



WALLAGAUNIVERSITY

SCHOOL OF GRADUATE STUDIES

**FEASIBILITY STUDY AND DESIGN OF SOLAR WITH HYDRO
MICROGRID SYSTEM:IN THE CASE OF JARSO BAM BECHE
VILLAGE**

MSC. Thesis

BY: ABDI GARUMA

20/Jun/2025 G.C

Nekemte, Ethiopia



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SCHOOLOFGRADUATESTUDIES

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MICROGRID SYSTEM:IN THE CASE OF JARSO BAM BECHE
VILLAGE**

**A Thesis Submitted to the College of Engineering and Technology in Partial
Fulfillment of the Requirements for the Degree of Master of Electrical Power
Engineering**

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STATEMENT OF THE AUTHOR

The author hereby declares and affirms that the thesis entitled Feasibility Study and Design of Solar with Hydro Microgrid System. in the case of jarso bam beche village” is my own work conducted under the supervision of **Dr. Gimbar Ensermu**. I have followed all the ethical principles of scholarship in the preparation, data collection, data analysis and completion of this thesis. All scholarly matter that is included in the thesis has been given recognition through citation. I have adequately cited and referenced all the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and I have not misrepresented, fabricated, or falsified any idea / data / fact / source in my submission. This thesis is submitted in partial fulfillment of the requirement for a degree from the Post Graduate Studies at Wollega University. I further declare that this thesis has not been submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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Sincerely,

Abdi Garuma

ACRONYMS AND ABBREVIATIONS

AC:	Alternative Current
AD:	Anaerobic digestion
AD:	Daily Autonomy
Ah:	Ampere Hour
AS:	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
Gmin:	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
L _p :	Pipe Length
LWL:	Low Water Level(m)
L:	Length
M ³ :	Meter Cube
MHP:	Micro 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)
N _p :	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)
P:	The power to be generated (kW)
PV:	Photovoltaics
Q:	Discharge of water (m ³ /sec)
RES:	Renewable Energy Source
RPM:	Revolution Per Minute
RT:	Retention time
I _{sc} :	short circuit current
S _d :	Daily substrate input
T:	peak duration hours (hour)
T ₁ :	mechanical time constant
T ₂ :	electrical time constant of motor
V:	Flow velocity
V _e :	The storage capacity of re-regulating reservoir
V _n :	Nominal Battery Voltage
W:	Width

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ABSTRACT

Ethiopia possesses vast renewable energy potential, particularly from hydropower, solar, wind, and geothermal sources. However, rural electrification remains a significant challenge due to the high costs of grid extension and the dispersed nature of settlements. This study explores the Feasibility Study and Design of solar-hydro microgrid systems as a sustainable off-grid solution, focusing on Jarso Bam Bache village in Leka Dullecha Woreda. The research assessed local renewable resources, including solar radiation and hydropower potential, while evaluating the energy consumption patterns of 530 households. The findings reveal a residential peak load of 24.20 kW and a daily residential energy demand of 77.77 kWh. Including additional community services and deferrable loads, the total village peak load increases to 30.20 kW, with a total daily energy consumption of 95.77 kWh. Based on this analysis, a hybrid system was designed, integrating micro-hydro generators (91.52 kW), an expandable solar PV system (28.73 kW), and a battery bank for energy storage. This system leverages the complementary nature of solar and hydro resources to ensure a reliable electricity supply. Simulations using HOMER and MATLAB software demonstrated the system's reliability, cost-effectiveness, and energy efficiency. Economic comparisons with grid extension revealed significant cost savings, emphasizing the practicality of decentralized off-grid solutions. Additionally, the hybrid system reduces reliance on biomass and fossil fuels, promoting environmental sustainability while lowering operational costs. This study presents a framework for implementing hybrid solar-hydro microgrids in rural Ethiopia, highlighting their potential to enhance energy access, strengthen climate resilience, and support sustainable development. The findings show that a microgrid system is 89.2% more cost-effective than a grid-connected alternative, making it a highly viable solution for electrifying remote villages. These insights contribute to the advancement of renewable energy initiatives and provide a pathway to addressing Ethiopia's rural electrification challenges with clean, sustainable solutions.

Key word: *Battery bank, HOMER and MATLAB software, Micro-hydro generators, solar pv,*

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Energy plays a pivotal role in transforming lifestyles and driving development, directly or indirectly influencing social, political, and economic activities globally. Access to reliable energy is a critical enabler of economic growth, improved living standards, and technological advancements. However, many developing nations face significant challenges in providing consistent and accessible energy to their populations. Ethiopia, as Africa's second-most populous country, exemplifies this struggle. A significant portion of its population, particularly in rural areas, relies heavily on traditional biomass, such as firewood and animal dung, for energy. This dependence not only limits economic opportunities but also poses severe environmental challenges, such as deforestation and carbon emissions (Gebre Meskel *et al.*, 2021). Addressing this issue requires sustainable and environmentally friendly energy solutions. Energy sources can be broadly categorized as non-renewable or renewable. Non-renewable sources, including fossil fuels and oil, are finite and deplete over time. Their extraction and use result in significant environmental harm, particularly through greenhouse gas emissions. Additionally, these sources are often costly and less accessible for developing nations. Renewable energy sources, on the other hand, are naturally replenished and widely available. These include hydropower, wind, solar, geothermal, and biogas energy, all of which produce minimal environmental pollution and offer a cost-effective alternative. Ethiopia is particularly well-positioned to harness renewable energy due to its abundant resources, such as water bodies for hydropower, consistent sunlight for solar energy, geothermal reserves, and organic waste for biogas production (Feyissa *et al.*, 2024).

A promising and cost-effective approach to energy generation is the use of hybrid power systems, which integrate multiple renewable energy sources. This approach optimizes energy reliability and efficiency by combining the strengths of different energy types. In Ethiopia, hybrid power systems are already gaining traction. The most commonly utilized renewable sources for power generation include hydropower, wind, geothermal, and, to a lesser extent, solar energy, particularly for communication and data centers. The Ethiopian government has prioritized the expansion of alternative energy sources, achieving a national grid energy supply

potential of 58.43% by 2011 EC. However, this progress still falls short of meeting the nation's growing energy demands (Tsegai *et al.*, 2022).

Hybrid power systems face challenges due to the intermittent nature of renewable sources, their low energy densities, and the need for sophisticated integration technologies. Solar, biogas, and mini-hydro sources, for instance, require deterministic modeling to optimize their energy output. These systems can be configured as grid-connected or standalone units. Grid connections offer higher energy capacity but are expensive to establish, especially in remote areas. Standalone systems, while cost-effective, typically provide limited power capacity, making them more suitable for small-scale applications in rural communities (Aziz *et al.*, 2019).

Among hybrid systems, the integration of solar and hydro energy in microgrids has shown great promise for electrifying off-grid areas. These systems leverage advancements in electric power technology to provide reliable energy solutions tailored to rural communities. Solar-hydro microgrids offer an efficient balance of energy availability and cost, enabling sustainable development in regions with limited access to national grids. This approach aligns with Ethiopia's renewable energy goals and represents a scalable solution for addressing its energy challenges (Rad *et al.*, 2023).

Ethiopia's transition to sustainable energy is critical for achieving its development goals and mitigating environmental risks. By leveraging its abundant renewable energy resources and advancing hybrid power systems, the country can enhance energy accessibility, reduce reliance on biomass, and promote environmental sustainability. While challenges remain, the adoption of innovative technologies and policy support can pave the way for a more sustainable and energy-secure future.

1.2 Problem Statement

Ethiopia possesses abundant renewable energy resources, including solar, wind, hydropower, and biomass. These resources have been harnessed in some rural areas, such as the use of micro-hydro systems in Tigray and solar energy systems in parts of Oromia, to provide electricity. However, many rural and isolated regions, such as Leka Dullecha Woreda's Jarso Bam Bache village, still lack consistent access to electricity.

The primary barriers to electrification in these areas include the logistical challenges of extending the national grid to scattered communities. Since rural areas are often far from the national grid and their communities are dispersed, connecting them to the national grid is

impractical and financially burdensome. Establishing substations and transmission lines in such regions requires significant investment and effort. Consequently, rural households depend on expensive and hazardous energy sources like kerosene, firewood, and cow dung, which are detrimental to human health and contribute to environmental problems like deforestation and soil erosion.

To address this disparity, sustainable and affordable off-grid energy solutions are essential. This thesis proposes a hybrid solar system integrated with other locally available renewable energy sources, such as micro-hydro power, as a practical and feasible approach to electrification. Jarso Bam Bache village, located 30 km from Getema town, exemplifies the need for this solution, as highlighted in Figure 1.1.



Figure 1.1 Living style of rural area communities

The study aims to investigate the potential and Feasibility Study and Design of renewable energy resources in Leka Dullecha Woreda, focusing on the village of Jarso Bam Bache. The study also aims to encourage local communities to embrace these technologies, bridging the energy gap and fostering sustainable development.

1.3 Motivation

This study is driven by the urgent need for alternative energy solutions for rural Ethiopian communities without access to the national grid. Leka Dullecha Woreda, with its reliable river and solar resources, presents an opportunity to develop an off-grid solar-hydro micro grid system. By leveraging these resources, the research aims to evaluate the technical Feasibility Study and Design, economic viability, and environmental benefits of a hybrid system, offering a sustainable and affordable model for rural electrification in Ethiopia and similar contexts across Africa.

1.4 Objectives

1.4.1 General Objective

The General objective of this study is to assess the Feasibility Study and Design a solar-hydro micro grid power generation system to provide reliable electricity for rural areas in Leka Dullecha Woreda, specifically Jarso Bam Bache village, Ethiopia.

1.4.2 Specific Objectives

Specific Objectives of the Study:

- ✓ To Conduct a Feasibility Study and evaluate the potential availability of micro-hydro and solar energy resources in the area.
- ✓ To Determine the energy requirements for each household within the community.
- ✓ To Design a solar hydro Microgrid system and perform a cost and investment analysis for its implementation.

1.5 Scope of the Study

This study focuses on designing a renewable energy-based solar-hydro micro grid system for Jarso Bam Bache village. It includes sizing key components such as PV modules, batteries, inverters, charge controllers, and the micro-hydro system to meet the village's energy needs.

1.6 Significance of the Study

Combining solar and micro-hydro energy provides complementary power sources, ensuring reliable electricity by reducing outages and enhancing energy security. This hybrid system supports modern living practices, improving the quality of life in isolated villages like Jarso Bam Bache.

1.7 Research Limitations

Geographic Focus: The study is limited to Jarso Bam Bache village, and the results may not be directly applicable to other rural areas with different geographical or climatic conditions. The renewable resources, like solar and hydro availability, can vary significantly across different regions.

Economic Assumptions: The economic analysis is based on assumptions related to the cost of components, energy demand, and maintenance. In real-world scenarios, these factors can fluctuate due to changes in the market or economic conditions. Battery and system costs are often subject to technological advancements and market changes that may not have been fully accounted for in the study.

Infrastructure Limitations: Infrastructure challenges in remote areas, including transportation and installation of the necessary technology, were not extensively discussed. These logistical challenges can affect the overall implementation timeline and costs.

1.8 Thesis Outline

Chapter One provides an introduction, including the problem statement, objectives, scope of the study, significance of the study, and motivation for the study. Chapter Two presents the literature review, covering topics such as renewable energy potential, solar power technologies, solar PV system components and working principles, advantages of solar PV, hydropower, classification of hydropower plants, micro-hydropower systems, components of a micro-hydropower system, power generation estimation for micro-hydropower, civil work components, powerhouse components, determination of design parameters for a micro-hydropower system, and a review of related works. Chapter Three describes the study area and provides a detailed electricity load estimation for the community, including primary and deferrable loads. It also includes an assessment of both solar and hydro potential. Chapter Four discusses the use of HOMER and MATLAB tools, including climatic input data, cost values of all components, economic inputs, constraint inputs, sensitivity values, optimization analysis, sensitivity analysis, simulation results, and discussions. Chapter Five presents the conclusions and recommendations.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 Renewable Energy

Hydropower, biogas, and solar power are pivotal in Ethiopia's energy strategy. Hydropower, which already forms a substantial part of the national grid, continues to be a key energy source due to the country's rich river systems. However, solar power is gaining attention as a clean, decentralized, and cost-effective solution. Advances in solar technology, including cheaper and more efficient photovoltaic (PV) systems, have made solar a more viable energy option for Ethiopia, particularly in rural areas where grid infrastructure is lacking

2.2 Renewable Energy Potential

Ethiopia has a lot of potential for renewable energy, particularly solar electricity, because of its ideal geographic and climatic characteristics. Solar radiation levels in the nation average 5.26 kWh/m² per day, peaking at 6.55 kWh/m² during the arid months (Netsnet et al., 2016). As a result, solar energy is a sustainable and feasible resource that enhances hydropower in Ethiopia's mix of renewable energy sources. Ethiopia's varied terrain, which includes both highlands and lowlands, makes it possible for a number of renewable energy sources, such as solar and hydropower, to be used to meet the nation's expanding energy needs.

Ethiopia's electricity sector has faced challenges, particularly in rural electrification. In 2009, only 2% of rural areas had access to electricity (Reiche *et al.*, 2000). The government's Rural Electrification Strategy launched in 2002 aimed to bridge this gap, focusing on grid extension and off-grid solutions, including solar PV and micro-hydro systems. This initiative, supported by public and private entities, has facilitated the expansion of renewable energy sources to remote regions, improving access to electricity for millions of Ethiopians.

2.2.1 Solar Power Technology

Photovoltaic (PV) technology converts sunlight into electricity using semiconductors. The most common PV cells are silicon-based, offering efficiencies ranging from 14% to 18% for monocrystalline cells and 10% to 13% for polycrystalline cells (Ali *et al.*, 2017). Recent developments in thin-film technology have reduced costs and enhanced the affordability of solar systems, making them accessible to more users, including those in rural Ethiopia.

A. Solar PV System Components

Solar cells, modules, and arrays make up a typical PV system. The photovoltaic effect is how the cells produce power. An electric current is created when sunlight strikes semiconductor material, dislodging electrons. To produce more electricity, PV cells are arranged in arrays and modules (Dambhare *et al.*, 2021). PV performance is affected by a number of variables, including temperature, shade, sunlight intensity, and the condition of the cells and modules. According to (Luque *et al.* 2011), monocrystalline silicon cells are the most efficient, followed by polycrystalline and thin-film cells.

B. Advantages of Solar PV

Solar PV systems offer multiple benefits, particularly for rural areas. These include the sustainability of solar energy, low operating and maintenance costs, energy independence, and scalability. Once installed, PV systems have minimal environmental impact, as they produce no emissions. Solar power also offers reliable electricity even in remote areas, reducing dependence on imported fossil fuels and enhancing energy security (Duffie *et al.*, 2020). With Ethiopia's abundant sunlight, solar PV is poised to significantly contribute to meet the country's energy needs.

Despite the promising potential of solar PV, there are challenges to widespread adoption in Ethiopia. High initial costs, while decreasing, remain a barrier, particularly for rural communities. The intermittent nature of solar power necessitates efficient energy storage solutions, such as batteries, to ensure reliable supply. Additionally, there is a need for technical expertise in system installation and maintenance. The Ethiopian government, with support from the Rural Electrification Fund (REF), is actively addressing these barriers to promote solar PV adoption, focusing on providing loans, technical support, and policies that encourage renewable energy investments. However, challenges such as initial costs, storage requirements, and technical expertise need to be addressed to fully realize the benefits of solar energy.

2.2.2 Hydropower

Hydropower is one of the oldest and most reliable forms of renewable energy, harnessing the energy from flowing or falling water to generate electricity. The energy originates from solar-driven evaporation that powers the hydrological cycle, leading to continuous water flow in rivers, streams, and oceans. This energy is especially useful in regions rich in water resources, making it a key technology for both large-scale and micro-level power generation (Messenger *et al.*, 2018).

The river's consistent flow, derived from several tributaries, makes it an ideal site for micro-hydropower projects. The sustainable nature of this resource is essential for supporting rural electrification efforts in Ethiopia, a country with abundant hydrological potential (Raja A.K. *et al.*, 2006).

A. Classification of Hydropower Plants

Hydropower plants can be categorized based on various factors such as size, hydraulic characteristics, and power generation capacity. A widely accepted classification based on size includes:

- | | |
|---------------------------|-----------------------------|
| 1) Large-hydro (>100 MW) | 2) Medium-hydro (15–100 MW) |
| 3) Small-hydro (1–15 MW) | 4) Mini-hydro (0.1–1 MW) |
| 5) Micro-hydro (5–100 kW) | 6) Pico-hydro (<5 kW) |

This classification plays a crucial role in the design and development of hydropower plants, as smaller systems (micro and Pico) are typically used in rural or off-grid areas to provide energy to remote communities (Natural Resources Canada, 2004).

B. Micro-Hydropower Systems

Micro-hydropower systems have emerged as a viable solution for rural electrification, especially in developing countries. These systems typically generate electricity in the range of 5-100 kW and are designed to operate on smaller streams or rivers with sufficient flow and head. The basic operation of a micro-hydropower system involves diverting water from a river into a penstock, where it flows downhill to a turbine. The turbine converts the potential energy of the flowing water into mechanical energy, which is then converted into electricity by a generator (Messenger *et al.*, 2018).

Micro-hydropower systems are environmentally friendly, reliable, and suitable for remote areas where grid connection is not feasible. The technology requires minimal infrastructure and is often based on run-of-river systems, meaning there is no large-scale water storage (Anise *et al.*, 2017).

