Faculty of Electrical Technology and Engineering

DEVELOPMENT OF PICO HYDRO POWERED IRRIGATION SYSTEM

MUHAMMAD AMIR AMIN BIN JAILANI

Bachelor of Electrical Engineering Technology with Honours

2025

DEVELOPMENT OF PICO HYDRO POWERED IRRIGATION SYSTEM

MUHAMMAD AMIR AMIN BIN JAILANI

A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electrical Engineering Technology with Honours

Faculty of Electrical Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2025

DECLARATION

I declare that this project report entitled "Development of Pico Hydro Powered Irrigation System" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Student Name : Muhammad Amir Amin Bin Jailani

Date : 2/1/2025

APPROVAL

I hereby declare that I have checked this project report and in my opinion, this project report is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical Engineering Technology with Honours.

Signature :

Supervisor Name : Dr. Azhan AB Rahman

Date : 2/1/2025

DEDICATION

This report is dedicated to my family and friends, whose unwavering support and encouragement have been my greatest source of strength throughout my academic journey. To my parents, who have always believed in me and provided endless love and guidance. To my friends, for their constant companionship and understanding, making this experience more enjoyable and less daunting.

I would also like to dedicate this work to my mentors and professors, whose wisdom and insights have been invaluable in shaping my understanding and skills. Their dedication to teaching and their passion for knowledge have inspired me to strive for excellence. Lastly, I dedicate this report to all the fellow students who have walked this path with me, sharing both the challenges and the triumphs. May our hard work and perseverance pave the way for future successes.

Thank you all for being an integral part of this journey.

ABSTRACT

Agriculture is one of the oldest activities and the most important economic pillar in the world. Malaysia, rich in natural resources, has integrated modern innovations into this crucial sector. However, the development of these innovations has still not been able to solve national food issues, rural area development, and the use of conventional methods such as diesel which pollute the environment. This is because previous innovation systems did not incorporate elements of clean energy, self-sufficiency, monitoring, and required high labor. This project aims to develop a functional and efficient pico hydro-powered irrigation system, tailored for the use of water pipelines and rainwater harvesting, especially in rural and residential areas. It will provide a comprehensive analysis of the system's performance, focusing on energy production, water delivery efficiency, and crops management while incorporating Arduino-based automation to simulate clean water energy management and optimize irrigation processes. This development can be carried out with the help of TinkerCad simulations which show that pico hydro can generate around 0.9W of electricity while the sensor reading for moisture requiring water is less then 901Ω and 554Ω at ideal moisture levels. The development of this project have the potential to contribute to an agricultural revolution that enables small-scale agricultural systems in urban, rural, and residential areas to achieve our SDG's goals.

ABSTRAK

Pertanian merupakan sebuah aktiviti tertua yang menjadi pendokong ekonomi paling penting di dunia. Malaysia yang kaya dengan hasil bumi telah menggabungkan inovasi moden kedalam sektor penting ini. Namun, perkembangan inovasi ini masih tidak mampu untuk menamatkan isu makanan dunia, sistem pengairan di tempat terpencil dan juga penggunaan cara konvensional seperti diesel yang mencemarkan alam. Ini disebabkan sistem inovasi terdahulu yang tidak menerapkan unsur tenaga bersih, berdikari, pemantauan dan memerlukan tenaga kerja yang tinggi. Projek ini bertujuan untuk membangunkan sistem pengairan berkuasa pico hidro yang berfungsi dengan cekap, yang disesuaikan dengan penggunaan paip laluan air serta takungan air hujan khususnya di kawasan luar bandar dan perumahan. Ia akan menyediakan analisis menyeluruh mengenai prestasi sistem, yang memfokuskan kepada pengeluaran tenaga, kecekapan penyampaian air, dan pengurusan tanaman sambil menggabungkan automasi berasaskan Arduino untuk mensimulasikan pengurusan tenaga air bersih dan mengoptimumkan proses pengairan. Pembangunan ini dapat dilakukan dengan bantuan simulasi TinkerCad yang menunjukkan pico hidro mampu menjana lebih kurang 0.9W elektrik manakala bacaan pada penderia kelembapan yang memerlukan air ialah 901Ω dan bacaan 554Ω pada kelembapan yang ideal. Dengan adanya pembangunan projek ini dapat menyumbang kepada revolusi pertanian yang membolehkan sistem pertanian berskala kecil di bandar, luar bandar serta di kediaman sendiri.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to my supervisor, Dr. Azhan AB Rahman for their precious guidance, words of wisdom and patient throughout this project.

I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) and family for the financial support through my academic which enables me to accomplish the project. Not forgetting my fellow colleague, BELT S1/1 for the willingness of sharing their thoughts and ideas regarding the project.

My highest appreciation goes to my parents and family members for their love and prayer during the period of my study. An honourable mention also goes to my fellow PSM group members for all the motivation and understanding.

