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Title: Hybrid PV/ Hydropower plant generation optimization using Linear Programming
Case Study of Mutobo Hydro power plant

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DECLARATION

I declare that this Dissertation contains my own work except where specifically acknowledged, and it has been passed through the anti-plagiarism system and found to be compliant and this is the approved final version of the thesis.

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December, 2023

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To achieve to what we need regardless challenges we faced, we need help from God that it is why I thank God for protecting and advising me.

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ABSTRACT

The optimization of the Hybrid PV/Mutobo-Hydropower plant generation using linear programming is very important in the operation of power plant. The suitable choice of the hybrid system that optimizes its size and costs components are crucial and challenging jobs, funding for the system sanity. In this thesis, the issue is stated as an optimization maximize the cost profitability. The hybrid system design process makes use of the suggested approach. The case study is Mutobo hydropower plant located in Rwanda, northern province. The suggested linear programming's dependable, quicker and offers outstanding, practically optimal solution of the investment costs systems with many renewable energy sources included. The outcomes demonstrated the viability of the hybrid PV and hydropower system and its ability to mitigate the effects of power shortages in distant places during the dry season.

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ABBREVIATIONS

IPP'S: Independent Power Producers Integrated personnel and Payroll system

PSO: Particle Swarm Optimization

DE: Differential Evolution

NSWOA: Non-dominated Sorting Whale Optimization Algorithm

HES: Hybrid Energy Systems

AC: Alternating Current

PV: Photovoltaic

DC: Direct Current

RES: Renewable Energy Systems

HPP: Hydropower Plant

KW: Kilowatt

Chapter I. Introduction

1.1. Background

Many countries have been investing in energy generation to meet the load demand. Different technologies have been employed. Sometimes, hybrid systems are used, yet a strong optimization tool is needed to optimize a hybrid system. Rwanda as other countries has been using some hybrid technologies to meet the load demand behavior. Similarly, independent power producers Integrated personnel and Payroll system (IPPS) in Rwanda use such kind of system with various tools of optimizing the energy production. Popular hybrid system is PV/Hydropower system because it combines two green technologies. To move towards the green energy optimum use for the future, it's important to use renewable energy sources to increase the power generation which is a good idea to use a mix of different renewable energy sources like solar and Hydro power. Using these different sources together makes the energy system more reliable and reduces the need for big storage systems. Choosing the right combination of energy sources and the right size for the system is important, but it can be tricky. There are different methods and tools that scientists use to figure out the best way to design these systems. Some methods are based on math and logic, while others are based on trial and error or past experience[1][2].

In Rwanda, many small, mini and pico- hydro power plants have potential to be upgrade to the hybrid system. The solar is the best candidate source of energy to be involved in the hybrid generation system since in Rwanda the solar energy is abundant. Using this hybrid system can help small, mini and pico- hydro power plants to be reliable. Many of this hydro power plants have been having a challenge to meet the power purchasing agreement because they face a kind of power shortage due to water flow variation, especially in summertime. Mutobo hydro power plant located in Rwanda, Northern province is one among the small, mini, and pico- power plant that are facing this challenge. It was built in 2009 and has an installed capacity of 200 KW. Since its construction time, it has been not a reliable power plant because during the high sunshine time its power production decreases[3][4].

1.2. Problem Statement

Mutobo hydro power plant needs a solution to mitigate the challenge of power production reduction during the sunny periods. Combining a PV system with Mutobo hydro power plant can be a solution. Yet, a problem is to know which optimization tool that is efficient while Mutobo power plant is combined with a PV system to become a hybrid system. In other words, many hybrid system optimization tools were used. Some are complex and expensive and the question comes to which simplest PV/hydro power plant generation optimization tool to minimize the PV initial cost as well as the cost of maintenance and operation while maximizing the generation power.

1.3. Objectives

1.3.1. Main objective

The main objective is to optimize the Hybrid PV/ Mutobo-Hydropower plant generation using linear programming.

1.3.2. Specific Objectives

The specific objectives of the present study are as follows:

- i. Model the Hybrid PV/ Hydropower plant generation
- ii. Optimization of the Hybrid PV/ Hydropower plant generation
- iii. Analyze the findings

1.4. Scope of the study

Due to the financial and time constraints, this thesis is focusing the Hybrid PV/ Hydropower plant generation optimization using Linear programming, the case Study of Mutobo Hydro power plant.

1.5. Expected Outcomes and Significance of the Study

1.5.1. Expected Outcome of the Study

Once the study is successfully conducted, there will be:

- **Maximized Power Generation:** The linear programming model can optimize the operation to maximize the total power output of the hybrid system. It considers factors like sunlight availability for the PV panels and water flow for the hydropower turbines. The goal is to efficiently use both resources to produce as much electricity as possible.
- **Cost Minimization:** Another objective could be to minimize the cost of energy production. Linear programming can help in determining the most cost-effective way to operate the hybrid system, considering factors such as equipment maintenance, fuel costs for backup generators (if any), and operational expenses.

1.5.2. Significance of the Study

The benefit of combining hydro and solar energy is that the two sources work well together because each system's peak operating periods fall during distinct seasons of the year. Such a hybrid system may generate power more consistently and dependably. The system uses a variety of generation techniques to deliver a high level of energy security, ensuring maximum supply reliability, security and constant generation regardless of the change in season. The system is dependable since it uses renewable energy sources that cannot be depleted and are environmentally friendly.

1.6. Organization of the Study

This thesis describes the modeling, optimization, and analysis of Hybrid PV/ Hydropower plant generation optimization using Linear programming, a case Study of Mutobo Hydro power plant. The Thesis aims to optimize the Hybrid PV/ Mutobo-Hydropower plant generation using linear programming.

Chapter 1: Introduction; this chapter describes the general introduction of the whole thesis and it briefly provides the problem to solve and the expected outcomes once the project is fully conducted.

Chapter 2: Literature review; this chapter briefly discusses the related literature focusing on optimization using different tools in hybrids.

Chapter 3: Methodology; This chapter provides overview of the research steps, starting from the location to collect data, the data to be collected and method to analyze them targeting the objective of the research.

Chapter 4: Modelling and optimization of the Hybrid PV/ Hydropower plant generation: This chapter discusses optimizing and modeling using programming tools.

Chapter 5: Conclusion and recommendation It discuss the conclusion with respect to the result obtained and recommends the future researchers.

CHAP II: LITERATURE REVIEW ON PV/HYDRO POWER PLANT OPTIMIZATION

2.1. Introduction

PV/hydro power plant optimization is an interesting topic and many researchers have published various articles on it. A literature review on this topic typically covers several key aspects. However, for the present thesis the literature review focuses on hybrid in Power system, a PV hydro power plant hybrid system (system configuration), A hybrid optimization techniques.

2.2. Hybrid types in Power systems

Hybrid optimization techniques in power system refer to the combination or integration of different energy sources to improve the efficiency of a power generation station. The hybrid technique aims to leverage the strengths of two or more energy sources to overcome the limitations or weaknesses of individual sources. The following figure summarizes different configuration of hybrid types in power systems.

