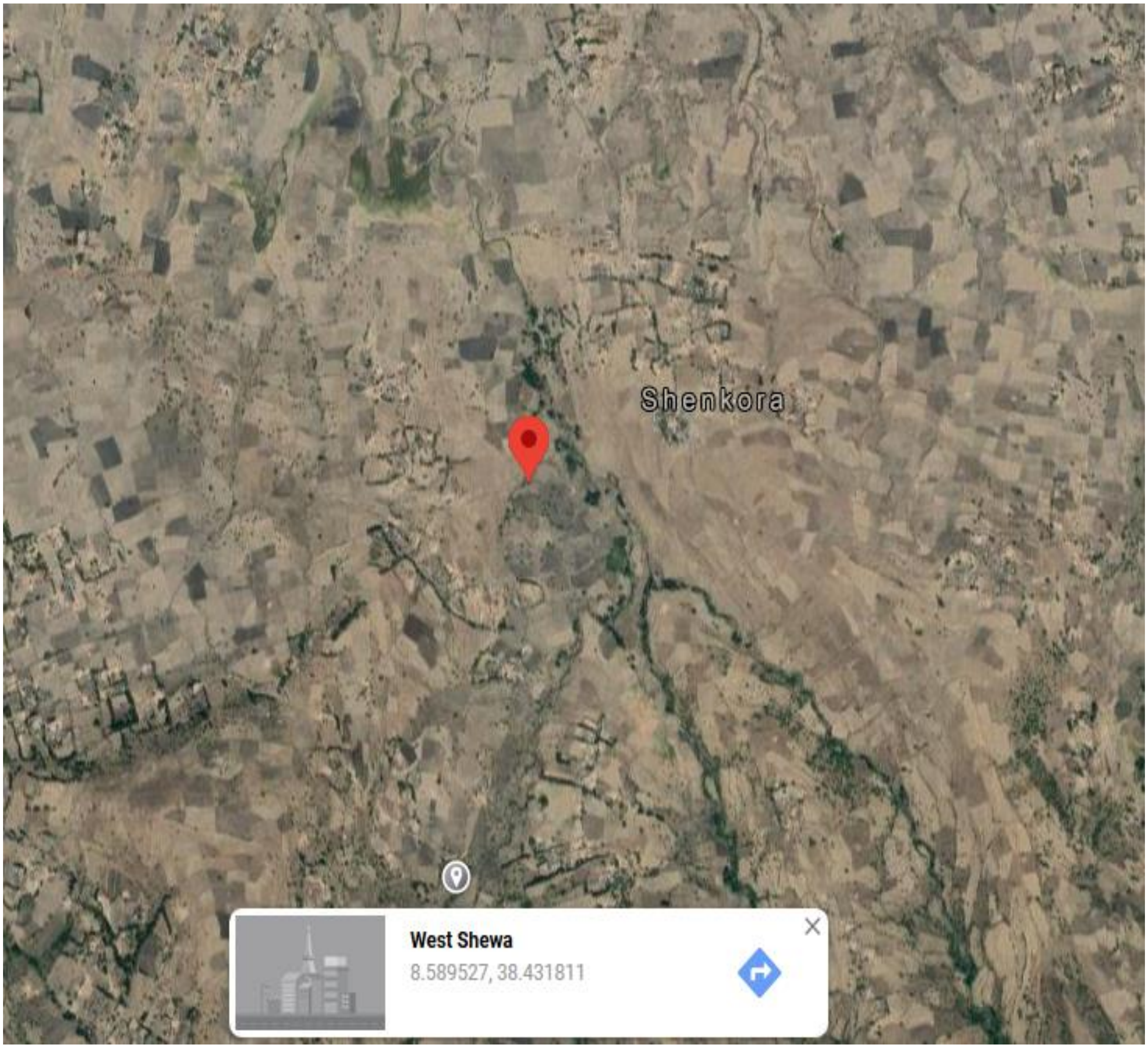


Figure 1.2 Location of the site (Minjar-Shenkora Woreda, Ethiopia) [7]

Figure1.2 shows the map, of minjare Shenkora woreda (west Shewa of Ethiopia) [7].

1.7 Research question

In general, the research have been guided to address the following questions:

1. How much can the energy resource available at the site produce the required energy?
2. How much is the hybrid systems technically and financially effective?

1.8 Thesis Outline

This thesis is organized into five chapters as follows.

This thesis is organized into five chapters as follows.

The First Chapter is about the Introduction

The Second Chapter Presents Theoretical Background and Literature Review

The Third Chapter Presents Data Analysis and Design of The Hybrid Energy Source

The Fourth Chapter deals with Simulation Result and Discussion

The Fifth Chapter Presents the Research Conclusions and Recommendations.

CHAPTER TWO

2 THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Theoretical Background

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 kilometer of the Sun's surface emits energy equal to the global supply for primary energy on Earth [8].

2.1.1 Solar Energy System and Solar Energy Resources

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 / m2. This means that only one-fifth of a square kilometer of the Sun's surface emits energy equal to the global supply for primary energy on Earth [8].

2.1.2 Photovoltaics 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 [9].

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 [10].

Figure 2.1 solar panels in Dubetu health post

Figure 2.1 show the instuled solar panel for Dubetu health post. The energy source used for refregrator to keep pharmaceutical.

A sun-powered cell which changes over photons in Sun-powered beams to direct-current (DC) and voltage. The related innovation is called Sun-powered Photovoltaic (SPV). A commonplace silicon PV cell may be a lean 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 made close 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, producing a DC output source. This can be known as the Photovoltaic effect [11].

Figure 2.2 Solar module in Rarati

Figure 2.2 Solar module in Raratifor lighting.

2.1.4 Working principle of a PV cell

Photovoltaic is the direct conversion of mild into electricity at the atomic level. Some materials exhibit a property acknowledged as the image electric impact that motives them to take in photons of light and release electrons. When these free electrons are captured electric powered contemporary outcomes can be used as electricity. When mild power strikes the solar cell, electrons are knocked free from the atoms in the semiconductor material. If electrical conductors are attached to the tremendous and poor sides forming an electrical circuit, the electron can be captured in the shape of an electric current. That is electricity. The electrical energy can then be used for electricity a load [12] [13].

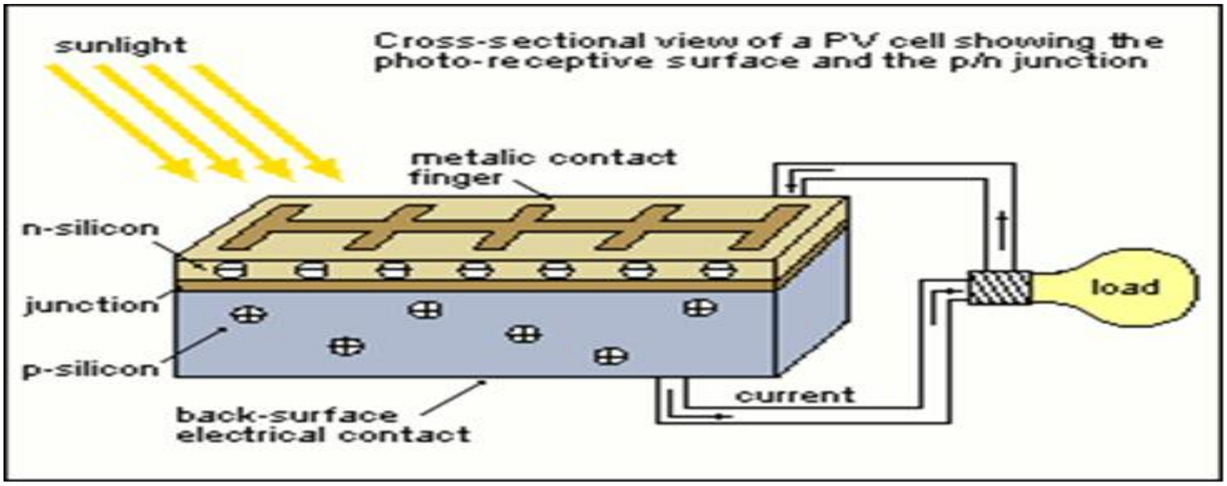


Figure 2.3 working principle of a PV cell [13]

2.1.5 Equivalent Electrical Circuit of PV Cell

To recognize the digital behavior of a photovoltaic cell, it is helpful to create a model that is electrically equivalent and is especially primarily based on discrete electrical components whose conductivity is properly known. An ideal solar cell may be modeled by a current source in parallel with a diode, so a shunt resistance and a series resistance component are delivered to the model. The current (I) at the output terminals is equal to the light-generated current I_L, less the diode current I_D, and the shunt-leakage current I_{sh}. The collection resistance R_s represents the inside resistance to the current flow and depends on the p-n junction depth, impurities, and contact resistance. The shunt resistance R_{sh} is inversely associated with the leakage current to the ground. In an ideal PV cell, $R_s = 0$ and $R_{sh} = \infty$ The PV conversion efficiency is sensitive to a small variation in R_s but insensitive to variations in R_{sh}. A small increase in R_s can minimize the PV output drastically [14].

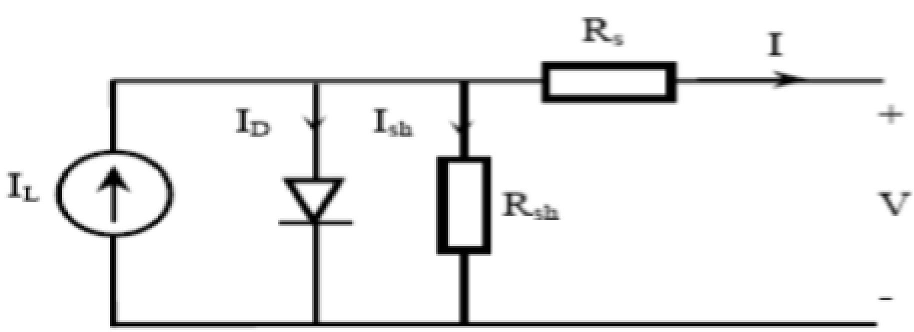


Figure 2.4 The Equivalent Circuit model of a solar cell [14]

Characteristic equation

From the equivalent circuit it is evident that the current produced by the photovoltaic cell (I) is equal to that produced by a current source (I_L), minus that which flows through the diode (I_D), minus that which flows through the shunt resistor (I_{SH})

$$I = I_L - I_D - I_{SH} \tag{2.1}$$

The open-circuit voltage V_{oc} of the cell is obtained when the load current is zero and is given by the following:

$$V_{oc} = \left(I_L - I_D\right) R_{SH} \tag{2.2}$$

The diode current is given by the classical diode current expression

$$ID = I_o \left[\exp\frac{qV_{oc}}{AKT} - 1\right] \tag{2.3}$$

where Io is the saturation current of the diode (A), q is electron charge $\left(1.6\times10^{-19}C\right)$, A is curve fitting constant, K is Boltzmann steady $\left(1.38\times10^{-23}\,\frac{J}{°K}\right)$, T is the temperature on absolute scale °K. The last term is the leakage current to the ground. Cells, it is negligible in contrast to I_L and I_o and is commonly ignored. The maximum Photovoltaic is produced under the open-circuit voltage. A gain by ignoring the ground leakage current, equation 2.3 with I give the open-circuit voltage as follows:

$$V_{oc} = \frac{AKT}{q}\ln\left(\frac{I_L}{I_o} + 1\right) \tag{2.4}$$

2.1.6 Types of PV modules

Modules can be classified according to cell type as mono crystalline, poly crystalline and amorphous.

- **Mono crystalline**

In order to produce this type of cell, used silicon must be extremely pure which means it is the most expensive type of solar cell. However, they are the most efficient type of PV panels .their performance is somewhat better in low light conditions. They are usually blue-grey in color and have a fairly uniform consistency [8].

Figure 2.5 Mono crystalline modules [8]

- **Polycrystalline**

Polycrystalline (or multi-crystalline) silicon produces the next most efficient type of PV cell and is the most popular choice as it provides an excellent balance of performance and economy. Recent improvements in polycrystalline panel technology are bringing these modules closer to monocrystalline in size, efficiency and heat tolerance characteristics [8].

Figure 2.6 polycrystalline PV panel [8]

- **Amorphous**

Amorphous (or thin-film) silicon uses the least amount of silicon and also produces the least efficient PV cells. This means thin film system take up more area than the other two which is an important factor to consider in relation to possible future upgrades [8].

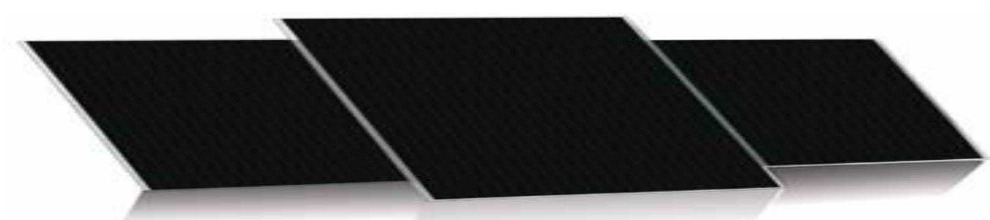


Figure 2.7 Amorphous PV panel [8]

- **Selection criteria for PV modules**

A number of factors should be considered when selecting PV modules for a lighting application. These criteria include:

1. Electrical performance (rated output)
2. Physical properties (e.g. size, weight)
3. Mechanical properties (construction materials, mounting attachment, etc.)
4. Efficiency and surface area requirements for modules
5. Cost, lifetime and warranty.

Based on the above criteria polycrystalline module are selacted

2.1.7 PV Module models and characteristics

PV modules are connected in the collection to produce an excessive voltage while in parallel to result in the greater current. The most energy production takes place at an identical voltage when the modules are connected in parallel. Similarly, most power production takes place at the equal current when the modules are connected in series. To limit the current fuses are connected in series. If a fault exists in one string, the current from the normal string in reverses direction will be constrained through the fuse of the failure string [8].

❖ **Chief characteristics**

Short circuit current (I_{sc}) - flows when plus and minus are wired directly without being connected to a load. The voltage falls to 0 volt and maximum current flows.

Open circuit voltage (V_{sc}) –the maximum voltage occurred when no current is being drawn from the module and the resistance between plus and minus is thus infinity.

Maximum power point (MPP) –an operating point at which the maximum output will be produced by the module at operating conditions. Solar radiation and temperature determine the maximum output (MPP).

The maximum power Pm is given by

$$P_m = I_m \times V_m \tag{2.5}$$

Where I_m is the maximum current at P_m and V_m is the maximum voltage at Pm.

❖ **Factors that affect the performance of the module**

Factors that affect the performance of the solar module are

✓ Load resistance

✓ Sunlight intensity

- ✓ Cell temperature
- ✓ Shading

Load resistance – when the loads appropriately match with a module V-I curve, the module will operate at the maximum point that results in the highest possible efficiency.

Radiation –solar radiation directly proportional to the power output from the module.

Cells temperature – an increase in temperature from the standard operating temperature of 25^0C causes reduction of voltage and module operate less efficiently.

Shading – even partial shading of a solar module influences its characteristics curve and will result in massive output reduction. The shaded cell is considered as load and produces a negative voltage which is equal to the sum of all the open circuit voltages of fully irradiated cells. Thus, the shaded cell produces heat to cause the hot spot effect and the cell will be damaged permanently. It is possible to prevent this effect by wiring a bypass diode in anti-parallel to bypass the cell in the event of shading. The output reduction in the event of shading depends on module wiring (series or parallel). Shading can be caused by dust or any other shadowing effects.

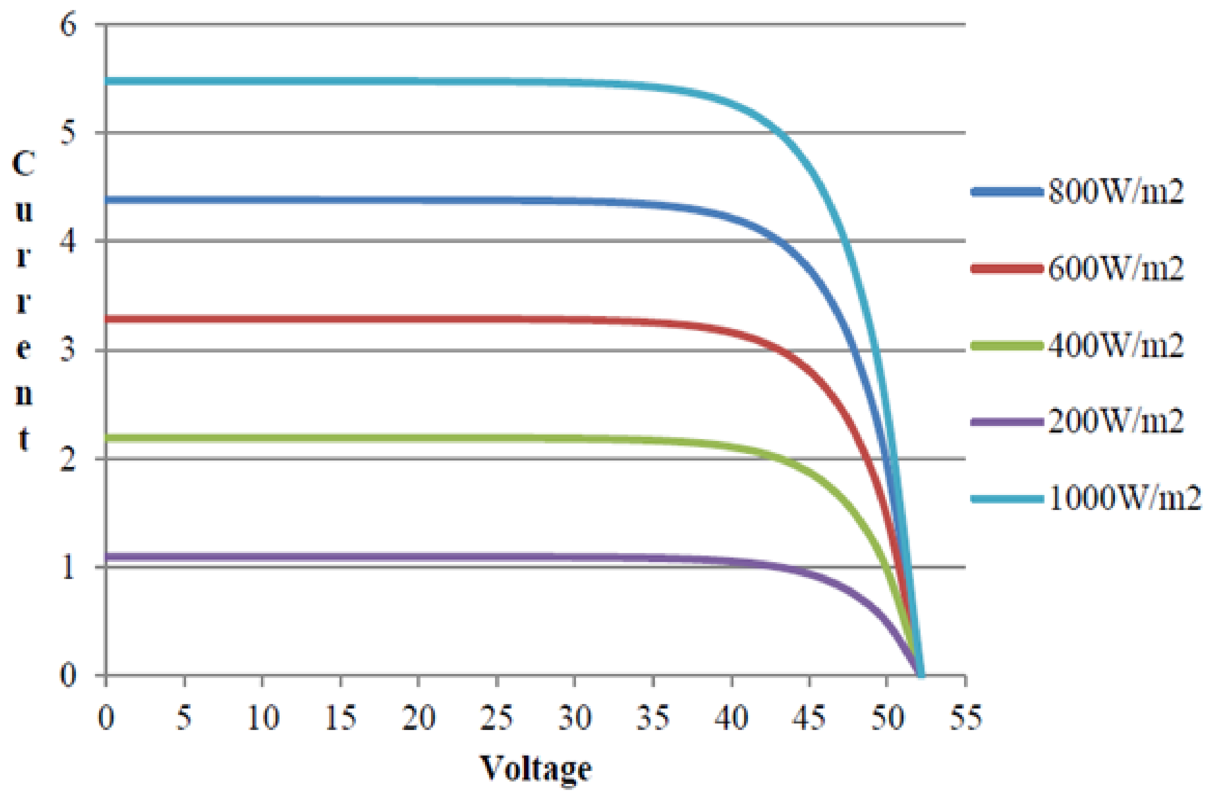


Figure 2.8 V-I and V-P characteristics of a solar module under various solar radiation [15]

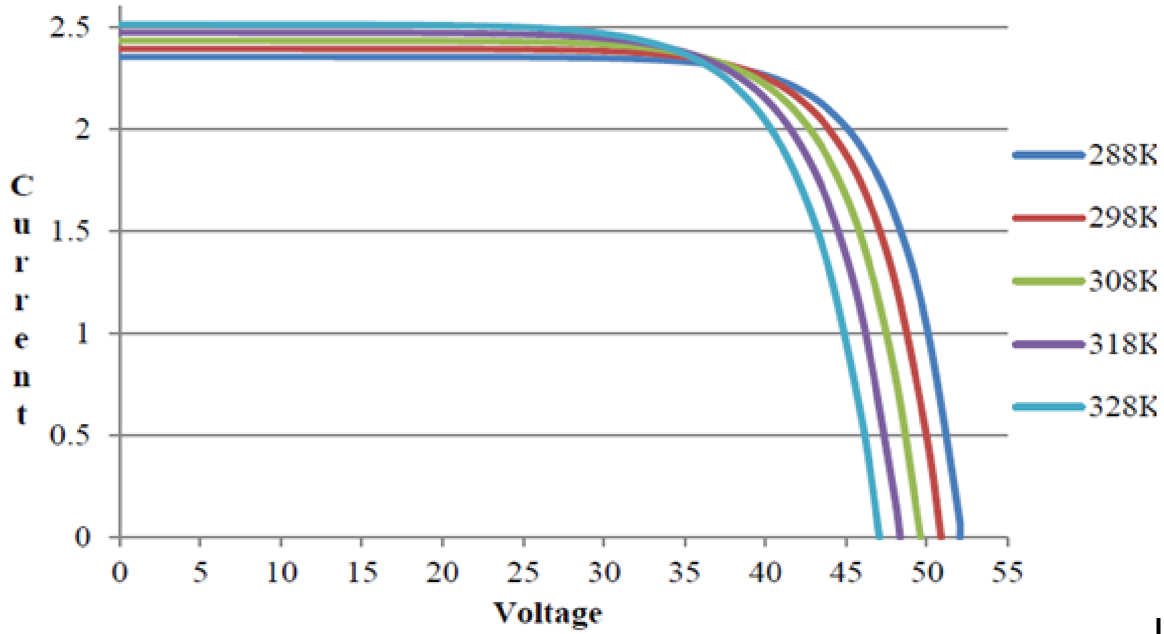


Figure 2.9 V-I and V-P characteristics of a solar module under various temperatures [15]

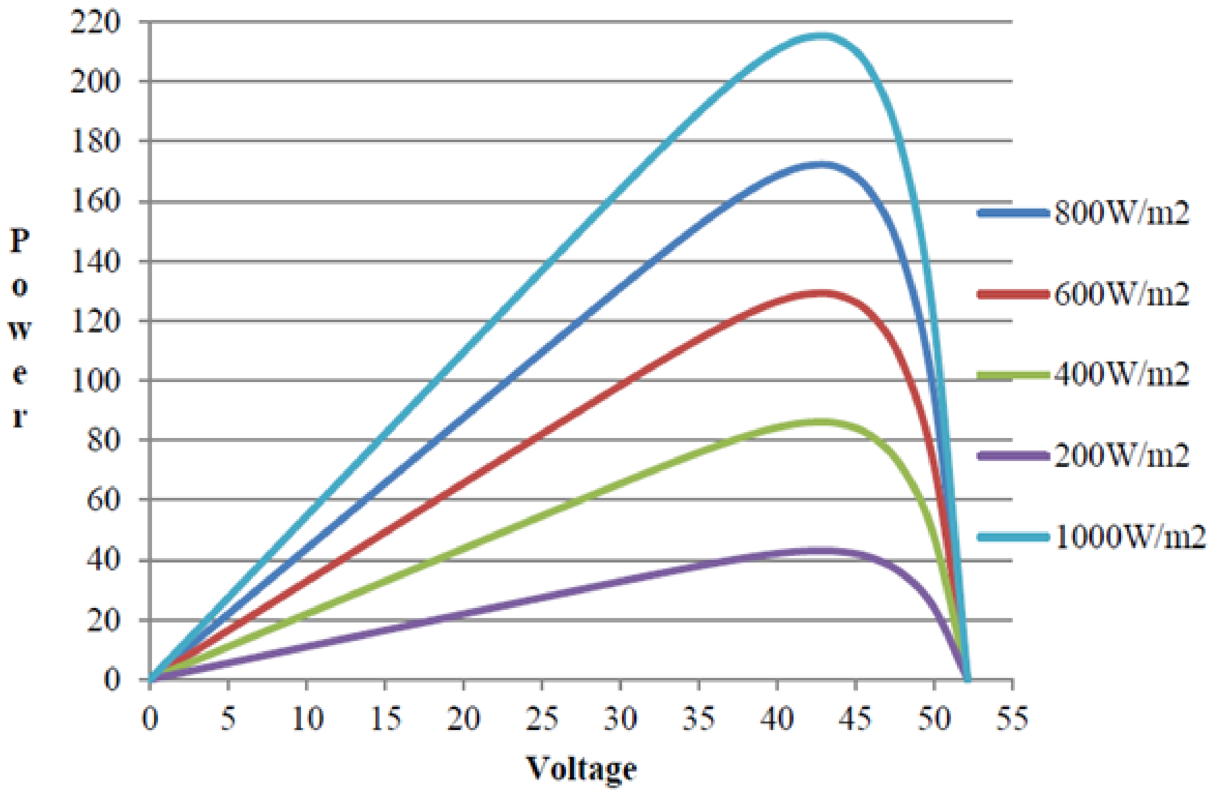


Figure 2.10 Power – Voltage curve at different irradiance [15]

2.1.8 Solar Radiation

Solar Radiation is described as the main source of renewable energy as well as possible applications of this energy through thermal conversion and PV conversion. It is the radiation or energy we get from the sun. It, also known as short wave radiation solar radiation, comes in many forms, such as visible light, radio waves, heat(infrared), x-rays, and ultraviolet rays. Measurements for solar radiation are higher on a clear, sunny day and typically low on cloudy days. Solar radiation reaching the earth's surface varies significantly with location, atmospheric conditions including cloud cover, ozone layer condition, time of day, earth/sun distance, earth rotation, and activity. Standard spectra have been developed to provide a basis for the theoretical assessment of the effects of solar radiation and a basis for simulator design. Seasonal variation of daily solar radiation (irradiation) occurring on a horizontal surface outside the Earth's atmosphere in the Northern Hemisphere is strongly dependent on latitude [8].

2.1.9 Photovoltaic Energy Conversion

The special attraction of photovoltaic energy, compared to other power generation technologies, lies in the fact that solar radiation is directly converted into electrical energy by an electronic solid-state process. Photovoltaic systems, therefore, operate quietly and can offer extremely high reliability, low maintenance requirements, and long service life. Due to the nature of the conversion process, direct as well as diffuse radiation can also be used in moderate climates with higher fractions of diffuse radiation. Another important advantage of PV is its modularity, which allows a very flexible system for integration into buildings and for decentralized applications with very small load requirements [16].