C. Components of a Micro-Hydropower System

Micro-hydropower systems consist of several key components:

- A. Penstock: A pipe that channels water from the intake to the turbine. The diameter and material of the penstock must be selected to minimize friction and prevent damage to the system.
- B. Turbine: The turbine converts the kinetic energy of the flowing water into rotational energy. Common turbine types include Pelton, Turgo, Francis, and Kaplan, each suited to different head and flow conditions (Kunwor *et al.*, 2012).
- C. Generator: The generator converts mechanical energy from the turbine into electricity. Synchronous and induction generators are commonly used in micro-hydropower systems.
- D. Shut-off Valve: A critical safety feature that allows for the immediate cessation of water flow to prevent system damage.
- E. Battery Bank: In some systems, a battery bank is used to store excess electricity for use during periods of low water flow or high demand (Anise *et al.*, 2017).

D. Power Generation Estimation for micro hydro power

The power potential of a micro-hydropower system is determined by two main factors: the flow rate (Q) and the head (H). The basic formula for calculating the power is:

$$P = \text{Flow rate } (Q) \times \text{Head } (H) \times \text{Gravity}(g) \dots\dots\dots 2.1$$

Where:

$$P = \text{Power } (W)$$

$$Q = \text{Flow rate } \left(\frac{m^3}{s} \right)$$

$$H = \text{Head } (m)$$

$$g = \text{Gravitational constant } \left(9.81 \frac{m}{s^2} \right)$$

The energy generated is directly proportional to the head and flow rate, with greater head or flow resulting in higher power output. However, efficiency losses in turbines and other system components can reduce the overall electrical output (Bary *et al.*, 1945).

E. Civil Work Components

The civil components discussed in this section play a crucial role in the system and include structures such as the intake, sand trap, spillway, headrace canal, settling basin, fore bay tank, penstock pipes, and tailrace. These elements are essential for regulating water flow, managing sediment, and ensuring the efficient operation of the system (*Bekele, T. 2017*).

- A. Intake: Water diversion represents the uppermost section of a hydro system, where water is channeled from the lake into the penstock that directs flow to the turbine. Side intakes are frequently utilized, especially in systems with lower intake structures.
- B. Headrace Canal: The conveyance system is responsible for transporting the engineered discharge between different stages of the hydro system. While channel systems are commonly used in all micro-hydro power projects, pipe systems are typically employed in challenging terrains. Canals can be either lined with concrete or left unlined, and their cross-sections in micro-hydropower schemes are traditionally designed in rectangular, trapezoidal, triangular, or semi-circular shapes.
- C. Settling Basin: The civil component designed to capture and settle sediments allows for periodic flushing within the basin. Since sediment can damage both civil and mechanical structures, it is essential to trap, settle, store, and flush a specified percentage of particles. This process is achieved by increasing friction in the water carrying the sediment. To minimize turbulence, settling basins are constructed along the conveyance system. These basins, being straight with larger flow areas, significantly reduce transit velocity and turbulence, enabling the targeted sediments to settle. The accumulated sediment must then be effectively flushed back into natural river systems.
- D. Spillway: A spillway is a structure designed to safely divert excess water back to the river. It is crucial for managing floodwaters, ensuring that the additional water is released without causing harm to other components of the micro-hydro system (MHS). Spillways are typically built in the settling basin and fore bay, where excess water can be efficiently diverted back to the original water source.
- E. Fore-bay Tank: The civil component that ensures a steady flow of water through the penstock to the turbine is the fore bay. It also functions as the final settling basin, allowing any remaining particles to settle before the water enters the penstock. The fore bay can also serve as a reservoir, storing water depending on its depth. Additionally, a sluice gate may

be used to control the closure of the penstock entrance, and a trash rack is typically installed in front of the penstock to prevent debris from entering the system.

- F. Penstock Pipe: The pump transports water from the fore bay tank to the turbine under pressure. As the vertical drop increases, not only does the moving water flow to the turbine, but the enclosing structure also generates head pressure. The penstock channels all the water's energy to the bottom of the pipe, where the turbine is situated.

Powerhouse Components

The powerhouse contains electro-mechanical equipment, including turbines, generators, and governors. A turbine is a device that transforms the energy from falling water (water pressure) into mechanical shaft power, which is then used to drive an electric generator. Choosing the appropriate high-performance turbine for a specific hydro site depends on factors such as the design head and flow rate. Each turbine has its own set of characteristics, meaning it operates most efficiently at a specific combination of speed, head, and flow. The turbine's speed is primarily determined by the head under which it functions (*Bekele, T. 2017*), (G.A.M.F.H.P.D. 2011).

A. Governor

The system comprising mechanical components such as the hydraulic turbine, penstock, controller, hydraulic servo motor, control valve, and electrical parts like the generator is known as the Hydro Turbine Governor. This governor regulates the operation of the water valve, opening and closing based on electricity demand. It adjusts the load side, which influences the size of the device, and takes necessary actions to control electricity generation. The governor plays a crucial role in managing the electricity generation network.

B. Turbine

A turbine is a device that transforms the potential energy of water into mechanical power.

I. Types of Turbines

The choice of turbine is critical in determining the efficiency of a micro-hydropower system. Turbines are classified into two main categories: impulse and reaction turbines.

1. Impulse Turbines: These turbines, such as Pelton and Turgo turbines, extract energy from the kinetic energy of water jets.
2. Reaction Turbines: Examples include Francis, Kaplan, and Propeller turbines, which convert the potential energy of pressurized water into mechanical energy.

The turbine type is selected based on the available head and flow conditions at the project site. For low-head sites, Kaplan and Francis turbines are typically used, while high-head sites require Pelton or Turgo turbines (Kunwor *et al.*, 2012).

II. Turbine Selection Criteria

The form, geometry, and dimensions of a turbine are primarily determined by the characteristics of the specific site. One of the key factors in selecting a turbine is the net head, which is the first criterion to be considered. The head calculation is crucial in choosing an appropriate turbine, especially in low-head systems where large water discharges need to be managed efficiently (Penche, C. L. 1998).

1. Range of Flow volume and Discharges through the Turbine

A single flow value on its own holds limited significance. It is essential to understand the site's flow regime. The appropriate range of turbine types for a specific site and flow conditions is determined by the measured flow and net head. One effective way to select the correct turbine type is by using graphical tools that illustrate the compatibility of various turbine designs with the head, flow volume, and power output (Research Gate. 2020).

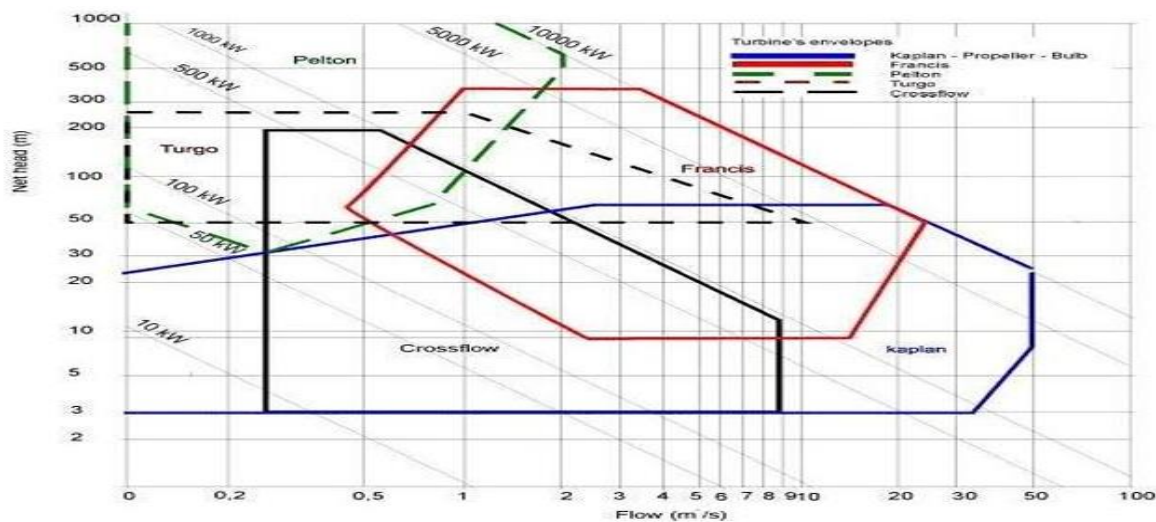


Figure 2.1 Micro Hydro Turbine Selection Chart (Bekele, T. 2017).

The specific speed is a dependable criterion for selecting a turbine. To generate electricity in a system with a net head of H_n (m) and a P (kW) turbine directly connected to a standard N (rpm) generator, the specific speed must be calculated using the following equation:

$$Ns = N * \frac{\sqrt{\frac{P}{H_n^3}}}{1.25} \dots \dots \dots 2.2$$

Once the specific speed is calculated, it becomes possible to select the appropriate turbine type or determine if a speed-increasing mechanism, such as belts and gears, is needed. By utilizing all these tools, one can make an informed choice regarding the turbine best suited for the specific site (Bekele, T. 2017).

2. Turbine Efficiency

The relative efficiencies of different turbine types are a key factor when comparing them at the design stage for each flow condition. The output of the selected turbines changes based on the percentage of the turbine flow.

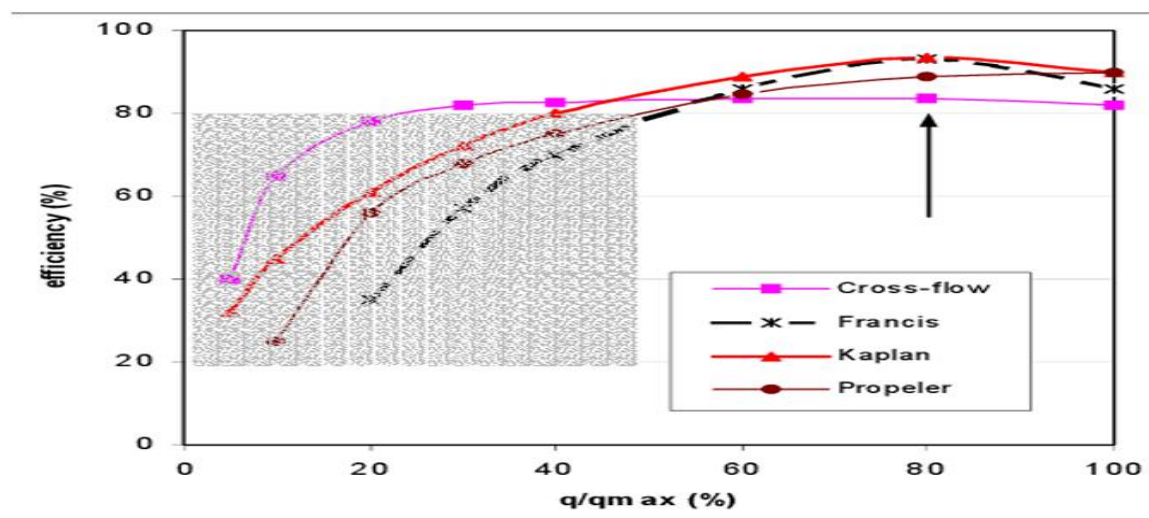


Figure 2.2 Efficiency of Various Turbines based on Discharge rate (Bekele, T. 2017).

C. Generator

A generator is an electrical machine that converts mechanical power into electrical power. In a hydropower system, the turbine and generator together form a generating unit. There are several types of generators, including synchronous generators, induction generators, and DC generators. Synchronous generators are the most commonly used in hydropower applications, while induction generators are typically used in grid-tied systems. DC alternators produce rectified alternating current and are easy to maintain. The turbine, generator, and electrical control components must all be housed in a weatherproof building that can withstand harsh weather, animals, and unauthorized access. It is recommended to install a strong lock for security. For this design, a synchronous generator is used (University Tun Hussein Onn Malaysia. 2012).

I. Generator Selection

In most micro-hydro power systems, the synchronous generator is used because it can establish its own operating voltage and maintain frequency while functioning in remote locations.

Table 2.1 Selection of Generator Type (Water Turbines. 2020).

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

D. 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 (University Tun Hussein Onn Malaysia. 2012).

Determination of Design Parameters of a Micro Hydro Power System

A. Head Measurement

The head is defined as the vertical distance, in meters, from the point where water enters the penstock to the point where it exits the turbine housing at the tailrace. A higher head means faster water flow and greater force applied to the turbine blades. This can be measured using tools such as an altimeter, GPS, and topographical maps to estimate the vertical drop of a stream.

B. Gross Head and Effective Head

The head is the vertical distance between the water surface at the intake and the tailrace for reaction turbines, or the nozzle level for impulse turbines. The effective head is lower than the gross head due to pressure losses in the penstock. Once the gross head is determined, the net head can be calculated by subtracting the losses along the system's path. Several factors influence the frictional losses in the pipe, including the fluid's viscosity, the roughness of the pipe's internal surface, elevation changes between the pipe ends, the pipe's length, the flow velocity, and the internal diameter of the pipe (Bekele, T. 2017).

There are various methods for calculating frictional losses in pipes, but the Darcy-Weisbach formula is considered the most accurate for determining pipe friction losses (Bekele, T. 2017). The Darcy-Weisbach the formula is as follows:

$$HL = F \left(\frac{LP * V^2}{2Dpg} \right) \dots\dots\dots 2.3$$

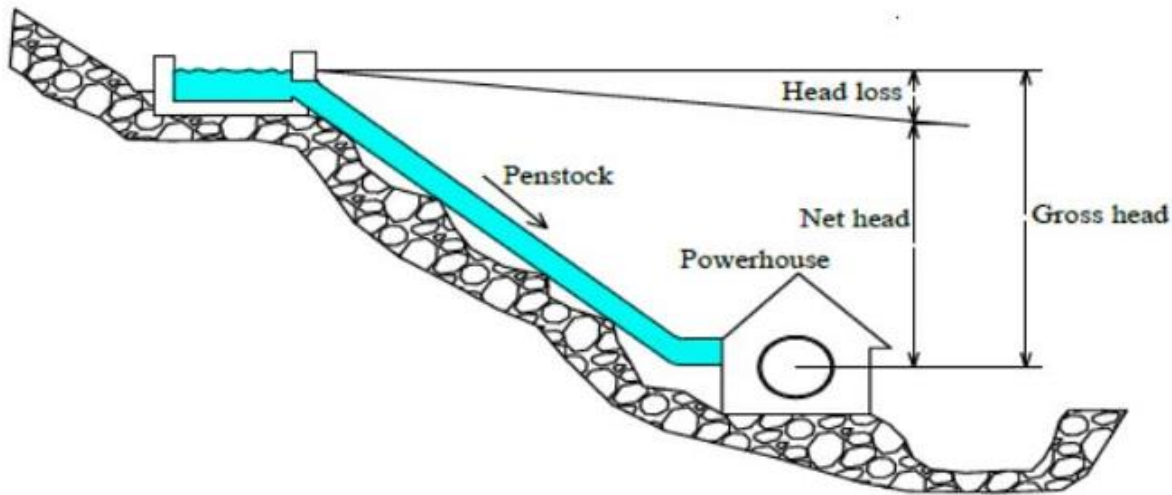


Figure 2.3 Net and gross head (Tesfaye, Y. 2014).

The equation includes a dimensionless friction factor, known as the Darcy friction factor, which is not constant and is specific to the system. It depends on the pipe's characteristics and the properties of the fluid flowing through it, but it can be determined with high accuracy for certain flow conditions. This friction factor can be calculated through various theoretical methods or obtained from published charts. The most widely used charts for this purpose are Moody diagrams, named after L.F. Moody, and the friction factor is sometimes referred to as the Moody friction factor. Moody charts connect key factors that contribute to overall frictional losses in the system, including the Reynolds number and the relative roughness (Moody *friction factor.n.d.*).

The Reynolds number “Re” is defined as:

$$Re = \frac{V * DP}{\nu} \dots\dots\dots 2.4$$

Where ν = the kinematic viscosity of water = $1.004 \times 10^{-6} \left(\frac{m^2}{s} \right)$

The energy balance is maintained in a pipe (penstock), but energy is lost due to friction, which is proportional to the interior surface of the pipe. This energy loss is influenced by the Reynolds number, which characterizes the flow regime within the pipe.

C. Penstock Design

Penstocks are used to transport water from the intake to the powerhouse. They can be constructed either above or below ground level, depending on factors such as land availability, penstock materials, environmental considerations, and ambient temperature. The internal diameter of the penstock (D_p), along with the flow rate, pipe length, and gross head, can be calculated to determine the appropriate specifications for the system (E. S. H. P. A. (ESHA). 2010).

$$D = 2.69 \left(\frac{np2Q2LP}{Hg} \right)^{0.1875} \dots \dots \dots 2.5$$

The tensile strength of the penstock depends on several factors, including the materials used in the pipe, its compressive strength, the diameter of the piping system, and the operating pressure. The minimum recommended material thickness is often specified in millimeters, based on these factors, to ensure the penstock can safely withstand the pressures and stresses during operation (Nasir, B. A. 2014).

The Feasibility Study and Design of micro-hydropower projects depends on site-specific conditions, including the availability of water, the head, and the flow rate. Hydrological studies are essential to determine whether a site can reliably provide sufficient water flow throughout the year. In regions with seasonal variation in water availability, a micro-hydropower system may require storage systems, such as reservoirs or battery banks, to ensure consistent power generation (Raja A.K. *et al.*, 2006).

Additionally, the economic viability of micro-hydropower systems depends on factors such as the initial capital cost, maintenance, and operation costs, as well as the economic benefits of providing electricity to remote areas (Bary *et al.*, 1945).

Micro-hydropower systems are considered environmentally friendly compared to fossil fuel-based power generation. They have minimal environmental impact, especially when used in run-of-river systems, as they do not require large dams or significant alterations to the landscape. Additionally, micro-hydropower systems can contribute to the socio-economic development of rural areas by providing reliable electricity for homes, schools, and small industries (Messenger *et al.*, 2018).