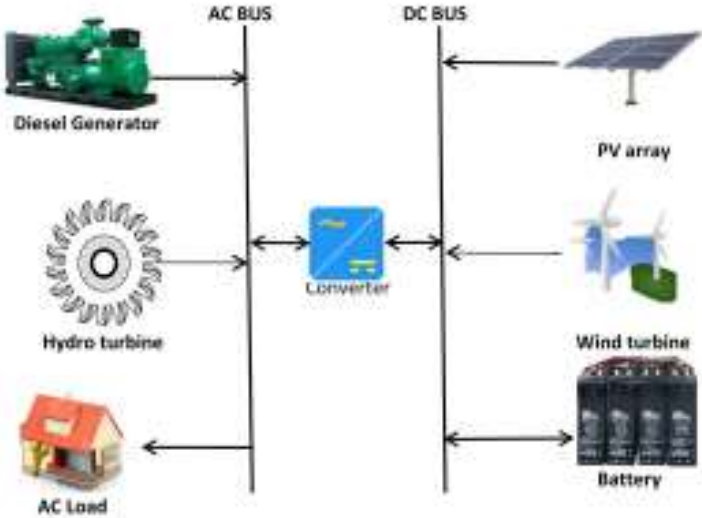


Figure 1: hybrid of Hydroelectric, a wind turbine and solar PV power plant with a diesel generator and storage system

As shown in Figure 1, A hydropower system, a photovoltaic solar system, a wind turbine system with batteries, and a diesel generator (DG) make up the hybrid energy system (HES)[5]. Micro-hydro systems are installed in regions with year-round river runoff (stream water) so that a hydroelectric plant can produce power. The diesel plant only turns on when the RESs are unable to supply the load requirement and the battery state of charge falls to 40% or below. The energy-producing apparatus combined both AC and DC buses through a bi-directional converter in order to sustain the flow of power between the following components: solar panel, wind turbine and battery storage on a DC bus, hydro turbine, and diesel generator on an AC bus to provide a more sustainable energy mix and minimize greenhouse gas emissions.

In Rwanda, mostly hybrid systems are Diesel/PV and Hydropower plant, because in order to guarantee consistency and dependability in its power supply, Rwanda seeks to diversify its energy sources. The nation may have a more dependable energy supply by combining various sources, such as hydroelectricity, which is more constant but weather-dependent, with diesel or photovoltaic (PV) systems, which offer flexibility and can operate regardless of weather conditions. Systems that are hybridized are more resilient to power outages. Dry seasons may put a restriction on hydroelectricity; however, diesel or solar power can make up for it, guaranteeing a steadier supply of electricity. Like many other countries, Rwanda is worried about lowering its carbon impact. Reducing dependency on fossil fuels like diesel through the integration of renewable energy sources like hydro and solar.[5][3].

2.2.1. Diesel hydro power plant hybrid system

A Diesel-Hydro hybrid power system integrates both diesel generators and hydroelectric power to generate electricity. The system combines the reliability of diesel generators with the renewable and generally more environmentally friendly aspects of hydroelectric power.

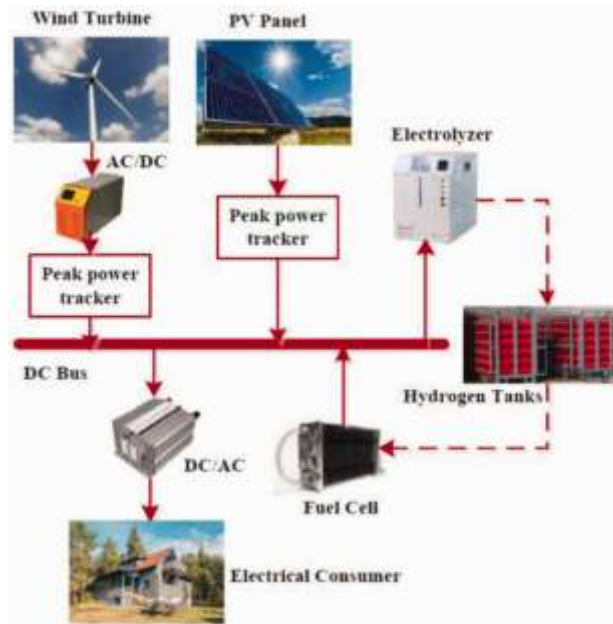


Figure 2: Diesel hydropower plant

The working principle involves utilizing both diesel generators and hydroelectric power generation components in a complementary manner. When energy demand is low or moderate, the hydroelectric power system supplies energy. During peak demand or when additional power is required, diesel generators supplement the hydroelectric generation to meet the energy demand.

Advantages

The advantages of hybrid of Diesel and hydro are listed below:

- **Reliability and Stability:** Hybrid systems provide a more reliable power supply. Hydropower is consistent and reliable, while diesel can serve as a backup during low water availability or peak demand periods.
- **Reduced Emissions:** Hydropower is a clean energy source that produces no direct emissions. By using it in combination with diesel, the overall emissions can be reduced compared to a standalone diesel plant, as diesel usage can be minimized.
- **Cost Savings:** Using hydropower, which has low operating costs once the infrastructure is in place, can reduce the reliance on diesel, which can be expensive due to fuel costs and maintenance.

- **Flexibility:** Diesel generators can be easily turned on or off to meet varying energy demands. This flexibility complements the steadiness of hydropower, allowing for better management of fluctuating energy needs.
- **Energy Security:** Having a hybrid system ensures energy security, as it lessens dependence on a single source of energy. This is especially beneficial in remote areas or regions with inconsistent grid connections.

Disadvantages:

The disadvantages of hybrid of Diesel and hydro are listed below

- **Initial Investment:** The upfront cost of implementing a hybrid system can be higher than setting up a standalone diesel or hydropower plant due to the need for both technologies and their integration.
- **Environmental Impact:** While hydropower is cleaner, it can still have environmental impacts such as habitat disruption, alteration of water flow, and potential effects on aquatic life. The diesel component, if used extensively, can contribute to pollution and environmental degradation.
- **Maintenance Challenges:** Combining two different technologies can increase maintenance complexity. Managing both diesel generators and hydropower infrastructure requires specific expertise and regular upkeep.
- **Resource Dependency:** Hydropower plants are dependent on adequate water supply and flow, which can be affected by droughts or changes in precipitation patterns. Reliance on this resource may limit the consistency of power generation.
- **Regulatory Challenges:** Complying with regulations related to both diesel emissions and hydropower operations can be complex. Meeting environmental standards for emissions while ensuring hydropower operations meet regulatory requirements can pose challenges.

2.2.2 PV hydro power plant hybrid system

A PV-hydro power plant hybrid system refers to the combination of solar panels (PV technology) and a hydroelectric power plant. It involves integrating these two renewable energy sources to generate electricity. The majority of research on hybrid hydro-photovoltaic systems ignores matching power demand to generation in favor of optimizing system power production.

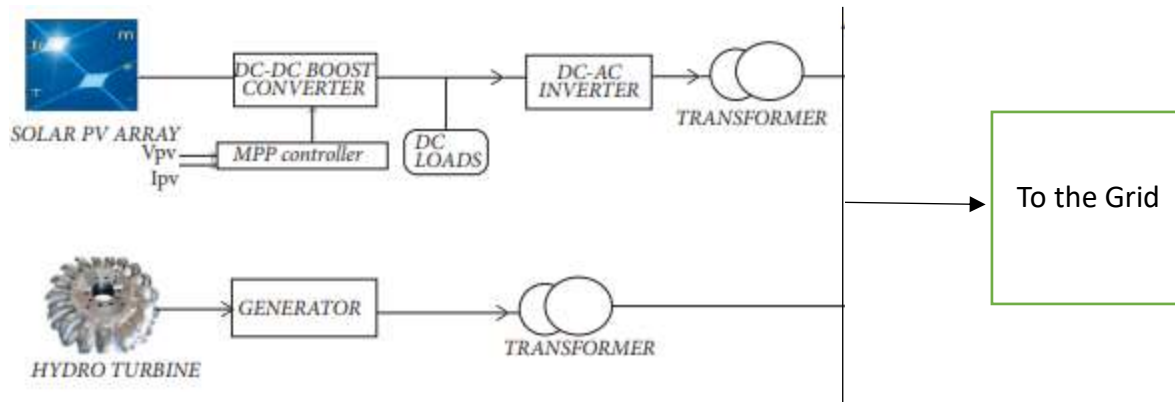


Figure 3: Hybrid of PV-Hydro system block diagram

The way that hydropower and photovoltaic energy are produced complements each other. During a bright summer day, when photovoltaic output is at its highest. When compared to the HPP generation, the PV generates more energy in this instance. This outcome should be averaged throughout the course of the year, taking into account cold and winter days when HPP energy output increases and surpasses PV energy production without requiring any modifications to the fundamental infrastructure or grid connections.