❖ There are two types of solar energy conversion mechanism

Direct and indirect solar energy conversion

➢ Direct solar energy conversion for different application: -

✓ For heating commercial and residential

✓ For electricity production

➢ An indirect solar energy source

2.1.10 Growth and Challenges of PV System

As per the statics, the solar PV module word market is steadily growing at a rate of 30.5% per year. The reason behind this growth is that the reliable of the system. Production electricity without fuel Consumption anywhere there is light and the flexibility of the PV system. Earlier, a large variety of solar PV applications found to be in industries but now it is being used for commercial as well as for domestic needs, efficiency has currently improved, depending on the technology that is used. Solar energy producer cells individually slightly better efficiency than the module. This is due to the space between the solar cell arrays in the module. The overall efficiency of the system includes the efficiency and performance of all components of the system and depends on the solar installation. Here there is another numerical drop in value when compared to the module efficiency, this being due to conductance losses, in the case of the inverter, it converts the DC output from the solar PV module to the AC off-grid voltage with a certain degree of efficiency. It depends upon conversion efficiency and precision of the MPP tracking called tracking efficiency. MPP tracking which is having an efficiency of 25-30% is available in the market; each MPPT has based on a tracking algorism [17].

Current research indicates that all materials have physical limits to the electricity they can generate. The efficiency of existing laboratory cells has already reached an efficiency value of over 25%. PV modules with components known as the PV system as a whole. This system is usually sufficient to meet energy requirements, such as powering the water pump, the appliance, and the lights in the home and the electrical appliance [18].

In the cost of PV systems and computer acceptance, the reliability of PV arrays is a crucial factor. Using fault-tolerant circuit design, the reliability of the panel can be improved considering various redundant features in the circuit to control the effect of partial failure on the overall module and array power degradation. Degradation can be limited by dividing the modules into many parallel solar cell networks. The type of design can also improve module losses caused by broken cells. The hot spot can be removed using a bypass diode [17].

2.1.11 Batteries

A battery is a device that stores direct current (DC) electrical strength in electrochemical structure for later use. The quantity of energy that will be saved or delivered from the battery is managed through the battery charge controller. Electrical energy is saved in a battery in the electrochemical structure and is the most extensively used system for electricity shop in a variety of applications [19].

In stand-alone photovoltaic systems, the electrical power produced via the PV panel can't usually be used when it is produced. Because the demand for power does no longer usually coincide with its production, electrical storage batteries are in many instances used in PV systems. The major features of a storage battery in a PV machine are to: -

- ✓ To keep electrical energy when it is produced using the PV panel and to provide electricity to electrical masses as wanted or on-demand.
- ✓ To furnish strength to electrical hundreds at secure voltages and currents, by suppressing or ‘smoothing out ‘transients that may also happen in PV systems.
- ✓ To supply surge or excessive peak running currents to electrical loads or appliances.

❖ Types of batteries

The most utilized types of batteries are:

- ✓ Lead-acid (Pb-acid)
- ✓ Nickel-cadmium (NiCd)
- ✓ Nickel- metal hydride (NiMH)
- ✓ Lithium-ion (Li-ion)

The determination of a battery for a given application may be a matter of execution and take cost optimization.

➢ Lead-acid

This is the foremost common type of rechargeable battery utilized nowadays since development, and execution overtaken a cost ratio proportion, indeed though it has the slightest vitality thickness by weight and volume. During discharge of lead acidic battery water and lead, sulfate is formed, and this water dilutes the sulfuric acid electrolyte and the specific gravity of the electrolyte decreases with the decreasing state of charge. Additionally, during the charging time, the lead oxide layer is formed at both negative and positive plat at the time of charging [19].

➢ Nickel-cadmium batteries

Nickel-cadmium (Ni-cad) batteries are secondary or rechargeable batteries. It has attractive performance compare to Lead-acid for both standalone and grid-connected solar system the advantage includes long life of battery, very small cost of maintenance, relatively secured from battery excessive discharges, low-temperature capacity retention, and non-critical voltage regulation requirements. The main disadvantage of nickel-cadmium batteries is their high cost and limited availability compared to lead-acid designs [19].

- **Nickel-Metal Hydride**.

The NiMH is an extension of NiCd technology and affords improvement in energy density over that in NiCd. The primary building difference is that the anode is made of a metal hydride this eliminates the environmental worries of cadmium. Another performance enhancement is that it has a negligible memory effect. The NiMH, however, is less capable of turning in high peak power, has a high self-discharge rate, and is inclined to harm due to overcharging. Compared to NiCd, NiMH is highly-priced at present, although the future price is expected to drop significantly. This expectation is primarily based on modern improvement programs targeted for large-scale purposes of this technology in electric vehicles [19].

- **Lithium-Ion battery**

A kind of battery composed of lithium, the lightest metal, and the metal that has the perfect electrochemical potential. However, Lithium is an unstable metal, so Lithium-Ion batteries are made from lithium ions from chemicals. Because of its lightness and excessive energy density, Lithium-Ion batteries are great for transportable devices, such as notebook computers. Besides, Lithium-Ion batteries have no reminiscence influence and do no longer use poisonous metals, such as lead, mercury, or cadmium. The only disbenefit to Lithium-Ion batteries is that they are presently extra luxurious than NiCad and NiMH batteries [19].

Based on performance over cost ratio lead-acid battery has been selected for this thesis.

Table 2.1 compartion of the battery systems [19]

System	Energy density, Wh/kg	Battery cost, $/kWh	Cycle life, 80%	Calendar life, Years
Lead-acid	40	150	1800	20
Ni-Cd	50	500	2000	20
Ni-MH	80	600	1500	10
Ni-Zn	60	450	300	5
Li-NCA	180	600	1800	7
$Na\text{-}NiCl_2$	90	600	4000	20
Na-S	110	500	4000	15

Based on performance over cost ratio lead-acid battery has been selected for this thesis.

2.1.12 Charge Controllers/Regulator

It is the element to protect the battery towards risking situations as overloads and over-discharge. The battery charge controller works as a voltage regulator. The principal characteristic of a charge controller (CR) is to disconnect the module or array from the battery when the battery is charged to a preset degree and disconnect the load (which is linked to the battery) when the battery is discharged to the preset level. The controller's common efficiencies vary from 95% to 98%. Advanced CR also senses the battery temperature and adjusts the charging contemporary accordingly. Another, but much less important, use of the CR is as an assembly factor of all the cables coming from module to battery and battery to load. In different words, the CR additionally serves the cause of the junction box [20].

- **Types of Charge Controllers**

  - **Basic Charge Controllers**

The basic cost controller is designed to protect the battery from any shape of harm due to overcharge or undercharge and prevents any reverse modern that might also be drawn from the battery for the duration of the time duration in which the solar panels are not generating any power.

Overcharging some kinds of batteries can harm the battery as well as reason viable explosions or leaking. If electricity is constantly utilized to the battery after it has attained full capacity, then the battery voltage will elevate inflicting chemical reactions, which will finally overheat the battery and damage it. The batteries' lifestyles cycle will be dramatically shortened if the batteries are undercharged for too long a duration of time. In this situation, the charge controller will disconnect the battery, recognized as Low Voltage Disconnect (LVD), from any masses (lamps, appliances, etc.) once a positive capacity is reached to prevent the battery from dropping any greater charge. The fundamental charge controllers are crucial to the acceptable charging of batteries to shield the batteries from damage [20].

  - **PWM Charge Controllers**

PWM cost controllers are comparable to the simple charge controller. While fundamental charge controllers can only disconnect or connect the battery to cease overcharging, PWM cost controllers can control the quantity of cutting-edge charging the batteries to optimize the charging time. When the battery nears full capacity, the PWM cost controller switches the charging on and off the use of PWM (pulse width modulation) causing a trickle charge, which approves the battery to hold a full charge. This characteristic optimizes the pace and effectivity of charging the battery. PWM and fundamental charge controllers both manipulate the present day going into the battery but do now not strive to optimize the efficiency of the solar panel [20].

- **Maximum Peak Power Trackers (MPPT) Charge Controllers**

Maximum Peak Power Trackers (MPPT) charge controllers can optimize the electricity output from the photovoltaic panel, as nicely as charge the battery up to its most effective charge capacity. The problem with the PWM cost controller and basic cost controllers is that they operate the solar panels at the voltage degree unique by using the voltage level of the battery. As tested earlier, the V–I characteristic of the solar panel is now not linear. By operating at a constant voltage level, nothing ensures that this voltage level is the place the maximum quantity of strength can be drawn. Further, the maximum strength point will trade due to irradiance and temperature guaranteeing that the PWM and primary charge controllers will not often draw the maximum amount of power from the solar panel. The MPPT tracks this maximum power point and modifications the operating factor of the solar panels to constantly draw the maximum quantity of electricity available. The MPPT permits the maximum effectivity of the photovoltaic panel to be reached as well as manage the batteries charging necessities [21].

Table 2.2 efficiency of the charge controllers versus the average radiation and temperature [21].

Controller	Temperature (°C)	Insolation (W/m2)	Efficiency (%)
PWM	39.35	812.95	71.42
MPPT	41.9	743.86	86.82

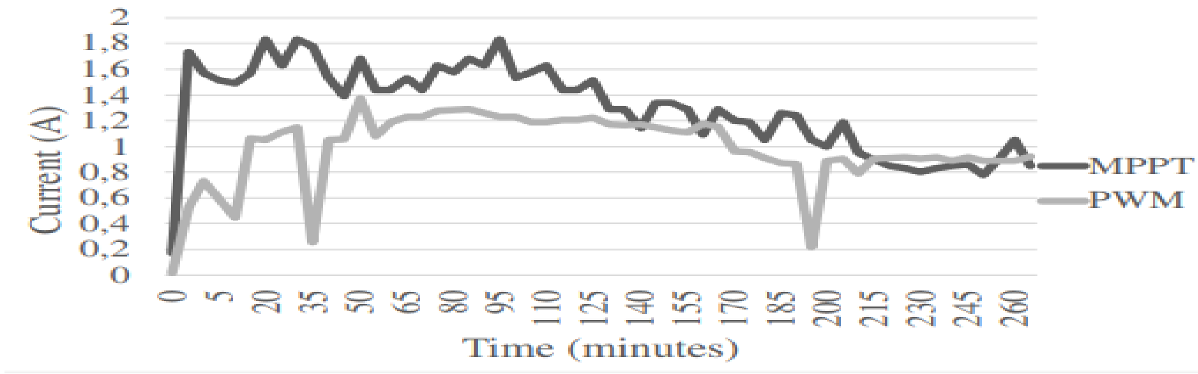


Figure 2.11 Comparison of the current delivered to the battery versus time in the charging process [21].

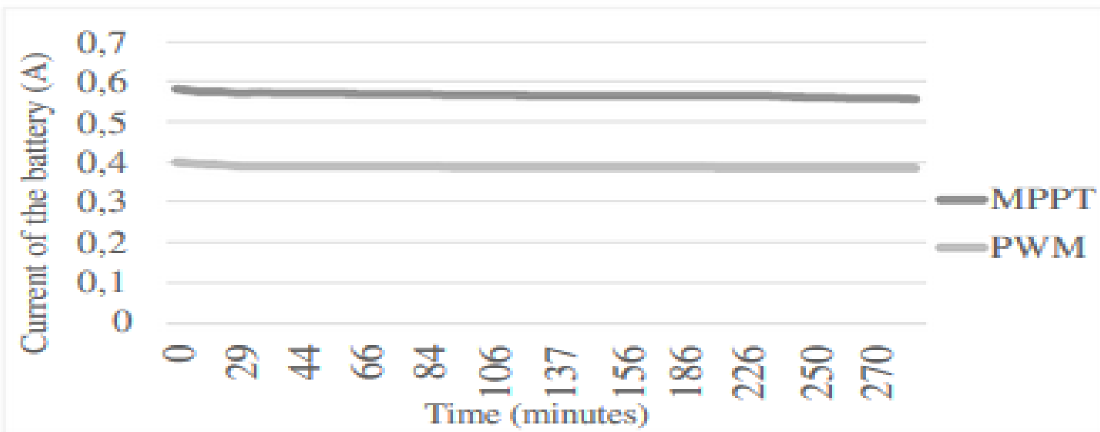


Figure 2.12 Comparison of current delivered from the battery to the load versus time in the discharging process [21].

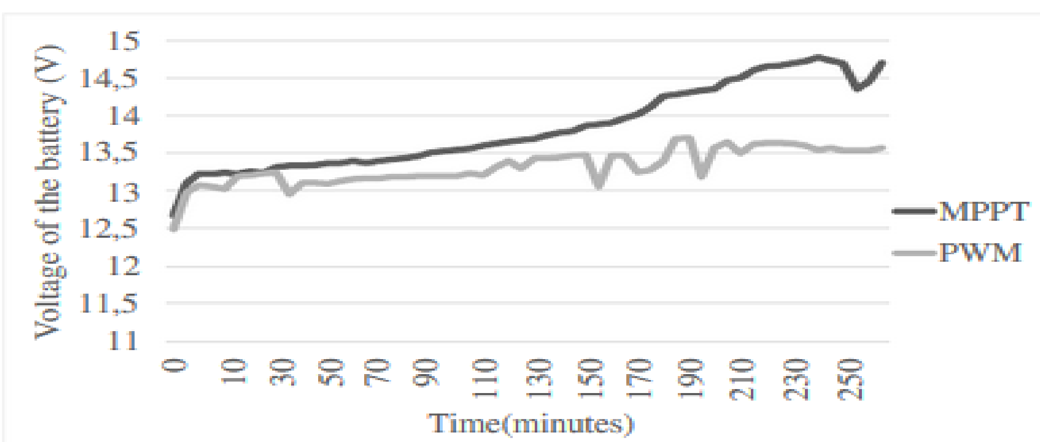


Figure 2.13 Comparison of voltage on the battery versus time in the charging process [21].

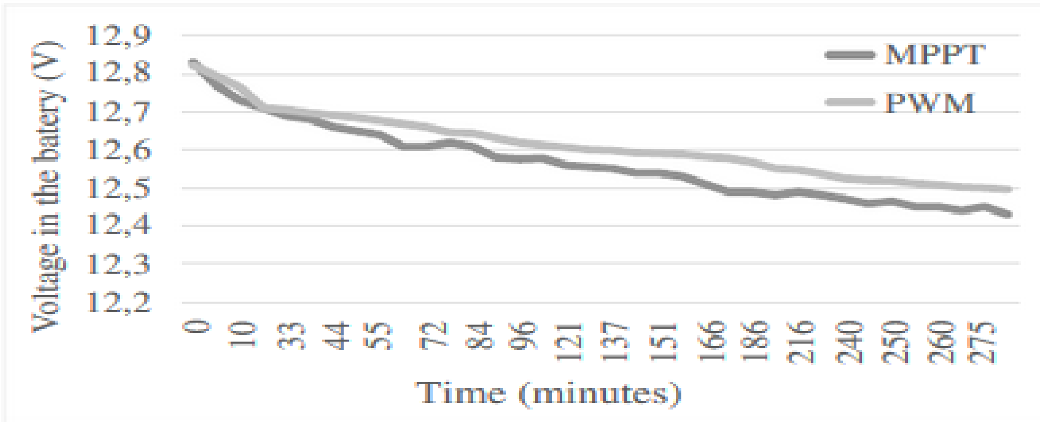


Figure 2.14 Comparison of voltage in the battery versus time in the discharging process [21].

Based on Temperature, Efficiency (%) and Insolation (W/m^2) performance PWM (pulse width modulation) charge controller has been selected.

2.1.13 Converter

The inverter is an electronic device that converts DC voltage into the AC voltage of the required magnitude and frequency. In solar PV applications Inverter are used to electricity the equipment/devices that function from the AC source. The DC to AC conversion is required as the solar PV system generates and stores strength in the form of DC voltage and current only. The normal output ac waveform of Inverter is a sine wave with a frequency of 50/60Hz. The inverter is someday called DC-AC converters [22].

In this thesis bi-directional DC/AC or AC/DC converter type was considered as part of the hybrid system component. The incorporation of the bi-directional converter is used to switch the DC voltage that comes from battery and PV, moreover to change the AC voltage from the hydro and biogas into DC when it is needed to charge the battery. In order to determine the size ofan inverter, the determination of all the demanding loads from all consumers which are likely to function at the same time is an important step, however in this thesis case since power is provided from hydro and biogas directly to the consumers so inverter size can be smaller than the load to be supplied at one time. The rectifier and the inverter are the two main power electronics components of the solar PV systems. DC electricity generated from PV is converted into AC electricity by using an inverter, and hence, this electricity is the one connected to individual household's appliances [22].

2.1.14 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 [23]. 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 [24].

Table 2.3 Composition of Biogas

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)	∠1
Nitrogen (N_2)	∠1
Oxygen(O2)	∠1

Methane and additional hydrogen there maybe make up the combustible part of biogas. Methane is a colorless and odorless 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 [24].

2.1.15 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 [25].

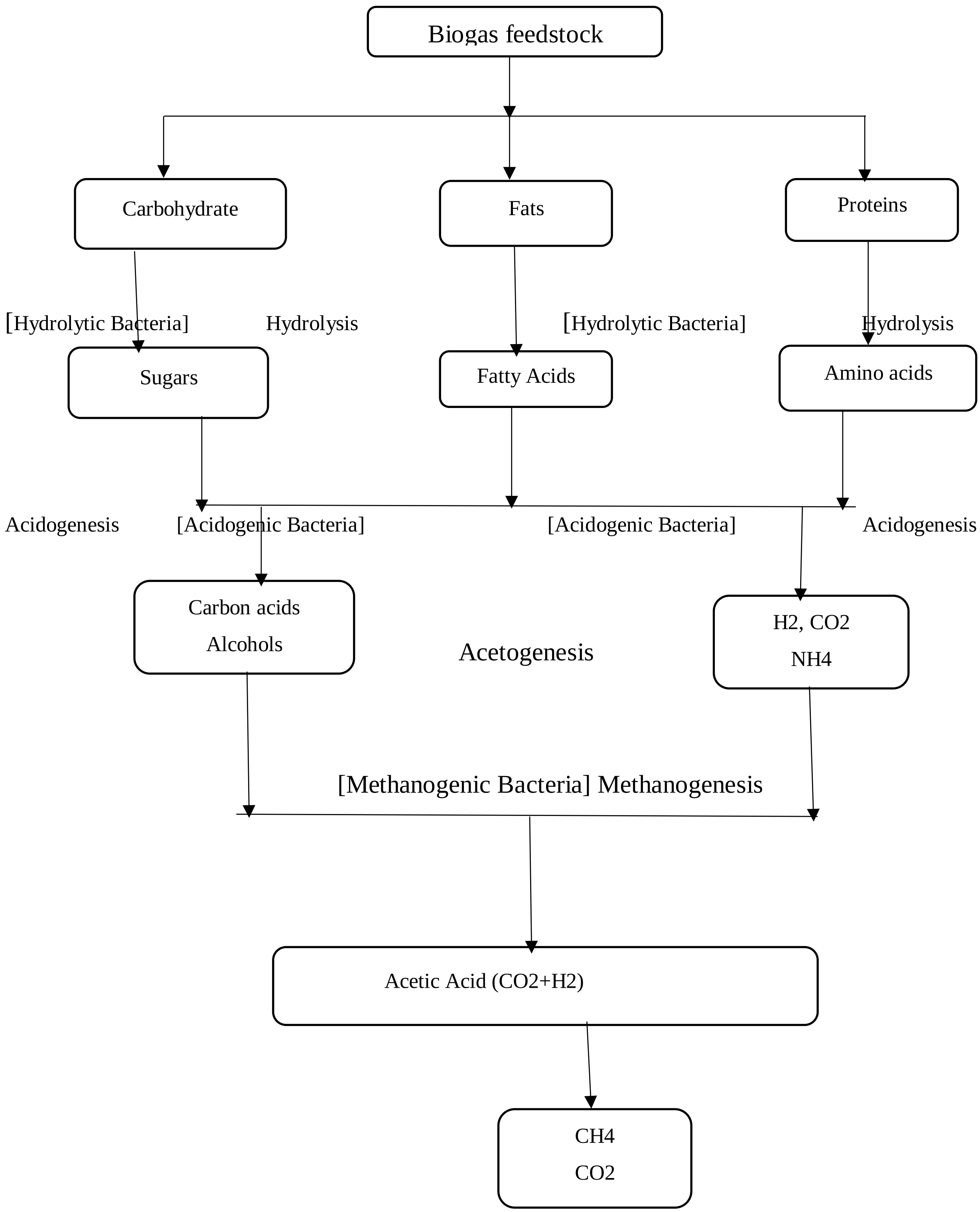


Figure 2.15 The main process steps of biogas production by AD

The brief notes of the four main process steps of AD: hydrolysis, acidogenesis, acetogenesis, and methanogenesis are given below.

A. Hydrolysis

Hydrolysis is theoretically the first step in AD, during which complex organic polymers are decomposed into smaller mono and polymers. During hydrolysis, polymers such as carbohydrates, lipids, nucleic acids, and proteins are transformed into glucose, glycerol, purine, and amino acids. Hydrolytic microorganisms excrete hydrolytic enzymes, transforming biopolymers into less complicated and soluble enzymes.

$$\text{Lipids} \xrightarrow{\text{lipase}} \text{fatty acids, glycerol}$$

$$\text{Polysaccharide} \xrightarrow{\text{cellulose, cellobiase, amylase}} \text{monosaccharide}$$

$$\text{Proteins} \xrightarrow{\text{protease}} \text{amino acids}$$

B. Acidogenesis

During acidogenesis, the products of hydrolysis are transformed by fermentative bacteria into methanogenic substrates. Simple sugars, amino acids, and fatty acids are degraded into acetate, carbon dioxide, and hydrogen (70%) as properly as into volatile fatty acids (VFA) and alcohols (30%) [25].

C. Acetogenesis

Products from acidogenesis, which cannot be at once converted to methane through methanogenic bacteria, are converted into methanogenic substrates during acetogenesis. For methanogenic substrates such as acetate, hydrogen and carbon dioxide, VFA and alcohols are oxidized. VFA is oxidized into acetate and hydrogen with carbon chains longer than two gadgets and alcohols, with carbon chains longer than one unit. Hydrogen development raises the component pressure of hydrogen. This can be considered as an acetogenetic waste product and inhibits the acetogenic bacteria 's metabolism. Hydrogen is converted to methane in the form of methanogens. As a symbiosis of two organizations of organisms, acetogenesis and methanogens normally run parallel [26].

D. Methanogenesis

Methanogenic bacteria are used to extract methane and carbon dioxide from intermediate materials. 70% of the methane produced is derived from acetate, while the remaining 30% is derived from the conversion of hydrogen (H) and carbon dioxide (CO2) to the following equations:

$$\text{Acetic acid} \xrightarrow{\text{methanogenic bacteria}} \text{methane + carbon dioxide}$$

$$\text{Hydrogen + carbon dioxide} \xrightarrow{\text{methanogenic bacteria}} \text{methane + water}$$

Methanogenesis is a crucial step in the entire cycle of anaerobic digestion because it is the process's slowest biochemical reaction. Methanogenesis is seriously affected by conditions of activity. Examples of factors affecting the phase of methanogenesis are the composition of the feedstock, feeding rate, temperature, water content, NH_3 concentration, and pH [27].

2.1.16 pH-values and optimum intervals

The pH-value is the measure of acidity/alkalinity of a solution respectively of substrate mixture, in the case of AD. An expression of the intensity of the alkaline or acidic strength of water. Values range from 0-14, where 0 is the most acidic, 14 is the most alkaline and 7 is neutral. The pH value of the AD substrate influences the growth of methanogenic microorganisms and affects the dissociation of some compounds of importance for the AD process (ammonia, sulphide,organic acids). Experience shows that methane formation takes place within a relatively narrow pH interval, from about 5,5 to 8,5 , with an optimum interval between 7,0-8,0 for most methanogens. Acidogenic microorganisms usually have lower value of optimum pH. The optimum pH interval for mesophilic digestion is between 6,5 and 8,0 and the process is severely inhibited if the pH-value decreases below 6,0 or rises above 8,3. The solubility of carbon dioxide in water decreases at increasing temperature. The pH-value in thermophilic digesters is therefore higher than in mesophilic ones, as dissolved carbon dioxide forms carbonic acid by reaction with water [28].

The value of pH can be increased by ammonia, produced during degradation of proteins or by the presence of ammonia in the feed stream, while the accumulation of VFA decreases the pH-value. The value of pH in anaerobic reactors is mainly controlled by the bicarbonate buffer system [28].

Therefore, the pH value inside digesters depends on the partial pressure of CO2 and on the concentration of alkaline and acid components in the liquid phase. If accumulation of base or acid occurs, the buffer capacity counteracts these changes in pH, up to a certain level. When the buffer capacity of the system is exceeded, drastic changes in pH-values occur, completely inhibiting the AD process. For this reason, the pH-value is not recommended as a stand-alone process monitoring parameter [28].

2.1.17 How to secure continuous feedstock supply

The first step in developing a biogas project idea is to make a critical inventory of the available types and amounts of feedstock in the region. There are two main categories of biomass that can be used as feedstock in a biogas plant. The first category includes farm-based products such as municipal solid waste, energy crops (e.g. maize, grass silage), vegetable residues, agricultural by-products, and farm-based wastes etc [28].

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.

2.1.18 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) [27].

2.1.19 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 [28]: -

- 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

1. The fixed-dome type of biogas plant

- ❖ **Construction**

The biogas plant is a brick and cement stricture having the following five sections

1. Mixing tank present above the ground level

2. Inlet chamber: the mixing tank opens underground into a sloping inlet chamber.

3. Digester: the inlet chamber opens from below into the digester which is a hung tank with a dome-like ceiling. The ceiling of the digester has an outlet with a valve for the supply of biogas.