Micro-hydropower systems offer a sustainable and efficient solution for rural electrification, particularly in areas with sufficient water resources. The technology is cost-effective, environmentally friendly, and capable of providing reliable electricity to off-grid communities. With careful site selection, proper system design, and efficient turbine selection, micro-hydropower can be a key contributor to the renewable energy mix in developing regions like

Ethiopia. Further research and technological advancements will continue to improve the efficiency and Feasibility Study and Design of these systems, expanding their potential for global energy solutions.

A solar-hydro microgrid system combines the advantages of solar energy and micro-hydropower to provide reliable electricity, particularly in remote or off-grid locations. This hybrid system can overcome the intermittent nature of solar power by integrating it with the consistent power generation of micro-hydropower, leveraging both resources to ensure continuous energy supply. Several studies emphasize the Feasibility Study and Design and efficiency of such hybrid systems in rural electrification projects, particularly in developing regions where both solar resources and small rivers or streams are abundant (Lund *et al.*, 2020). The integration of solar panels with micro-hydro systems allows for load balancing, as solar power generation peaks during the day while micro-hydro systems can provide a steady power supply, especially during the night or cloudy days. This hybrid system can significantly reduce the reliance on fossil fuels and provide sustainable, clean energy solutions for remote communities (Chen *et al.*, 2021).

The Feasibility Study and Design study of solar-hydro microgrids involves assessing various factors such as the availability of solar irradiation, the water flow rate for the hydro component, and the power demand of the community. Key to the design is ensuring that both power sources are optimized for energy generation based on local conditions. Site-specific assessments are essential, including hydrological studies for the micro-hydro system and solar resource mapping for the photovoltaic (PV) component (Kumar *et al.*, 2021). Advances in hybrid microgrid technologies and storage systems, like batteries, have made these systems increasingly viable and cost-effective. Recent studies show that solar-hydro microgrids are not only technically feasible but also economically sustainable, offering long-term benefits for rural communities by providing energy independence and supporting socio-economic development (Davis *et al.*, 2022).

2.3 Review of Related Works

Numerous studies have been carried out on hybrid off-grid power generation both globally and in Ethiopia. Researchers have employed various technological options and methodologies to assess different configurations of renewable energy sources, including solar energy and micro-hydropower, as well as their hybrid systems. Several findings have been published, and some of the reviewed thesis papers are discussed in the following paragraph.

Gohain *et al.* (2024) explored the integration of micro-hydro and solar energy systems as a solution to the energy access and sustainability challenges in Assam, India. The research highlighted the complementary nature of these two technologies. Micro-hydro systems were identified as a reliable source of power in areas with abundant water resources, providing steady electricity generation, while solar energy was recognized for its flexibility, particularly during dry periods when water availability may be limited. The authors reviewed various hybrid power solutions that combined these two renewable resources to provide a more sustainable and reliable energy supply for remote regions of Assam.

The study provided an in-depth analysis of the technical, economic, and environmental impacts of hybrid micro-hydro and solar energy systems. Case studies were used to support the evaluation of these systems, demonstrating their potential to address power shortages and reduce dependence on conventional energy sources. However, the research also identified several key challenges in implementing such systems. These challenges included geographical constraints, where not all areas in Assam may have the required water resources for micro-hydro, and technical inefficiencies, which could limit the system's overall performance. Furthermore, financial barriers and a lack of supportive policy frameworks were significant obstacles to the widespread adoption of these hybrid systems.

The authors emphasized the need for additional data to assess the long-term performance and socio-economic impacts of hybrid systems, which would be essential for evaluating their scalability in Assam. They argued that addressing these challenges would require comprehensive policy support, improved financial mechanisms, and technological advancements to enhance the efficiency and Feasibility Study and Design of hybrid energy solutions. Overcoming these barriers could pave the way for more sustainable and widespread use of hybrid power systems in rural and remote areas of Assam, improving energy access and contributing to environmental sustainability.

Dusenge *et al.* (2022) examined the Feasibility Study and Design of implementing hybrid hydroelectric and photovoltaic (PV) systems in off-grid rural areas to enhance energy access and sustainability. The study analysed the technical, economic, and environmental aspects of integrating hydro and solar power. It assessed factors such as the availability of water resources, solar potential, system efficiency, and cost-effectiveness. The findings indicated that hybrid

systems were viable and efficient solutions for rural electrification, offering a reliable energy alternative for remote locations.

The research highlighted several challenges associated with hybrid systems, including dependency on specific geographic conditions, the substantial initial capital required, and maintenance difficulties in isolated areas. Additionally, limited policy support for hybrid energy initiatives in rural regions was identified as a significant barrier. The study emphasized the need for targeted policies and investments to address these obstacles and enable broader adoption of hybrid energy systems.

Valsan et al. (2022) investigated the application of regression models to forecast rainfall in isolated regions of Kerala, aiming to enhance energy management within micro-hydro grids. The study illustrated how rainfall prediction could optimize micro-hydro system operations by estimating water availability, ensuring more stable energy production. A predictive model was developed using regression analysis of historical rainfall data, providing valuable insights for improved energy planning and resource allocation.

The research highlighted several limitations, including the reliance on accurate and comprehensive historical data, which could constrain the model's effectiveness. Challenges also arose in adapting the model to account for fluctuating weather patterns and integrating rainfall-based predictions with the flexible operations of micro-hydro systems. These issues were further complicated in remote communities where infrastructure and data access were often limited, underscoring the need for refined models and additional support for effective implementation.

Matagira-Sánchez and Irizarry-Rivera (2015) assessed the integration of solar photovoltaic (PV) energy with micro pumped hydro storage to improve the stability and reliability of Puerto Rico's electrical grid. The study focused on the Feasibility Study and Design of using pumped hydro storage to address the intermittency of solar power by storing excess energy during periods of peak sunlight and releasing it when demand increased or solar output decreased. The authors evaluated various factors, including storage capacity, system efficiency, and the economic viability of the hybrid approach.

The study also identified several constraints, such as the significant initial costs of building pumped hydro infrastructure, the necessity for suitable topography and water resources, and potential environmental and regulatory challenges that could hinder implementation. Despite these limitations, the integration of micro pumped hydro storage with solar PV systems was

deemed a promising solution for enhancing grid reliability and supporting the transition to renewable energy in Puerto Rico.

Muhammad et al. (2024) conducted a Feasibility Study and Design analysis of a hybrid solar and hydropower system for off-grid rural areas in Ranau, Sabah, Malaysia, utilizing HOMER software for optimization. The study focused on designing a system that could efficiently meet the energy demand while considering factors such as local resource availability, energy consumption patterns, and environmental impacts. The results indicated that the hybrid system offered a cost-effective and environmentally friendly solution for providing reliable electricity in remote areas, where access to the grid is limited.

The research identified several key benefits of combining solar and hydro systems. Solar energy provided a flexible and renewable source of power, while hydropower helped ensure consistent energy production, particularly in regions with stable water resources. This hybrid approach allowed for a more reliable and sustainable power supply compared to relying on a single energy source. However, the study also emphasized the challenges associated with the implementation of such systems in off-grid locations, including the variability of solar irradiance and water availability, which were essential for ensuring the system's effectiveness.

Several limitations were highlighted in the study. The success of the hybrid system was highly dependent on local geographical and environmental conditions, which could vary seasonally or regionally, affecting the reliability of energy production. The initial capital costs for setting up the system were a significant barrier to adoption, especially in economically disadvantaged rural areas. Moreover, integrating solar and hydro components posed technical challenges, and the need for skilled labour to maintain and operate the system in remote locations further complicated its Feasibility Study and Design. The study also noted that real-world operational conditions might differ from model predictions, adding uncertainties to the long-term performance of the system.

Rajadurai et al. (2017) examined the integration of solar PV and micro-hydro systems for household applications, focusing on their technical aspects. The study provided insights into strategies for system design, control, and power management to ensure a consistent power supply for residential use. The research concluded that hybrid systems could significantly reduce reliance on conventional energy sources, enhance reliability, and contribute to sustainability.

However, the study had several limitations. It was dependent on specific geographical and climatic conditions, which limited the generalizability of the findings to other regions. Additionally, scalability for larger applications was not extensively addressed, and the study did not thoroughly explore the long-term maintenance and cost challenges that could affect the broader adoption of such hybrid systems.

Kusakana and Munda (2017) explored the Feasibility Study and Design of using a hybrid solar PV and micro-hydro system for rural electrification in areas with limited grid access. The study emphasized the technical and economic viability of this hybrid approach, which utilized local renewable resources to address energy shortages and promote sustainable development. It highlighted how combining solar and micro-hydro systems could provide a reliable and consistent energy supply in off-grid regions.

However, the research identified several limitations. The effectiveness of the hybrid system was highly dependent on the availability of local resources, which could vary significantly by location. Additionally, the study did not thoroughly address the long-term maintenance needs of the system, nor did it provide an in-depth analysis of the high initial installation costs, which could pose barriers to wider implementation and scalability.

Laksono and Fahreza (2019) studied the optimal sizing of micro-hydropower components in hybrid renewable energy systems to improve efficiency and reliability. The research emphasized the significance of accurately sizing system components to meet the energy needs of small communities, ensuring stable power generation while minimizing energy waste. The findings demonstrated that well-optimized systems could provide a reliable and sustainable energy source for off-grid areas.

However, the study had some limitations. Its scope was confined to specific parameters, which may not be applicable to other regions or climates, reducing the generalizability of the results. Additionally, the research did not include a detailed economic analysis of installation and maintenance costs, leaving unanswered questions about the financial Feasibility Study and Design and long-term sustainability of such systems.

Mane, Madiwal, and Patil (2021) introduced an off-grid photovoltaic (PV) system with a pulse-width modulation (PWM) inverter, specifically designed for islanded micro-grids that provide power to critical loads in remote areas. These off-grid systems are particularly important in locations without access to conventional grid infrastructure, where reliable energy supply is crucial for supporting essential services. The study focused on the need for stable and high-

quality electricity to power critical infrastructure, such as healthcare facilities and emergency response systems.

The research highlighted the key role of the PWM inverter in stabilizing the power output of the PV system. By efficiently controlling the power flow and ensuring consistent voltage levels, the inverter enabled the system to meet fluctuating energy demands effectively, even in isolated environments. The ability to provide uninterrupted power to critical loads was a central feature of the study, showcasing the system's potential to enhance the reliability of energy supply in remote areas where conventional grid connections are not feasible.

Overall, the study emphasized the importance of maintaining a continuous and stable energy supply for essential services in remote locations. While the study addressed the technical performance of the system in detail, it did not thoroughly explore the economic implications of large-scale deployment or the long-term maintenance and durability requirements of such off-grid systems. These aspects are vital for assessing the overall viability and sustainability of using off-grid PV systems for critical infrastructure in harsh, isolated environments.

However, the study has some limitations. It primarily focuses on technical aspects, such as inverter performance and load stability, and does not delve deeply into the economic implications of scaling up such systems. Furthermore, it does not address the long-term durability and maintenance needs of the off-grid PV systems, which are vital for ensuring reliable operation in remote areas, especially in harsh environmental conditions. These limitations highlight the need for further research to confirm the system's practicality and resilience under real-world conditions.

While previous studies have examined hybrid renewable energy systems in various global and regional contexts, few have addressed the unique challenges of rural electrification in Ethiopia using a localized, data-driven design framework. This study bridges that gap by conducting a comprehensive feasibility assessment and system design for a hybrid solar-hydro microgrid tailored to the specific conditions of Jarso Bam Bache village.

Unlike many prior works, this research integrates detailed local load profiling, solar and hydro resource assessments, and simulation-based analysis using both HOMER and MATLAB tools. Furthermore, it evaluates the system's technical, economic, and environmental viability, offering a replicable design methodology for other rural Ethiopian settings.

CHAPTER THREE

3 DESIGN OF SOLAR HYDRO MICRO GRID ENERGY SOURCE

3.1 Introduction

A solar-hydro micro grid Feasibility Study and Design study explores integrating solar and hydropower systems, leveraging their complementary resources for reliable energy. It includes site analysis, resource evaluation, system design, and cost assessment to promote energy independence and socio-economic development, providing sustainable solutions for off-grid areas.

3.1.1 Background of the Case Study Area

Jarso Bam Bache village is located in Leka Dullecha Woreda, in the Oromia Region of Ethiopia, at latitude 8.994813° N and longitude 36.295020° E. Positioned at an elevation of 2,142 meters above sea level, the village lies in a highland area with moderate temperatures and favorable conditions for diverse agricultural practices. These topographic and climatic features present strong potential for harnessing renewable energy sources, particularly micro-hydropower and solar photovoltaic (PV) systems. The village is home to approximately 2,120 people across 530 households, with an average household size of four. Most residents rely on subsistence agriculture, small-scale trade, and traditional energy sources such as biomass and kerosene. The community currently lacks access to a reliable electricity supply, which adversely affects health, education, and economic development. Jarso Bam Bache was selected as the case study area due to several compelling reasons. Firstly, its complete lack of grid connectivity makes it a suitable candidate for implementing and evaluating standalone hybrid renewable energy systems. Secondly, the availability of renewable resources specifically a perennial river (locally known as Lag Guddaan) and abundant solar irradiance supports the technical feasibility of a micro-hydro and solar hybrid system.

Table 3:1 Average Monthly Flow Rate Over 5 Years (in m³/s) (2018-2022) (Leka Dullecha water and energy bureau).

year	Month												
	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct	Nov.	Dec.	Avg.
2018	1.2	1.1	1.3	1.6	2.0	2.3	2.4	2.2	1.6	1.4	1.2	1.0	1.2
2019	1.3	1.2	1.4	1.7	2.1	2.2	2.4	2.3	1.8	1.4	1.3	1.1	1.8
2020	1.4	1.3	1.2	1.6	1.9	2.4	2.3	2.2	1.8	1.5	1.1	1.2	1.6
2021	1.5	1.2	1.4	1.5	2.0	2.1	2.6	2.4	1.7	1.4	1.0	1.1	1.2
2022	1.3	1.4	1.5	1.6	2.2	2.3	2.4	2.3	1.6	1.3	1.2	1.0	1.5

The Lag Guda river, located in the Jarso Bамbeche area, flows year-round during both the rainy and dry seasons. With an average flow rate of 1.5 cubic meters per second and a height of 10 meters, the river has the potential to generate between 5kW and 100kW of power through a micro-hydro system. By harnessing the energy of the Lag Guda river in combination with solar power, the village can provide electricity to its households from renewable sources, improving living standards and contributing to sustainable development in the Oromia region.

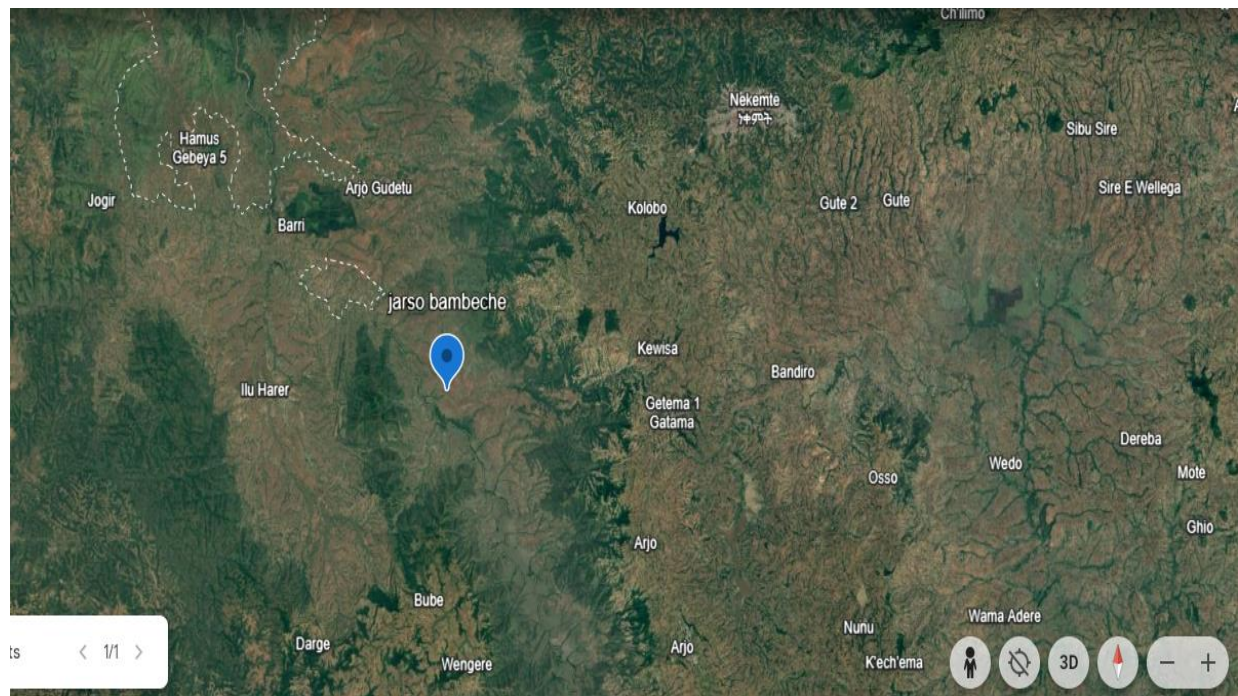


Figure 3.1 Google map picture of study area

3.1.2 Primary and Secondary Data

➤ Primary Data

The following data were gathered directly from the Jarso Bam Bache site through surveys, community interviews, and on-site measurements:

Residential Electrical Load: Daily and seasonal energy consumption patterns of households.

Deferrable Load: Non-critical loads such as water pumping and grain milling schedules.

Existing Power Sources: Availability, reliability, and limitations of current energy sources (e.g., diesel generators, traditional biomass).

River Flow Measurements: Direct measurements from the nearby river (Lag Guddaan) to assess micro-hydro potential (e.g., flow rate, seasonal variation).