Using inverter parallel control techniques, the system integrates a PV power generating system with a run-of-river hydropower station.

Advantages:

1. **Renewable Energy Combination:** Combining PV and hydro utilizes two renewable sources, increasing overall reliability.
2. **Energy Stability:** Hydroelectric power offers a stable, predictable output, which complements the intermittent nature of solar energy.
3. **Optimized Land Use:** Utilizes existing hydro infrastructure while adding solar panels, optimizing land use.
4. **Lower Environmental Impact:** Both sources are clean and have low greenhouse gas emissions.

Disadvantages:

1. Complex Integration: Integrating two different technologies can be technically challenging and may require sophisticated control systems.

1. **Cost:** Initial investment for both PV and hydro systems can be high, including installation and integration costs.
2. **Location Specific:** Suitable sites with access to both solar and hydro resources are limited.

2.3. Hybrid optimization techniques

Hybrid optimization techniques involve combining multiple algorithms or methods to leverage their strengths and address the limitations of individual techniques. The literature review of the present study summarizes three types of hybrid optimization techniques that are often used:

2.3.1. Particle Swarm Optimization (PSO) with Differential Evolution (DE):

Particle Swarm Optimization (PSO) offers a realistic stochastic multi-objective optimization of a PV-hydropower system utilizing the MATLAB-programmed PSO and Differential Evolution (DE). To enhance the combined operation of a hybrid solar-hydro system, a workable control method utilizing PSO and DE is proposed for a joint PV-hydropower plant [6].

2.3.1.1. Hydropower system modelling

The following formula shows the model of a hydropower system of a Particle Swarm Optimization (PSO) as follow.

$$P_H = \begin{cases} 0 & \text{for } Q < Q_{min} \\ \rho X g x H n x \eta T G Q & \text{for } Q_{min} \leq Q < Q_{max} \\ \rho x g x H n x \eta T G Q_{max} & \text{for } Q \geq Q_{max} \end{cases} \quad (1)$$

Where:

P_H = Power produced by Hydro

H_n = the net head expressed in meters (m)

Q = the flow rate expressed in m³ /s.

g = the acceleration due to gravity (9.8 m/s²).

η_{TG} = the product of the turbine and generator efficiency,

Q_{min} and Q_{max} are the turbine minimum and maximum stream flow

Y = water density (1000kg/m³)

H_n = net head in meter (m)

$$Q_{min} \leq Q \leq Q_{max}$$

$$P_{min} \leq P \leq P_{max}$$

2.3.1.2. PV system Modeling:

The following formula shows the model of a PV system of a Particle Swarm Optimization (PSO) as follow;

$$P_{out_PV} = N_{PV} P_{rated_PV} \eta_{PV} \times (G/ G_{ref}) \times [1 + K_T (T_c - T_{ref})] \quad (2)$$

Where:

N_{PV} = the number of PV arrays,

η_{PV} = the array efficiency,

P_{out_PV} = the output power from the PV system,

P_{rated_PV} = the rated power at reference conditions,

G = the solar radiation (W/m²),

G_{ref} = the solar radiation at reference conditions ($G_{ref} = 1000$ W/m²),

T_{ref} = the cell temperature at reference conditions ($T_{ref} = 25$ °C),

K_T = the temperature coefficient of the maximum power ($K_T = - 3.7 \times 10^{-3}$ /°C)

$$T_c = T_{amb} + (0.0256 \times G) \quad (3)$$

Where: T_{amb} is the ambient temperature

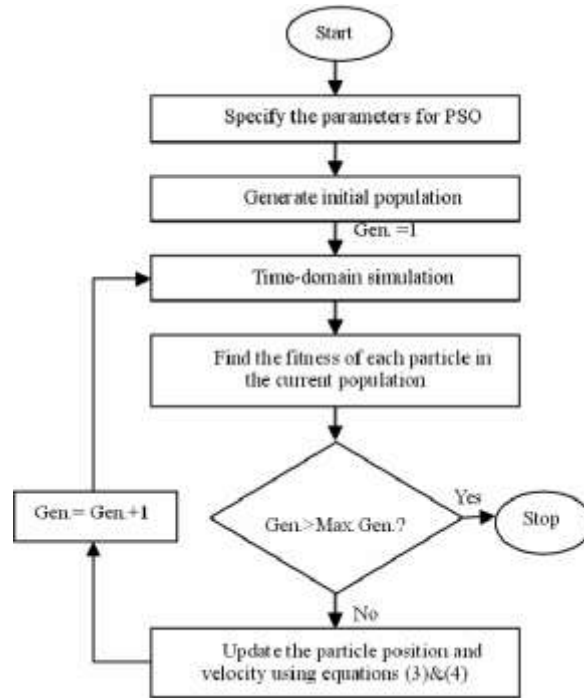


Figure 4: Particle Swarm Optimization (PSO) Flowchart

2.3.2. Non-dominated sorting Whale optimization Algorithm

A Non-dominated sorting Whale optimization Algorithm (NSWOA) is a meta-heuristic technique that utilized to resolve challenging optimization issues. It is modeled after the humpback whale's bubble-net hunting strategy. A modified version of NSWOA is provided in order to get a solution set for the proposed model. The findings demonstrate that the amended NSWOA may provide decision-makers with a range of options for the optimal decisions and that hydropower, with its superior adjusting capabilities, may successfully balance PV generation[7][8].

2.3.2.1. Hybrid power generation model

A mathematical model of Hybrid power generation requires a formulation of objective functions. These objective functions combine the benefits of all sources involved in the hybrid system. In addition, a formulation of constraints is needed since the objective function must be subjected to some constraints. Constraints can reflect time, space and cost.

i. Objectives functions

Objective function can be formulated depending on both behavior of the problem and an algorithm in the place. For a non-dominated sorting Whale optimization Algorithm (NSWOA), the objective function is formulated as follows:

$$\max f_1 = \max E = \max \sum_{t=1}^T P_{t_0t}(t)\Delta t = \max \sum_{t=1}^T 1 * (P_{hc}(t) + P_{P_v}(t) + P_w(t)\Delta t \quad (4)$$

$$\min f_2 = \min \delta = \min \sqrt{\frac{1}{T} \sum_{t=1}^T C P_{t_0t}(t) - \bar{P}_{t_0t}} \quad (5)$$

Where:

P (t)= total monthly output power;

P total (t) = average output power of system during time t;

E = total generated energy of the system;

δ = standard deviation of monthly output power.

Δt = is the time length

C= investment cost of the system

T= period time

$P_{hc}(t)$ =the power output of cascade hydropower stations during time t;

$P_w(t)$ is the actual power output during time t

P_{pv} is the actual power output;

ii. Decision variables and constraints

The constraints of a non-dominated sorting Whale optimization Algorithm (NSWOA) are founded as follow:

$$\text{Water balance equation: } V_i(t + 1) = V_i(t) + (I_i(t) - Q_i(t))\Delta t \quad (6)$$

$$\text{Hydraulic connection: } I_{i(t)} = Q_{i-1(t)} + q_{i(t)} \quad (7)$$

$$\text{Upstream level constraint: } Z_{i(t)}^{\min} \leq Z_{it} \leq Z_{i(t)}^{\max} \quad (8)$$

$$\text{Discharge flow constraints: } Q_{i(t)}^{\min} \leq Q_i(t) \leq Q_{i(t)}^{\max} \quad (9)$$

$$\text{Output power constraints: } N_{i(t)}^{\min} \leq N_{i(t)} \leq N_{i(t)}^{\max} \quad (10)$$

where N is the hydro station's output power, t is the time duration, I is the income flow, i q is the inflow between reservoirs i1 and i, and V is the water storage of reservoir i during time t. Reservoir I is denoted by the subscript i, while each constraint's upper and lower bounds are denoted by the superscripts max and min. The period $Z_{i,up t}$ and $Z_{i,down}$, which are the reservoir's upstream and downstream water levels during time t, and Q, which is the reservoir's discharge flow during time t, are represented by the parameter t in parenthesis.