4. Outlet chamber: the digester opens from below into an outlet chamber

5. Overflow tank: the outlet chamber opens from the top into a small overflow tank

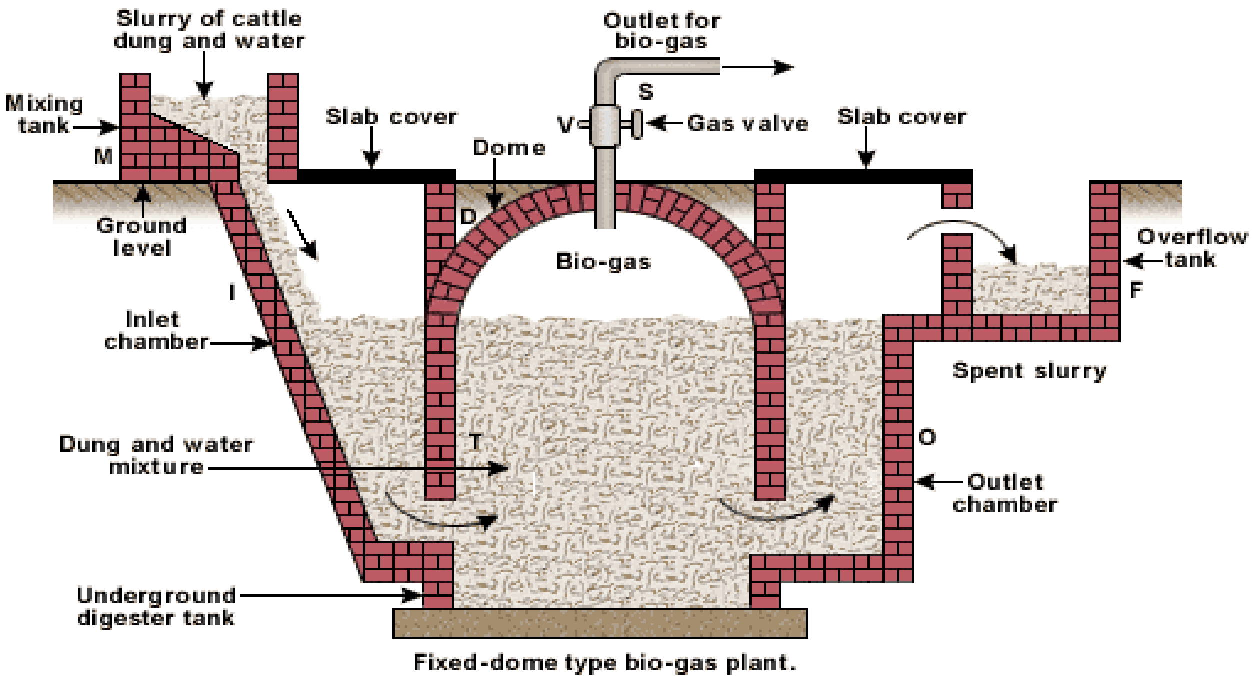


Figure 2.16 fixed dome type biogas plant [29]

Advantages of fixed dome type of biogas plant

- The construction needs easily and locally available materials
- Inexpensive
- Simple to construct

Due to this the plant is known as a local or social Biogas plant.

2. Floating gas holder type of biogas plant

❖ **Construction of the floating gas holder type plant**

The floating gas holder type of biogas plant has the following chamber section:

- Mixing tank –present above the ground level.
- Digester tank –deep underground well-like structure .it is divided into two chambers by a partition wall in between.

  It has two long cement pipes

  i. Inlet pipe opening into the inlet chamber for the introduction of slurry
  ii. Outlet pipe opening into the overflow tank for removal of spent slurry.

- Gasholder –an inverted steel drum resting above the digester the drum can move up and down i.e. Float over the digester the gas holder has an outlet at the top which could be connected to gas stoves.
- Overflow tank –present above the ground level

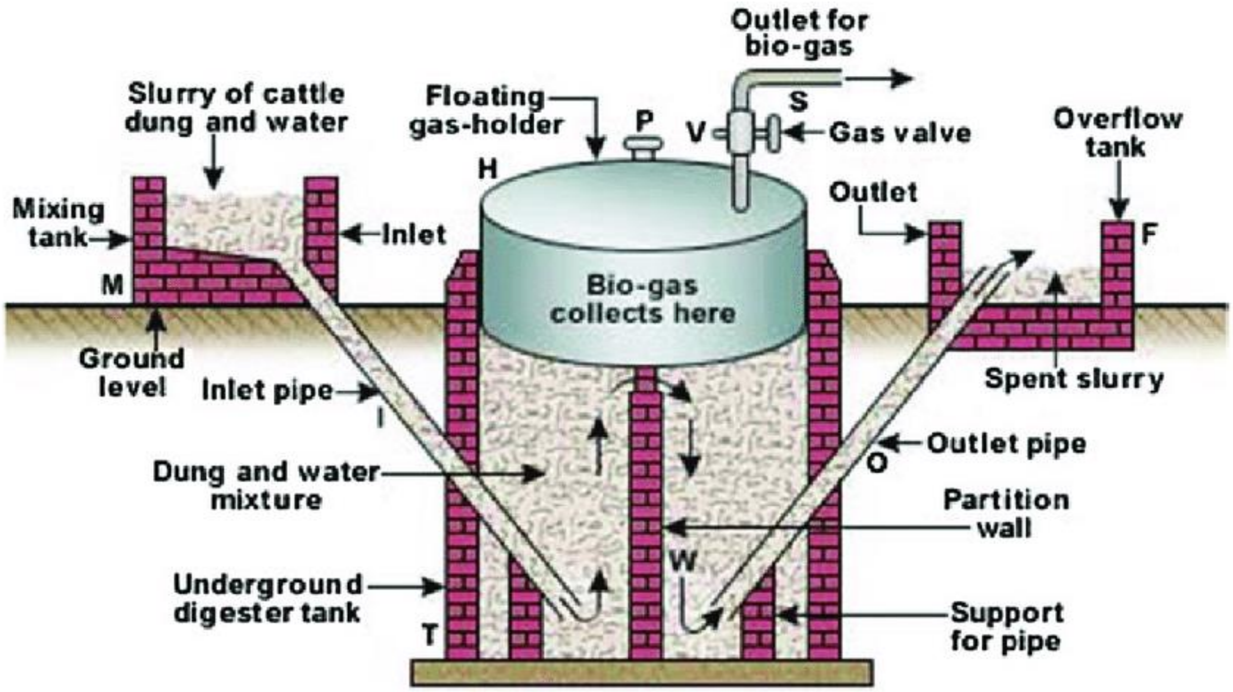


Figure 2.17 Floating gas holder type biogas plant [30]

The disadvantage of floating gas holder type biogas plant

- Expensive
- Steel drum may rust
- Requires maintenance

2.1.20 Temperature

The AD process can take place at different temperatures, divided into three temperature ranges: psychrophilic (below 25°C), mesophilic (25°C – 45°C), and thermophilic (45°C –70°C). There is a direct relation between the process temperature (Table 2.2) [28].

Table 2.4 Thermal stage and typical retention times [28]

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 to 20 days

2.1.21 Advantage of biogas as fuel

- High calorific value
- Clean fuel
- No residue produced
- No smoke produced
- Non-polluting
- Economical
- Can be supplied through pipelines

Burns readily-has a convenient ignition temperature uses of biogas

Uses of Biogas

- Domestic fuel
- For street lighting
- Generation of electricity

2.1.22 Advantage of biogas plant

- Reduce the burden on foresters and fossil fuels
- Produces clean fuel-helps in controlling air pollution
- Provides nutrients rich (N& P) manure for plants
- Control waste water pollution by decomposing sewage, animal dung, and human extra.

2.1.23 Disadvantage of biogas plant

- The initial construction cost of the plant is extremely high.

2.1.24 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 [31] [28].

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 [31].

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 [31].

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 [31].

2.1.25 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 in dams is extremely difficult because it's nonlinear or time-varying behavior like sudden changes in reservoir water level [32] [33][60].

2.1.26 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 2.18 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, Baryaw yemotebet 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 2.19 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 [34].

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 2.20: Kesem Kebena Dam

Figure 2.21 Kesem Kebena Dam

Figure 2.22 Kesem Kebena Dam water level view

Figure 2.23 Kesem Kebena Dam structure view

Figure 2.24 Kesem Kebena Dam outer surface

2.1.27 Civil Work Components

The civil components mentioned in this section are such important components as intake, sand trap, spillway, headrace canal, settling basin, fore-bay tank, penstock pipes, and tailrace [35].

Intake: water diversion is the highest point of a hydro system where water is diverted to the penstock that feeds the turbine from the lake. Side intake is common, with low intakes.

Headrace Canal: conveyance system that transports engineered discharge from one stage to the next. Channel systems are generally used in all micro-hydro power schemes whereas pipe systems are used in specific difficult terrain. A canal may be unlined or lined concrete. The traditional cross-sections of the canal used in micro-hydropower schemes may be in shape rectangular or trapezoidal, or triangular or semi-circular.

Settling Basin: the civilian component which settles down sediments for periodic flushing in the basin. Since the sediment is harmful to civil and mechanical structures and components, it is important to capture, settle, store, and flush the particular size of the specified percentage sediment. This can be done only by raising the friction of the water-bearing sediment. The turbulence can be reduced by constructing settling basins along with the conveyance system. Since the settling basins are straight and have bigger flow areas, the transit velocity and turbulence are significantly reduced allowing the desired sediments to settle. The sediment thus settled must be properly flushed back to the natural rivers.

Spillway: a structure that diverted excess water safely to the river. Spillways need to be designed to remove the excess water due to floods, to minimize the adverse effects to the other components of the MHS spillways are often constructed in settling basin and the fore-bay, from which the excess water is safely diverted to the water source.

Fore-bay Tank: the civilian portion which flows steadily through the penstock into the turbine. For-bay also serves as the last settling basin which helps the last particles to settle down before the penstock gets into the bath. Fore-bay may also be a reservoir for storing water according to depth. A sluice would allow the closing of the penstock entrance. A trash rack should be placed in front of the penstock.

Penstock Pipe: the pump, which transmits water from the fore-bay tank to the turbine under pressure. As the vertical drop increases, it is not only the moving water to the turbine but also the enclosure that creates head pressure. The penstock concentrates all water power at the bottom of the pipe, where the turbine is located.

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 [35] [36].

- ✓ **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 [37].

- ✓ **Turbine**

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

➢ 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 [38].

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 [39].

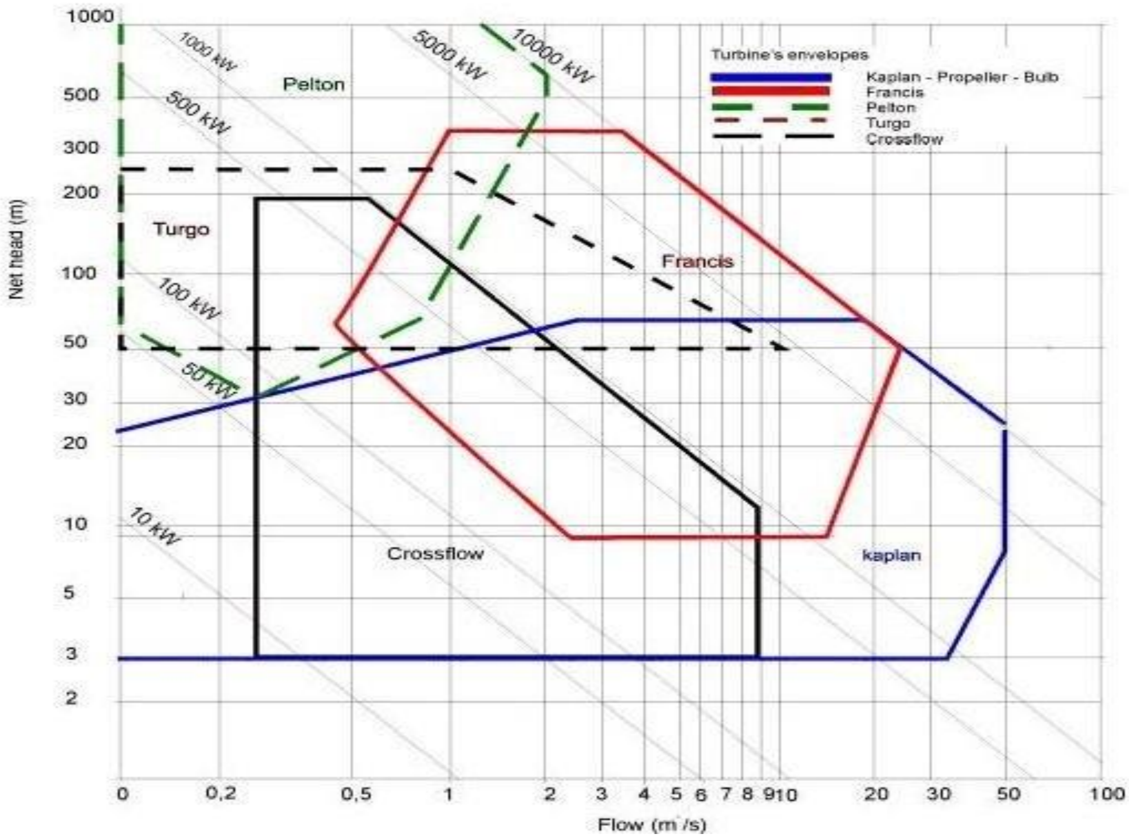


Figure 2.25 Mini Hydro Turbine Selection Chart [39]

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:

$$Ns = N \times \left(\frac{P^{1/2}}{Hn^{1.25}} \right) \quad (2.5)$$

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 [39].

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.

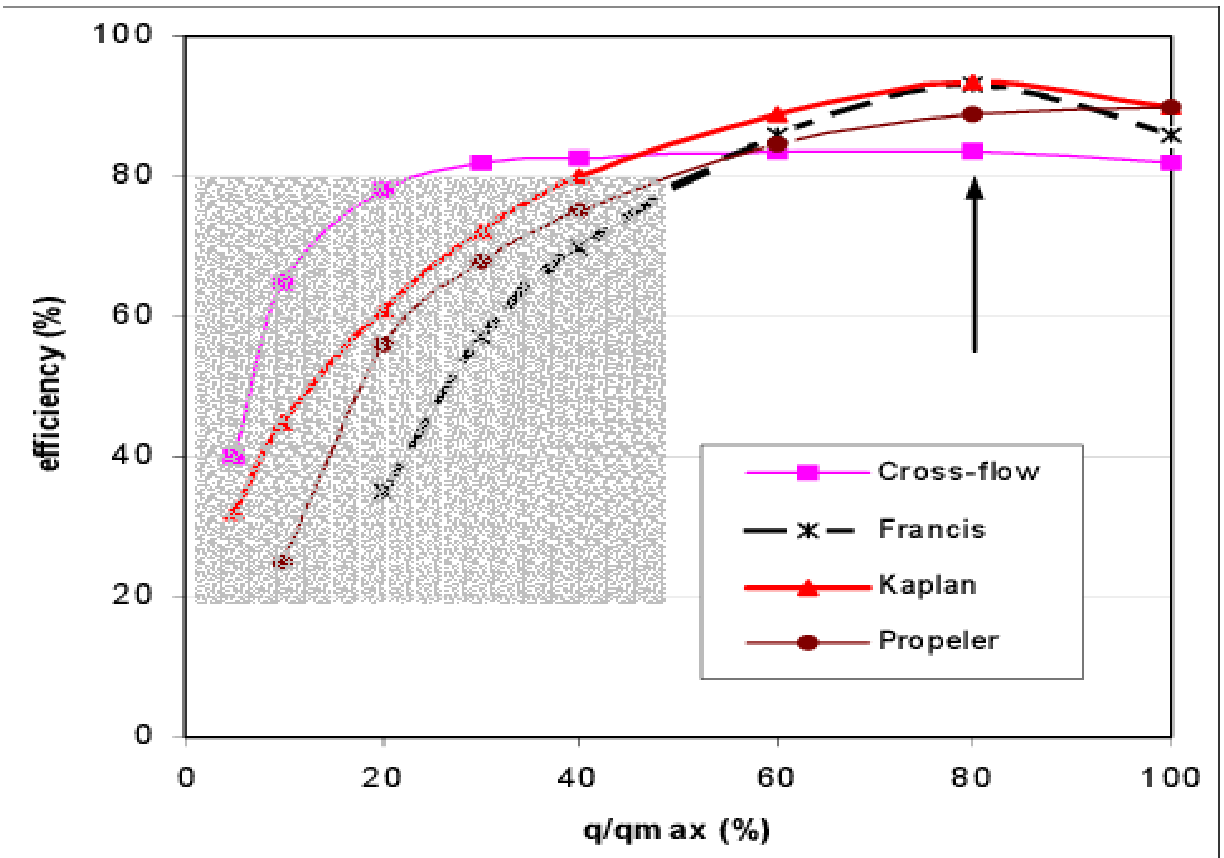


Figure 2.26 Efficiency of Various Turbines based on Discharge rate [40]

- ✓ **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 [41].

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 2.5 Selection of Generator Type [42]

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

- ✓ **Shut-off Valve**

A shut-off valve is especially important and is at once in the front of the turbine in case an immediate shutdown of the system is required. This valve is of high performance and exceptionally durable. It is recommended that the change of the valve controller must be in a usually close condition which means the valve to be in an open position then does not work when most needed [41].

2.1.28 Determination of Design Parameters of a Mini Hydro Power System

Head Measurement: is defined as the vertical height in meters from the level at which the water enters the penstock to the level at which the water leaves the (tailrace) turbine housing. The higher the head, the faster the waterfalls, the more force it exerts on the blades of the turbine. This can be achieved using an altimeter, GPS, and topographical maps to estimate a stream's vertical drop [43].

Gross Head and Effective Head: is the vertical distance, between the water surface level at the intake and the tailrace for reaction turbines and the nozzle level for impulse turbines. The effective head is less than the gross head due to the pressure losses in the penstock. Once the gross head is known, the net head can be computed by simply subtracting the losses along its path. There are some factors which affect the frictional losses in the pipe including the viscosity of the fluid, the roughness of the internal surface of the pipe, the change in elevation between the ends of the pipe, the length of the pipe through which the fluid travels, the velocity of the flow and the size of the internal pipe diameter [35].

There are different methods for calculating the frictional losses in pipes but Darcy-Weisbach the formula is considered as the most accurate pipe friction loss formula [35].

The Darcy-Weisbachthe formula is as follows:

$$H_L = f\left(\frac{LP \times V^2}{2DPg}\right) \tag{2.6}$$

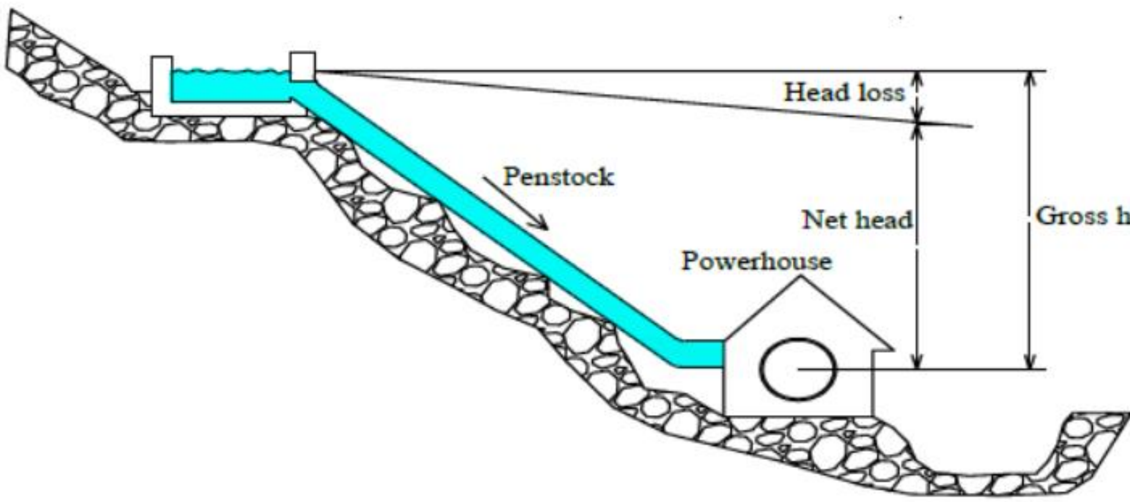


Figure 2.27 Net and gross head [2]

The equation contains a dimensionless friction factor known as the Darcy friction factor. This is not a constant value and is system-specific. It is dependent on the parameters of the pipe and the properties of the fluid flowing through it but is known to extremely high accuracy for certain flow regimes. This friction factor can be obtained through various theoretical calculations or can be acquired from various published charts. The most commonly utilized types of these charts are known as Moody diagrams, named after L.F.Moody and so the factor is sometimes called the Moody friction factor. Moody charts link several key factors that contribute to the overall frictional losses in the system and these are the Reynolds number and the relative roughness [44].

The Reynolds number “R_e” is defined as:

$$R_e = \frac{V \times D_p}{v} \tag{2.7}$$

Where

v = the kinematic viscosity of water = 1.004x 10-6 (m²/s)

The energy balance is maintained in a pipe (penstock), but energy is lost in proportion to the interior surface of the pipe as defined by the number of Reynolds.

Penstock Design: are used to transport water to the powerhouse from intake. They may be built above or below level, depending on factors such as the very existence of the land, Penstock materials, environmental requirements, and ambient temperature. The internal penstock diameter (D_p) of the flow rate, the length of the pipe and the gross head can be calculated as [43]:

$$D_p = 2.69\left(\frac{np^2 Q^2 L_P}{H_g}\right)^{0.1875} \tag{3.8}$$

The penstock tensile strength depends on the materials used in the pipe, its compressive strength, the diameter of the piping system, and the operating pressure. The minimum recommended material is known in millimeters [45].

2.1.29 Classification of Hydropower Plants

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

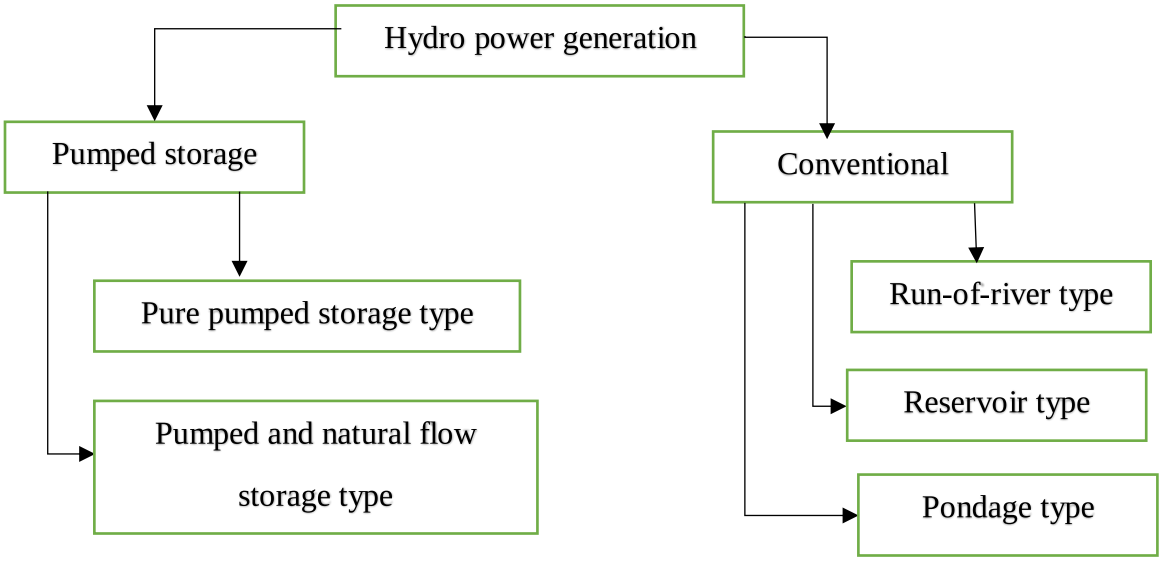


Figure 2.28 Classification of hydropower based on water flow

Water can be harnessed on a different scale. The categories, which are commonly used to define the power output form hydropower, are outlined as follows [46]:

- Large hydro: more than 100 MW and usually feeding into a large grid
- Medium-hydro: 15 - 100 MW and usually feeding a grid
- Small-hydro: 1 - 15 MW and usually feeding into a grid
- Mini- hydro: between 100 kW and 1 MW; either standalone schemes or more often feeding into the grid
- Micro-hydro: ranging from a few hundred watts for battery charging or food processing applications up to 100 kW, providing power for a small community or rural industry in remote areas away from the grid
- Pico-hydro power with a range of less than 5KW.

2.1.30 Advantage and disadvantage of hydropower

- **Advantage of hydropower**
    - **Global environment issues**

Energy demands are increasing every year all over the world. In most developing country deforestation is highly expanding to use for fundamental needs as a result desertification is increasing; these lead global warming and greenhouse effect so, to control the problem hydropower plants are one of the ways [36].

- **The economic development of countries**

The production of electrical sources significantly modifies the economic growth rate. Since hydropower is environmentally sustainable if it operates at low operating costs it raises the country's income [36].

- **Local energy source**

Most of the population live in the ruler area without the use of clean energy, and the main concentration of electricity consumption in the cities. A relatively mini development of hydropower plays an important role not only in local electrification but also in improving local development. It helps improve renewable energy and decrease biomass reliance for cooking and lighting [36].