➤ Secondary Data

Secondary data were obtained from credible institutions as follows:

- I. Ethiopian Construction Corporation:
 - ✓ Technical specifications and cost estimates of micro-hydro system components.
 - ✓ Site-specific construction considerations for civil works (e.g., penstock, intake structures).
 - II. Ministry of Water, Irrigation, and Energy:
 - ✓ National energy policies and rural electrification plans.
 - ✓ Benchmark data for load forecasting and hybrid system standards.
 - ✓ performance of similar hybrid energy systems in comparable regions.
 - III. NASA (Surface Meteorology and Solar Energy Database):
 - ✓ Hourly and monthly solar radiation data.
- ✓ Temperature and cloud cover for solar PV performance modelling.

3.2 Solar Insolation Data- Jarso Bam Bache

Solar insolation, or the amount of solar radiation energy received on a given surface area during a given time, is crucial for assessing solar energy potential. For Jarso Bambeche, located at latitude 8.994813 and longitude 36.295020, the average daily solar insolation varies throughout the year.

Below is an approximate monthly breakdown of average daily solar insolation, measured in kilowatt-hours per square meter per day (kWh/m²/day), for the years 2020 to 2022:

Table 3.2 Solar insolation data of Jarso Bam Bache [2019-2023]

Month		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
year	2019	5.7	5.8	5.9	5.5	5.3	5.3	5.1	4.7	5.0	5.4	5.5	5.6	5.4
	2020	5.7	5.7	5.7	5.4	5.2	5.0	4.8	5.1	5.1	5.3	5.5	5.6	5.34
	2021	6.0	6.2	6.0	5.7	5.3	4.8	4.5	4.7	5.1	5.8	6.0	6.2	5.52
	2022	6.2	6.3	5.7	5.6	5.5	5.0	4.1	4.7	5.5	5.7	5.8	6.1	5.54
	2023	6.1	6.2	5.7	5.5	5.3	5.1	4.7	4.5	5.2	5.5	5.6	5.7	5.43
Average of Solar insolation														5.45

Solar insolation is the total amount of solar radiation that reaches the Earth's surface, measured in kWh/m²/day. These values can vary depending on several factors, including: Local weather conditions, Cloud cover, Atmospheric Composition Altitude and topography. This information is critical in designing and assessing the Feasibility Study and Design of solar power systems, especially for remote or rural electrification projects.

3.3 Load Estimation

Residential load: The load refers to the energy requirements that the energy-providing system must meet immediately, which includes lighting, refrigeration, television, radio, and other appliances. In estimating the load, the electricity consumption for each household is assumed uniform and constant throughout the year. The load determination for the village was conducted based on a total population of 2,120 and 530 households. During this estimation, the nature of the load was carefully analyzed to ensure sustainable energy demand satisfaction, as electric loads can vary over time and across seasons. In this energy design system, the selected appliances were chosen for their low wattage to ensure affordability in accessing electric energy.

Deferrable load: The electrical load refers to the energy that needs to be supplied within a certain timeframe, although the exact timing is not critical. In Jarso Bam Bache, nearly all residents are farmers who utilize water pumps for irrigation purposes.

Table 3.3 AC Load gives the appliances, with their power rating, and the energy use within specified time of the day.

Type of Loads	Qty .	Rating (W)	Power (kW)	Time of usage	Hrs. /Day	Energy/day(kW h/day)
Residential load in in JB						
Lighting	665	15	9.975	19:00-23:00	4	39.9
Radio	30	100	3	6:00-9:00	3	9
Tv	5	139.5	0.6975	12:00-14:00, 19:00-21:00	4	2.79
Stove	3	3000	9	7:00-8:00, 20:00-21:00	2	18
Smart phone charger	50	7	0.35	19:00-21:00	2	0.7
Computer	2	150	0.3	18:00-21:00	3	0.9
Health post in JB						
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 JB						
Lighting	12	15	0.18	18:00-20:00	3	0.54
Radio	1	100	0.1	10:00-11:00, 12:00-13:00, 15:00-16:00	3	0.3
Churches in JB						
Lighting	10	15	0.15	4:00-7:00, 18:00-19:00	6	0.9
Amplifier	3	100	0.3	4:00-7:00, 18:00-19:00	6	1.8
Total Load of JB			24.2025 kw			77.77 kwh/day
Deferrable load						
Water pump(2hp)	4	2*750	6		3	18
Total load			30.2025 kw			95.77kwh/day

Residential Peak load of is 24.2025kW with energy demand is 77.77kWh/day. The Deferrable load is 18kWh/day. The total load is 30.2025kW and total energy consumed is 95.77kWh/day.

3.4 Sizing of a Standalone PV System

The photovoltaic (PV) energy source is essential for maximizing power systems to meet the load requirements. By utilizing solar insolation on a tilted surface, alongside ambient temperature and the manufacturer's specifications for the PV modules as model inputs, the power output of the PV generator can be effectively calculated.

➤ PV- array sizing

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

The availability of energy sources in the Leka Dullecha Woreda, along with the power generation capacity of these resources, is detailed below in the solar and hydropower design aimed at meeting the estimated total load. A significant portion of the load is supported by hydropower, a renewable energy source, while the remainder is provided by the PV system.

Therefore, solar system is expected to cover 30% of the total load.

$$Total\ energy = \frac{95.77kWh}{day}$$

30% of the total energy is covered by the solar.

$$E_{pv} = 0.3 * \frac{95.77kWh}{day} = \frac{28.731kWh}{day} \dots\dots\dots 3.1$$

G_{min} = 4600Whm² day, consider summer season

$$P_{pv} = \frac{E_{pv}}{G_{min}} * \frac{1000W}{m^2} \dots\dots\dots 3.2$$

$$P_{pv} (pick) = \frac{\frac{28.731kwh}{day}}{\frac{4600wh}{m^2day}} * \frac{1000w}{m^2}$$

$$= 6.246kw$$

$$\text{Fill factor (FF)} = \frac{\text{Max. power from solar module}}{I_{sc} * V_{oc}} \dots\dots\dots 3.3$$

$$= \frac{145w}{8.78A * 22.3V} = 0.74$$

$$P_{\text{array}} (w) = FF * P_{\text{array}} (wp) \dots\dots\dots 3.4$$

$$= 0.74 * 6.246kw$$

$$= 4.621943kw$$

Total number of modules

$$N_m = \frac{P_{\text{array}}(w)}{\text{Rating per module}} \dots\dots\dots 3.5$$

Maximum power for selected module is 145w

$$N_m = \frac{4.621943kw}{145w} = 31.875 \text{ modules,}$$

Round up to next whole number, $N_m \cong 32 \text{ module.}$

Number of modules in the string,

$$N_s = \frac{\text{total number of modules}}{\text{nominal module voltage}} \dots\dots\dots 3.6$$

$$N_s = \frac{32 \text{ modules}}{12v} = 2.667$$

Round up to next whole number, $N_s \cong 3$

$$N_p = \frac{\text{total } N_m}{N_s} = \frac{32}{3} = 10.667 \dots\dots\dots 3.7$$

Round up to next whole number, $N_p \cong 11$

Total number of solar module required, $N_s * N_p = 3 * 11 = 33 \text{ Module}$

3.4.1 Sizing and Specifying Battery Bank

A battery acts as a storage unit for direct current (DC) energy sources. Considering the area's temperature variations and the required days of energy autonomy, Trojan SSIG 12V, 230Ah lead-acid batteries were selected. These batteries are designed with a depth of discharge of 70%. The selection aligns with findings from a study comparing the performance of PWM and MPPT charge controllers, highlighting the importance of optimal charging for battery longevity (Laguado–Serrano *et al*, 2019).

The storage capacity of a battery

$$CAh = \frac{EL * AD}{\eta_{inv} * \eta_{bat} * Vn * DOD} \dots\dots\dots 3.8$$

$$EL = 28.731 \text{ kWhday}$$

$$AD = 2 \text{ days}$$

$$Vn = 12 \text{ v}$$

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

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

$$DOD = 70\%$$

$$CAh = \frac{\frac{28.731 \text{ kWh}}{\text{day}} * 2 \text{ day}}{0.95 * 0.85 * 12 * 0.7} \dots\dots\dots 3.9$$

$$= \frac{57.462 \text{ kWh}}{6.783} = 8.4714728 \text{ kWh} = 8471.4728 \text{ Ah}$$

Number of batteries connected in parallel

$$Bp = \frac{CAh}{Bc} \dots\dots\dots 3.10$$

$$= \frac{8471.4728 \text{ Ah}}{230 \text{ Ah}} = 36.83 \cong 37$$

Number of batteries connected in series

$$Bs = \frac{Vn}{Vb} = \frac{12 \text{ v}}{12 \text{ v}} = 1 \dots\dots\dots 3.11$$

*Total Number of batteries required is, $Bp * Bs = 37 * 1 = 37$ battery*

3.4.2 Sizing and Selecting Charge Controller and Inverter

A. Charge Controller

The SPS series Solar Regulation System is an advanced electronic control unit designed for solar power supplies in remote areas. It prevents overcharging, minimizes electrolyte loss, and stops over-discharge, all of which contribute to extending battery life and reducing maintenance needs. This system combines cutting-edge technology with a simple modular design, resulting in superior performance and features compared to other regulators in its class. All control settings are fully adjustable and can be modified remotely. These systems are user-friendly, easy to maintain, and currently support telecommunications in some of the world's most isolated locations (Laguado–Serrano *et al.*, 2019).

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

The short circuit current (I_{sc}) of the selected PV module times number of a module in parallel

The total current of the charge controller:

$$\text{Charge controller, } (I_{tot}) = I_{sc} * N_p * \text{oversizing} \dots\dots\dots 3.11$$

$$I_{tot} = 8.78 * 11v * 1.2 = 115.89A \cong 116A$$

$$\text{Number of charge controller} = \frac{\text{Total current}}{\text{selected charge controller}} \dots\dots\dots 3.12$$

$$= \frac{116A}{75A} = 1.54 \cong 2$$

B. Inverter

The inverter should be sized 25-30% larger than the total wattage of the appliances it will support (Cronem berger *et al.*, 2012).

Considering 25% of the total watts of the appliance becomes;

$$4.621943kw + 25\% * 4.621943kw = 5.77k \dots\dots\dots 3.13$$

From the standard 40kW by 220V

3.4.3 The Total Area Covered by the Solar Panel

Sizing of the area covered by solar module is a very important during design of solar system so, considering the PV module length and width:

$$L = 2000mm,$$

$$w = 1168mm \text{ considering with the space.}$$

$$A = l \times w \dots\dots\dots 3.14$$

$$A = ((2000mm \times 11) \times (1168mm \times 3))$$

$$A = 77,088,000mm^2 = 77.088m^2$$

3.4.4 Cable Sizing

The rural villages are located more than 67 km away from the Nekemte substation in Ethiopia. Extending the system from the grid would result in significant voltage drop, making a standalone system the best solution for electrifying remote areas while minimizing voltage loss.

When selecting cable sizes, it is important to consider the distance and voltage drop. The cables should cause no more than 3% voltage loss between the PV modules and the charge regulator, less than 2% between the battery and the charge regulator, and under 5% between the charge regulator and the load, all at maximum current conditions. For instance, assuming a 3% voltage drop between the PV modules and the charger controller, with a short circuit module current and an oversize factor of 120%, a cable length of 10 meters is taken into account.

$$\text{Maximum current} = 1.20 \times 8.78 = 10.536A \dots\dots\dots 3.15$$

$$\text{Resistivity of copper} = 1.72 \times 10^{-8} \text{ ohmmeter}$$

$$\text{Conductivity of copper} = 58 \times 10^6 \frac{s}{m}$$

$$\text{Cross sectional area of cable } A (mm^2) = \frac{2 * I * L}{58 \times 10^6 \frac{s}{m} * V_{drop}} \dots\dots\dots 3.16$$

$$A (mm^2) = \frac{2 * 10.536A * 10}{58 \times 10^6 \frac{s}{m} * 0.03 * 24v}$$

$$A = 7.5689mm^2$$

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

➤ 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 = 116A

$$\text{Cross sectional area of cable } A (\text{mm}^2) = \frac{2 * I * L}{58 \times 10^6 \frac{\text{s}}{\text{m}} * V_{\text{drop}}} \dots\dots\dots 3.17$$

$$= \frac{2 * 116 * 10}{58 \times 10^6 \frac{\text{s}}{\text{m}} * 0.02 * 24}$$

$$A = 83.33\text{mm}^2$$

83.33mm², used 95mm² 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 = 116A

$$\text{Cross sectional area of cable } A (\text{mm}^2) = \frac{2 * I * L}{58 \times 10^6 \frac{\text{s}}{\text{m}} * V_{\text{drop}}} \dots\dots\dots 3.18$$

$$A (\text{mm}^2) = \frac{2 * 116 * 15}{58 \times 10^6 \frac{\text{s}}{\text{m}} * 0.05 * 24}$$

$$A = 50 \text{ mm}^2$$

50mm², used 50mm² from IEE cable sizing table

3.5 Hydro Electric Power

A hydropower plant is a power source that harnesses the energy of water, either through the natural flow of a river or by utilizing an artificial reservoir. To generate electricity, it requires water as a resource along with various mechanical and electrical systems. Initially, the kinetic energy of the water is transformed into mechanical energy via the turbine, which is then converted into electrical energy by the generator. However, there are energy losses associated with both the turbine and generator during these processes (Ichimura *et al*, 2021).

3.5.1 Analysis of power generation by hydro power

To design hydropower, by using the natural flows of the river.

Power from the hydropower is given by;

$$P(w) = \rho . g . H . Q \dots \dots \dots 3.19$$

$$\text{Where: } \rho = \text{water density} = \frac{1000kg}{m^3}$$

$$g = \text{gravitational constant} = \frac{9.81m}{s^2}$$

$$H = \text{head (m)} = 10m$$

$$Q = \text{water flow} \left(\frac{m^3}{s} \right) = \frac{1.5m^3}{s}$$

$$= 1000kg * 1.53m^3 * \frac{9.81m}{s^2} * 11m$$

$$= 165.1023kw \text{ theoretical output power}$$

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

$$\eta_t = 0.603$$

$$\eta_g = 0.9$$

$$P(w) = \rho . g . H . Q . \eta_t . \eta_g \dots \dots \dots 3.20$$

$$= 165.1023kw * 0.603 * 0.9$$

$$= 89.6 kw$$

Hydro Power covers around 93.557% of the total load

A. 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:

$$\begin{aligned}
 \text{Plant factor (\%)} &= \frac{\text{Annual energy generation(kwh)}}{\text{maximum output(kw)} * 8760} * 100 \dots\dots\dots 3.21 \\
 &= \frac{\frac{89.6\text{kwh}}{\text{day}} * 365\text{day}}{95.83\text{kw} * 8760\text{hr}} * 100 \\
 &= \frac{32704\text{kwh}}{839470.8\text{kwhr}} * 100 \\
 &= 0.0389 \text{ or } 3.89\%
 \end{aligned}$$

B. 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

$$\begin{aligned}
 \text{Load Factor (\%)} &= \frac{\text{mean load (kw)}}{\text{max. load (kw)}} * 100 \dots\dots\dots 3.22 \\
 P_{mnL} &= \frac{0.93557 * \frac{95.77\text{kw}}{\text{hr}}}{\frac{24\text{hr}}{\text{day}}} \\
 &= 3.7333\text{kw} \\
 P_{maxm} &= 0.93557 * 30.2025 = 28.25655\text{kw} \dots\dots\dots 3.23 \\
 &= \frac{3.7333\text{kw}}{28.25655\text{kw}} * 100 = 13.2\%
 \end{aligned}$$

C. 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.

$$\begin{aligned}
 \text{Regulating capability factor (\%)} &= \frac{\text{Active storage capacity (m3)}}{\text{Annual in flow (m3)}} * 100 \dots\dots\dots 3.24 \\
 &\text{Live Storage is 38.00 million m3 and Inactive (Dead) Storage is 12 million m3} \\
 &\text{from the total water capacity of } 50 * 10^6\text{m3} \\
 \text{Regulating capability factor (\%)} &= \frac{38.000\text{million m3}}{50.000\text{million m3} * 365} * 100 \\
 &= 0.208\%
 \end{aligned}$$

D. 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.

$$\text{Flow utilization factor (\%)} = \frac{\text{Annual plant discharge}(m^3)}{\text{Max. plant discharge} \frac{m^3}{s} * 365 * 86400} * 100 \dots\dots\dots 3.25$$

$$\begin{aligned} \text{Flow utilization factor (\%)} &= \frac{18250}{1.5 \frac{m^3}{s} * 365 * 86400} * 100 \\ &= 0.0386\% \end{aligned}$$

3.5.2 Controller Design for Servo Motor and Turbine

A. PID Control in Servo Motors and Turbines

PID controllers are widely used in industrial applications, accounting for over 85% of control systems. These controllers are often used in position control systems, but their implementation in a closed-loop configuration can lead to instability. Several methods for tuning PID controllers exist, including conventional techniques like the Ziegler-Nichols (Z-N) method, pole placement, good-gain method, and other soft computing approaches. For this study, two tuning methods, namely Ziegler-Nichols and the Good-Gain method, were applied to improve system performance (International Journal of Engineering Research & Technology [IJERT], (Javiya et al., 2016).

PID tuning for position control systems is a time-consuming process, and significant efforts have been made to analyse servo systems and control both servo motors and hydraulic turbines. The Ziegler-Nichols method is a conventional technique commonly used for PID controller tuning. This method involves two primary approaches: the step response method and the frequency response method. In this research, the step response method was used to tune the PID controller.