2.3.3. The Linear Programming

An optimization method called linear programming may be applied to solve problems where the choice variables' linear functions represent the constraints and the objective function[9].

The standard matrix of a Linear programming problem is stated as:

$$\min_x f_x^T$$

$$\text{Such that: } A_x \leq b; \quad (11)$$

$$A_{eq} x = b_{eq}; \quad (12)$$

$$L_b \leq x \leq u_b \quad (13)$$

Where f, x, b, b_{eq} , L_b , U_b are Vectors and A and A_{eq} are Matrices

Characteristics of linear programming in standard form are:

- The objective function is of the minimization type.

- All the constraints are of the equality type.
- All the decision variables are nonnegative.

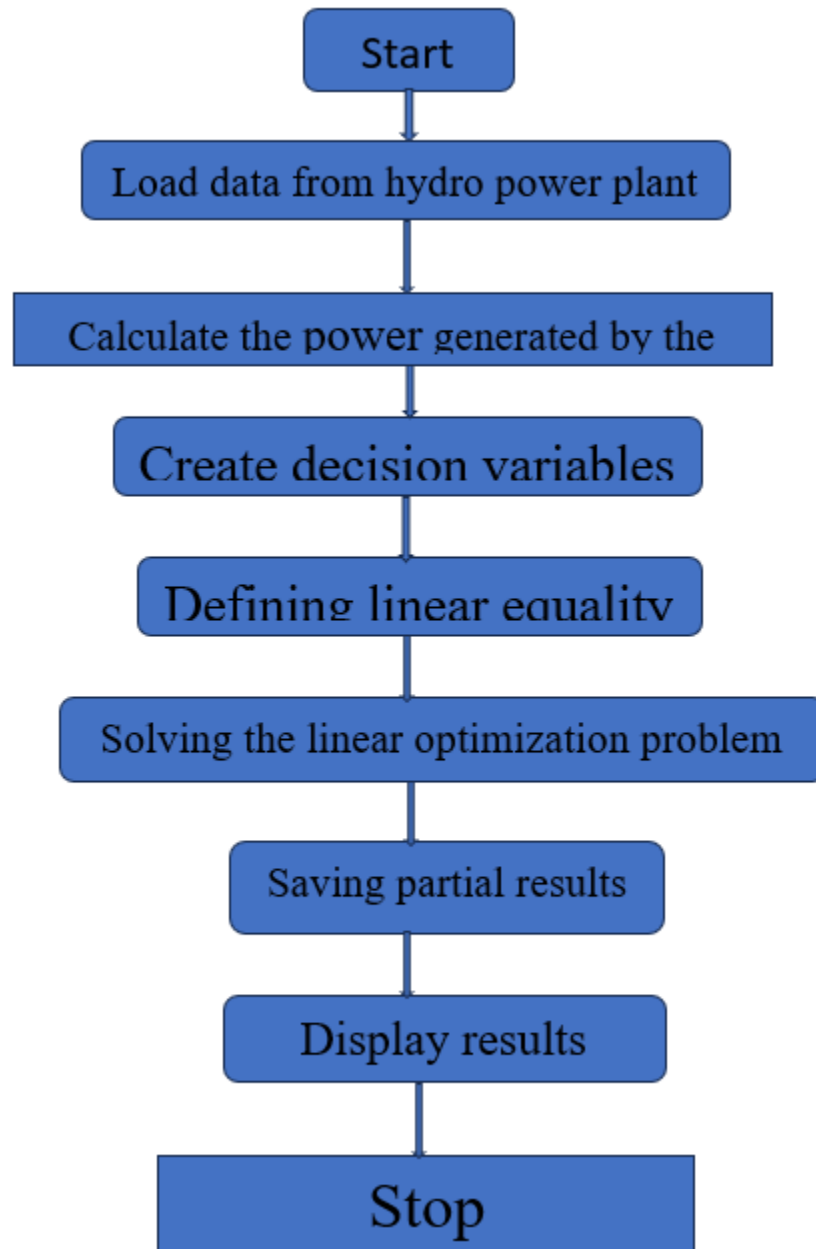


Figure 5: Flowchart of Linear programming optimization Algorithm

All in all, they are many programming models by which are implemented them but some are more complex and expensive and they are others which are less complex in optimizing and modelling the hybridization of power systems.

2.4. Related works on hybrid optimization techniques.

Numerous studies have been done on the affordability and reliability of solar-Hydropower systems using optimization models, with the primary goal being to maximize solar and hydropower energy by doing their hybridization. And then, According to Chu Donatus I. et al, in 2023 [6], they published that There are tools that help make renewable energy systems work better. These tools can be really helpful for countries that have lots of renewable energy resources but not a lot of electricity in rural areas. But it's still hard to make these energy systems work perfectly, especially when they use different types of energy sources together. In this paper, the authors used Particle Swarm Optimization (PSO) to design and improve a system that uses solar power, water power, and batteries. However, They failed to demonstrate that, in order to approach the issue holistically from a socio-technical and economic standpoint, research must also concentrate on the very unstable societal components that have synergy with RE. [6][10]. Also, Negasa Muleta [11] in simple terms shown that sometimes it's difficult to bring electricity to faraway places because it can cost a lot of money. But there's a way to provide electricity to these places using a small and affordable system called a Microgrid. This study is all about figuring out the best way to design this Microgrid so that it works well and doesn't cost too much. They also want to make sure it doesn't harm the environment. Various optimization techniques are applied, such as Particle Swarm Optimization, Differential Evolution, Manta Ray Foraging Optimization, Shuffled Frog-Leaping Algorithm, Reptile Search Algorithm, and Runge Kutta Optimizer, to determine the optimal design. The goal of all these methods is to find the most reliable and affordable way to provide electricity. Although they didn't show the best mix of renewable energy sources (RES) and battery packs that are reliable, affordable, and don't produce a lot of greenhouse gas emissions.

The research of Ali thaeer [12] outlined the significance of hydropower units' ideal generating timing for electrical systems. The optimal timetable for producing electricity from hydropower units is the aim of long-, mid-, and short-term hydro scheduling (LMSTHS). This means using

the available water resources to produce the most energy possible during a certain time period. There are many different ways to solve this problem, including traditional methods and newer approaches based on experience. This article looks at all these different methods and how they have been used to find the best generation schedule for hydropower systems. However, they failed to demonstrate how the pumped water storage affects the LMSTHS issue solution, which merits further research and might be looked at.[12] Basing on the research of Salisu Muhammad [13] It became evident that model-based design, simulation, energy conditioning, hybrid energy storage systems, hybrid controllers for automation to attain power supply reliability, and feasibility studies are all necessary for an optimal hybrid renewable energy power system. The design procedure of a hybrid renewable energy system (HRES) presents difficulties for a dependable power supply. Therefore, it is important to carry out the following procedures: hybrid energy harvester, energy conditioner, energy storage and controller feasibilities, selection and unit size, and system designs. As was previously said, this section covers hybrid energy system components for power and reliability applications. However, they failed to demonstrate the benefits of the best possible hybrid energy system design, which offers a viable long-term fix for dependable power supplies. Their paper written by Kusakana [9] explains how renewable energy sources like solar, wind, and water power can be used to create an economic system. They used linear programming to figure out the best way to connect these energy sources together to save money. They wanted to make sure that they had enough energy for their needs, but also make it affordable. To help explain, they gave an example using solar panels, wind turbines, and water power. Although, they had a gap of the variations in load and energy resources, and the hybrid system's operation control through the use of reliability indices that will be considered during the process of entire cost optimization and sizing[9]. Scientists and Engineers like Numbi [14] were keen on making renewable energy systems as small and cheap as possible using Linear programming to figure out how to achieve it but with this gap focusing on changes in the amount of energy they had and how much they needed that will be considered when figuring out the best way to use a mix of different energy sources. They were also use certain measures of how dependable the system was to decide how big it should be and how much it will cost. The research of, Amevi Acakpovi et al, [15] describe that The goal is to maximize energy costs from the consumer's point of view by implementing the ideal mix of starting renewable energy facilities that meet the necessary load for a allotted time. An analytical

representation of a wind, sun, and hydropower plants were initially suggested and then integrated with cost standards in order to produce an objective function. The refinement the issue was expressed in linear form with limits on inequality. and was resolved by computational techniques using the unique MATLAB function linprog. Information was gathered on three distinct places in Ghana, such as Navrongo and Kumasi as well as Accra and supplied into the software. However they did not show how it will be appropriate to compare this approach to other techniques such as PSO, GA, HOMER optimization[15].