- **Efficiency improvement in the entire power system**

Power demands generally fluctuate considerably depending on the time of day. One important feature of a reservoir or pond age-controlled hydropower plant and a pumped hydropower plant is that it can respond to such fluctuations instantly. Contrary to this, while thermal power plants provide high efficiency through constant operation, fluctuations in demand do not, however, result in a quick load following characteristics. The combination of hydropower and thermal power, therefore, provides greater efficiency across the entire power system [36].

- **Stabilization of electricity rate**

Hydropower generation does not bear any fuel costs, but the initial high expenditure is reflected in the significant proportion of capital costs in the cost of producing electricity. Although the cost of production at the beginning of service life is much higher than that of a nuclear power plant, no fuel costs mean lower unit output costs relative to inflation until the plant has been completed, ensuring a steady production and low-priced power supply for a very long period [36].

- **The disadvantage of hydropower**

Large reservoirs associated with traditional hydroelectric power stations result in submersion of extensive areas upstream of the dams, sometimes destroying biologically rich and productive lowland and riverine valley forests, marshland and grasslands. Damming interrupts the flow of rivers and can harm local ecosystems, and building large dams and reservoirs often involves displacing people and wildlife. The loss of land is often exacerbated by habitat fragmentation of surrounding areas caused by the reservoir. Additionally, investment cost is very high [36].

2.2 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 [28] [47].

2.3 System Description

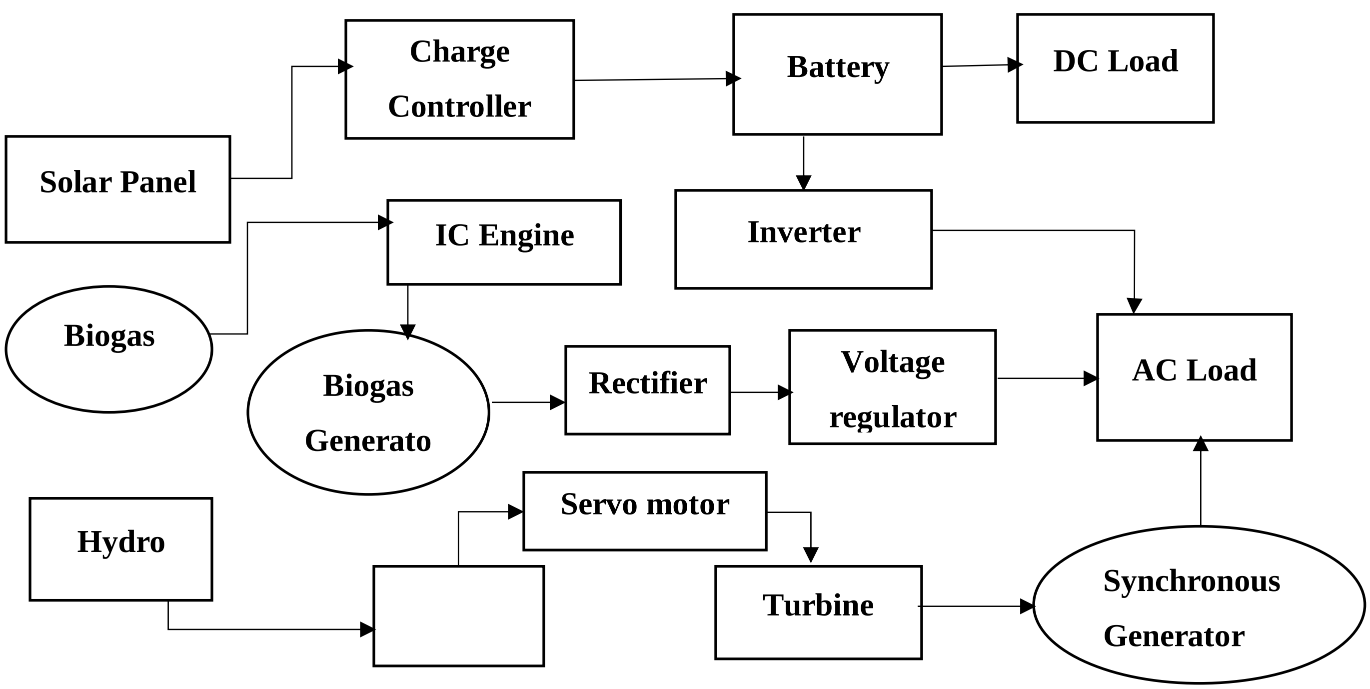


Figure 2.29 Block diagram of the PV/Biogas/Hydro Hybrid system

2.4 Literature Review

Several researchers have conducted different views on energy generation system. Most of them are used the best hybrid configuration, the chose based on the availability of the resource which closes to the selected site. Many of the have similar characterstics situations with Ethiopian context and thus referred for the study. Yet there lacks additional.

Berihun G. [33] presented a case study of rural areas in Ethiopia with a paper entitled "Modeling and Simulation of a Micro Hydro-Wind Hybrid Power Generation System for the Rural Area of Ethiopia". His objective was to develop a cost-effective hybrid energy supply system for a remote model community of 660 households with one primary school, two churches, one mosque, and one health center. He discussed two options, the Wind / Micro Hybrid and the Standalone Micro Hydro system, by comparing the cost of energy to determine the competitive one for the remote. According to the study, the most favorable wind / micro-hybrid system with COE is $0.112 / kWh selected. The COE of the standalone Micro-hydro system is $0.035 / kWh. He concluded that the micro-hydro system is the most economical in meeting the energy demand of the village. However, if he includes solar resources in the hybrid configuration, his hybrid system may be cost-effective regarding his title.

Ali Saleh Aziz, Mohammad Faridun Naim Tajuddin, Mohd Rafi Adzman, Makbul A. M. Ramli and Saad Mekhilef [4] have studied the Energy Management and Optimization of a PV/Diesel/Battery, Hybrid Energy System Using a Combined Dispatch Strategy for a remote villages located in Muqdadiyah District, Diyala, Iraq for a model community of 40 households with a total number of people of around 150 by using HOMER software. According to their work the remote villages can be electrified at a cost of COE ($0.21/kWh,). But, their system is not environmentally friendly due to high emission of carbon gas to the surrounding environment.

Leong Kit Gan, Jonathan K.H. Shek, Markus A. Mueller [16] presented a paper titled “Hybrid wind–photovoltaic–diesel–battery system sizing tool development using an empirical approach, life-cycle cost, and performance analysis: A case study in Scotland”. The research evaluated a number of optimum configuration for the hybrid wind–PV–diesel system with battery storage. Inevitably, the obtained configuration has struck the balance of batteries and diesel generator usage, giving the lowest cost solution. The optimal solution cost is approximately just under 50% less than a diesel-only solution. However, the cost of energy (£/kWh) is approximately £1.10/kWh, far exceeding the cost of utility generated electricity.

Further analysis showed that 83% of the excess energy generated by the RES is not being utilized.

Aysar Yasin [10] presented a case study of a Remote Village in Palestinian Territories with a paper entitled "Optimum Design of a Stand-alone Hybrid Energy System". This paper proposes a method of electrification for rural areas using a stand-alone hybrid based more often than not on renewable power sources (PV, Wind) and Diesel generator. The determination of optimum size of each component for a hybrid system goal of this work. The small village comprises about 25 households with some service buildings. The average energy demand is the 275kWh/day. The location has abundant photo voltaic radiation viable with an everyday average of 5.4kWh/m2and a common wind pace of 4.22m/s. The design of this elaborate hybrid machine is primarily based on HOMER Pro software which requires incident photo voltaic radiation data, wind speed data, electrical energy demand profile for the village, gasoline cost, tool's characteristics, and costs. The optimization results showed that the best hybrid system among all feasible configurations is photovoltaic/wind/energy storage systems with a diesel generator. The cost of energy (COE) produced is US$0.427/kWh. In this research, the cost of energy is high in addition to this the researcher didn't show the profits earned from reducing gas emissions.

CHAPTER THREE

3 DATA ANALYSIS AND DESIGN OF THE HYBRID ENERGY SOURCE

3.1 INTRODUCTION

In this chapter assessment and analysis of the collected data is presented and based on that the design of the Hybrid system is accomplished.

3.1.1 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

3.1.2 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.

3.1.3 Primary Data

These data, collected directly from the selected site, are considered as the primary data, and these include the total residential and differential load and the existing power source of the village.

The size and cost of hybrid system components are highly influenced by the size of the electric loads. Properly analyzing load profile is an important initial point to design a hybrid system of the Solar/ Biogas/Mini hydro power generation system.

3.2 Solar Insolation Data- Minjarna Shenkora

The solar insolation data of Minjarna Shenkora at Latitude: 8.598565 or ($8^{0}35^{l}55^{ll}$), Longitude: 38.433785 or ($38^{0}26^{l}2^{ll}$) is given in Table 3.1

Table 3.1 Solar insolation data of Minjarna Shenkora [2018]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Solar insolation (kw/m^2)	6.15	6.1	6.19	5.55	5.92	5.22	4.94	4.6	5.94	6.17	5.91	6.18	5.74

Source [48]

Solar insolation is the total solar radiation that reaches on the earth surface and measured by w/m^2

3.3 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 analyzed 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.

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 purpuses.

The Table 3.2 AC Load gives the appliances, with their power rating, and the energy use within specified time of the day.

Table 3.2 Summary of Loads at Dubetu and Rarati

Location and type of Loads	Quantity	Rating (W)	Power (kW)	Time of usage	Hrs. /Day	Energy/day(kWh/day)
Residential load in Dubetu						
• Lighting	4083	15	61.245	6:00-7:00, 18:00-23:00	6	367.47
• Radio	1000	100	100	7:00-21:00	14	1400
• Tv	152	139.5	21.204	12:00-14:00, 19:00-23:00	6	127.224
• Stove	50	3000	150	6:00-8:00, 12:00-14:00, 19:00-21:00	6	900
• **Flour Mill**	3	7500	22.5	8:00-13:00, 14:00-19:00	10	225
Health post-Dubetu						
• Lighting	4	15	0.06	0:00-6:00, 18:00-23:00	13	0.78
• Refrigerator	1	90	0.09	0:00-23:00	24	2.16
Elementary school in Dubetu						
• Lighting	25	15	0.375	18:00-20:00	3	1.125
• Radio	3	100	0.3	10:00-11:00, 12:00-13:00, 15:00-16:00	3	0.9
Churches in Dubetu						
• Lighting	24	15	0.36	4:00-8:00, 18:00-20:00	6	2.16
• Amplifier	1	100	0.1	4:00-8:00, 18:00-20:00	6	0.6
Residential load in Rarati						
• Lighting	3414	15	51.21	6:00-7:00, 18:00-23:00	6	307.26
• Radio	1000	90	90	7:00-22:00	15	1350
• Tv	88	139.5	12.276	12:00-14:00, 19:00-23:00	6	73.656
• Stove	50	3000	150	6:00-8:00, 12:00-14:00, 19:00-21:00	6	900
• **Flour Mill**	3	7500	22.5	8:00-13:00, 14:00-19:00	10	225
Health post in Rarati						
• Lighting	3	15	0.045	0:00-6:00, 18:00-23:00	13	0.585
• Refrigerator	1	90	0.09	0:00-23:00	24	2.16
School in Rarati						
• Lighting	125	15	1.875	18:00-21:00	3	5.625
• Radio	5	100	0.5	10:00-13:00, 15:00-17:00	6	3
Churches and mosque in Rarati						
• Lighting	30	15	0.45	4:00-7:00, 18:00-19:00	6	2.7
• Amplifier	2	100	0.2	4:00-7:00, 18:00-19:00	6	1.2
Total Load Dubetu and Rarati			356.234,			3027.419, 2871.186
Differential load in Dubetu and						
Water pump(3.5hp)	13	3.5*750	34.125	7:00-12:00, 13:00-18:00	10	341.25
Water pump(2hp)	60	2*750	327	7:00-12:00, 13:00-18:00	10	3270
Total Differential Load			361.125			3611.25
Total Load	Total watt		1046.505kW	Total energy		9509.855kWh/day

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. 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.

3.4 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.

✓ 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 describe below in Biogas, and Hydro power design to meet the estimation total load. Due to this huge number of load is covered by the two renewable energy source and the remain are covered by PV system. Therefore, Solar system are expacted to cover 2% of the total load.

Total energy =9509.855kWh/day

2% of the total energy is coverd by the solar

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

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

$$P_{PV} = \frac{E_{PV}}{G_{min}} \times 1000\text{w / m}^2 \quad (3.1)$$

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

$$FF = \frac{\text{Max. power from solar module}}{Isc * Voc} \tag{3.2}$$

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

$$\text{PV array}(w) = \text{fill factor} \times \text{PV array}(wp) \tag{3.3}$$

$$\text{PV array}(w) = 0.74 * 41.34719565kW$$

$$= 30.596925kW$$

Total number of modules

$$N_m = \frac{PV_{\text{array size(w)}}}{\text{Rating per module}} \tag{3.4}$$

Maximum power for the selected module is 145w

$$N_m = \frac{30.596925kW}{145W} = 211.0133$$

Round up next the whole number = 212modules

$$\text{Number of modules in the string, } N_s = \frac{\text{Total number of modules}}{\text{nominal module voltage}} \tag{3.5}$$

$$N_s = \frac{212\text{modules}}{24v} = 8.833$$

Round up next whole number, $N_s = 9$

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

Round up next whole number, $N_P = 23$

- Total number of solar modules required, $N_S * N_P = 9 * 23 = 207\text{modules}$

3.4.1 Sizing and Specifying Battery Bank

Battery is a storage device which used to store a DC source. Considering temperature varation 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 [49].

The storage capacity of a battery

$$C_{Ah} = \frac{EL * AD}{\eta_{inv} * \eta_{bat} * V_n * DOD} \tag{3.6}$$

$EL = 190.57kWh/day$

$AD = 2days$

$V_n = 24v$

$\eta_{inv} = 95\% = 0.95$

$\eta_{bat} = 85\% = 0.85$

$DOD = 70\% = 0.7$

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

- Number of batteries connected in parallel

$$B_P = \frac{C_{Ah}}{B_c} \tag{3.7}$$

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

$$B_P = 122.15 \approx 123$$

- Number of batteries connected in series

$$B_s = \frac{v_n}{v_b} \tag{3.8}$$

$$B_s = \frac{24}{24} = 1$$

- Total number of batteries required is, $B_p \times B_s = 123 \times 1 = 123$batteries

3.4.2 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 [50].

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

$$\text{Charge controller}, \left(I_{tot}\right) = I_{SC} \times N_P \times \text{oversize factor} \quad (3.9)$$

$$\text{Charge controller}, \left(I_{tot}\right) = 8.78A * 22.3V * 1.2$$

$$I_{tot} = 234.953A \simeq 235A$$

$$\text{Number of charge controller} = \frac{\text{Total Current}}{\text{Selected Charge Controller}} \quad (3.10)$$

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

$$\simeq 4$$

Inverter

The Inverter size should be 25-30% bigger than the total watts of the appliance [22]. Considering 25% of the total watts of the appliance becomes: -

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

From the standard 40kW by 220V

3.4.3 The Total Area Covered by the Solar Panel

Sizing of the area coverd by solar module is avery important during design of solar system so, considering the pv module length and width:

L= 2000mm w = 1168mm considering with the space

$$A = l \times w \quad (3.11)$$

$$A = \left(2000mm \times 23\right) \times \left(1168mm \times 9\right)$$

$$A = 483,552,000mm^2 = 483.552m^2$$

3.4.4 Cable Sizing

The rural villages are far away from mojo substation of Ethiopia with a distance of more than 64km. If the system are extaned from the grid leads to a high voltage drop. So stsndalone system is the solution to electrifay the remote area with minimum system voltage drop.

The cable size must consider the distsnce and voltage drop.The cables must cause less than 3% of voltage losses 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 = $1.72\text{x}10^{-8}$ ohmmeter

Conductivity of copper = $58\text{x}10^{6}$s/m

$$\text{Cross sectional area of cable A}\left(\text{mm}^2\right) = \frac{2\times \text{I}\times \text{L}}{58\text{x}10^6\text{s}/\text{m}\times \text{V}_{\text{drop}}} \qquad (3.12)$$

$$\text{A}\left(\text{mm}^2\right) = \frac{2\times 10.536\text{A}\times 10\text{m}}{58\text{x}10^6\text{s}/\text{m}\times 0.03\times 24}$$

$$\text{A} = 7.5689\text{mm}^2$$

$$= 7.5689\text{mm}^2\text{, used}10\text{mm}^2\text{from cable standard}$$

- If 2% of voltage drop between battery and charge controller.

The maximum controller to the battery is the large of the module to controller and controller to load current.

Length of cable 10m and

Maximum current =235

$$\text{Cross sectional area of cable A}\left(\text{mm}^2\right) = \frac{2\times \text{I}\times \text{L}}{58\text{x}10^6\text{s}/\text{m}\times \text{V}_{\text{drop}}}$$

$$\text{A}\left(\text{mm}^2\right) = \frac{2\times 235\text{A}\times 10\text{m}}{58\text{x}10^6\text{s}/\text{m}\times 0.02\times 24\text{v}}$$

$$\text{A} = 168.822\text{mm}^2$$

$$168.822\text{mm}^2\text{, used } 170\text{mm}^2\text{from IEE cable sizing table}$$

- If 5% of voltage losses between load and charge controller

The charge controller to load current is found by dividing the total load power by system voltage.

Length of cable = 15m

Maximum current = 235A

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

$$A\left(mm^2\right) = \frac{2\times 235A\times 15m}{58x10^6 s/m\times 0.05\times 24v}$$

$$A\left(mm^2\right) = \frac{7050mm}{69.6x10^6} = 0.0001012931mm$$

$$A = 101.2931mm^2$$

$$= 101.2931mm^2, \text{ used } 100mm^2 \text{ from IEE cable sizing table}$$

3.5 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 of 180m^3/day and 5400m^3/ month. Considering the temperature of Dubetu and Rarati to produce biogas, it needs 70-80 days.

To change biogas content into Energy

$$1m3/day = 2.4kWh, \text{standard } [23] \tag{3.13}$$

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

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

$$= 18kW$$

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,

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

3.5.1 Biogas Design

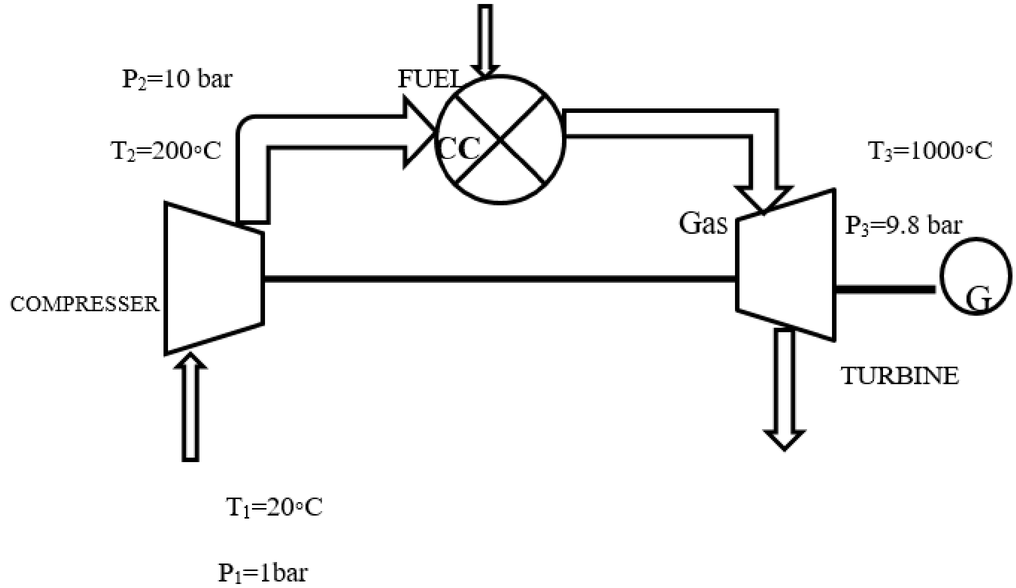


Figure 3.1 Micro-turbine structure[http://www.energysolutionscenter.org]

Using Thermal Energy Conversion Equations, Diagrams and Tables

Considering the efficiency of turbine $\eta_t = 98\% = 0.98$ and

efficiency of generator $\eta_g = 96\% = 0.96$

F: Stoichiometric Air to Fuel Ratio

$$LHV = h_{3air}\left(1+f\right)Dh_3$$

$$\beta = \frac{h_{3air} - h_{2air}}{LHV - h_{3air} - \left(1+f\right)Dh_3} \tag{3.14}$$

Using the 70% of biogas, $LHV = 17.972 MJ/kg$

$$\beta = \frac{(1089.5 - 202.2) kJ/kg}{(17972 - 1089.5 - \left(1+17.16\right)102.5) kJ/kg}$$

$$\beta = 0.0438 \simeq 0.044$$

$$P_{out} = m_{air}(1+\beta)(h_3 - h_4)\eta_t - m_{air}(h_2 - h_1)\ \eta_g \tag{3.15}$$

$m_{air:}$ a mass of air

$$m_{air} = \frac{P_{out}}{(1+\beta)(h_3 - h_4)\eta_t - (h_2 - h_1)\ \eta_g} \tag{3.16}$$

$$\text{But, } h_3 = h_{3air} + X \times Dh_3 \tag{3.17}$$

To find the value o f X

$$X = \left(1 + f\right) \times \frac{\beta}{(1+\beta)} \tag{3.18}$$

$$X = \left(1 + 17.16\right) \times \frac{0.044}{(1+0.044)}$$

$$X = 0.77$$

Then, $h_3 = h_{3air} + X \times Dh_3$

$$= 1089.5 + 0.77 * 102.5$$

$$= 1168.425\ kJ/kg$$

To find h4 T4 must be in the range of 400^0C-600^0C

Check on point:1 using average point $\rightarrow$ T4 =500^0C

$$T_m = \frac{500 + 1000}{2} = 750^0 C$$

$$T_m = 750^0 C \left(X = 0.77\right) \rightarrow k = 1.302$$

$$T_3 - T_4 = T_4 \times \eta_t \times 1 - \frac{1}{(\frac{P_3}{P_4}) \wedge \left(K_t - 1\right)/K_t} \tag{3.19}$$

T4=599.95^0C

Check on point:2 the selected point below the max temperature and much close to maximum point T4 = 599.95^0C

$$T_m = \frac{599.95 + 1000}{2} = 799.975^0 C$$

$$T_m = 799.975^0 C \left(X = 0.77\right) \rightarrow K = 1.299$$

T_4= 602.28^0C

Check on point:3 the selected point above the max temperature and much close to maximum point T_4 = 602.28^0C

$$T_m = \frac{602.28 + 1000}{2} = 801.14^0 C$$

$T_m = 801.14^0 C \left(X = 0.77\right) \rightarrow k = 1.298$ T4 = 603.06^0C

From this iteration T4 = 603.06^{0}C is closest to the **Check on point:3**

From (the ratio of specific heats table) at T4 = 603.06^{0}C approximate to 610^{0}C

$$h_{4air} = 640.4 kJ/kg, \text{ and } Dh_4 = 53.3 kJ/kg$$

$$h_4 = h_{4air} + X * Dh_4 \tag{3.20}$$

$$h_4 = 681.441 kJ/kg$$

$$m_{air} = \frac{18kW}{(1+0.044)(1168.425-681.441)0.98-(202.2-20.1)0.96}$$

$$= \frac{18kW}{323.4270701}$$

$$m_{air} = 55.654 kg/s$$

$$m_{air} = 55.654 kg/s \times 3600 s/h$$

$$= 200,354.4 kg/h$$

$$m_{fuel} = \beta \times m_{air} \tag{3.21}$$

$$= 0.044 \times 200,354.4 kg/h$$

$$= 8,815.5936 kg/h$$

$$\text{Or, } \frac{8,815.5936 \, kg/h}{1000 \, kg/ton}$$

$$= 8.8155936 \, ton/h$$

3.5.2 Sizing Digester

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

$$V_d = S_d \times RT \tag{3.22}$$

$$S_d = M_{biomass} \times m_{water} \tag{3.23}$$

$$M_{biomass} = 8,815.5936 \, kg/h \times 0.002 \, m^3/kg$$

$$V_d = 8{,}815.5936\,{}^{kg}\!/_{h} \times 0.002\,{}^{m^3}\!/_{kg} \times 12h$$

$$= 211.57425m^3$$

Considering reserve, it should be 4 times of the designed system digester so,

$$= 211.57425m^3 \times 4$$

$$= 846.297m^3$$

3.6 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 [36] [60].

3.6.1 Hydro Power Design

To design hydropower, there are two options.