The general form of a PID controller is given by:

$$U(t) = Kp e(t) + Ki \int (t) + Kd \frac{de(t)}{dt} \dots\dots\dots 3.26$$

Where Kp, Ki and Kd are the proportional, integral, and derivative gains, respectively, and e(t)e(t)e(t) represents the error between the set point and the output.

In the frequency domain, the PID controller output can be represented as:

$$U(s) = E(s)[Kp + ki/s + KdS \dots \dots \dots] \dots \dots \dots 3.27$$

For the Ziegler-Nichols method, the initial PID settings are determined by setting the proportional time (Tp) to infinity, and the integral time (Ti) and derivative time (Td) to zero. These settings provide an initial approximation for the PID values. The tuning parameters for the Ziegler-Nichols method are summarized in the table below:

Table 3.3 Z-N tuning parameter

Controller type	Kp	ki	kd
P	$\frac{1}{2} k_u$	∞	0
PI	$\frac{9}{20} k_u$	$\frac{1}{1.2} p_u$	0
PID	$\frac{3}{5} k_u$	$\frac{1}{2} p_u$	$\frac{1}{8} p_u$

Where Ku and Pu are the ultimate gain and ultimate period, respectively.

B. Servo Motors in Hydraulic Turbine Systems

An electric servo motor is designed to produce motion (usually linear) proportional to an electrical command signal. These motors are commonly used in flow control applications, particularly in micro-hydro power systems, due to their simple design, low maintenance requirements, and cost-effectiveness compared to conventional governors (Javiya & Department of Instrumentation and Control Engineering, 2016).

The transfer function for the servo motor with its driver is approximated as:

$$G(s) = \frac{1}{(1 + sT1)} + \frac{2}{(1 + sT2)} \dots \dots \dots 3.28$$

Whereas, $T1 = 0$ ad $T2 = 3$, resulting in:

$$G(s) = \frac{1}{(1 + 3s)} \dots \dots \dots 3.29$$

C. Hydraulic Turbine Modelling

Accurate modelling of hydraulic turbines requires accounting for the transmission reflections in the fluid-carrying pipes, which occur due to the compressibility of the fluid. The propagation velocity of these waves is around 120 meters per second, which makes traveling wave models necessary for long penstocks. The basic assumptions for the hydraulic turbine model include negligible hydraulic resistance, inelastic penstock pipes, and compressible water. The velocity of water is directly related to the gate opening and the square root of the net head. The turbine power output is proportional to both the head and the flow volume.

The hydraulic turbine transfer function is given by:

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

Whereas, $T_1 = 0$ and $T_2 = 3$, yielding the following transfer function:

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

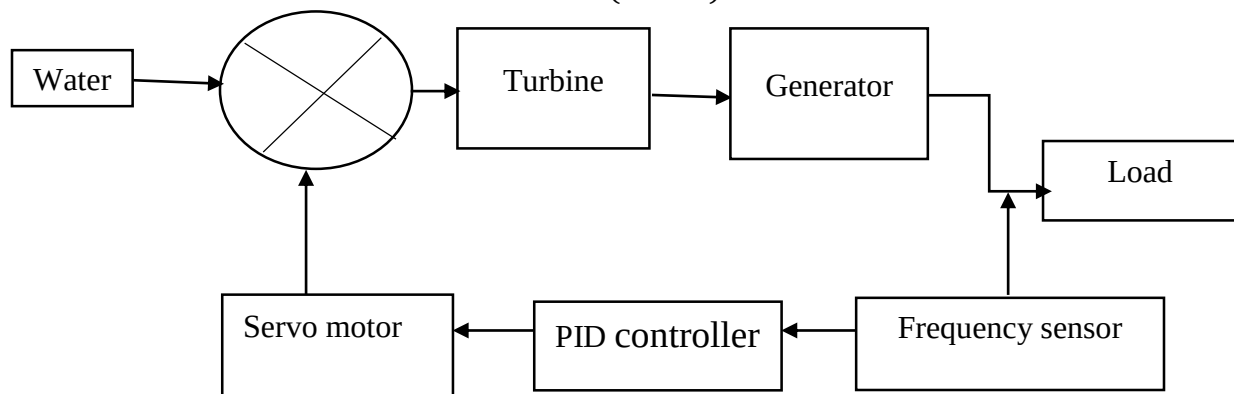


Figure 3.2 Block diagram of speed governor for power plants

I. Turbine

The turbine converts the kinetic energy of water flow into mechanical energy. There are several types of turbines used in micro-hydro systems, such as Francis turbines (for medium heads) and Kaplan turbines (for low heads with high flow rates). The selection of the turbine depends on the water head and flow rate available in the system. The turbine's efficiency is critical for optimizing energy output.

II. Generator

The generator converts the mechanical energy from the turbine into electrical energy (AC). Typically, a synchronous generator is used in micro-hydro systems, as it ensures the frequency stability required for grid connection or local consumption. The generator is designed to match the power output of the turbine to ensure efficient conversion of energy.

III. Servo Motor

The servo motor is used to control the turbine's gate opening and adjust the water flow into the turbine. This is important for maintaining a constant rotational speed of the turbine and ensuring efficient operation despite changes in water flow or load demand. The servo motor provides precise control, enhancing the system's responsiveness to fluctuations.

IV. PID Controller

A PID controller (Proportional-Integral-Derivative) is used to maintain the desired performance of the turbine and generator by continuously adjusting the control signals. In a micro-hydro system, the PID controller can regulate the turbine speed, water flow, and power output to optimize system efficiency. The controller helps in stabilizing the system's operation, preventing over-speeding or under-performance.

V. Frequency Sensor

The frequency sensor monitors the output frequency of the synchronous generator. It ensures that the electrical output matches the required frequency (typically 50 Hz or 60 Hz depending on the region). If the frequency deviates, the sensor triggers adjustments via the PID controller to regulate the system's speed and prevent frequency instability, which could damage electrical equipment.

VI. AC Load

The AC load consists of electrical devices or systems that consume the generated electricity, such as household appliances or industrial machinery. The micro-hydro system must be sized to meet the total load demand, accounting for peak and average power consumption. Inverters may be used to adjust the output of the generator for compatibility with AC loads.

VII. Integration and Control

These components work together to ensure a stable and reliable power supply from a micro-hydro system. The turbine generates mechanical energy from water flow, which is converted into electrical energy by the generator. The servo motor adjusts water flow, controlled by the PID controller to maintain consistent performance. The frequency sensor continuously monitors the system to keep the output frequency stable, ensuring compatibility with the AC load. Proper integration and optimization of these components are essential for maximizing efficiency and meeting load demands in the micro-hydro system.

3.6 System Design

A. Battery

The battery system stores excess energy for later use.

A bi-directional DC/DC converter connects the battery to the DC bus, enabling both charging and discharging. This allows energy to flow to the DC bus when needed or store surplus energy when available.

B. Solar Array:

The solar array generates DC electricity.

A DC/DC converter regulates the voltage from the solar panels and connects them to the DC bus. This ensures that the solar output matches the system's voltage requirements and optimizes power transfer.

C. Micro-Hydro System:

The micro-hydro system produces AC electricity, which is converted to DC using an AC/DC rectifier.

D. DC Bus:

The DC bus acts as the central point for integrating power from all sources (solar, micro-hydro, and batteries).

It collects and distributes power efficiently before converting it to AC for the load.

E. DC-AC Inverter:

The inverter converts DC power from the DC bus into AC power, compatible with local loads.

The inverter is essential for maintaining the correct voltage, frequency, and phase for the AC grid or local load.

F. AC Bus:

The AC bus distributes the inverter's output to the local AC load, ensuring seamless integration of the hybrid energy sources into the system. Local AC Load:

This refers to the end-user devices or appliances powered by the system, such as homes, businesses, or machinery. The system is designed to meet the load's peak and average power demands reliably.

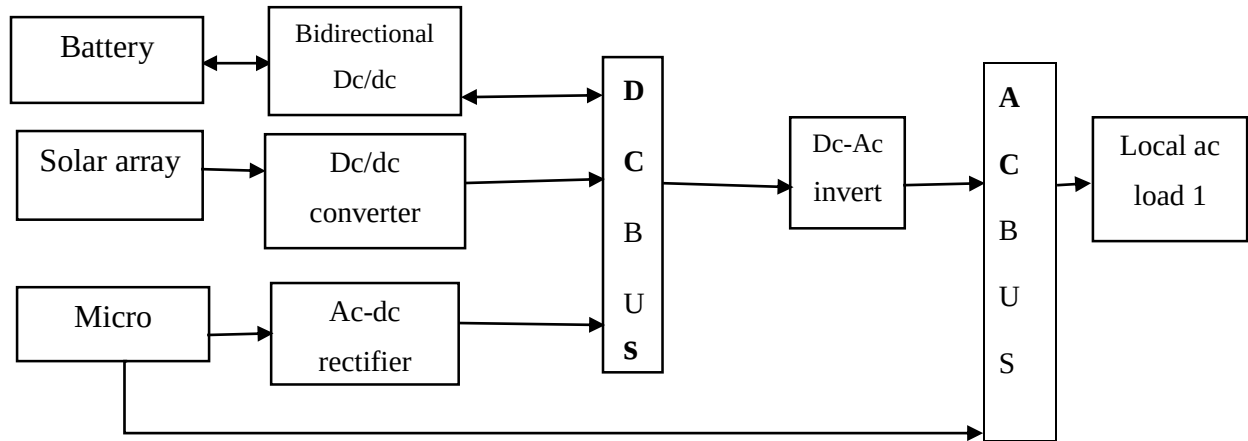


Figure 3.3 Proposed system block diagrams

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 have enlisted as below” (Lachore *et al.*, 2021).

1. Details about the types of appliances customers use.
2. The dimensions or overall area of residential buildings.
3. How old or recently acquired the equipment is.
4. Innovations and developments in technology.

5. Patterns in how consumers use electricity.
6. Trends in population growth and structure, typically factored into statistical and simulation models through the end-use method.
7. Financial indicators like average income per person.
8. The rate of employment within the population.
9. The cost of electricity is considered in econometric modelling.

Assume 1.5% energy demand growth, forecast for 15 years.

Future value = present value of energy (1 + %increases)^k3.28

$$\text{Total energy per year} = 365 * \frac{95.77 \text{kw}}{\text{day}} = \frac{34.956 \text{MW}}{\text{Year}}$$

$$\text{Energy demand after 15 years} = \frac{34.956 \text{MW}}{\text{Year}} * (1 + 0.015)^{15}$$

$$= \frac{34.956 \text{MW}}{\text{Year}} * 1.160540825$$

$$= \frac{40.56787 \text{MW}}{\text{Year}}$$

3.8 Annual Energy Loss Estimation

To evaluate the efficiency of the hybrid solar-hydro microgrid system designed for Jarso Bam Bache, it is essential to quantify the energy losses that occur annually due to system inefficiencies in hydraulic and electrical components.

A. Theoretical Annual Energy Output from Hydropower

Given:

Gross Head = 10 m

Flow Rate (Q) = 1.5 m³/s

Water Density (ρ) = 1000 kg/m³

Gravity (g) = 9.81 m/s²

The theoretical power output from the hydropower system is calculated using:

$$P_{\text{theoretical}} = \rho \cdot g \cdot H_{\text{gross}} \cdot Q = 1000 \cdot 9.81 \cdot 10 \cdot 1.5 = 147,150 \text{ W} = 147.15 \text{ kW}$$

Annual energy output (no losses):

$$E_{\text{theoretical}} = 147.15 \cdot 8760 = 1,288,314 \frac{\text{kWh}}{\text{year}}$$

B. Actual Annual Energy Output (Considering Losses)

Using the actual turbine and generator efficiencies:

$$\text{Turbine Efficiency} = 0.603$$

$$\text{Generator Efficiency} = 0.90$$

$$P_{\text{actual}} = 147.15 \cdot 0.603 \cdot 0.90 = 79.92 \text{ kW}$$

$$E_{\text{actual}} = 79.92 \cdot 8760 = 700,339.2 \frac{\text{kWh}}{\text{year}}$$

C. Total Annual Energy Loss

$$E_{\text{loss}} = E_{\text{theoretical}} - E_{\text{actual}} = 1,288,314 - 700,339.2 = 587,974.8 \frac{\text{kWh}}{\text{year}}$$

D. Loss Percentage

$$\text{Loss \%} = \left(\frac{587,974.8}{1,288,314} \right) * 100 \approx 45.65\%$$

The Jarso Bam Bache hybrid microgrid system experiences an estimated 45.65% of energy loss annually, primarily due to hydraulic friction, turbine inefficiencies, and electrical conversion losses. This represents approximately 45.65% of the theoretical energy potential, highlighting the critical importance of component selection and system optimization.

HOMER Software

The Hybrid Optimization Model for Electric Renewables (HOMER), created by the U.S. National Renewable Energy Laboratory (NREL), is a versatile software tool used in various energy generation applications. A primary function of HOMER is to support the design of hybrid power systems by effectively evaluating different renewable energy technologies. The software enables optimization by comparing a wide range of equipment under specific constraints and sensitivity factors, helping to refine system design.

HOMER simulates both the physical performance and life-cycle costs of a hybrid power system, which includes all expenses associated with installation and operation throughout the system's life. This model allows designers to assess various configurations from both technical and economic perspectives, making it easier to select the best option. Additionally, HOMER helps users understand and quantify the impact of uncertainties or input changes, delivering optimized, cost-effective solutions for power system challenges (Beluco *et al.*, 2020).

HOMER evaluates numerous system configurations to identify the best-performing option. In the optimization process, it selects the most optimal configuration from all those generated during the simulation, ensuring it meets all technical requirements and achieves the lowest life-cycle cost. The purpose of this optimization tool is to find the ideal value for each decision variable that is of interest to the modeler. HOMER determines the optimal sizes and quantities of each component by considering multiple size and quantity options, as specified by the designer in the optimization process (Lambert, 2006).

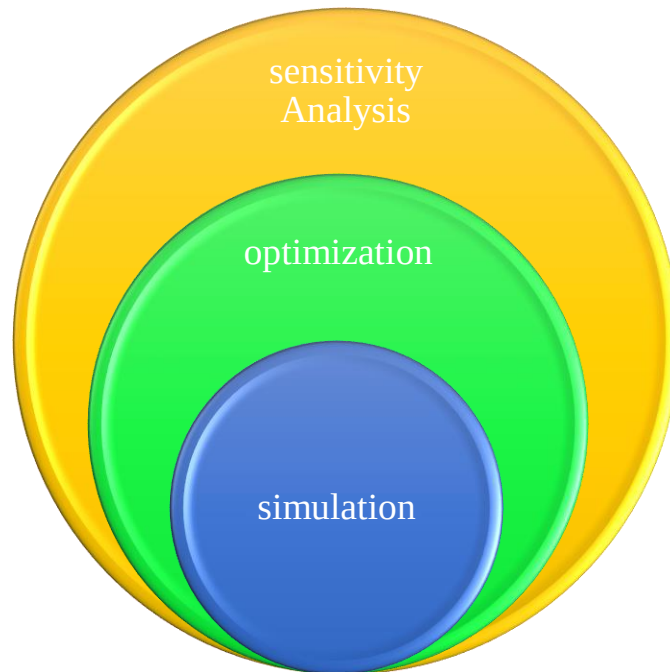


Figure 3.4 Relationship between simulation, optimization, and sensitivity analysis (Lambert, 2006).

Table 3.4 Sensitivity Analysis of Hybrid System

	Replacement Cost (\$) multiplication	Sensitivity to resource
PV	1.1	4.55 kW/m ² and 6.55 kW/m ²
Hydro	1.01	100L/s and 500L/s

Input data to the Homer Software

Resource availability is a crucial factor in electricity generation. Different energy sources, such as hydropower, biogas, and solar, play an important role in determining a system's Feasibility Study and Design of Solar resources are largely influenced by latitude and climate, while hydro resources depend on local rainfall and terrain, and biomass relies on local biological productivity.

Renewable resources often exhibit considerable variability, both seasonally and hourly, at any given location. The availability of these renewable energy sources directly impacts the performance and economic viability of renewable power systems. Therefore, precise modeling of renewable resources is essential for effective system design and optimization.