Chapter III: Methodology

This research aims to optimize the hybrid of PV and Hydropower system, by modeling using a Linear programming. The research was carried out in many stages, which included the selection of the study location, data collecting for the chosen site, modeling, and validation.

3.1. Data collection

In this research, the primary and secondary data were collected from REPRO (Rural Energy Promotion) Ltd which provide the information from Mutobo Hydropower.

Technical Data from Mutobo Hydropower plant.

Table 1: Average Power production (Year 2022)

Month	Monthly Index (MW)
January	0.138
February	0.124
March	0.135
April	0.133
May	0.139
June	0.124
July	0.121
August	0.125
September	0.132
October	0.132
November	0.134
December	0.14

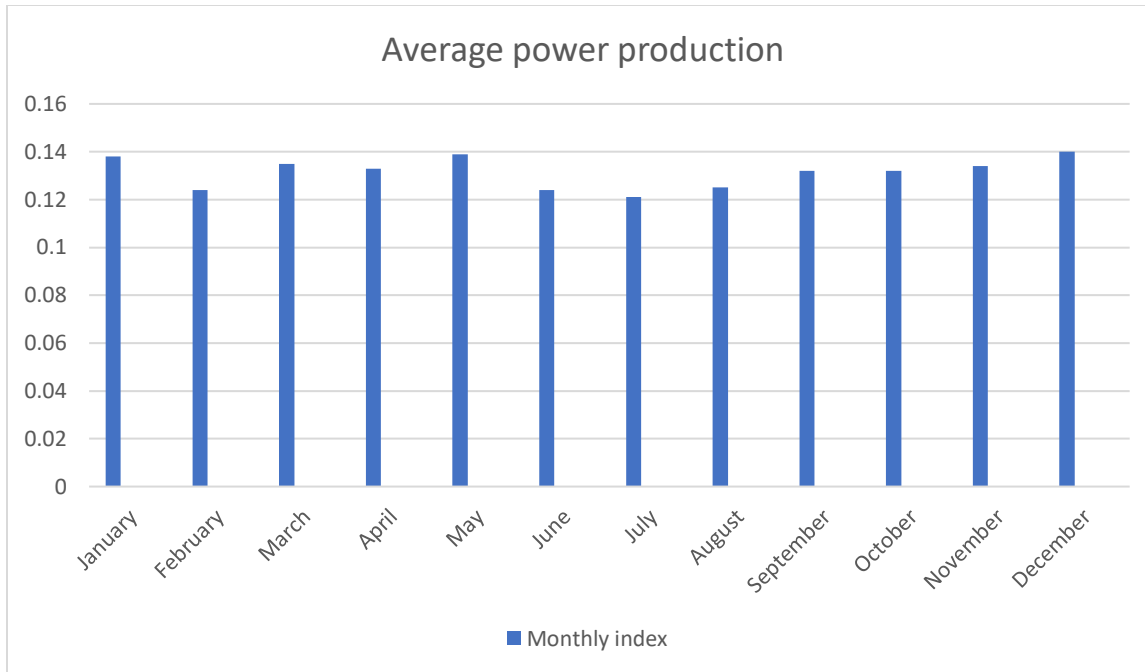


Figure 6: Average Production power plant.

The peak demand caused by high power load cause draws much current which is out of the grid-tie inverter range that result in power flow from both grid and PV system. To avoid this, the grid-tie inverter should be sized to support the flow of current at peak demand, if not the inverter can be damaged.

Table 2: Monthly global radiation data for the Selected village (Mutobo)

Month	Clearness Index	Monthly global radiation (kWh/m ² /day)
January	0.480	4.900
February	0.493	5.170
March	0.478	5.030
April	0.487	4.930
May	0.504	4.800
June	0.526	4.810
July	0.528	4.900

August	0.501	4.920
September	0.485	5.000
October	0.450	4.690
November	0.453	4.640
December	0.465	4.690

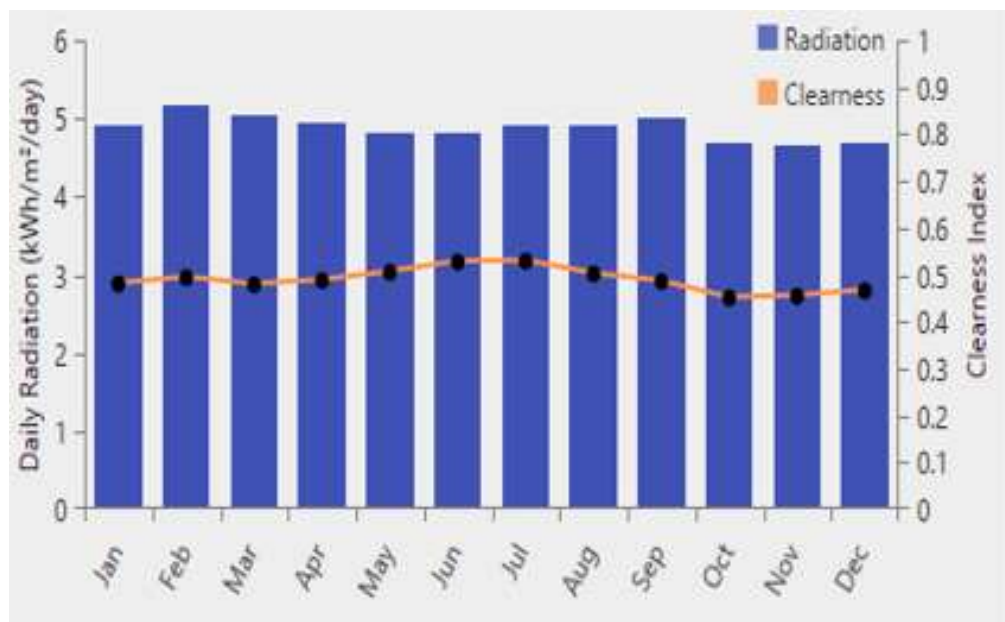


Figure 7: Clearness index and Irradiation

3.2. Modelling

The modelling data is done by mathematical models by which A Linear Programming model is used to find:

- the objective function which is a linear expression of the decision variables;
- the constraints which are given by a system of linear equations and/or inequalities.

3.3. Optimization

Where did the An optimization method for a system of linear constraints and a linear objective function is called linear programming. Finding the values of the variables that maximize or

minimize the objective function is the aim of linear programming. An objective function specifies the quantity to be optimized.

3.4. Validation

In validation the Homer pro Software is used to validate the effective cost of the Hybrid model.

And finally, by simulating, the results will be analyzed.