- The first options is 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 electriccity, 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

$$P(W) = \rho gHQ \tag{3.24}$$

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) = $3.497m^3/s$

$$= 1000kg \times 3.497m^3/s \times 9.8m/s^2 \times 53.748m$$

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

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

$$\eta_t = 0.603$$

$$\eta_g = 0.9$$

$$P(W) = \rho g H Q \eta_t \eta_g \tag{3.25}$$

$$= 1841.976209kW \times 0.603 \times 0.9$$

$$= 999.6405kW$$

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

3.6.2 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:

$$\text{Plant Factor}(\%) = \frac{\text{Annual energy generation}(kWh)}{\text{Maximum output}(kW)8760hr} \times 100 \tag{3.26}$$

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

$$= \frac{3,323,657.524kWh}{8,760,000kWhr} \times 100$$

$$= 0.379, \text{ or } 37.9\%$$

3.6.3 Load Factor

Power demand is called the load at the power supply side. The ratio of the mean load to the maximum load for a specific period is called the load factor. It is also called the daily load factor and the annual load factor, according to the period taken.

$$\text{Load Factor}(\%) = \frac{\text{Mean load}(\text{kW})}{\text{Maximum load}(\text{kW})} \times 100 \quad (3.27)$$

$$P_{ave} = \frac{95.565\% \times 9509.855\ \text{kWh}/\text{day}}{24\ \text{h}/\text{day}} = 378.67054\text{kW}$$

$$P_{max} = 95.565\% * 1046.505\text{kW} = 1000.1\text{kW}$$

$$= \frac{378.67054\text{kW}}{1000.1\text{kW}}$$

$$= 0.379, 37.9\%$$

3.6.4 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.

$$\text{Regulating capability factor}(\%) = \frac{\text{Active storage capacity}(m^3)}{\text{Annual in flow}(m^3)} \times 100 \quad (3.28)$$

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

$$\text{Regulating capability factor}(\%) = \frac{380.00\text{million}(m^3)}{500.00\text{million}(m^3) \times 365} \times 100$$

$$= \frac{380.00\text{million}(m^3)}{182500\text{million}(m^3)} \times 100$$

$$= 0.208\%$$

3.6.5 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.

$$\text{Flow utilization factor}(\%) = \frac{\text{Annual plant discharge}(m^3)}{\text{Max.plant discharge}\ m^3/s \times 365 \times 86,400\text{sec}} \times 100 \quad (3.29)$$

$$\text{Flow utilization factor}(\%) = \frac{1,822,500\left(m^3\right)}{3.497\, {m^3}/{s} \times 365 \times 86,400\text{sec}} \times 100$$

$$= \frac{1,822,500}{110,281,392} \times 100$$

$$= 0.01653 \text{ or } 1.653\%$$

3.6.6 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 [34].

Catchment Area= 13341km²

3.6.7 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 [35] [36].

$$\text{Head fluctuation rate} = \frac{\text{LWL - TWL}}{\text{HWL - TWL}} \text{ Greater or equal to 0.7} \tag{3.30}$$

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

$$\text{Head fluctuation rate} = \frac{910\text{m} - 860\text{m}}{930\text{m} - 860\text{m}} = \frac{50\text{m}}{70\text{m}}$$

$$= 0.714$$

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.

3.7 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. Factors Affecting Medium and Long Term Forecasting the end-use modeling, econometric modeling, and their combinations are the most often used methods for medium and long term load forecasting. Some of the most influencing factors that affects the Medium and Long term load forecasting can enlisted as below” [51]:

1)Descriptions of appliances used by customers.

2)The sizes of the houses.

3)The age of equipment.

4)Technology changes.

5)Customer behavior.

6)Population dynamics are usually included in the statistical and simulation models based on the so-called end-use approach.

7)Economic factors such as per capita incomes.

8)Employment levels, and

9)Electricity prices are included in econometric models.

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

$$\text{Future value} = \text{present value of energy}\left(1+\%\text{increase}\right)^{k} \tag{3.31}$$

$$\text{Total energy per year} = 365\text{day}\times\frac{9509.855\text{kWh}}{\text{day}} = 3471.097075\,{}^{\text{MWh}}\!/_{\text{year}}$$

$$\text{Energy demand after 10 years} = 3471.097075\,{}^{\text{MWh}}\!/_{\text{year}}\times\left(1+0.015\right)^{10}$$

$$= 4028.349863\,{}^{\text{MWh}}\!/_{\text{year}}$$

3.8 Controller Design for Servo Motor and Turbine

3.8.1 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 methodsare applied first Ziegler-Nichols (Z-N) and second Good-Gain method for PID tuning” [52] [53] [54].

“PID controllers tuning for positional control systems is a time-consuming A task, therefore considerable effort was made to analyze 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” [52] [53].

$$U(t) = K_p e(t) + K_i \int (t) + K_d \frac{de(t)}{dt} \tag{3.32}$$

Where K_p, K_i, K_d are proportional, Integral and derivative gains and e (t) =error set point-output.

The PID output in Frequency domain can be represented as:

$$U(s) = E(s)\left[K_p + \frac{K_i}{s} + K_d s\right]$$

The value of K_p, K_i, and K_d are determined using the given formulas. In this method, the proportional time (T_p) is set to infinity; the integral time (T_i) and derivative time (T_d) are set to zero. This is used to get the initial PID setting of the systems.

Table 3.3 Z-N tuning parameter

Controller type	K_p	K_i	K_d
P	$\frac{1}{2}K_U$	∞	0
PI	$\frac{9}{20}K_U$	$\frac{1}{1.2}P_U$	0
PID	$\frac{3}{5}K_U$	$\frac{1}{2}P_U$	$\frac{1}{8}P_U$

3.8.2 Servo motor modelling

An electric servo motor is motor whose function is to cause motion in the form of linear motion in proportion to a supplied electrical command signal. Here the controlled variable is the turbine power. The electric servo motors are preferable for the flow control of micro hydro power systems as they have a simple design, require less maintenance and are less expensive than conventional governors [55].

The approximate transfer function for the servo motor with driver is considered for the analysis and is given by:

$$G(s) = \frac{1}{1+sT_1} \times \frac{2}{1+sT_2} \tag{3.33}$$

Whare as, T1=3 ad T2=0

$$G(s) = \frac{2}{1+3s}$$

3.8.3 Hydraulic turbine model

Precise hydraulic turbine modeling requires the inclusion of line-like transmission reflections that occur in the compressible fluid-carrying elastic-walled pipe. The propagation velocity of such traveling waves typically is about 1200 meters per second. Traveling wave models may, therefore, be necessary if the penstock is long. In what follows, we will first develop hydraulic turbine and penstock systems models without traveling wave effects and assuming no surge tank is present. This can be define hydraulic turbine basic governing specifications [53].

The representation of the hydraulic turbine and water column instability studies are usually based on the following [55] [56]:

- The hydraulic resistance is negligible.
- The penstock pipe is inelastic, and the water is in compressible.
- The velocity of the water varies directly with the gate opening and with the square root of the net head.
- The turbine output power is proportional to the product of the head and the volume of flow.
- The essential elements of the hydraulic plant

$$G(s) = \frac{1}{1+sT_1} \times \frac{2}{1+sT_2} \tag{3.3}$$

Whare as, T1=0 ad T2=3

$$G(s) = \frac{2}{1+3s}$$

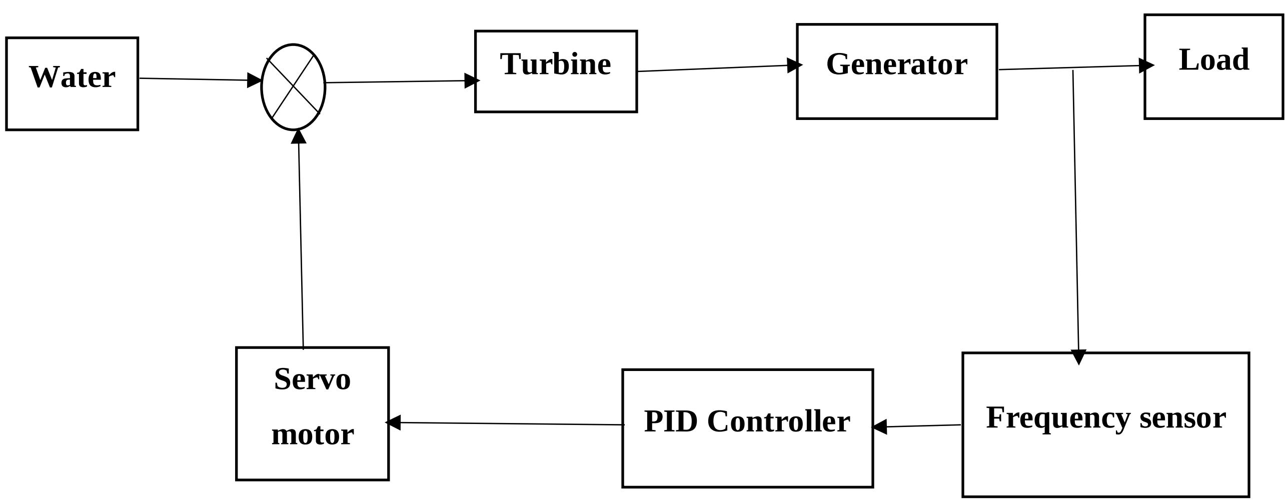


Figure 3.2 Block diagram of speed governor for power plants

3.9 HOMER Software

The Hybrid Optimization Model for Electric Renewable (HOMER) is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL), uses for different applications in the energy generation system. One of the major functions of HOMER is to assist in the design of hybrid power systems for the effective appraisal of various renewable energy power generation technologies. To optimize device design, it contrasts a wide variety of equipment with specific constraints and sensitivities. HOMER models the physical behavior and life-cycle cost of a hybrid power system that is the total cost of installing and operating the system over its lifetime. HOMER is suitable for designers to compare many different design options based on their technical and economic approaches. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs. It provides optimized solutions to the power system's problem based on cost-effectiveness [57].

HOMER simulates quite a few system configurations to decide the top-notch system configuration. In the optimization process, HOMER selects one exquisite most wonderful configuration out of all configurations generated in the simulation manner that fulfills all technical constraints and has the lowest life-cycle cost. The reason for the optimization device is to decide the top-quality fee of every desire variable that interests the modeler. The most useful sizes and numbers of each element that are used or HOMER to assume about more than one size and numbers in its optimization manner respectively are determined by using way of the clothier [58].

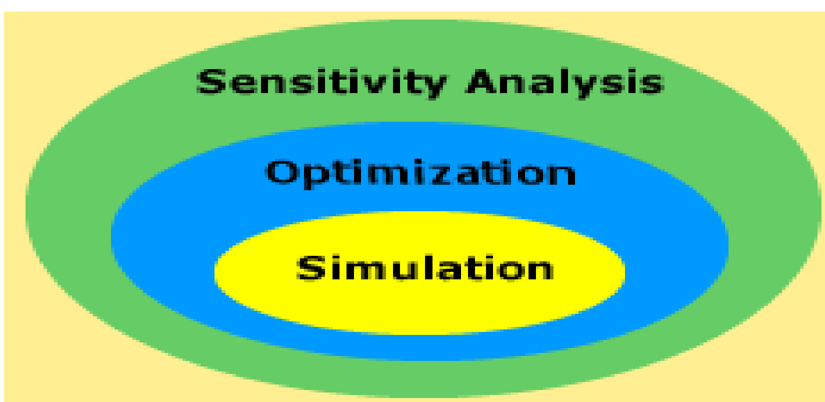


Figure 3.3 Relationship between simulation, optimization, and sensitivity analysis [58].

Table 3.4 Sensitivity Analysis of Hybrid System

	Replacement Cost ($) multiplication	Sensitivity to resource
PV	1.1	5.0 kW/m^2 and 5.74 kW/m^2
Biogas	1.01	-
Hydro	1.01	100L/s and 500L/s

3.9.1 Input data to the Homer 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 modeling of renewable assets is a required gadget mod problem [59].

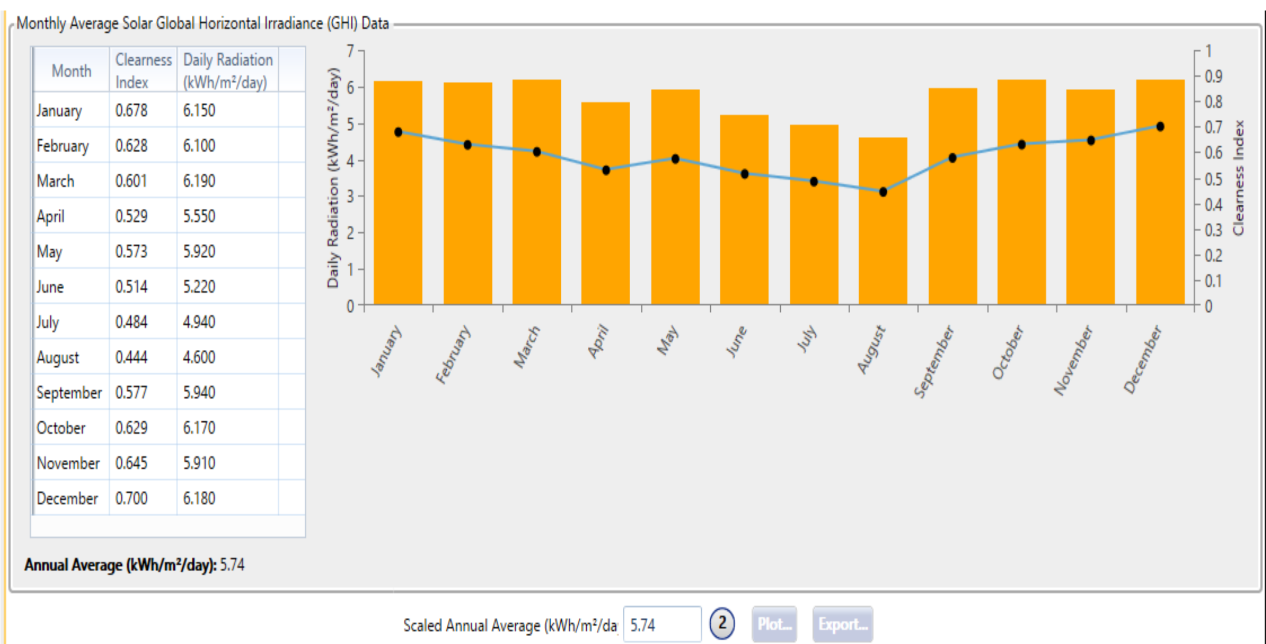


Figure 3.4 Solar resource

Figure 3.5 Biogas resource (tones/day)

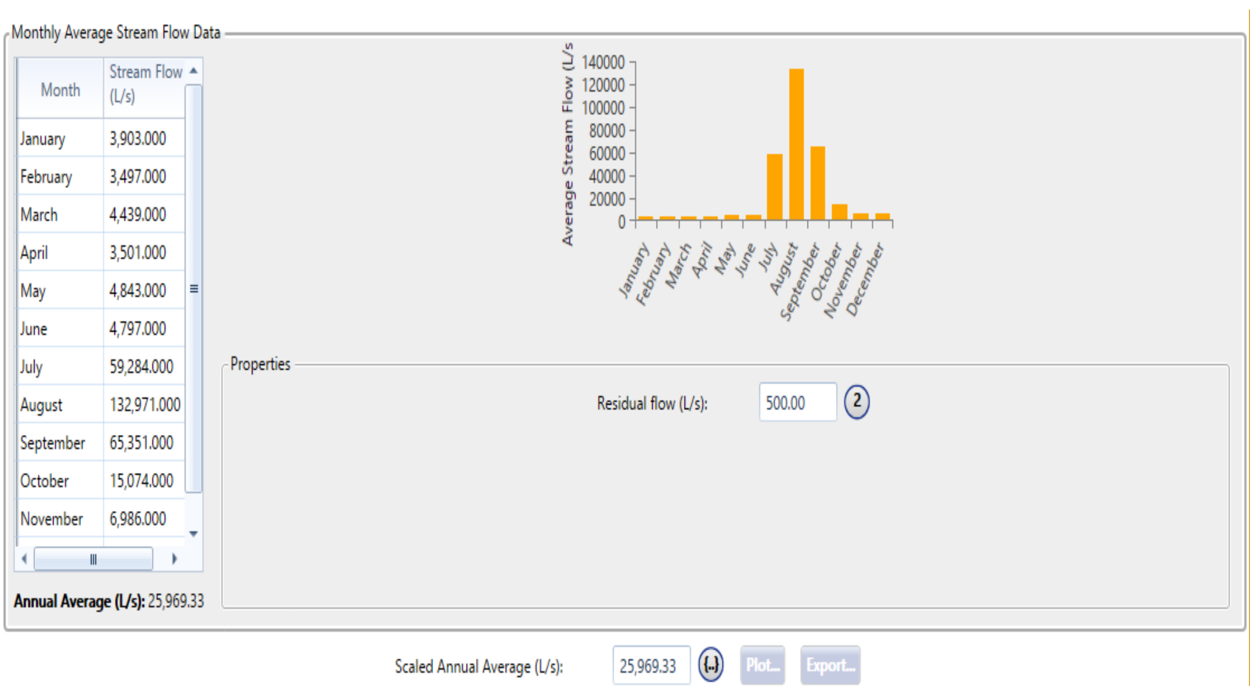


Figure 3.6 Hydro flow rate (L/s) resource

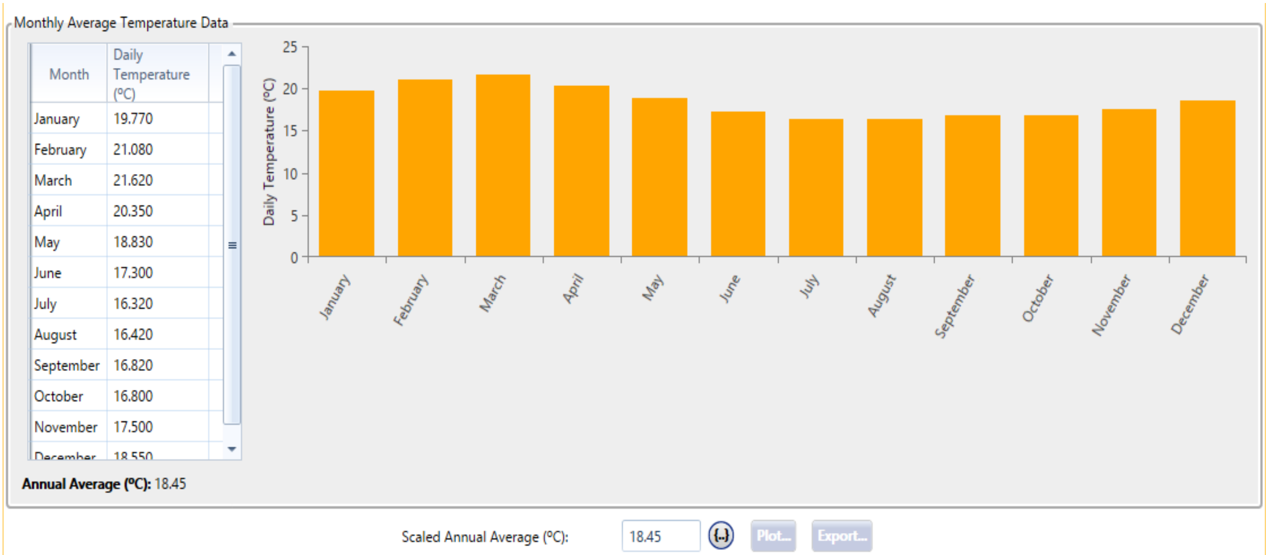


Figure 3.7 temperature

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.

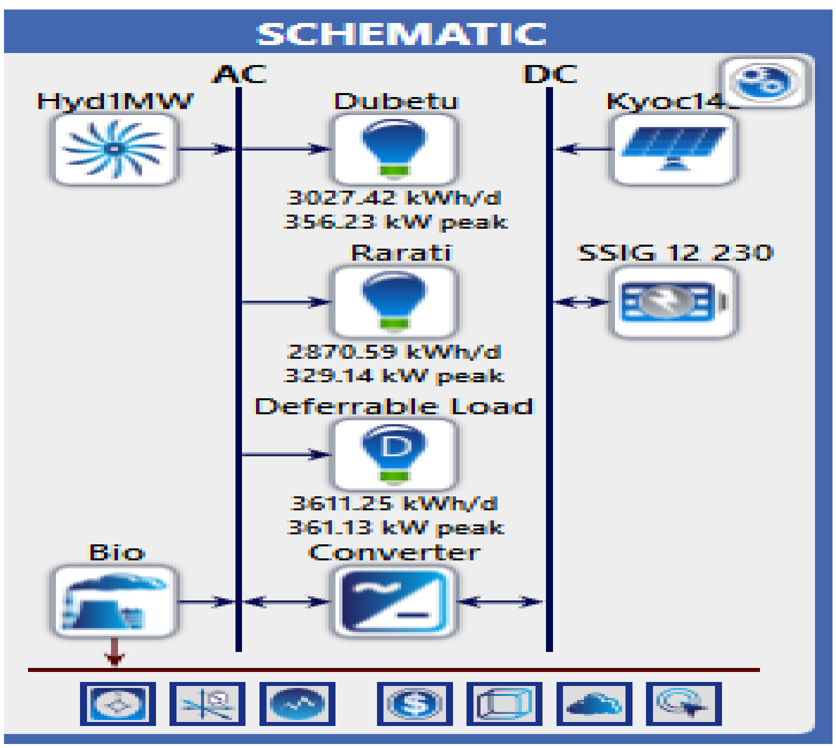


Figure 3.8 schematic configuration of a standalone system

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 3.7 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.

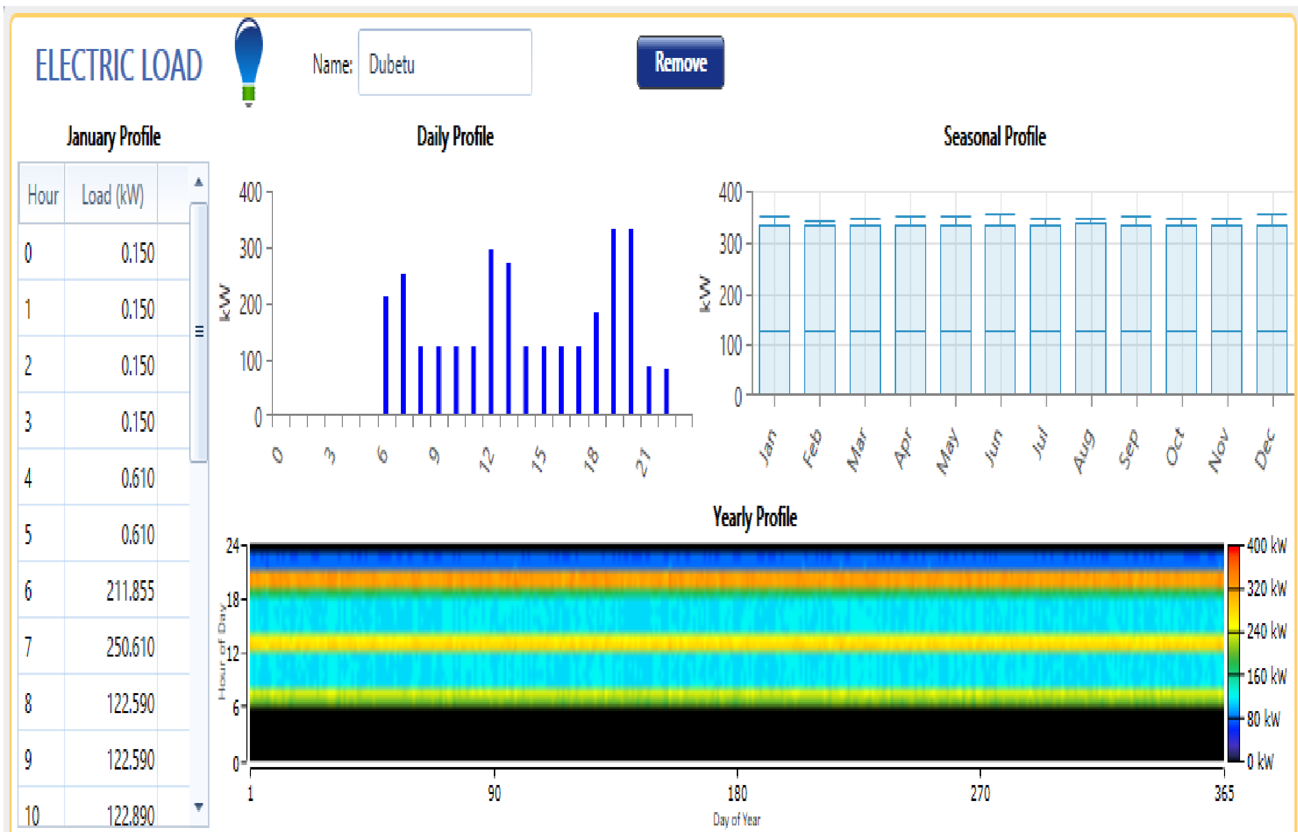


Figure 3.9 Residential load Profile in Dubetu

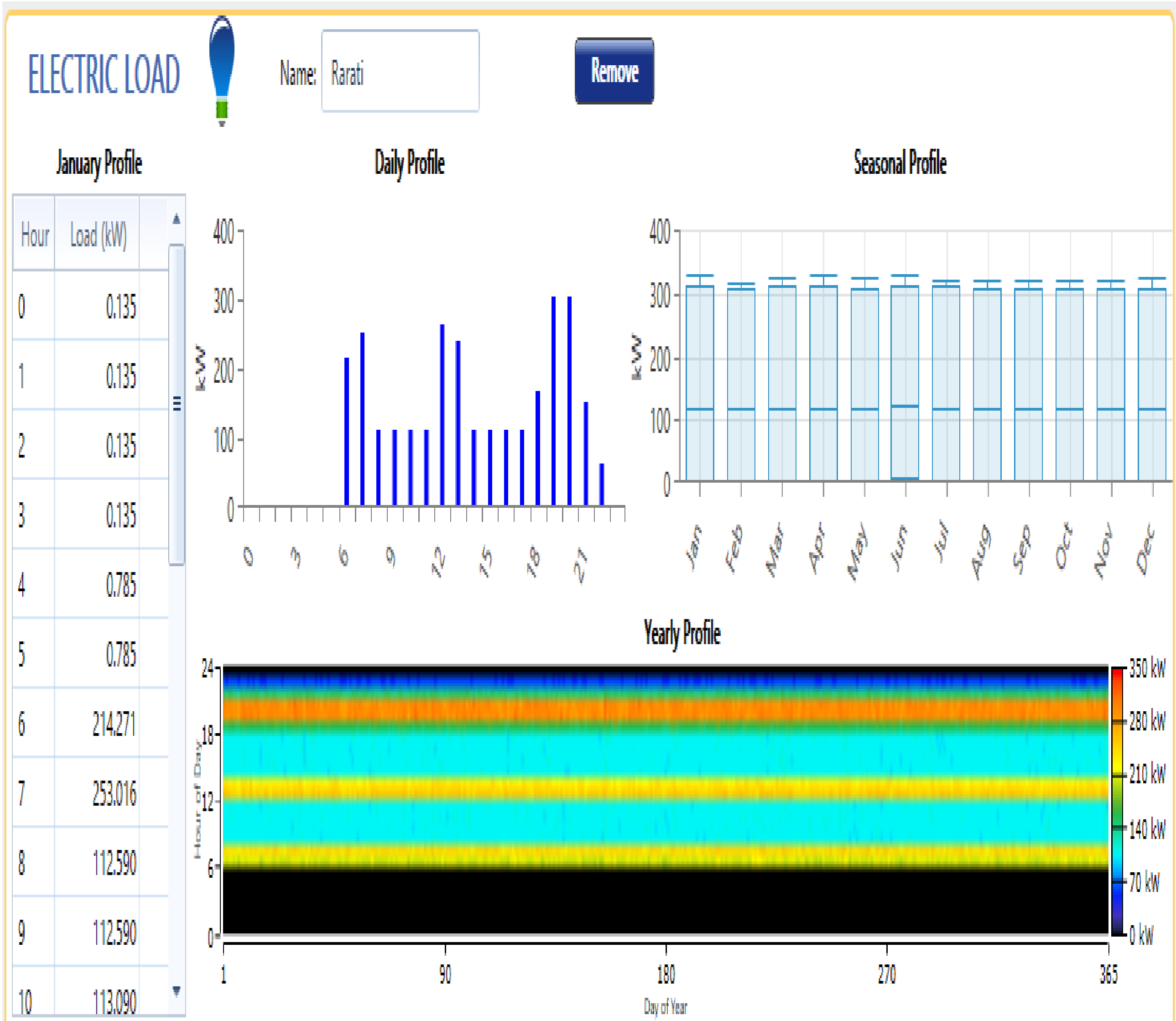


Figure 3.10 Residential load Profile in Rarati

CHAPTER FOUR

4 SIMULATION RESULT AND DISCUSSION

4.1 MATLAB Simulink

MATLAB software to offer modelling, simulation, and analysis of dynamical systems under Simulink environment. The overall system consists of the 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