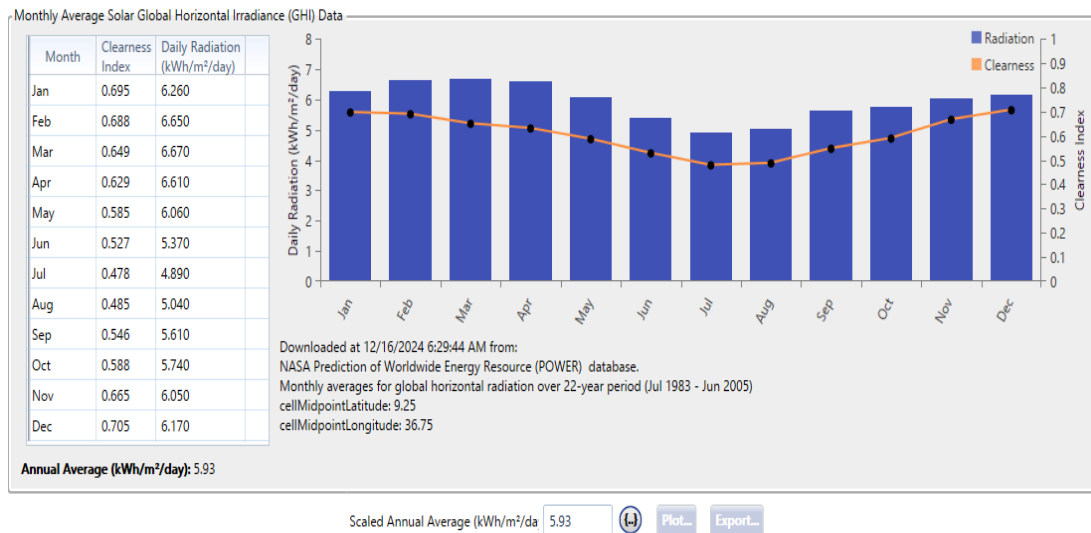


Figure 3.5 Solar resource

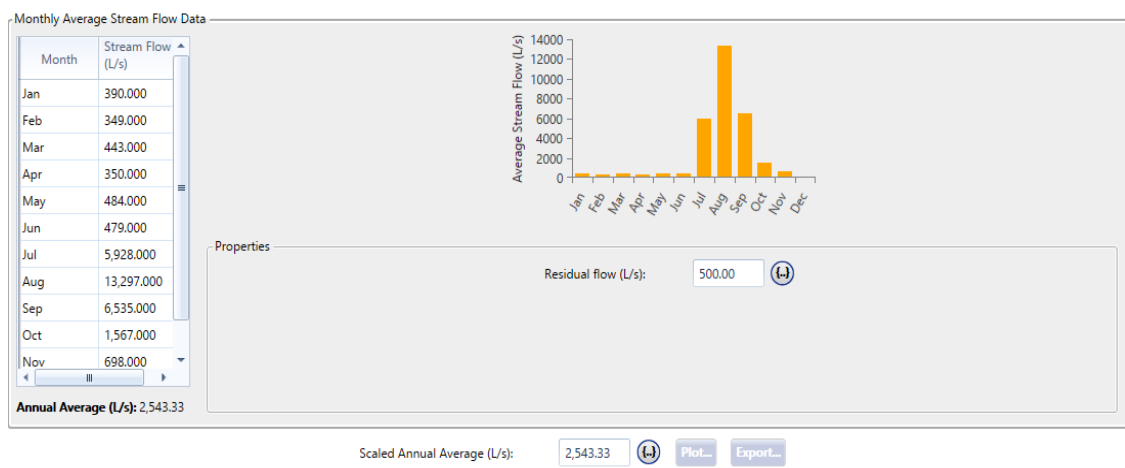


Figure 3.6 Hydro flow rate (L/s) resource

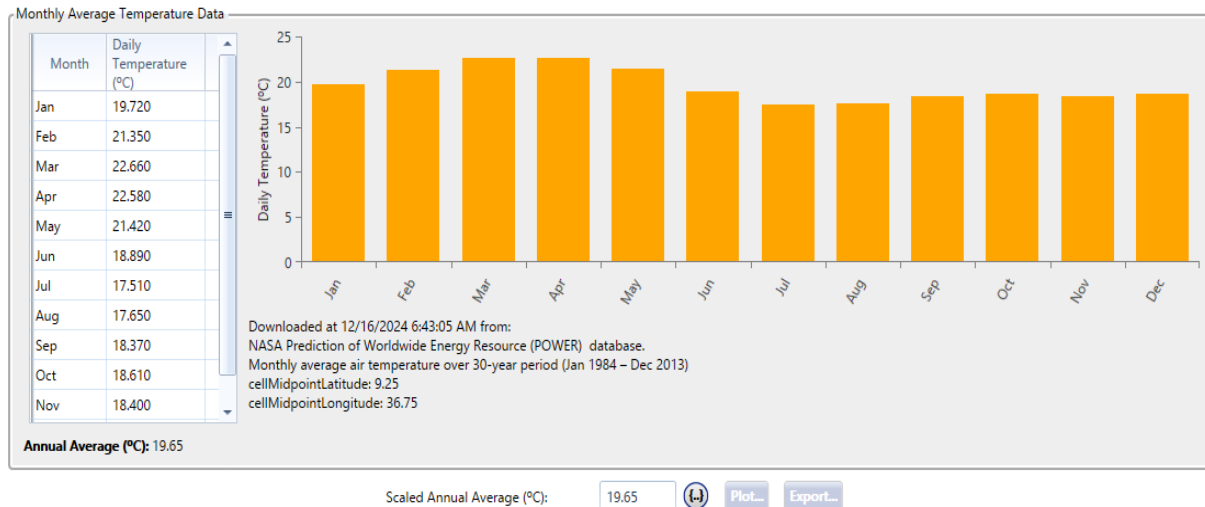


Figure 3.7 Temperature

HOMER can model loads for solar and micro-hydro systems to address various energy demands. Solar energy primarily supplies the primary load during daylight hours, meeting electrical demand based on a specific schedule. Micro-hydro systems, with their consistent energy generation, can complement solar energy by reliably meeting both primary and deferrable loads. Deferrable loads, which are less time-sensitive, can be managed effectively by utilizing the continuous output of micro-hydro or excess solar energy when available.

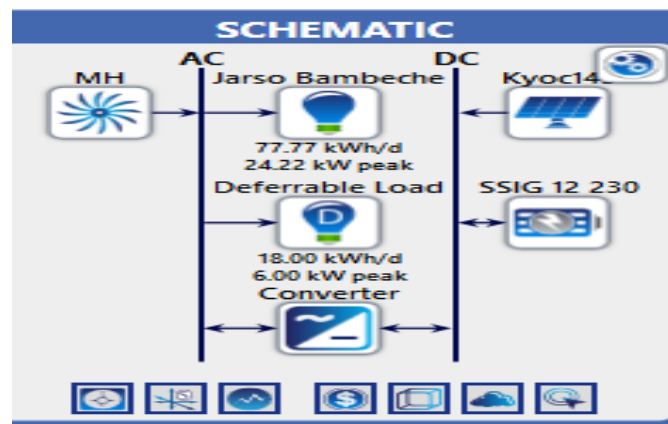


Figure 3.8 schematic configuration of a standalone system

The schematic diagram of the system includes the Solar Panel, Battery, Converter, Micro-Hydro hybrid power generator system, and a hybrid model configured for both Standalone and Grid-connected modes to supply energy to Jarso Bambeche's residential and deferrable loads.

Figure 3.9 presents the electric load profile of Jarso Bambeche village, highlighting both residential and community energy usage trends for the year 2022. The daily load pattern reveals higher consumption during afternoon and evening hours, mainly due to activities like lighting, operating radios, TVs, refrigerators, and a flour mill. The seasonal profile demonstrates fairly uniform energy demand across different months, with only slight fluctuations. The yearly heat map shows consistent daily load behavior, with occasional increases likely linked to seasonal or communal events. The input data includes total energy needs from households as well as public facilities such as the health post, elementary school, churches, and mosque, each contributing to the load at varying times of the day.

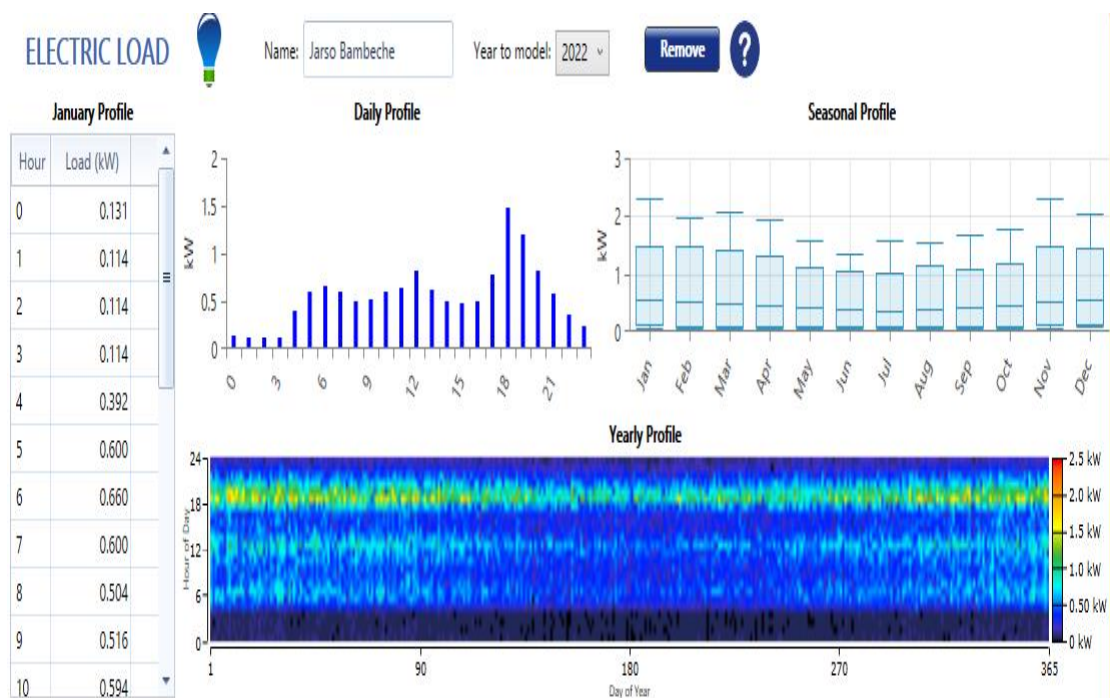


Figure 3.9 Residential load Profile in Jarso Bam beche

CHAPTER FOUR

4 SIMULATION RESULT AND DISCUSSION

4.1 MATLAB Simulink

MATLAB software is used to model, simulate, and analyze dynamical systems in the Simulink environment. The overall system consists of a PV, Battery, Converter, and Hydro Governor. Hydro systems are nonlinear in nature, and the output of the hybrid system is displayed. To manage these systems, a PID controller is implemented. Individual controllers are also used to extract the maximum voltage from the hydro and PV systems. The total generated power output from the hybrid model in this MATLAB Simulink setup is 30.2025kW.

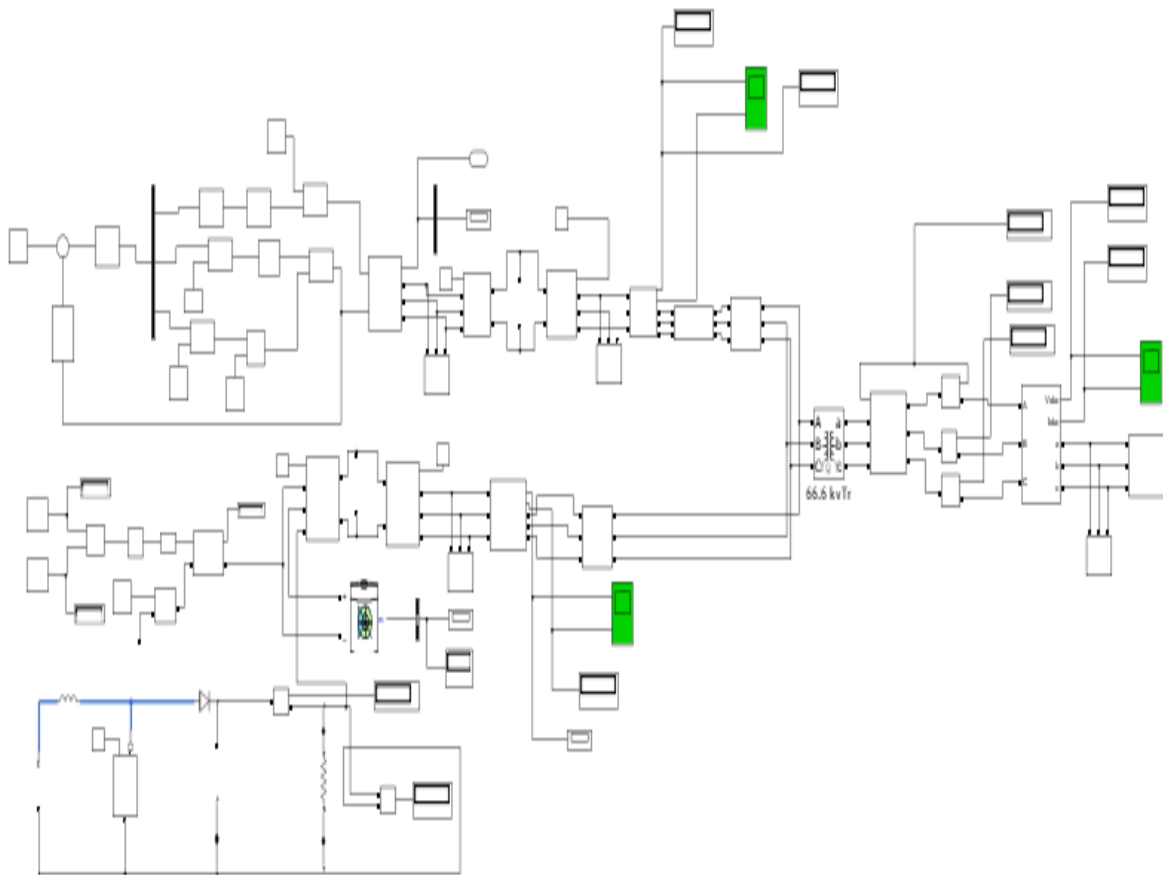


Figure 4.1 Overall simulation model of a hybrid system

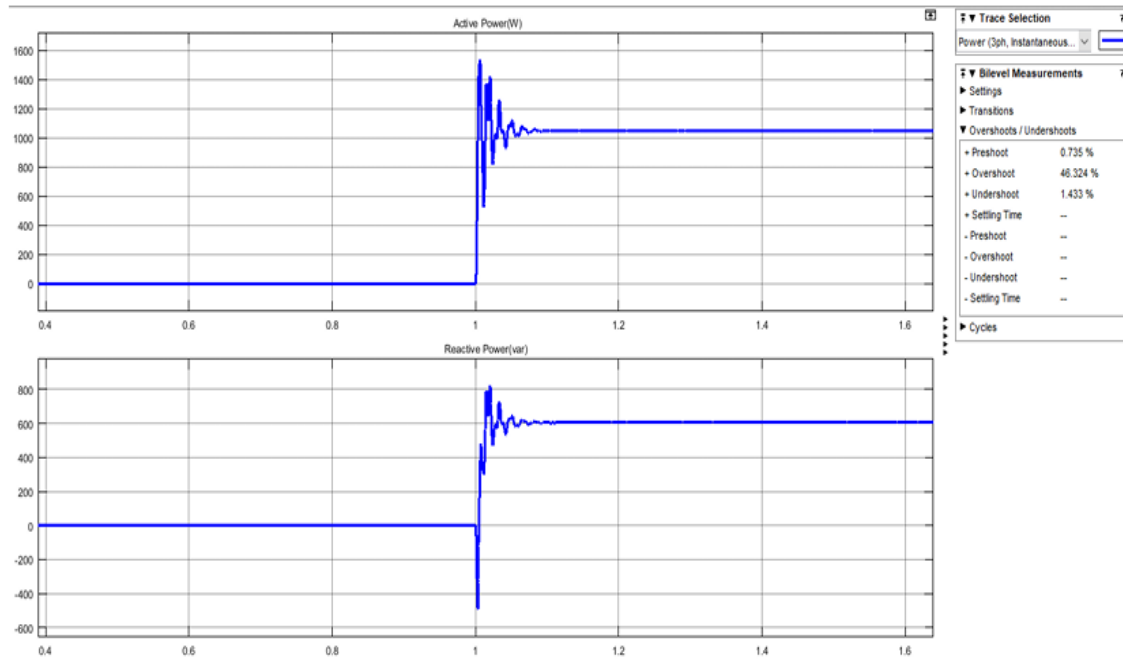


Figure 4.2 hybrid active and reactive power out put

Active Power (W)

The x-axis represents **time** (in seconds).

The y-axis represents **active power** in watts.

Initially, the system is steady (power = 0 W).

At $t \approx 1$ s, there's a sudden increase in active power.

This is followed by oscillations (transients) that gradually settle to a new steady-state value.

The system shows a **step response**, likely due to a load connection or inverter synchronization.

Reactive Power (Var)

Again, the x-axis is **time** (s), and the y-axis is **reactive power** in vars.

Initially, reactive power is constant.

At $t \approx 1$ s, there's a sharp dip followed by oscillations.

It stabilizes at a new value again showing a transient response

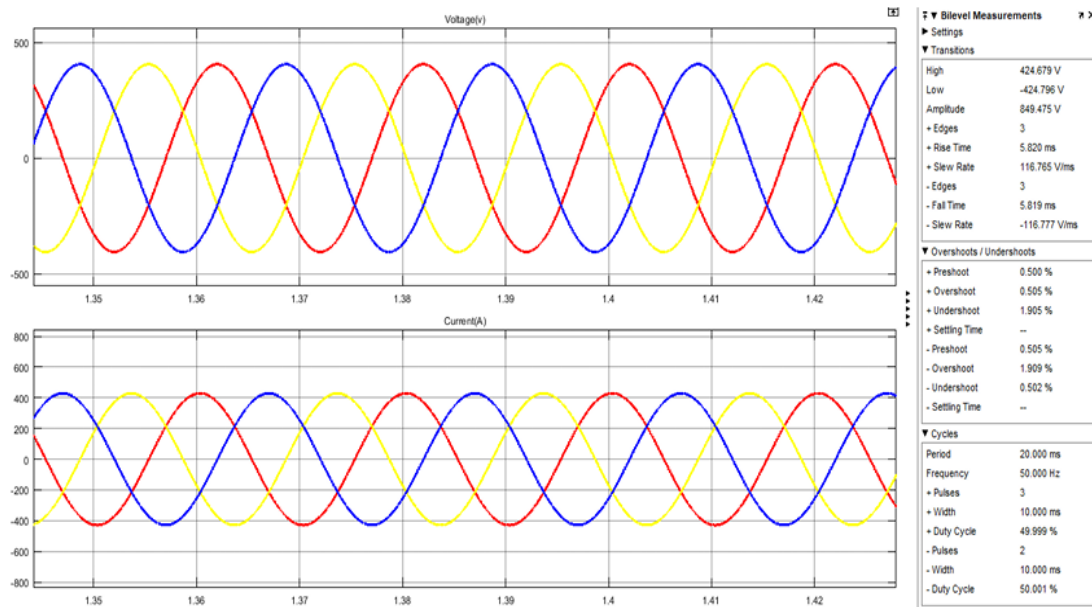


Figure 4.3 Three phase voltage and current of hybrid system

The simulation shows results after 1 second to highlight the steady-state sinusoidal behavior of the three-phase voltages and currents, avoiding the noisy or unstable transients present at startup. This approach ensures accurate analysis of system performance under normal operating conditions.