3.5. Flowchart showing the procedures of Methodology

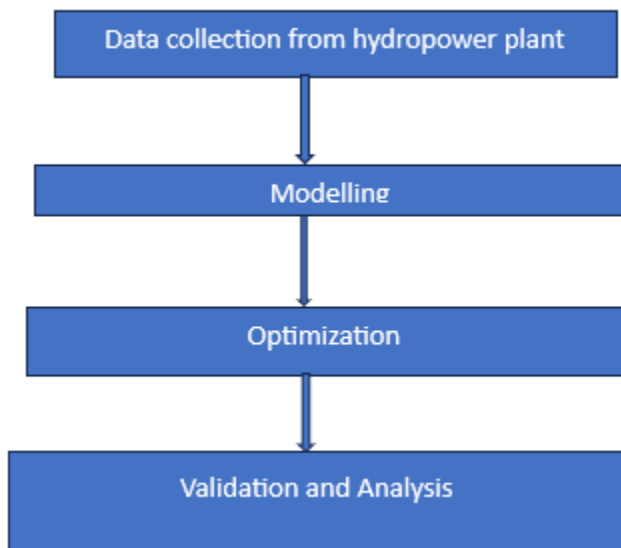


Figure 8: **The procedures of Methodology**

Figure 8 shows different steps involved in the thesis methodology which are Data collection from hydropower plant, modelling by using mathematical models, and optimizing the models, do the validation and finally analyses them.

Chapter IV: Modeling and Optimization of the Hybrid PV/ Hydropower plant generation
4.1. Flow rate of Mutobo/ year

This study's hydrological design is based on data on water flow collected throughout various time periods. The available river readings that were taken are of year 2021 and of year 2022.

Table 3: **Monthly flow rate 2021 and 2022**

Monthly flow rate(m³/S)/Period	2021	2022
January	0.47	0.48
February	0.53	0.52
March	0.74	0.75
April	0.89	0.88
May	0.74	0.74
June	0.35	0.36
July	0.36	0.35
August	0.36	0.36
September	0.62	0.64
October	0.69	0.69
November	0.79	0.78
December	0.86	0.85

Year 2021

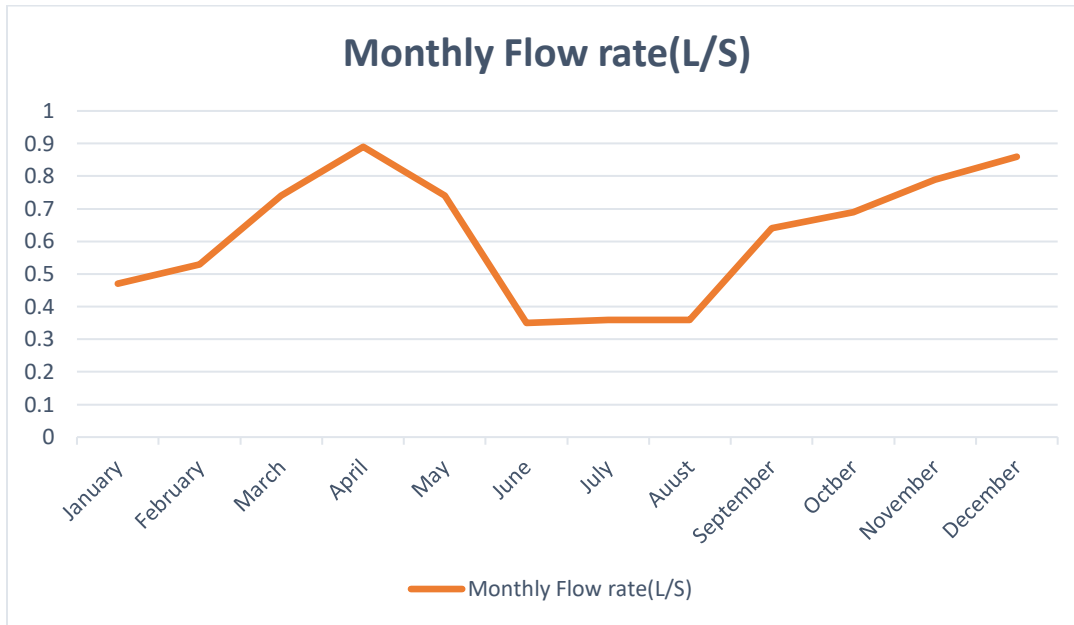


Figure 9: The procedures of Methodology

Year 2022

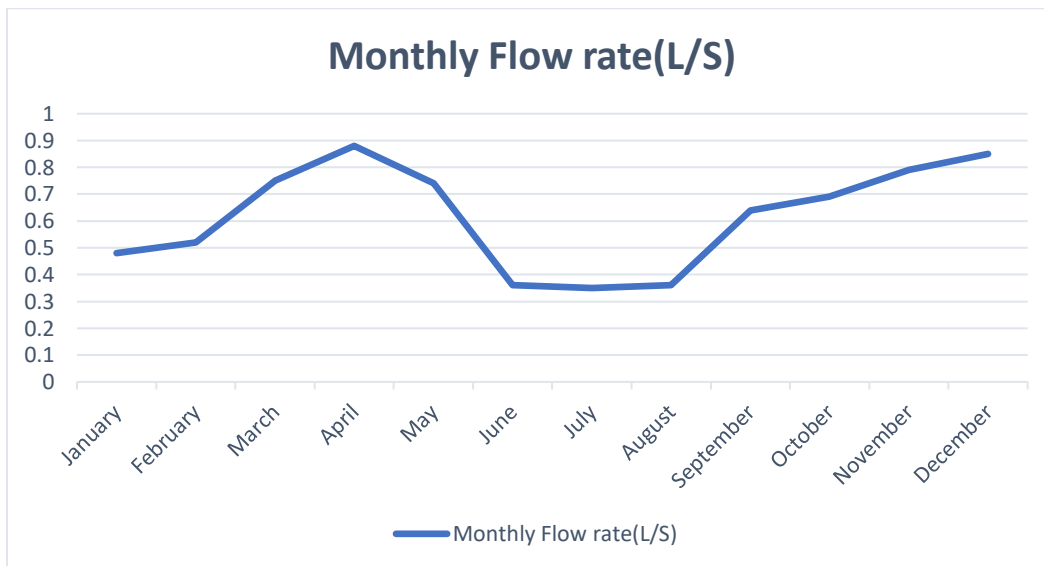


Figure 10: Monthly flow rate 2022

The net head and maximum water flow rate which the river must determine the kind, size, and speed of the turbine. Since micro-hydroelectric power plants are often constructed as run-off plants, the mean of the river or stream's flow duration must be used to calculate the maximum

water flow capacity of the turbine. The people who live along this river's flow utilize it as irrigation to raise plants [11].

4.2. Potential production of Mutobo power plant

When determining a hydroelectric power plant's precise potential production, the variables must be taken into account along with the design and placement of the facility.

Table 4: **Monthly Load profile 2021 and 2022**

Monthly (MW)/Period	Load 2021	2022
January	0.136	0.138
February	0.128	0.124
March	0.134	0.135
April	0.133	0.133
May	0.137	0.139
June	0.123	0.124
July	0.122	0.121
August	0.125	0.125
September	0.130	0.132
October	0.133	0.132
November	0.134	0.134
December	0.138	0.140

4.3. Load profile of the Mutobo power plant

The term "load profile" for a hydroelectric power plant describes the change in power production or electricity demand over a certain time period. It shows the power generated by the hydroelectric plant at different times of the day, week, month, or year.

The following illustrations show the load profile of Mutobo Hydropower plant of the year 2021 and 2022.