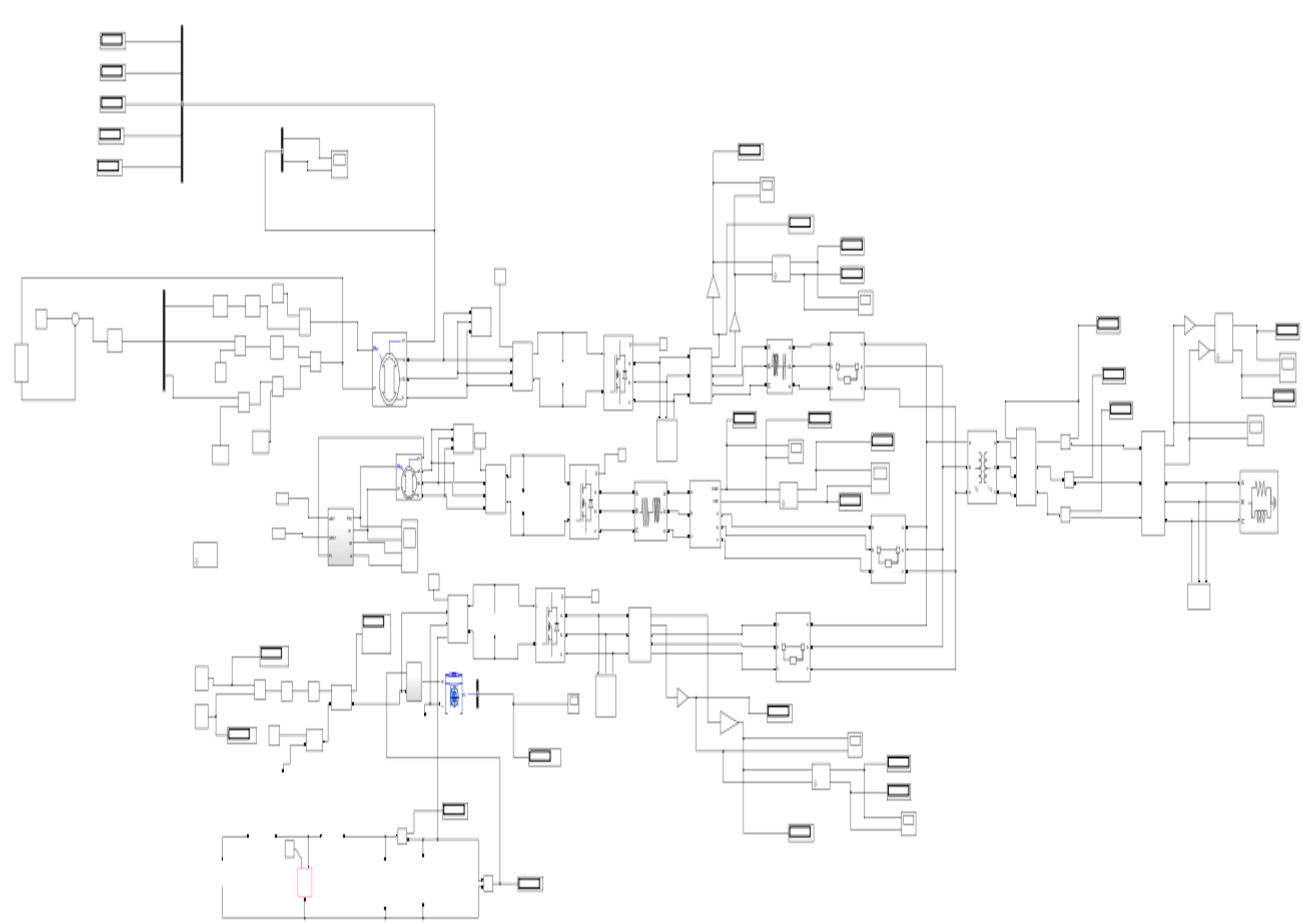


Figure 4.1 Overall simulation model of a hybrid system

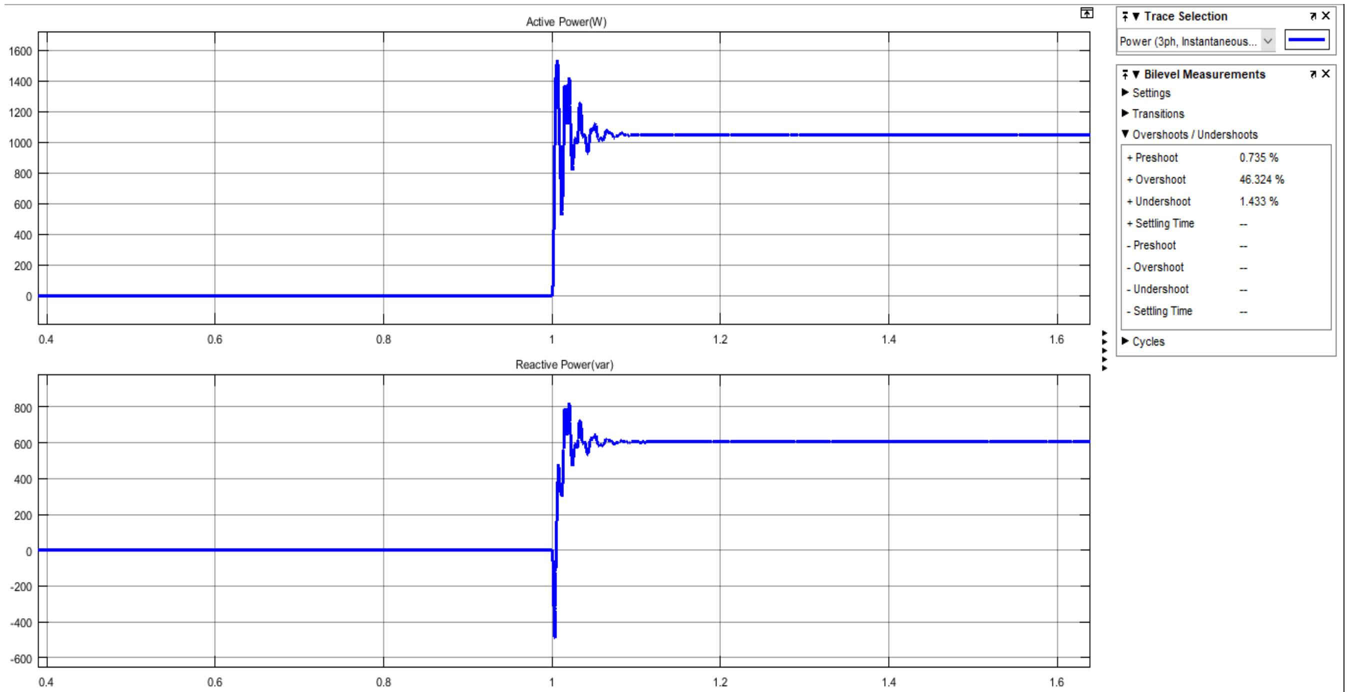


Figure 4.2 hybrid active and reactive power out put

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

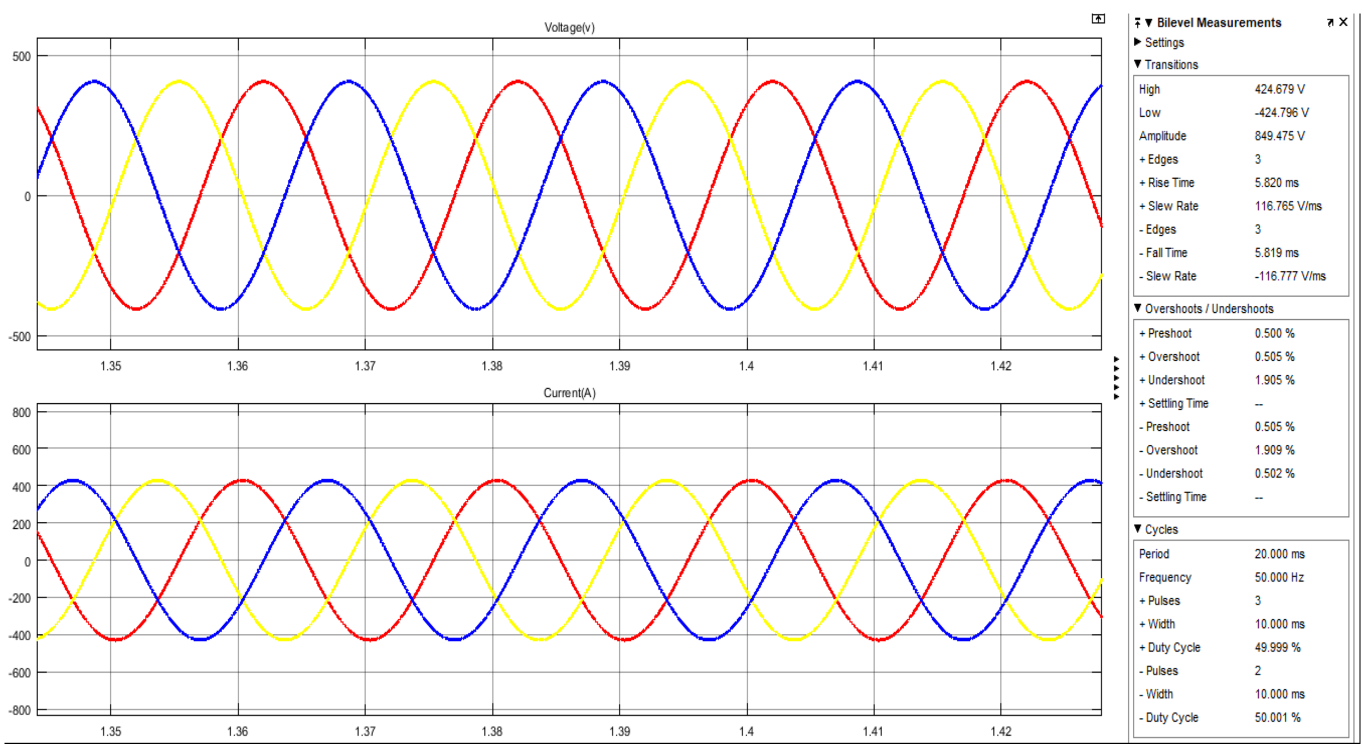


Figure 4.3 Three phase voltage and current of hybrid system

The figure 4.3 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 preshoot 0.500%, overshoot 0.505% and undershoot1.905% duty cycle 49.99% also for negative value preshoot 0.505%, overshoot 1.909% and undershoot0.502% duty cycle 50.001%.

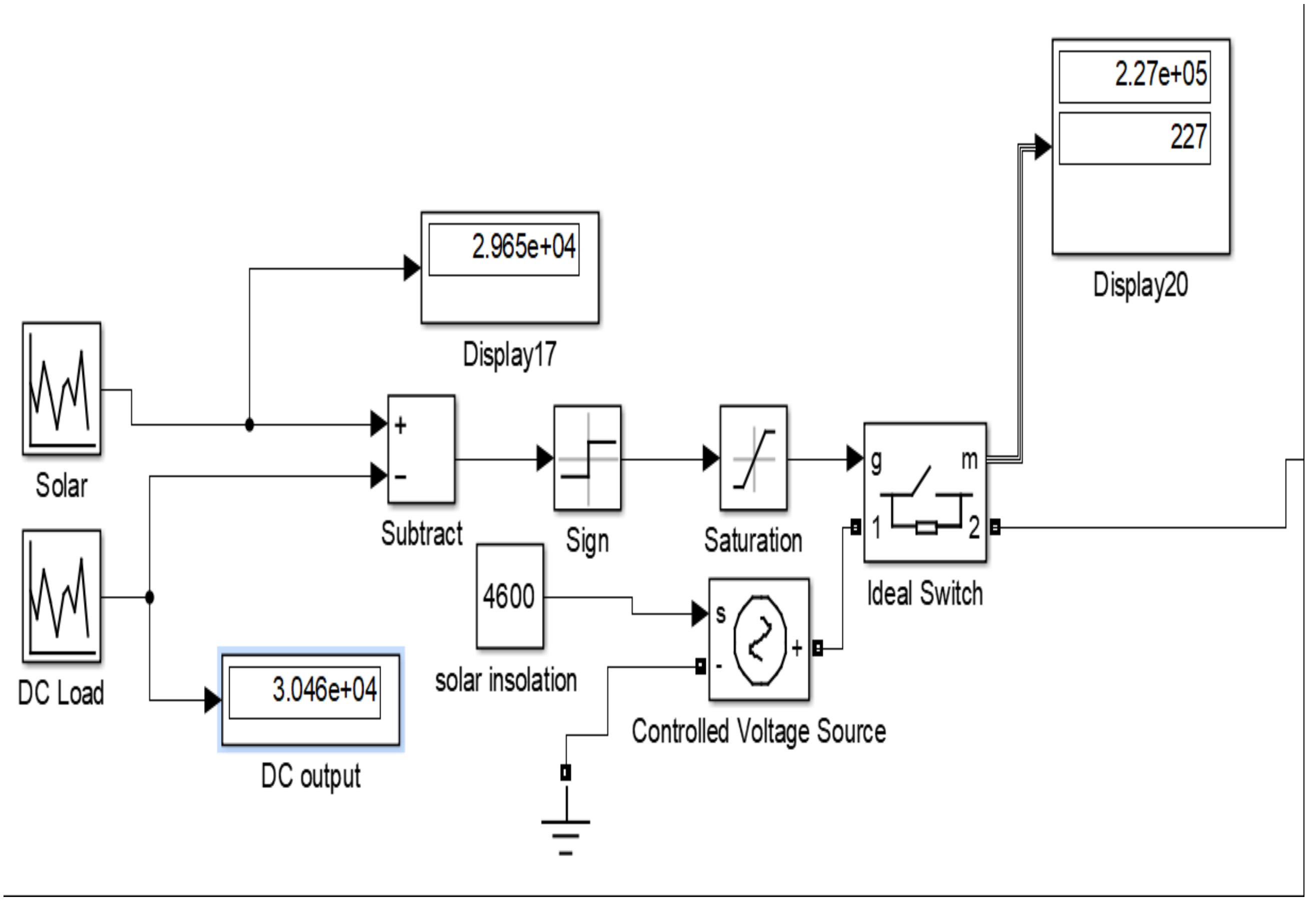


Figure 4.4 MATLAB Simulink model of solar PV system

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

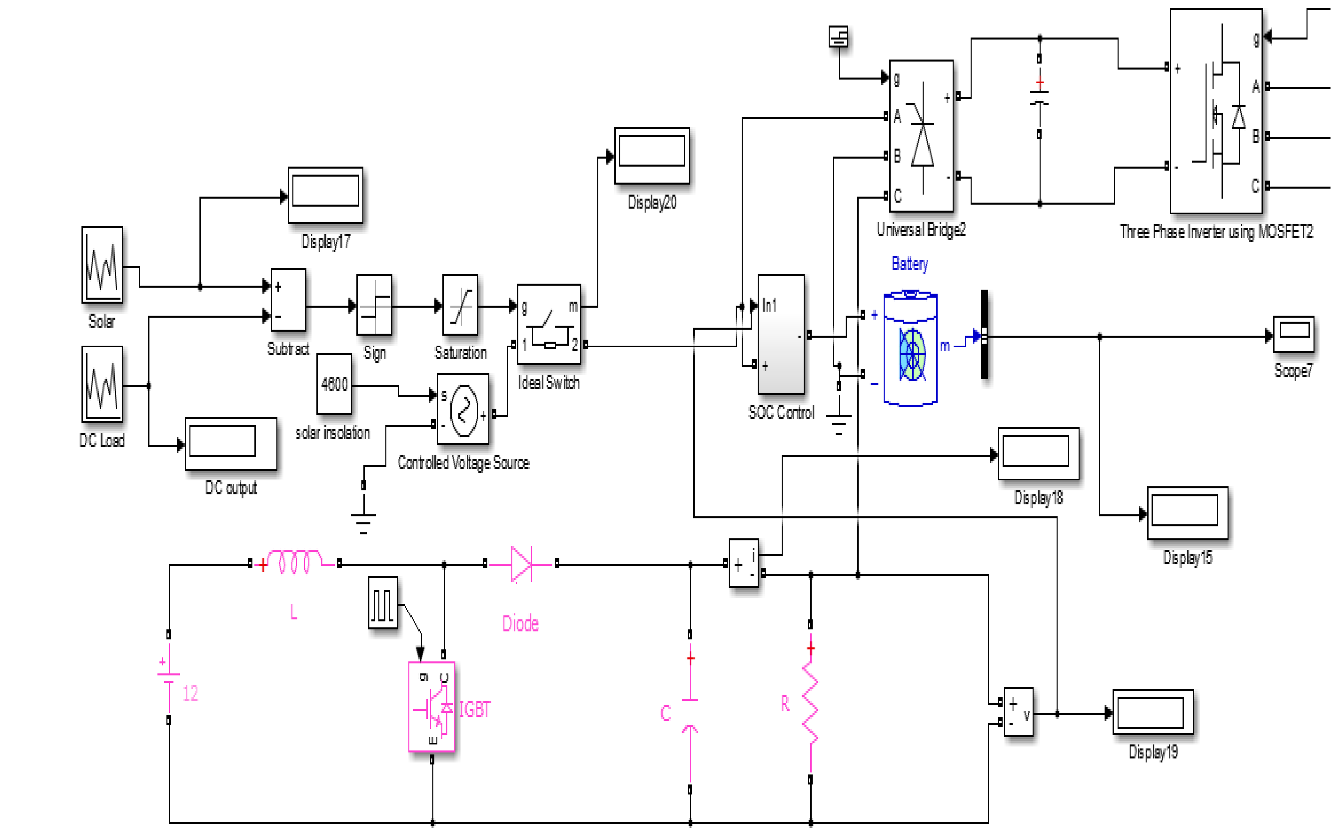


Figure 4.5 solar system with converter

Above Figure 4.5 The solar system with battery storage and converter. In this model the charge state of the battery is 99.98.

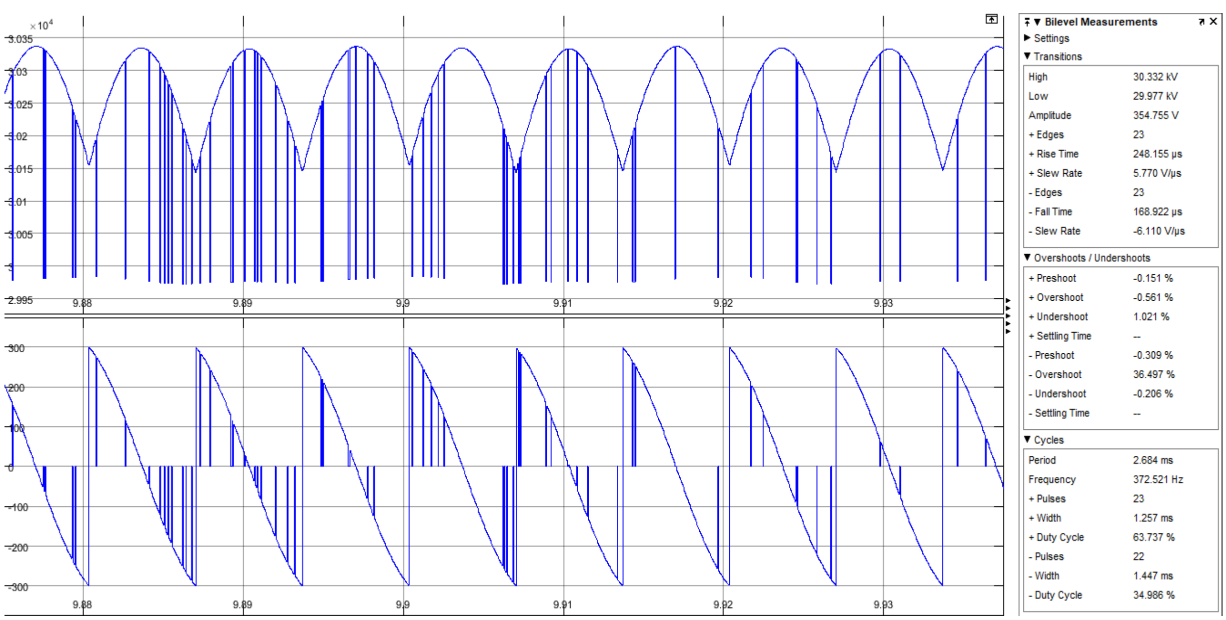


Figure 4.6 solar system output after converter

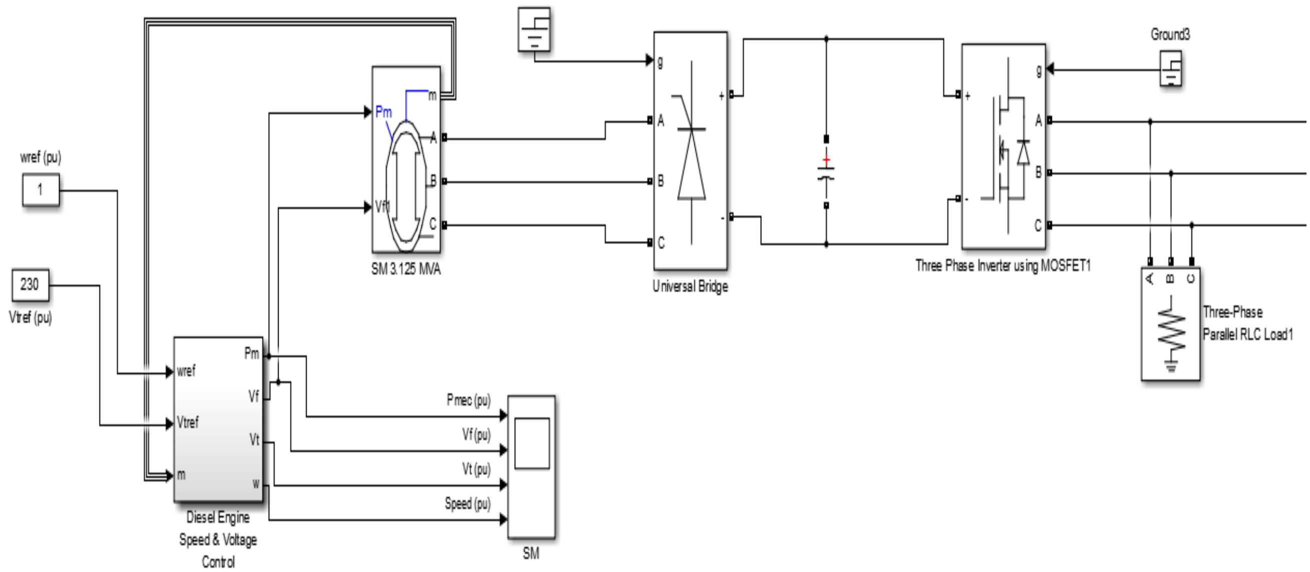


Figure 4.7 Biogas system

Figure 4.7 shows the model of Biogas energy source configuration model with controller and biogas .