Figure 4.3 illustrates both active and reactive power, indicating an output power of 30.2025 kW and a reactive power of 66.6 kVAR. The system exhibits a preshoot of 0.735%, an overshoot of 46.324%, and an undershoot of 1.433%.

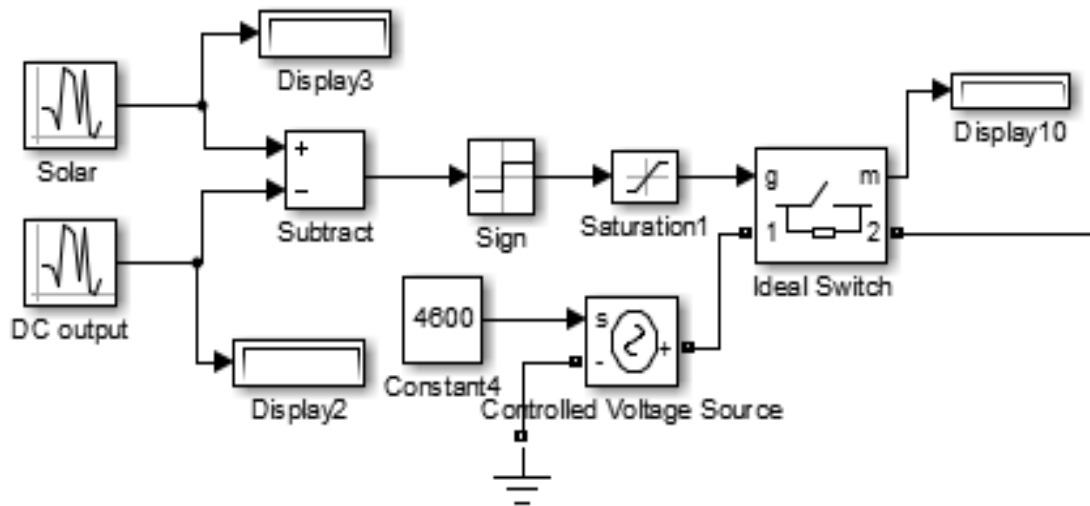


Figure 4.4 MATLAB Simulink model of solar PV system

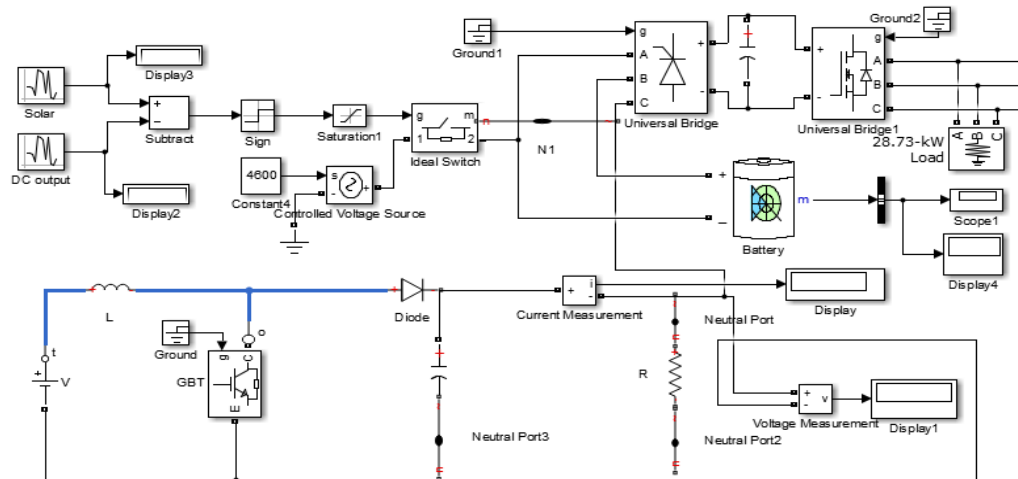


Figure 4.5 solar system with converter

This MATLAB Simulink model simulates a hybrid renewable energy system primarily powered by a solar PV array with battery storage, supplying a 28.73 kW AC load through a universal bridge inverter. It features a control mechanism using a voltage-controlled switch and feedback loop to regulate power flow from the DC source. The lower section includes a DC-DC converter circuit, which likely represents a grid interface or backup generator input. Current and voltage measurement blocks are used to monitor system behavior and ensure reliable energy delivery. The model evaluates the performance of energy conversion, control strategy, and load management within a hybrid standalone or grid-supported configuration.

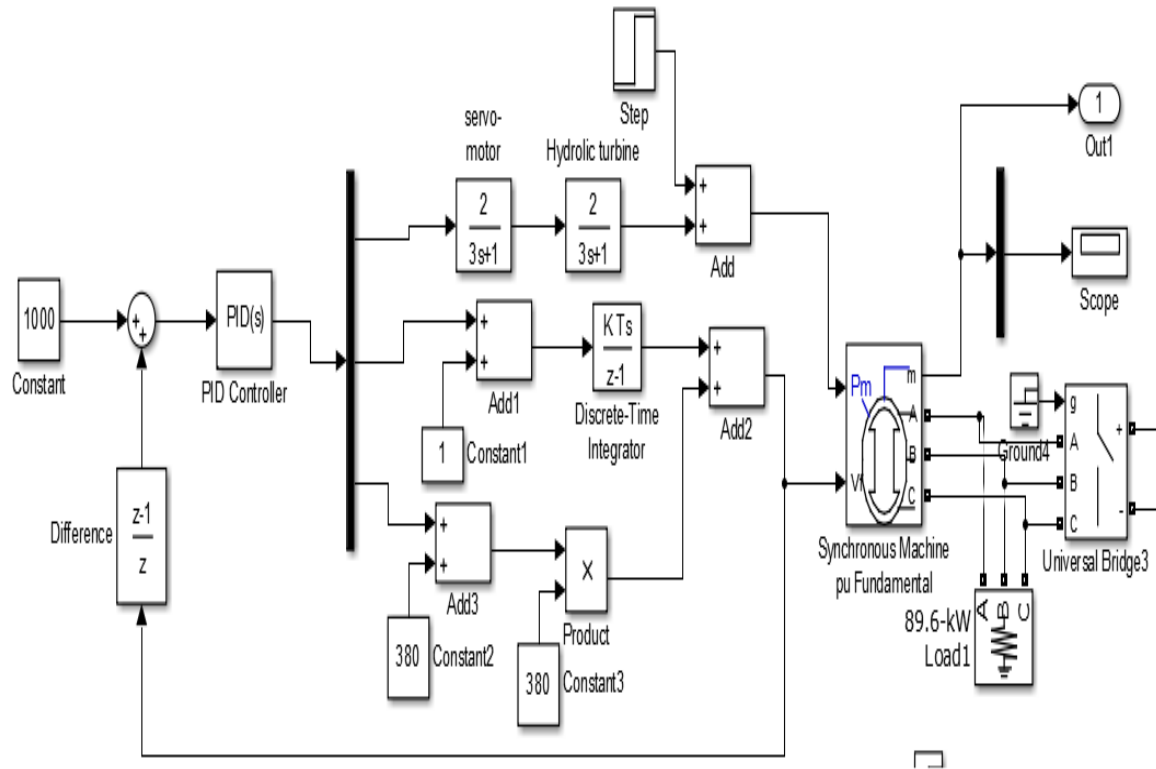


Figure 4.6 Hydropower system

4.2 Simulation result and discussion

In a standalone system, Figure 4.8 presents three optimized configurations:

First Case: This setup includes nearly all available energy sources

Second Case: This option consists of hydropower, a converter, and a battery.

Third Case: This configuration includes a photovoltaic (PV) system, a converter, and a battery.

Last Case: This setup combines PV, hydropower, and a converter.

Export...

Export All...

Sensitivity Cases

Compare Economics

Column Choices...

Click on a sensitivity case to see its Optimization Results.

Sensitivity		Architecture						Cost				System		Project Economics			
Nominal Discount Rate (%)	Diesel Fuel Price (\$/L)				PV (kW)	Gen (kW)	SSIG 12 230 (#)	Converter (kW)	Dispatch	NPC (\$)	LCOE (\$/kWh)	Operating cost (\$/yr)	CAPEX (\$)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Simple Payback (yr)
12.0	0.500				60.2		66	19.9	CC	\$95,301	\$0.202	\$6,141	\$47,138	100	0	76	1.3
3.00	0.500				56.6		72	18.0	CC	\$157,373	\$0.150	\$6,305	\$47,591	100	0	75	1.3
6.00	0.500				59.0		67	18.9	CC	\$127,825	\$0.166	\$6,313	\$47,118	100	0	76	1.3
12.0	1.00				60.2		66	19.9	CC	\$95,301	\$0.202	\$6,141	\$47,138	100	0	124	0.88
3.00	1.00				56.6		72	18.0	CC	\$157,373	\$0.150	\$6,305	\$47,591	100	0	122	0.89

Export...

Export Details...

Optimization Results

Double click on a system to see its Simulation Details.

Categorized

Overall

Architecture						Cost				System		Project Economics		Gen			
			PV (kW)	Gen (kW)	SSIG 12 230 (#)	Converter (kW)	Dispatch	NPC (\$)	LCOE (\$/kWh)	Operating cost (\$/yr)	CAPEX (\$)	Ren Frac (%)	Total Fuel (L/yr)	IRR (%)	Simple Payback (yr)	Hours	Production (kWh)
			60.2		66	19.9	CC	\$95,301	\$0.202	\$6,141	\$47,138	100	0	76	1.3		
			49.9	28.0	46	13.6	LF	\$110,691	\$0.227	\$7,848	\$49,140	79.6	4,623	66	1.5	1,050	12,629
				28.0	22	9.30	CC	\$200,150	\$0.411	\$22,397	\$24,491	0	23,173	89	1.2	4,403	68,997
			118	28.0			CC	\$234,146	\$0.481	\$23,572	\$49,269	14.3	22,758	20	5.5	6,522	53,188
				28.0			CC	\$256,412	\$0.527	\$30,907	\$14,000	0	31,614			8,760	75,875

Figure 4.7 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, Battery Autonomy 3.12hr, Excess Electricity 63.5, a capacity shortage 1.92, unmet electrical load 1.92, mean output power 30.2025kW and the model is 100% renewable. The COE and NPC are relatively the best compare to the other option.

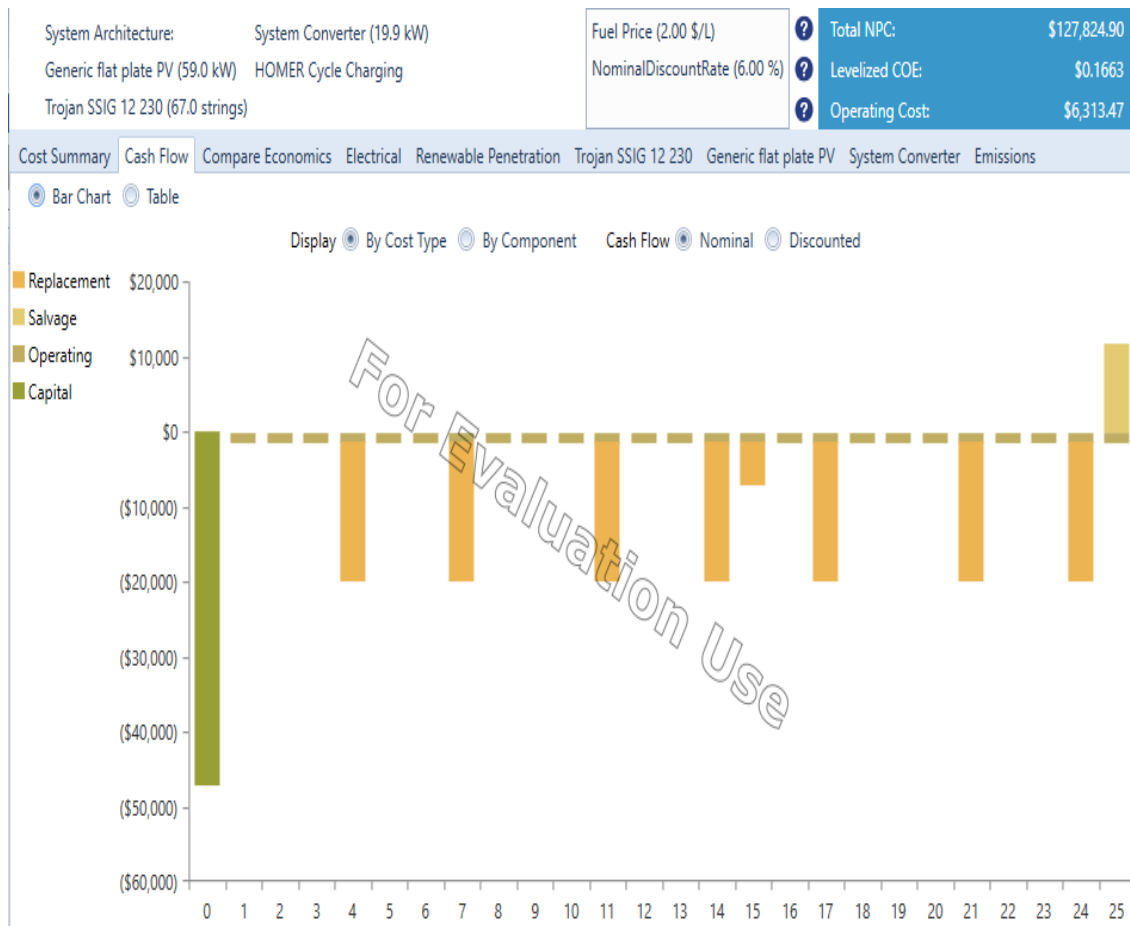


Figure 4.8 Standalone system of the component with a nominal value 1st case

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

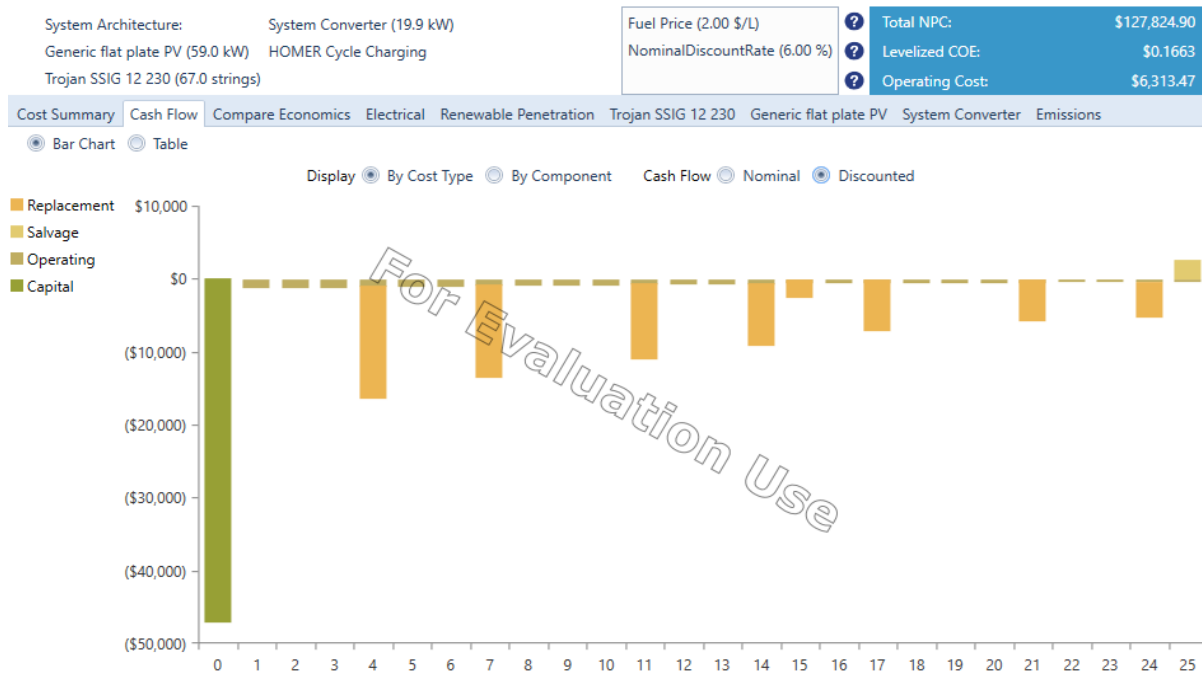


Figure 4.9 Standalone with discounted from the 1st option

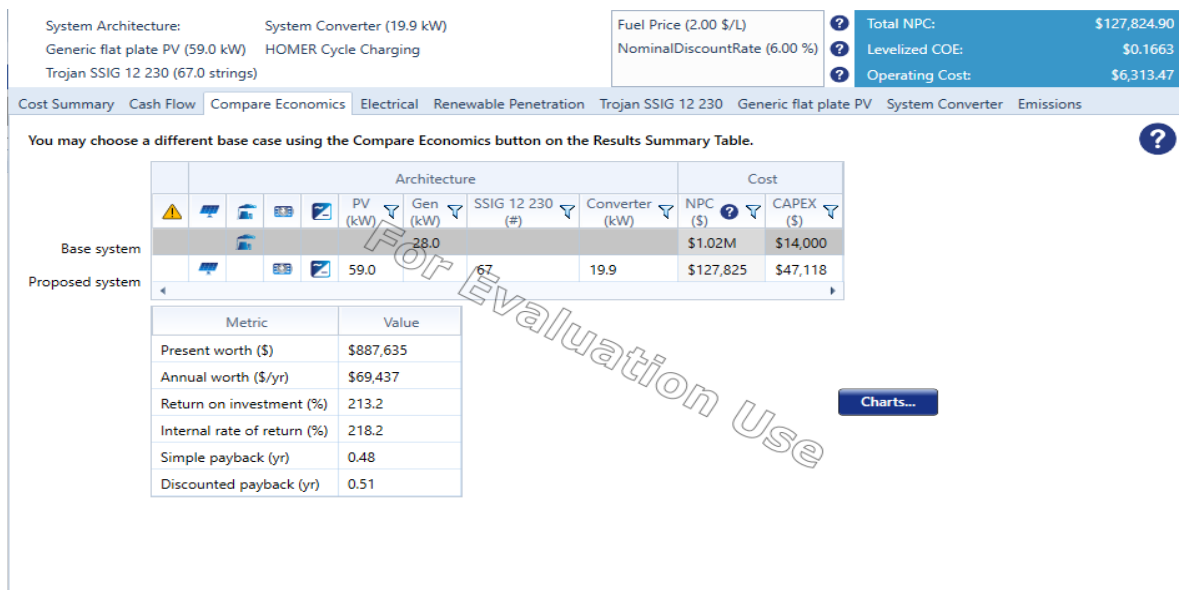


Figure 4.10 Economical comparison of standalone hybrid configuration from the 1st case

In the economic analysis comparing the base system with the current standalone hybrid configuration, the results show a present worth of \$887,635, an annual worth of \$69,437 per year, a return on investment of 213.2%, an internal rate of return of 218.2%, a simple payback period of 0.48 years, and a discounted payback period of 0.51 years.