Year 2021

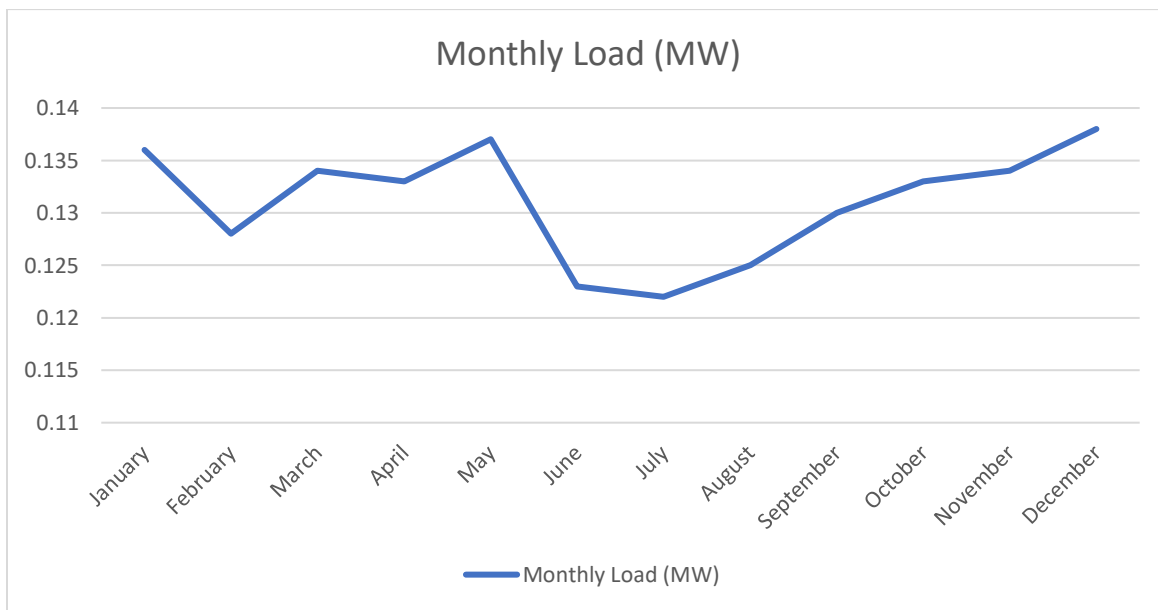


Figure 11: Load profile 2021

Year 2022

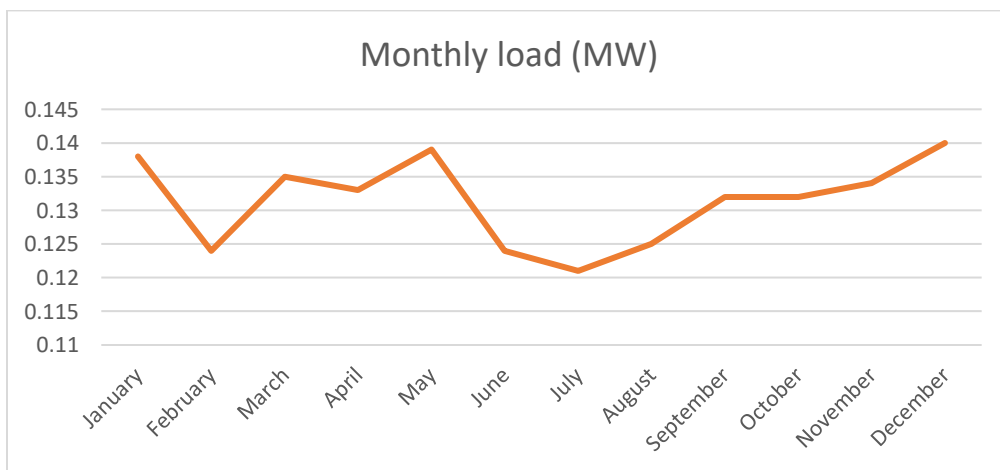


Figure 12: Load profile 2022

From the load profile stated above, the load decrease in dry season and increase in winter season.

4.4. Estimation of the production of from the PV power plant to be integrated in the Hybrid system.

From the data collected, the load in the dry season is between 120KW and 125KW, and the founded maximum power deficit is estimated to be 80 KW in order to complete the installed capacity of hydropower plant which is 200KW.

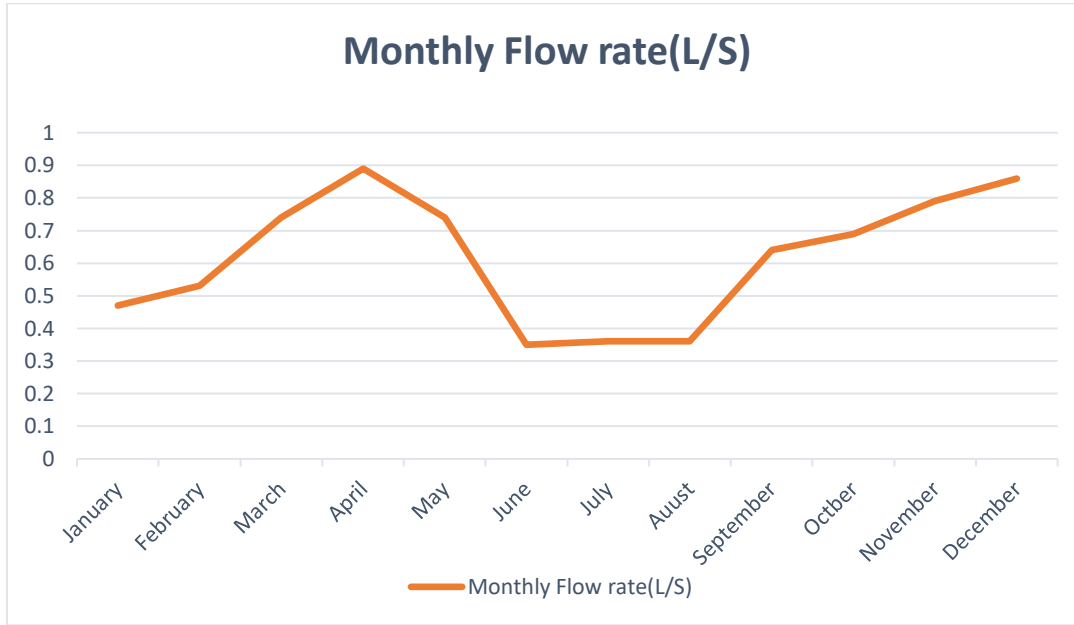


Figure 13: **Monthly flow rate**

Based on the graph above, the Load flowrate is high in the winter season, it means from January to May and September to December; and the flow rate decrease in summer season between June and August in this period, the PV may be integrated into the plant operation.

The following equation shows how the potential energy varies according to the time.

$$P(t) = \begin{cases} ghQ_1 & \text{for January – May} \\ ghQ_2 & \text{for June – August} \\ ghQ_3 & \text{for september – december} \end{cases} \quad (14)$$

Where P(t) is the potential energy, g is the gravitational energy, h is the head and Q is the flow rate.

4.5. Formulation of the objective function of the PV/Hydropower hybrid system

Integrating a PV system to Mutobo mini hydropower requires an optimization of the investment and a benefit projection. To achieve to this, the objective function combines both the Mutobo hydropower plant and the PV system behaviors and their relative potentiality. In this prospective, the objective function is formulated as follows:

$$\max f(x) = C_1E_1 + C_2E_2 \quad (15)$$

Where:

C_1 and C_2 are the investment cost of a PV and hydropower respectively

E_1 and E_2 are is the installed capacity of a PV and Hydropower respectively

Depending on the energy per unit and per generation technology from REG, the cost per unit of PV solar plant is 27.4 Rfw/KWh and the cost of Hydropower plant is 32.4 Rfw/KWh the objective function becomes as follows[16]:

$$\max f(x) = 27.4E_1 + 32.4E_2 \quad (16)$$

4.6. Formulation of the constraints

To optimize the investment cost of Mutobo hydropower plant, the objective functions are subjected to the constraints. To formulate the constraints, the installed capacity of a hydropower plant is 200KW and because from the graph shown in figure 5 the load is decreasing in June to August and is between 120KW and 125KW then from that load production of the plant there is a deficient of 80KW. The PV may have the installed capacity of a deficit power of 80KW. The constraints are formulated as follow:

$$\left\{ \begin{array}{l} 80E_1 + 120E_2 \leq 200 \\ 51.39E_1 + 5.29E_2 \leq 69.01 \end{array} \right. \quad (17)$$

Where 51.39 Rfw/KWh is the daily operating cost for a PV power plant and 5.29 Rfw/KWh is the daily operating cost of a hydropower plant. The ideal operating cost in power plant is 69.01 Rwf/KWh[16].