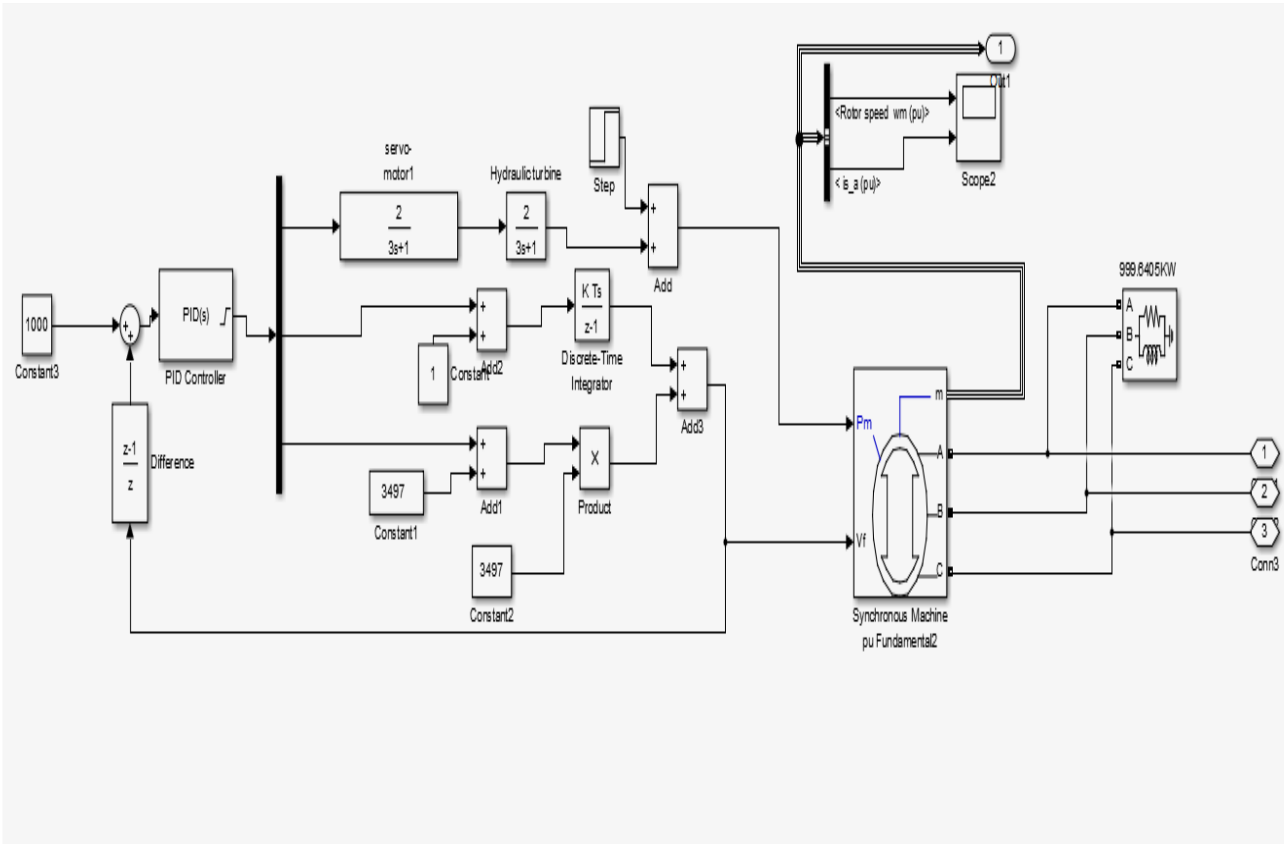


Figure 4.8 Hydropower system

Figure 4.8 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.

4.2 Simulation result and discussion

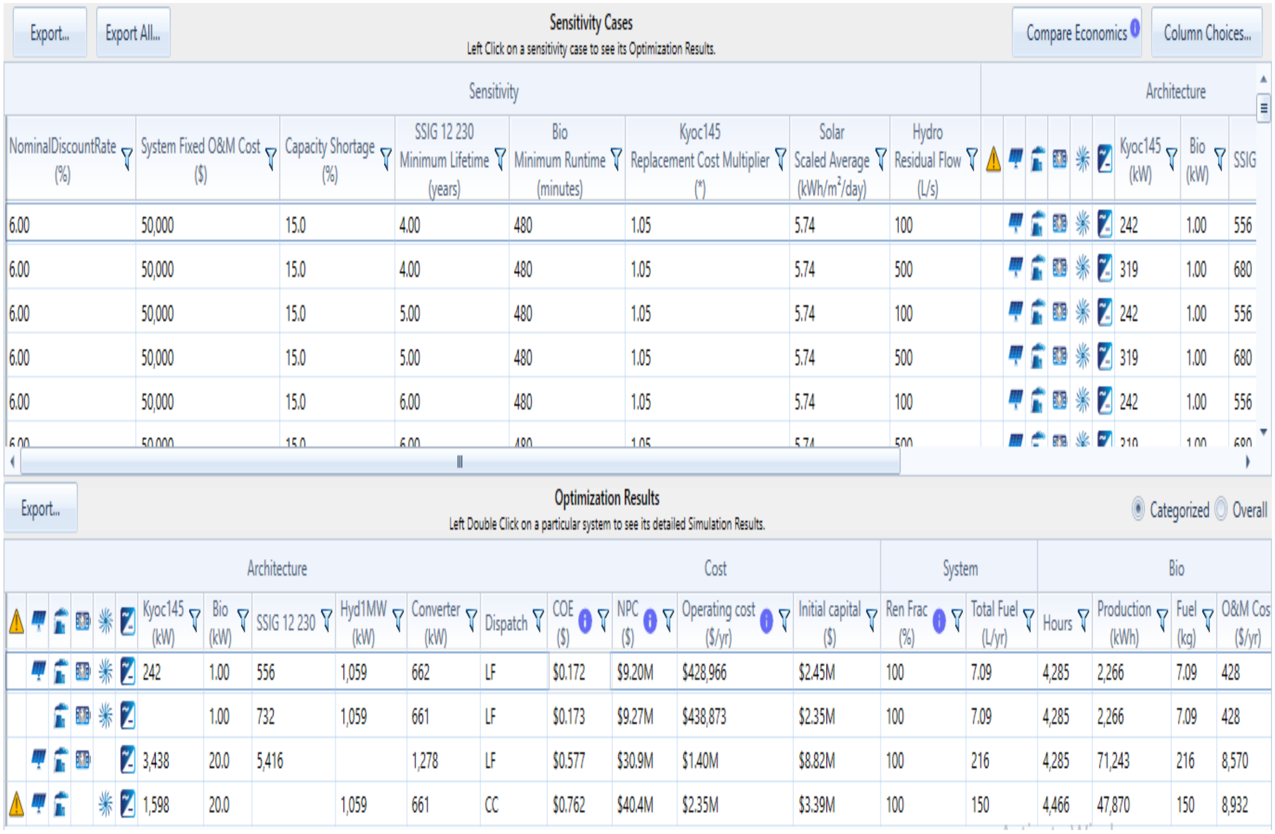
In standalone system there are three optimized option as seen in figure 4.9

First Case: in these categories almost all sources are existed

Second Case: 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.



Sensitivity								Architecture		
NominalDiscountRate (%)	System Fixed O&M Cost ($)	Capacity Shortage (%)	SSIG 12 230 Minimum Lifetime (years)	Bio Minimum Runtime (minutes)	Kyoc145 Replacement Cost Multiplier (*)	Solar Scaled Average (kWh/m²/day)	Hydro Residual Flow (L/s)	Kyoc145 (kW)	Bio (kW)	SSIG
6.00	50,000	15.0	4.00	480	1.05	5.74	100	242	1.00	556
6.00	50,000	15.0	4.00	480	1.05	5.74	500	319	1.00	680
6.00	50,000	15.0	5.00	480	1.05	5.74	100	242	1.00	556
6.00	50,000	15.0	5.00	480	1.05	5.74	500	319	1.00	680
6.00	50,000	15.0	6.00	480	1.05	5.74	100	242	1.00	556
6.00	50,000	15.0	6.00	480	1.05	5.74	500	319	1.00	680

Architecture						Cost				System		Bio			
Kyoc145 (kW)	Bio (kW)	SSIG 12 230	Hyd1MW (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (kg)	O&M Cos ($/yr)
242	1.00	556	1,059	662	LF	$0.172	$9.20M	$428,966	$2.45M	100	7.09	4,285	2,266	7.09	428
	1.00	732	1,059	661	LF	$0.173	$9.27M	$438,873	$2.35M	100	7.09	4,285	2,266	7.09	428
3,438	20.0	5,416		1,278	LF	$0.577	$30.9M	$1.40M	$8.82M	100	216	4,285	71,243	216	8,570
1,598	20.0		1,059	661	CC	$0.762	$40.4M	$2.35M	$3.39M	100	150	4,466	47,870	150	8,932

Figure 4.9 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 4.10 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

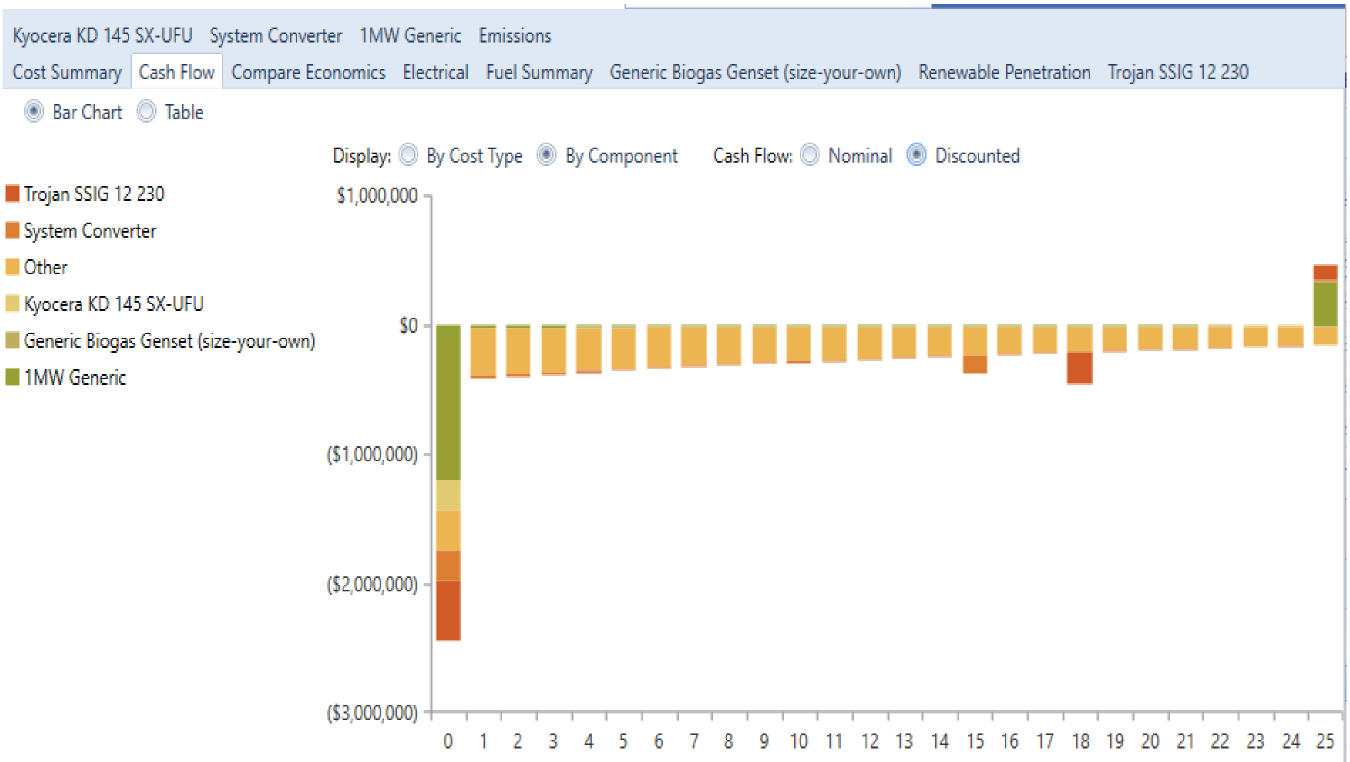


Figure 4.11 Standalone with discounted from the 1st option

Kyocera KD 145 SX-UFU System Converter 1MW Generic Emissions

Cost Summary Cash Flow Compare Economics Electrical Fuel Summary Generic Biogas Genset (size-your-own) Renewable Penetration Trojan SSIG 12 230

You may choose a different base case using the Compare Economics button on the Results Summary Table.

	Architecture						Cost	
		Kyoc145 (kW)	Bio (kW)	SSIG 12 230	Hyd1MW (kW)	Converter (kW)	NPC ($)	Initial capital ($)
Base system			1.00	608	1,059	534	$10.3M	$2.20M
Current system		242	1.00	556	1,059	662	$9.20M	$2.45M

Metric	Value
Present worth ($)	$1,125,656
Annual worth ($/yr)	$71,459
Return on investment (%)	32.1
Internal rate of return (%)	32.3
Simple payback (yr)	3.30
Discounted payback (yr)	3.60

Figure 4.12 Economical comparison of standalone hybrid configuration from the 1st case

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)

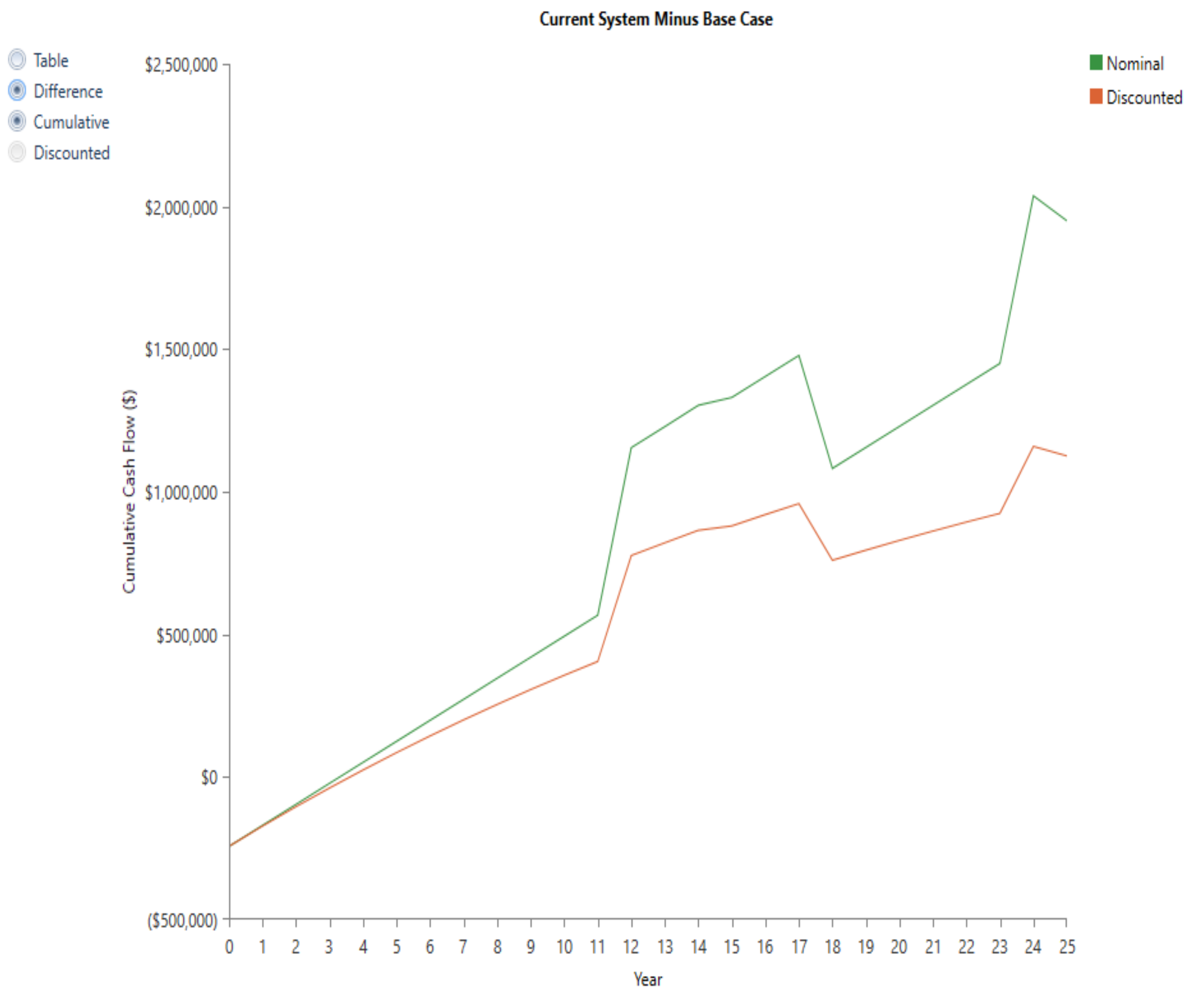


Figure 4.13 Current system mines base case standalone hybrid configuration from the 1st case

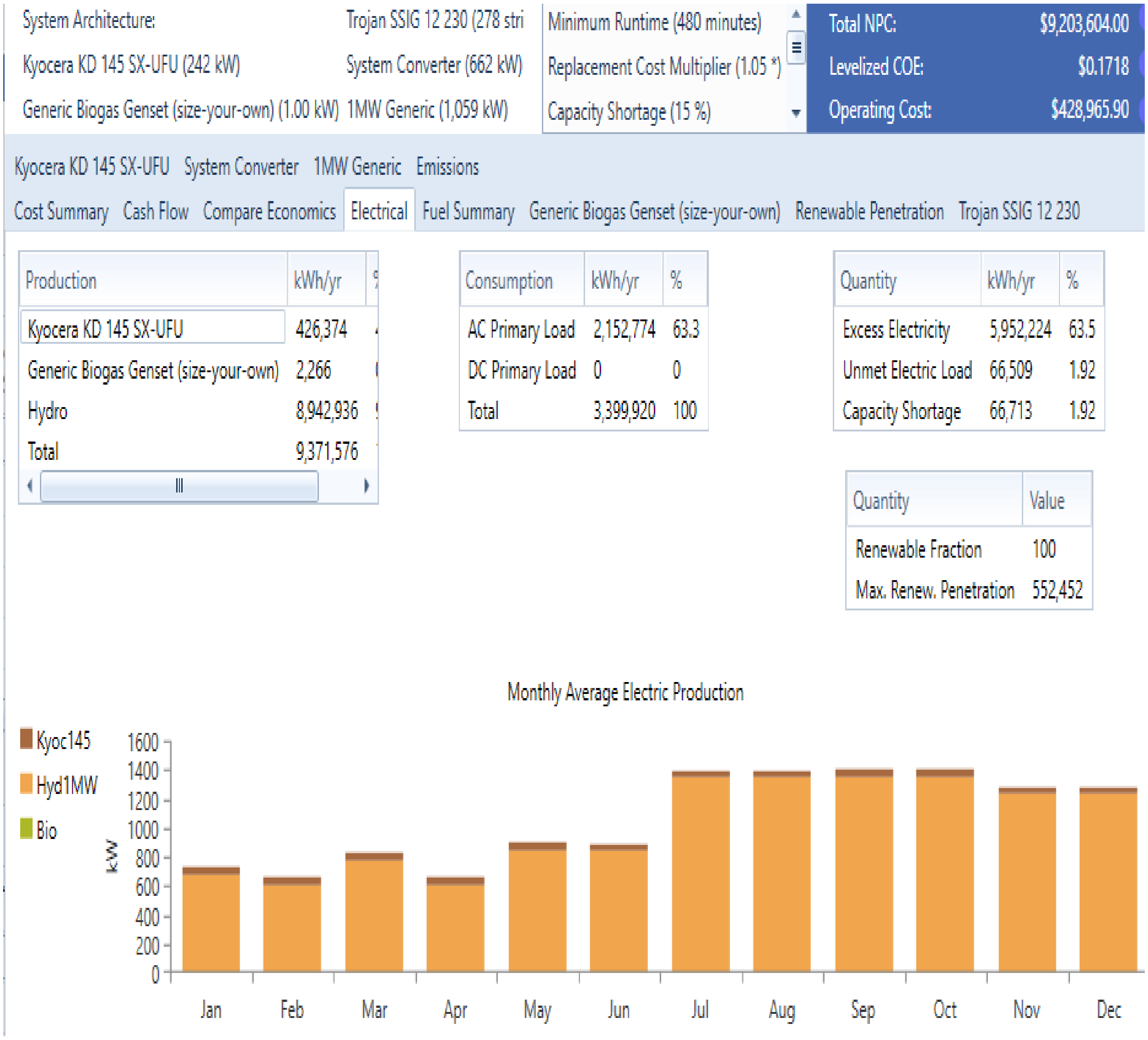


Figure 4.14 Electrical properties of standalone hybrid system from the 1st case

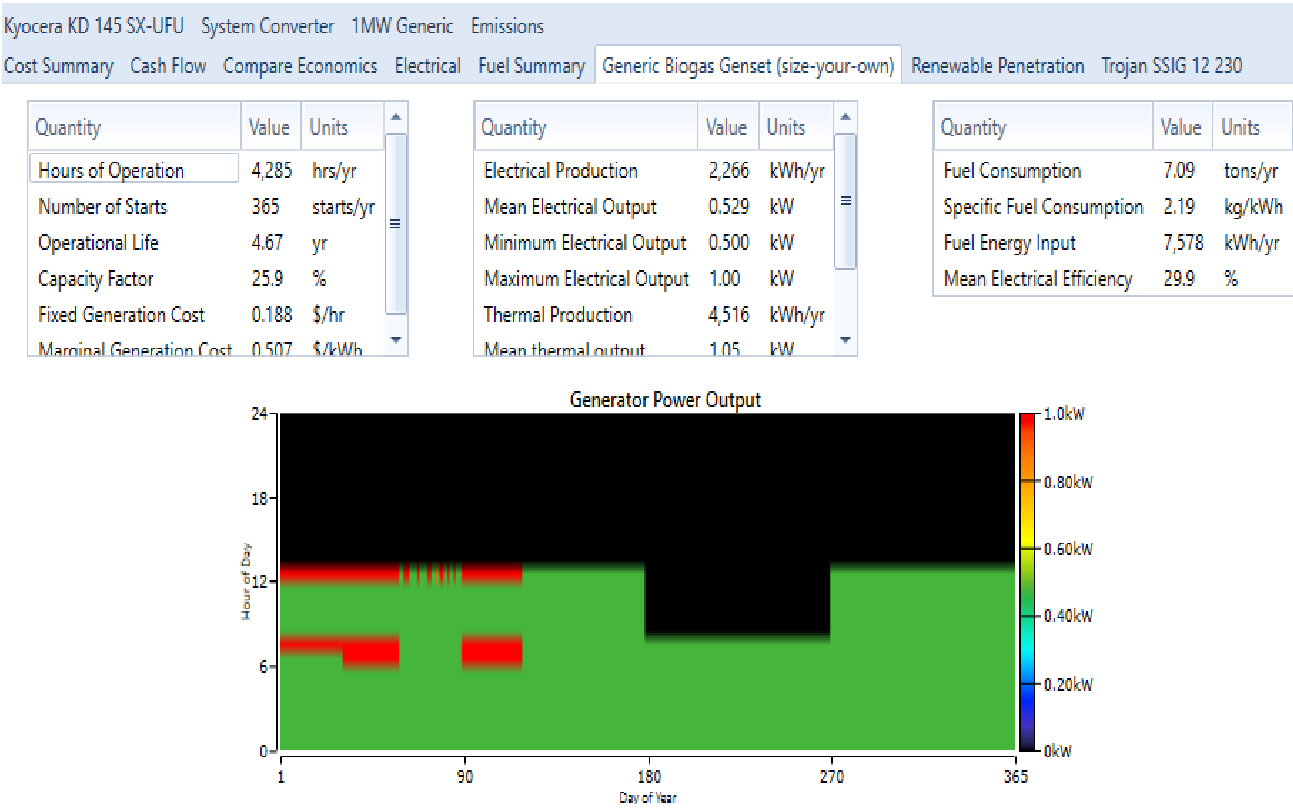


Figure 4.15 Biogas generator of standalone hybrid from the 1st case

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

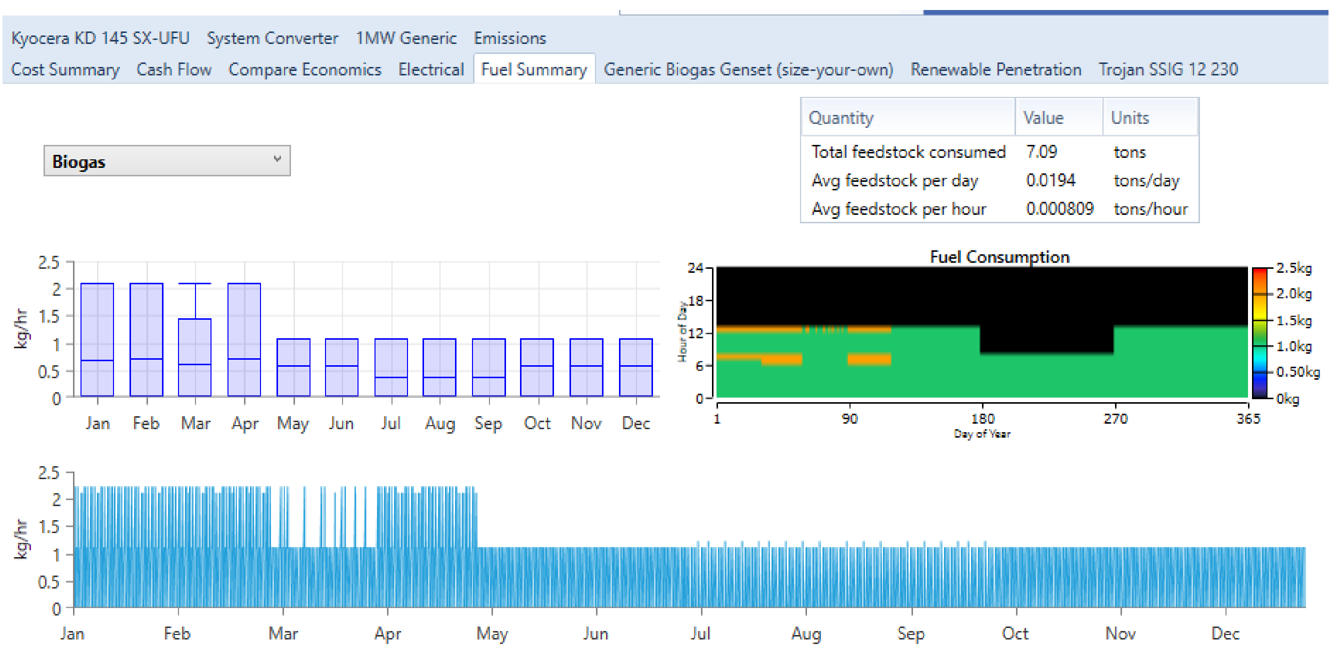
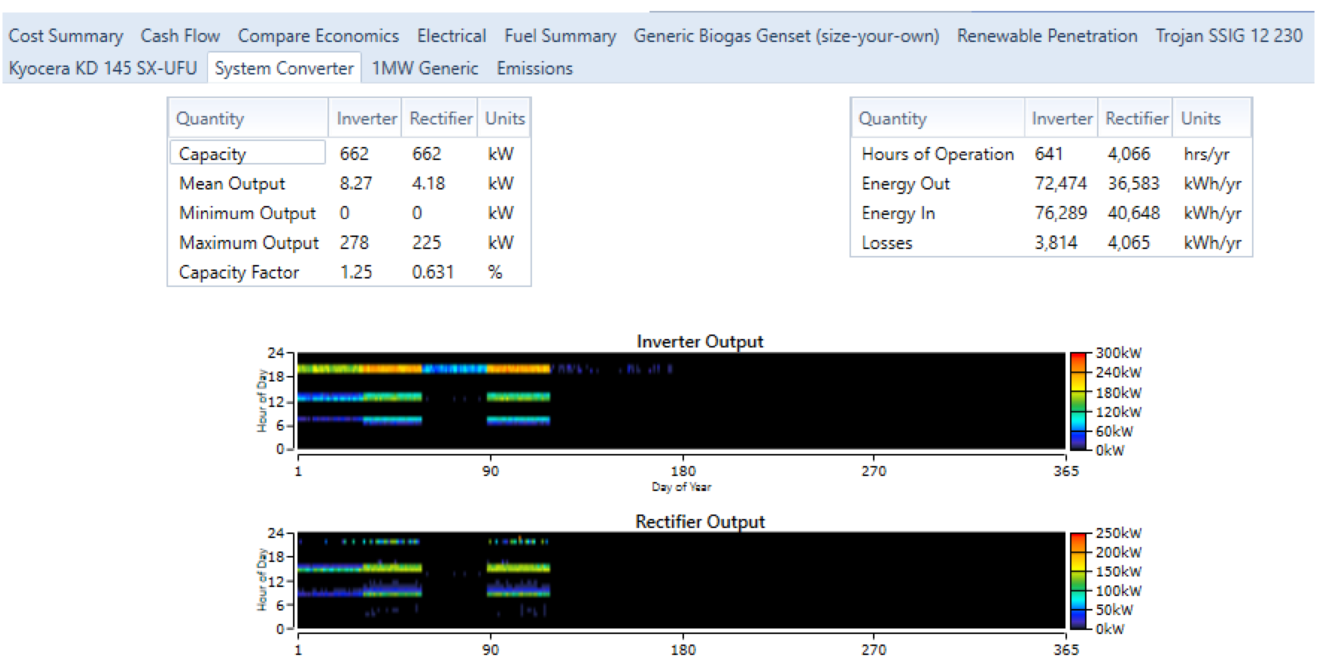