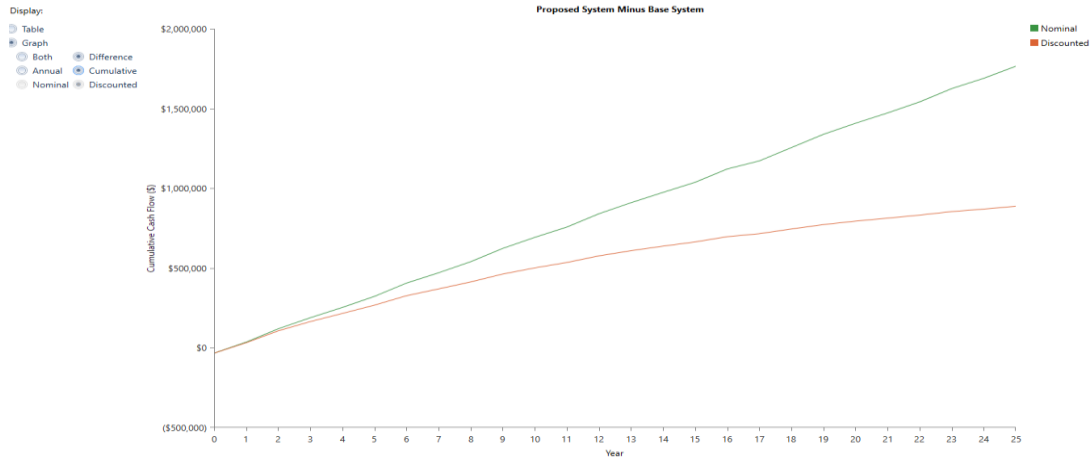


Figure 4.11 Current system mines base case standalone hybrid configuration from the 1st case

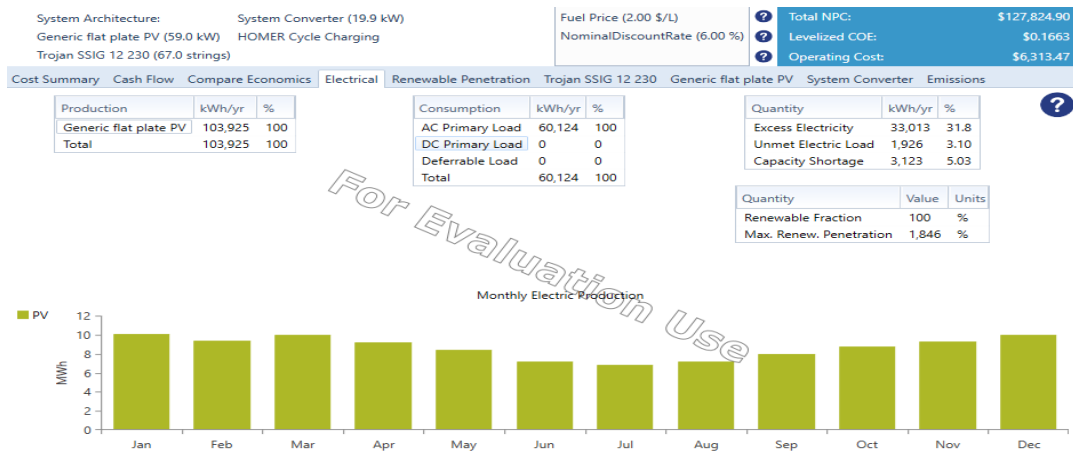


Figure 4.12 Electrical properties of standalone hybrid system from the 1st case

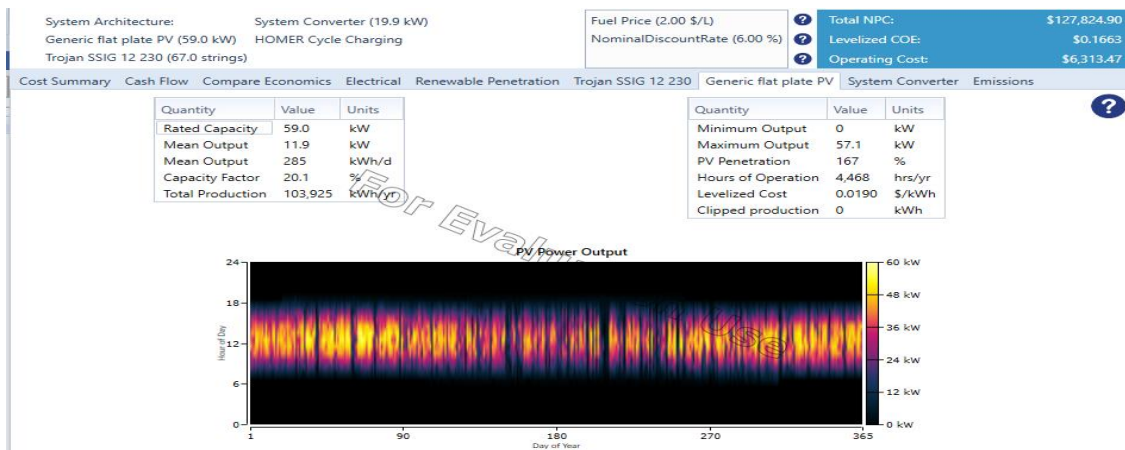


Figure 4.13 Solar result of a standalone hybrid system from the 1st case

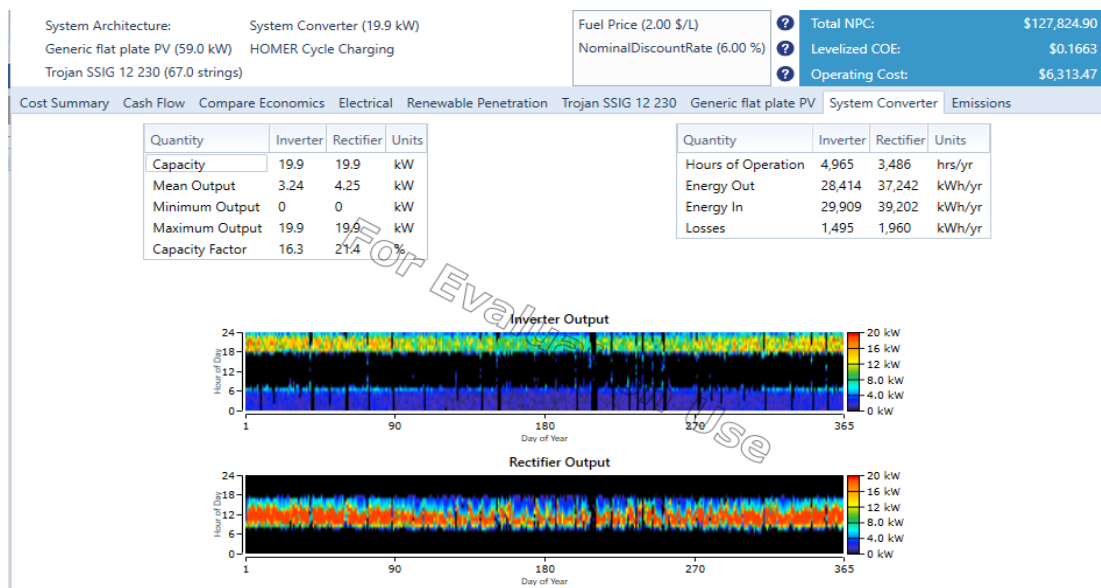


Figure 4.14 System Converter result of a standalone hybrid system from the 1st case

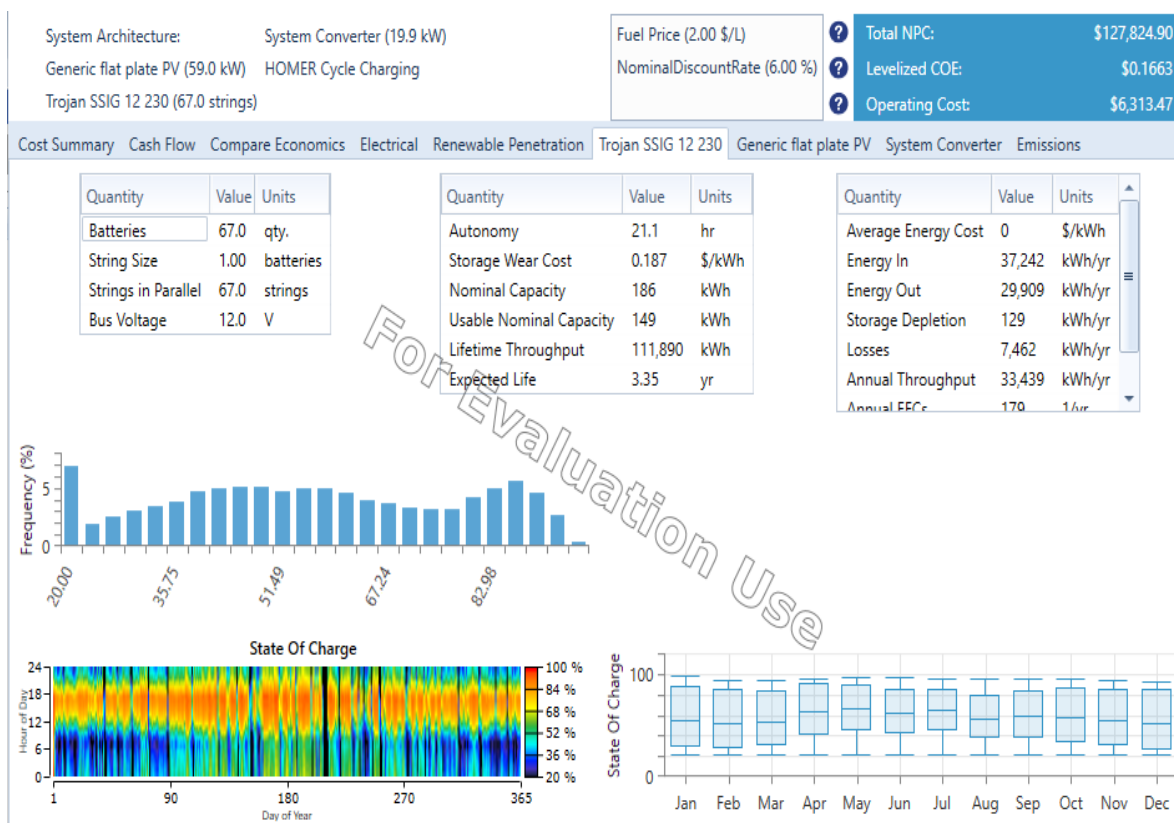


Figure 4.15 Battery result in standalone hybrid system from the 1st case

Second Case: This configuration includes hydro power, a converter, and a battery. The optimization results show a cost of energy (COE) of \$0.1730 per kWh, a net present cost (NPC) of \$9.27 million, and an annual operating cost of \$438,873. The yearly operation and maintenance (O&M) expense is \$428. The system offers a battery autonomy of 4.11 hours, with 61.6% excess electricity, a capacity shortage of 1.92%, and an unmet electrical load also at 1.92%. The average power output is 30.205 kW, and the model operates entirely on renewable energy. Although the COE and NPC are somewhat higher compared to the first option, the battery lifespan is notably better.

Third Case: This setup includes a photovoltaic (PV) system, a converter, and a battery. The optimization results indicate a cost of energy (COE) of \$0.5773 per kWh and a net present cost (NPC) of \$30.92 million. The annual operating cost is approximately \$1.40 million, with operation and maintenance (O&M) costs totaling \$8,570 per year. The system provides a battery autonomy of 30.4 hours, generates 33.9% excess electricity, experiences a capacity shortage of 1.93%, and has 1.92% unmet electrical load. This model is fully powered by renewable energy sources. The load is heavily reliant on solar power. While the COE and NPC show significant variation compared to other options, the battery life is superior to both the first and second configurations.

Last Case: This configuration includes PV, hydro power, and a converter. According to the optimization results, the cost of energy (COE) is \$0.762 per kWh, and the net present cost (NPC) is \$40.4 million. The system has an annual operating cost of \$2.35 million and an operation and maintenance (O&M) cost of \$8,932 per year. It produces 71.5% excess electricity, with a capacity shortage of 12.9% and an unmet electrical load of 2.94%. The model is entirely powered by renewable energy sources. The energy supply relies primarily on hydro (75.7%) and solar (23.9%). Compared to the first, second, and third scenarios which include batteries this option shows a significant increase in both COE and NPC.

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 3st case and the Last Case are not recommended due to expansively, 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 comparison of standalone system with national grid of Ethiopia

Table 4.1 Cost comparison of standalone with grid

Range of energy(kWh)	Designed standalone COE	Grid connected COE in 2015EC
>100	0.1718	1.5870

For a microgrid system, we can similarly compare the cost-effectiveness of a standalone microgrid versus a grid-connected system using percentage reduction:

$$\begin{aligned}
 \text{Percentage cost reduction} &= \frac{(\text{Grid COE} - \text{Standalone COE})}{\text{Grid COE}} * 100\% \\
 &= \frac{(1.5870 - 0.1718)}{1.5870} * 100\% \\
 &= 89.2\%
 \end{aligned}$$

This means that a microgrid system is 89.2% more cost-effective than a grid-connected system. Therefore, for electrifying remote villages, a microgrid system is strongly preferable over a grid extension due to its significantly lower cost of energy.

CHAPTER FIVE

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The feasibility study and system design for a standalone solar-hydro hybrid microgrid in Jarso Bam Bache village demonstrate the viability of decentralized renewable energy solutions for off-grid rural communities. The hybrid system integrates a 91.522 kW micro-hydro generator, a 28.731 kW solar PV array, and an appropriately sized battery storage system, designed to provide a continuous, stable, and reliable electricity supply that meets the village's daily energy demand of approximately 95.77 kWh.

Comprehensive simulations were conducted using HOMER Pro and MATLAB Simulink to validate the system's performance. The results indicate that the proposed hybrid system can operate efficiently year-round, leveraging the river's consistent flow for hydro generation and the region's high solar irradiance for photovoltaic energy production. The simulation outcomes reveal a Levelized Cost of Electricity (LCOE) of \$0.1718/kWh, which is substantially lower than the estimated cost of extending the national grid to this remote location. This makes the hybrid solution both technically feasible and economically competitive.

The integration of both energy sources allows for optimal resource use: during sunny daytime hours, the solar PV system supplements the hydro power and charges the battery bank, while during cloudy periods and at night, the micro-hydro and stored battery energy maintain the electricity supply. This synergy enhances system reliability and energy security, avoiding power shortages and reducing operational costs.

Beyond technical performance, the proposed hybrid system offers significant socio-economic and environmental benefits. It reduces reliance on traditional biomass and kerosene, thereby lowering indoor air pollution and deforestation risks. Furthermore, access to reliable electricity is expected to improve educational infrastructure, healthcare services, small business productivity, and irrigation potential in the village contributing to an overall improvement in quality of life.

In conclusion, the analysis confirms that the hybrid solar-hydro microgrid is a transformative solution for rural electrification in Jarso Bam Bache. The design is not only technically sound and economically justified but also aligned with national and global sustainability goals. This model can be replicated in similar off-grid rural areas across Ethiopia and Sub-Saharan Africa.

5.2 Recommendation

Ethiopia has abundant renewable energy resources that can be effectively utilized to electrify remote areas through off-grid systems. However, several challenges hinder rural electrification, including low purchasing power among local communities, unfavourable conditions for renewable energy adoption, and a lack of awareness regarding its benefits. Addressing these challenges requires a collaborative effort from the government, non-governmental organizations, and the private sector.

- ✓ This study focuses on a specific remote area in Ethiopia and does not encompass all rural communities. Future research should expand to other locations to ensure that more rural populations benefit from available renewable energy resources.
- ✓ To ensure a sustainable energy supply, a standalone solar hydro micro grid system is recommended for future implementation. Investments from the government and private sector in this system would contribute to national energy growth while also serving as a sustainable source of income. Implementing this hybrid system in the target area could significantly improve the community's living standards and lay the groundwork for further research across the country.
- ✓ Finally, the Feasibility Study and Design affordability of the proposed system have been demonstrated through simulations using MATLAB and HOMER software. To facilitate the transition of this research from theory to practical implementation, universities should establish strong collaborations with governmental and non-governmental organizations.

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