4.7. Optimization

As the aim of optimization is to minimize the investment cost, the capital cost of PV as well as hydropower are requested. In Linear programming there are two basics methods to solve a linear programming model. Those methods are Simplex methods and Graphical methods. The simplex approach can handle any dimension; however, the graphic method can only be utilized when the model has two variables. The graphic technique does not provide a workable solution for linear programming. given that the majority of linear programming issues involve a lot of variables.

4.7.1. Graphical method

This approach is centered on establishing the common region between these constraints, known as the Feasible Region, and drawing constraints from their two sites of intersection with the coordinate's axes. Region of Solutions (FSR). The angles in this area show the extreme locations where we derive the ideal values for the two factors in order to accomplish the goal function. We have examined a few models referred to be linear programming models. The aim function of the model in each scenario was to be maximized or minimized while adhering to a number of requirements or limitations[8].

4.7.2. Simplex method

The basic idea behind the simplex technique is to express a linear equation system representing an LP issue, and then a specific solution of the resulting system would be the best solution of the original LP problem.

The "smart" approach of finding a much smaller subset of fundamental answers that would be adequate to verify in order to determine the ideal solution is described by the simplex method[17].

In our case, the graphical method is going to be applied in order to do the optimization.

From the objective function founded above;

$$\max f(x) = 27.4E_1 + 32.4E_2 \quad (18)$$

To solve the aforementioned linear programming model using the graphical approach, each constraint inequality is transformed into an equation and each variable is set to zero (0). This creates two (2) coordinate points for each equation (i.e., using double intercept form). Once we have all of the coordinate points, we will determine the range of our variables, which will enable us to select the scale that works best for our graph. Next, we'll sketch the graph and join each coordinate point with the required straight line.

Then, the constraints become;

$$\begin{cases} 80E_1 + 120E_2 = 200 \\ 51.39E_1 + 5.29E_2 = 69.01 \end{cases} \quad (19)$$

For constraint 1: $80E_1 + 120E_2 = 200$;

$$\text{If } E_1 = 0 \text{ then, } E_2 = 200/120 = 1.6$$

$$E_2 = 0 \text{ then, } E_1 = 200/80 = 2.5$$

For constraint 2: $51.39E_1 + 5.29E_2 = 69.01$;

$$\text{If } E_1 = 0 \text{ then, } E_2 = 69.01/5.29 = 13.02$$

$$E_2 = 0 \text{ then, } E_1 = 69.01/51.39 = 1.3$$

Minimum value of E_1 is $E_1 = 0$. Maximum value of E_1 is $E_1 = 2.5$. Range of E_1 is $0 \leq E_1 \leq 2.5$.

Minimum value of E_2 is $E_2 = 0$. Maximum value of E_2 is $E_2 = 13.02$.

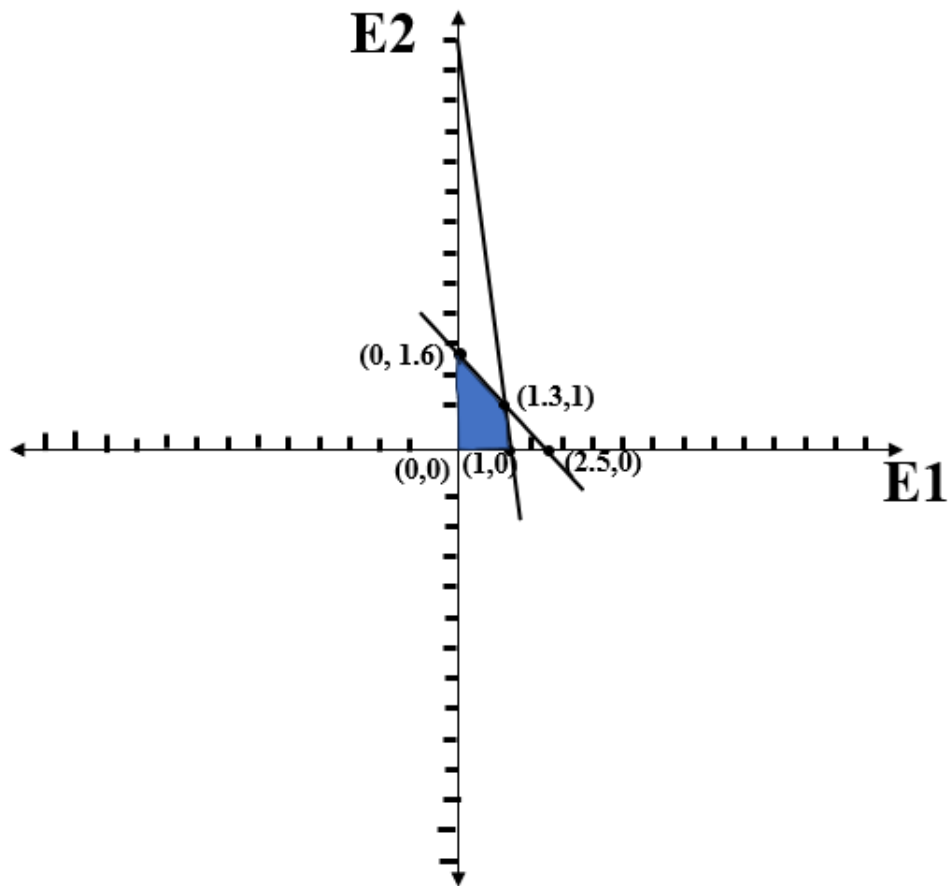


Figure 14 : Feasible area of the constraints

The constraints result in the set of workable solutions shown in the above graph. Now, in order to solve the linear programming problem, we need to identify the workable solution that maximizes the objective function. The list below includes a few potential fixes.

Table 5 : Table shows the optimum point

Feasible solution (A point in the solution set of the system)	Objective function $f(x) = 27.4E_1 + 32.4E_2$
(0,0)	$(27.4*0) + (32.4*0) = 0$
(0,1.6)	$(27.4*0) + (32.4*1.6) = 51.84$
(1.3,1)	$(27.4*1.3) + (32.4*1) = 68.02$
(1,0)	$(27.4*1) + (32.4*0) = 27.4$

Hence, maximum profit at point (1.3,0) and it is the objective functions which have optimal values of 68.02 Rwf/Kwh.

Chapter VI: Conclusions and recommendations

6.1. Conclusions

This thesis is aimed to optimize the hybrid of PV and hydropower system. The average flow rate of the Mutobo river was found to be 0.61 m³/s, but the flowrate of the run-of-river throughout the year is not constant and that cannot generate power at the same level. To overcome such difficulties, the integration of a PV system is required to cover the deficient of the power generation. Hence, the PV system is designed for the peak demand of 80 KW.

6.2. Recommendations

After carrying out this technical feasibility study, the following recommendations are encouraged. Based on the completed study, it can be advised that the relevant institution to implement this project as it has the aim of importing power. The seventh sustainable development objective states that by putting money into solar, wind, and thermal power, we can improve energy. It's critical to ensure everyone has energy and is productive. In order to accomplish SDG 7 by 2030, it is advised to further labor to thoroughly examine the nation. It could possess sufficient power in terms of solar power in gigawatts.

It is also advised to Rwanda's government, in particular the ministry of education, to make the effort into the field of solar technology. Due to the fact that it might be utilized for heating water, cooking, and producing electricity.

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