Figure 4.16 Fuel summary of a standalone hybrid system from the 1st case

Quantity	Value	Units
Rated Capacity	242	kW
Mean Output	48.7	kW
Mean Output	1,168	kWh/d
Capacity Factor	20.1	%
Total Production	426,374	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	248	kW
PV Penetration	19.8	%
Hours of Operation	4,473	hrs/yr
Levelized Cost	0.0377	$/kWh

Figure 4.17 Solar result of a standalone hybrid system from the 1st case



Quantity	Inverter	Rectifier	Units
Capacity	662	662	kW
Mean Output	8.27	4.18	kW
Minimum Output	0	0	kW
Maximum Output	278	225	kW
Capacity Factor	1.25	0.631	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	641	4,066	hrs/yr
Energy Out	72,474	36,583	kWh/yr
Energy In	76,289	40,648	kWh/yr
Losses	3,814	4,065	kWh/yr

Figure 4.18 System Converter result of a standalone hybrid system from the 1st case

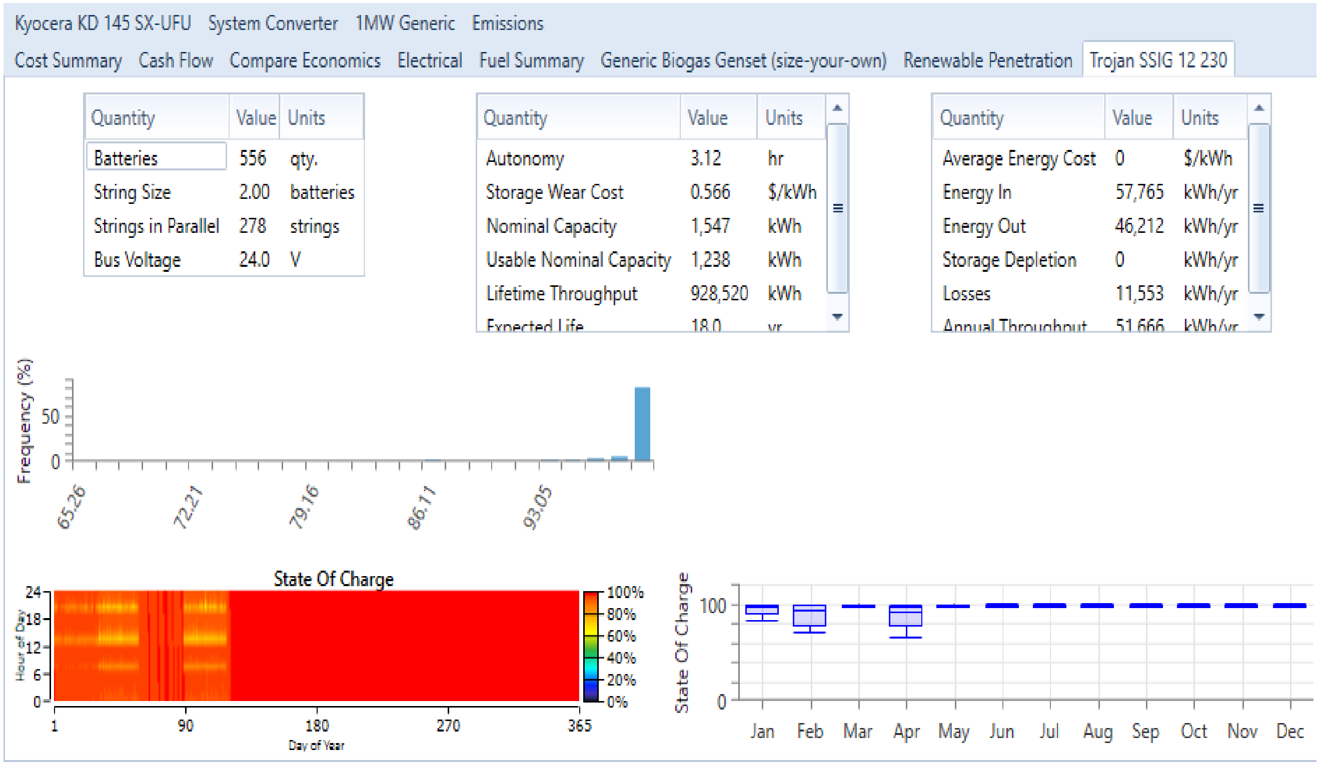


Figure 4.19 Battery result in standalone hybrid system from the 1st case

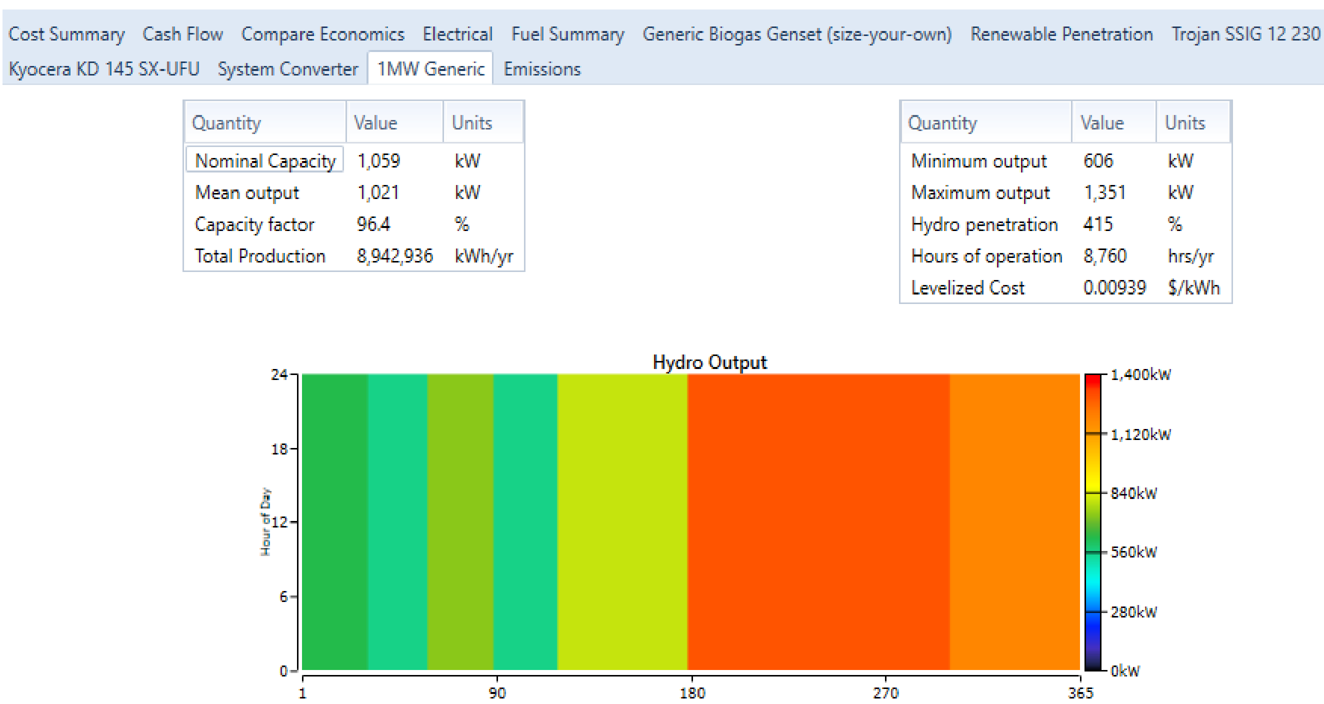
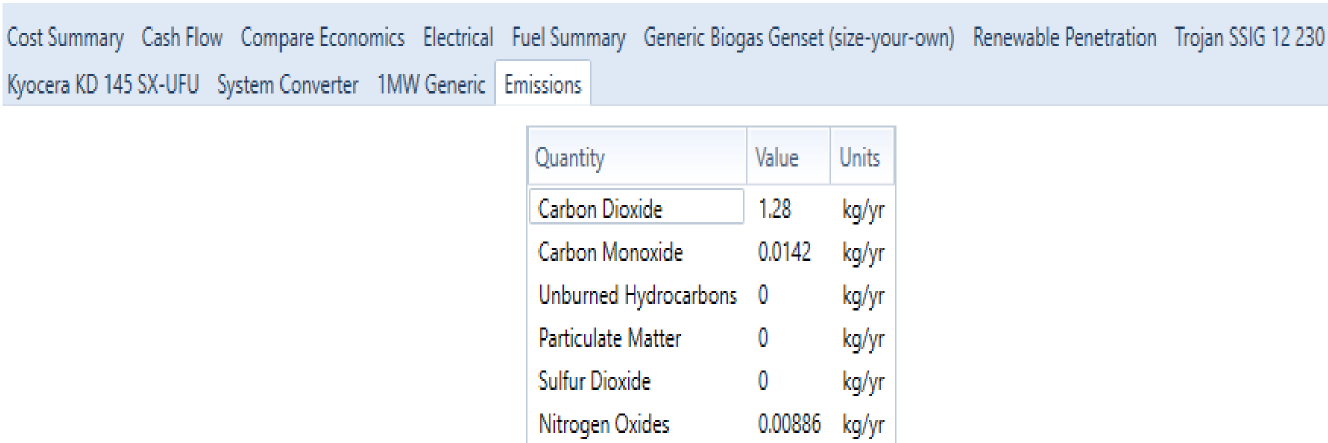


Figure 4.20 Hydro result in standalone hybrid system from the 1st case



Quantity	Value	Units
Carbon Dioxide	1.28	kg/yr
Carbon Monoxide	0.0142	kg/yr
Unburned Hydrocarbons	0	kg/yr
Particulate Matter	0	kg/yr
Sulfur Dioxide	0	kg/yr
Nitrogen Oxides	0.00886	kg/yr

Figure 4.21 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.

4.3 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** return 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** are the 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.

4.4 Cost compartion of standalone system with national grid of Ethiopia

Table 4.1 Cost compartion of standalone with grid

Range of energy(kWh)	Designed stabdalone 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 electrifay the remote vilage. So grid connected system isn't recomanded as option.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 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 th range of ten years.

Considering minimum solar Radiation of G_{min} 4600 Wh/m^{2}day, 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 are 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 $9.203604M. This system have excess electricity generation of 63.5%, capacity shortage 1.92%, and unmet electric load 1.92%. The COE for feasible option has the range between 0.1718 to 0.7620$ 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.

5.2 Recommendation

In this thesis, the following points are made out for the sake of recommendation. Ethiopia has a desirable viable of renewable energy resources, which can be used for electrification the remote place through the off-grid system. However, so many challenges are still obstacles to energize the rural community like low purchasing capacity of community, unfavorable conditions towards the utilization of renewable energies, absence of awareness on how to use these resources, etc. Thus, the government, non-governmental organizations, and private sectors should make combined efforts to improve the low rate of rural electrification in Ethiopia.

- The study only focused on selected remote area in Ethiopia and it doesn't cover all rural communities. So, future researchers should expand this research work in other sites and make the rural people advantagous with available renewable energy resources.
- Kesem Kebena irrigation project is more than mini hydro power potential if the government looks up to the irrigation project for a dual-purpose which may help to reduce power problem of the country.
- Standalone PV/mini- hydro/Biogas hybrid system is recommended to be built in the future for sustainable energy supply of the country. If governmental or privet sector are investing on this system, it improves the nation energy growth level, and produce for there on sustainable income source.
- The implementation of this hybrid system in the area can serve as advantages to change the living standard of the community and it opens the way for further researchers to dig out more in the whole country.
- Concerning environmental issues, kinds of hybrid systems have to be widespread to reduce greenhouse effects and pollution of the environment.
- Finally, the designed system is simulated using both MATLAB and HOMER software to show the feasibility and affordability to the community has been done so if the university has highly acceptable to link with a governmental and non-governmental organization in order to change this paperwork into implementation.

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7 APPENDIXES

Appendix A

Solar module specification

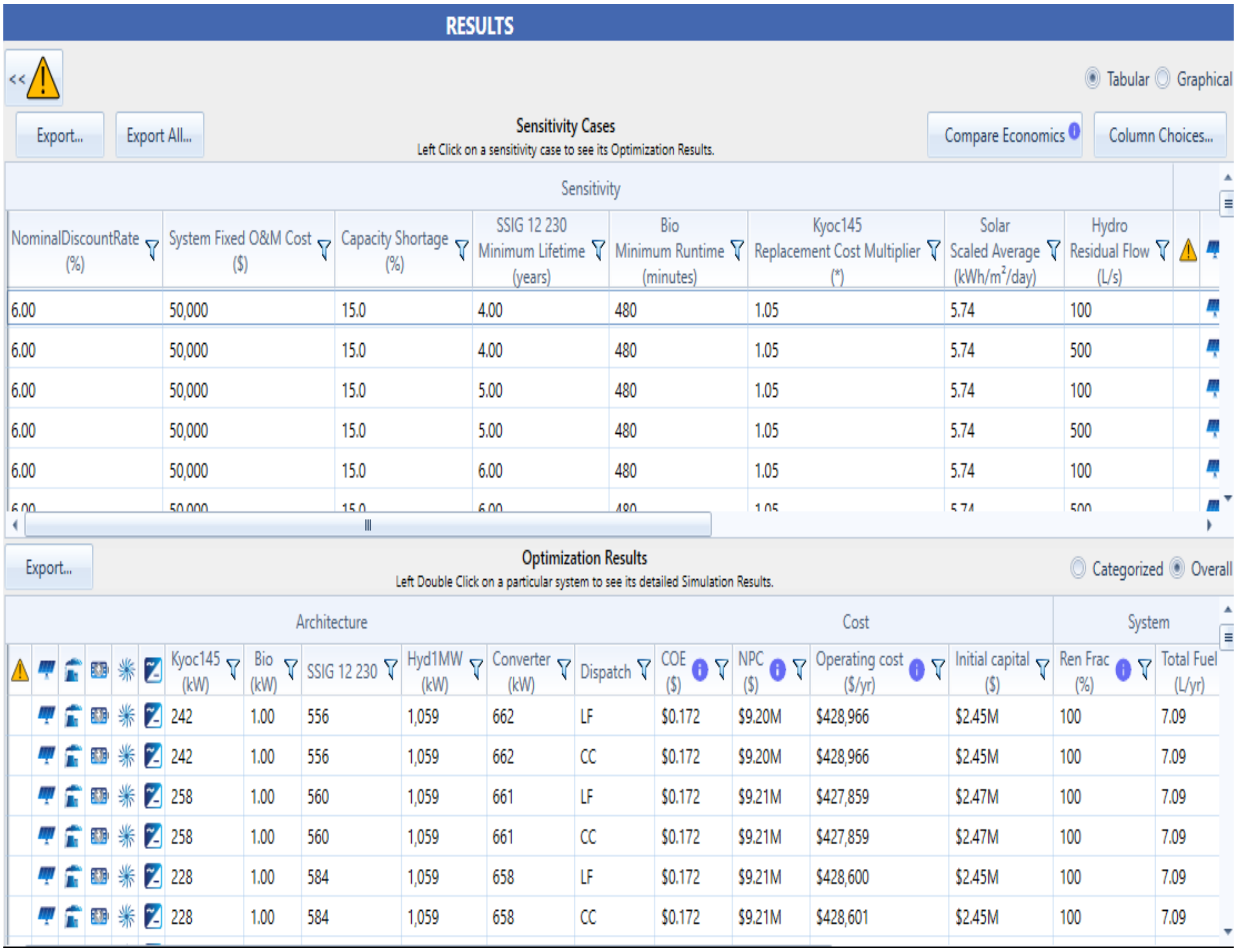
Standard Test Conditions (STC) STC=1000 W/M² irradiance, 25°C module temperature, AM 1.5 spectrum*		
	KD 145SX-UFU	
P_{max}	145	W
V_{mp}	17.9	V
I_{mp}	8.11	A
V_{oc}	22.3	V
I_{sc}	8.78	A
$P_{tolerance}$	+10/-0	%

Appendix B

Charge Controller

Type	SPS12D75, 100, 150, 200, 300	SPS24D75, 100, 150, 200, 250, 300	SPS48D75, 100, 150, 200, 250, 300
Voltage [V]	12 V	24 V	48 V
Charge Current [A]	75, 100, 150, 200, 300	75, 100, 150, 200, 250, 300	75, 100, 150, 200, 250, 300
Load Current [A]	50 A	50 A	50 A

Appendix C



RESULTS

Tabular Graphical

Export... Export All...

Sensitivity Cases

Left Click on a sensitivity case to see its Optimization Results.

Compare Economics Column Choices...

NominalDiscountRate (%)	System Fixed O&M Cost ($)	Capacity Shortage (%)	SSIG 12 230 Minimum Lifetime (years)	Bio Minimum Runtime (minutes)	Kyoc145 Replacement Cost Multiplier (*)	Solar Scaled Average (kWh/m²/day)	Hydro Residual Flow (L/s)
6.00	50,000	15.0	4.00	480	1.05	5.74	100
6.00	50,000	15.0	4.00	480	1.05	5.74	500
6.00	50,000	15.0	5.00	480	1.05	5.74	100
6.00	50,000	15.0	5.00	480	1.05	5.74	500
6.00	50,000	15.0	6.00	480	1.05	5.74	100
6.00	50,000	15.0	6.00	480	1.05	5.74	500

Export...

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

Categorized Overall

Kyoc145 (kW)	Bio (kW)	SSIG 12 230	Hyd1MW (kW)	Converter (kW)	Dispatch	COE ($)	NPC ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)
242	1.00	556	1,059	662	LF	$0.172	$9.20M	$428,966	$2.45M	100	7.09
242	1.00	556	1,059	662	CC	$0.172	$9.20M	$428,966	$2.45M	100	7.09
258	1.00	560	1,059	661	LF	$0.172	$9.21M	$427,859	$2.47M	100	7.09
258	1.00	560	1,059	661	CC	$0.172	$9.21M	$427,859	$2.47M	100	7.09
228	1.00	584	1,059	658	LF	$0.172	$9.21M	$428,600	$2.45M	100	7.09
228	1.00	584	1,059	658	CC	$0.172	$9.21M	$428,601	$2.45M	100	7.09

Figure 7.1 Over all simulation result

Appendix D

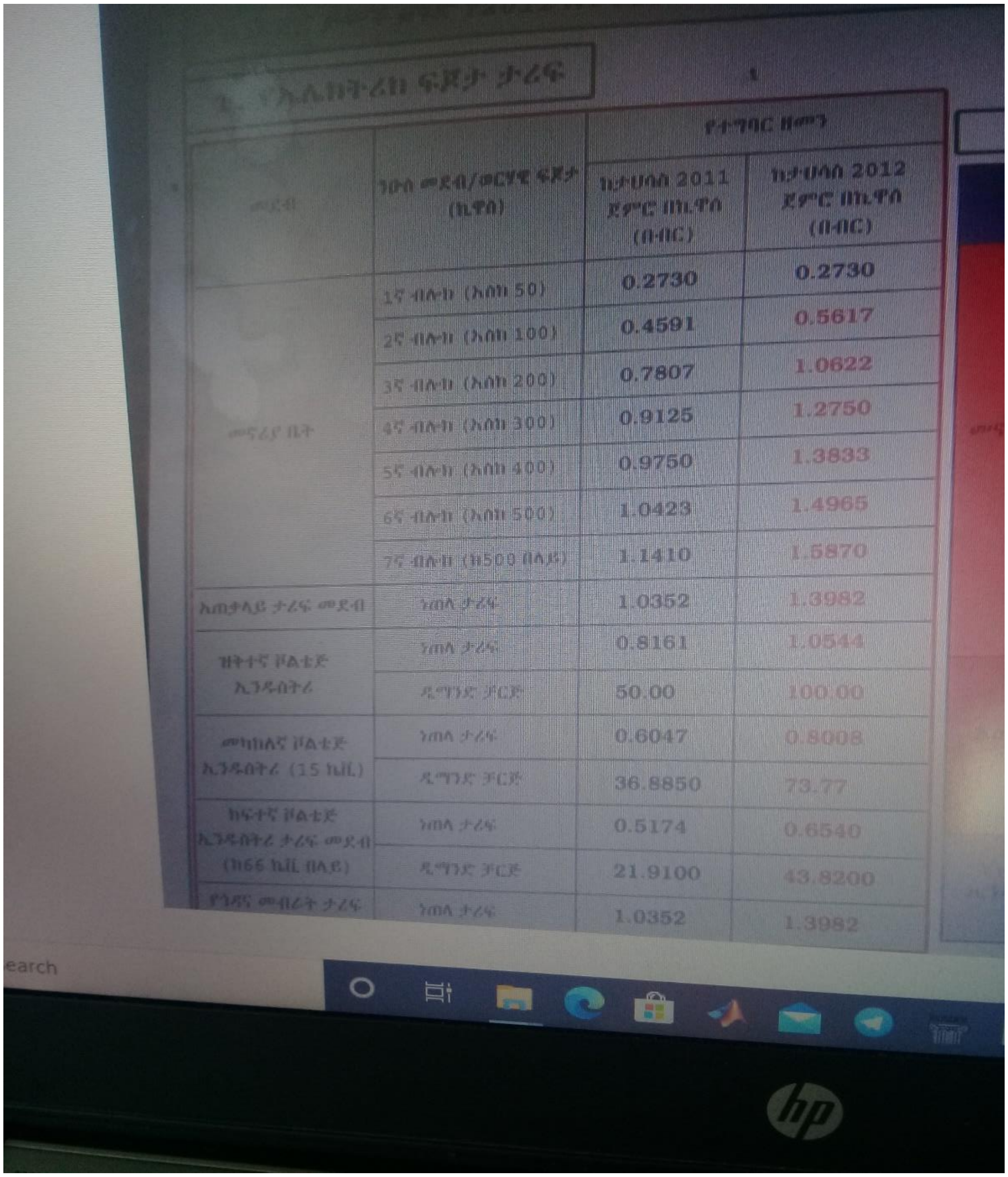


Figure 7.2 COE of national grid of Ethiopia