Finally, I would like to thank all the staffs at the UTeM, fellow colleagues and classmates, the Faculty members, as well as other individuals who are not listed here for being co-operative and helpful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

δ	-	Voltage angle
Ω	-	Ohm
$^\circ$	-	Angle
K_a	-	Absorption rate
	-	
	-	
	-	
	-	

LIST OF ABBREVIATIONS

V	-	Voltage
A	-	Ampere
P	-	Power
K	-	Kilo
W	-	Watt
I	-	Current
S	-	Second
M	-	Meter

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Agriculture, one of humanity's earliest activities, began around 10,000 BCE during the Neolithic Revolution, marking the shift from nomadic hunting and gathering to settled farming communities. This pivotal transition enabled the domestication of plants and animals, leading to reliable food sources, population growth, and the emergence of civilizations. Modern agricultural advancements focus on sustainability, climate-resilient crops, Agri-tech innovations, and alternative farming techniques. Efficient irrigation systems are crucial for optimizing water use and ensuring consistent crop yields, especially in regions with variable water availability [1].

For millennia, irrigation systems have been vital in agriculture, delivering water to crops in areas lacking sufficient rainfall. These systems have evolved from ancient surface irrigation methods, utilizing gravity, to modern techniques like sprinkler and drip irrigation, which offer enhanced efficiency and water management. The main advantages of irrigation include increased crop yields, improved crop quality, and economic stability for farming communities [2]. Nonetheless, challenges such as water scarcity, inefficient traditional methods, and soil salinization remain. Technological advances, including smart irrigation systems that incorporate sensors and automation, along with the integration of renewable energy sources like pico-hydro, are addressing these issues. These innovations aim to optimize water usage, ensuring sustainable and resilient agricultural practices aligned with goals for clean energy and zero hunger [3].

Pico hydro systems represent an emerging technology well-suited for small-scale, off-grid applications. These systems harness the energy from flowing water to generate electricity, which can then power irrigation systems in rural and remote areas. They provide a sustainable and eco-friendly solution by utilizing water's kinetic energy without relying on fossil fuels, making them ideal for rural communities where conventional grid connections are impractical or too costly. Typically requiring only a low water flow, these systems are perfect for residential pipelines. When used for irrigation, they ensure a reliable and consistent water supply to agricultural lands, especially in regions with seasonal water variability [4].

Rainwater storage irrigation systems are essential for sustainable water management in agriculture, particularly in areas with limited access to traditional water sources. These systems collect and store rainwater from rooftops or catchment areas, then filter and treat it before distributing it to fields or crops through a network of pipes or irrigation channels [5]. By reducing dependence on scarce groundwater and surface water resources, rainwater storage irrigation systems promote water conservation, cost savings, and drought resilience, making them crucial for small-scale farms, community gardens, and urban agriculture projects.

Figure 1.1 Agriculture Statistic Malaysia

1.2 Problem Statement

Limited access to reliable and affordable irrigation jeopardizes food security for rural farmers. Traditional methods such as diesel pumps are costly and environmentally harmful, while grid electricity is often unavailable. This project proposes a pico hydro-powered irrigation system as a sustainable alternative. By utilizing the energy from small streams to generate electricity for water pumps, the system aims to enhance crop yields, decrease dependence on fossil fuels, and encourage the use of local materials. Nevertheless, challenges such as initial investment costs, suitability of water sources, and technical know-how must be addressed through community engagement and potential subsidies. This initiative seeks to empower farmers, boost food security, and create a clean energy future for rural communities [6].

Pico hydro irrigation systems address two critical Sustainable Development Goals (SDGs): Zero Hunger (SDG 2) and Affordable and Clean Energy (SDG 7). By providing reliable irrigation powered by renewable hydropower, these systems enable farmers to increase food production (SDG 2) while reducing dependence on polluting fossil fuels (SDG 7), thus fostering a sustainable future for rural communities [3].

Rural communities facing food insecurity (SDG 2) often lack access to affordable and sustainable irrigation solutions (SDG 7). While diesel pumps are effective, they strain financial resources (SDG 2) and contribute to environmental pollution (SDG 7) through greenhouse gas emissions. This project suggests a pico hydro irrigation system as a viable solution, although issues such as initial costs and maintenance expertise need further investigation [3].

1.3 Objective

The aim of this project is to simulate, develop, and analyze a cost-effective and sustainable pico hydro-powered irrigation system to improve agricultural productivity and water management in a designated rural and residential area [7]. This system seeks to deliver reliable, clean energy for irrigation, thereby promoting sustainable agricultural practices.

- To simulate the pico hydro powered irrigation system with tinkerCAD software and hardware combination.

- To develop a functional and efficient pico hydro-powered irrigation system designed to meet the specific requirements for different settings.

- To analyze a pico hydro powered irrigation system performance based on power output, penstock length, flowrate, valve angle, time and type of soil.

1.4 Scope of project

The project scope defines the boundaries and objectives of the project, specifying what will be included and excluded from project activities. It delineates the specific goals, tasks, and resources required to meet the project objectives within a set timeframe and budget [7].

- A pico-hydro powered irrigation system comprises two main components: the generation system and the irrigation system, utilizing either residential pipeline water resources or rainwater storage to produce around 0.9W of electricity.
- The project design and simulation were conducted using tinkerCAD and fritzing to develop a functional project layout and create the necessary circuit.
- No fuel are included in this project, as it aligns with SDG 2 (clean energy).
- Project implementation targets residential and off-grid rural areas, focusing exclusively on promoting clean energy and achieving zero hunger.
- This project provides a solution for small-scale agriculture with multiple outputs and an automatic irrigation system.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review on pico hydro and irrigation systems offers a detailed overview of current research, theories, and methodologies in the field. This review aims to synthesize existing scholarship, identify research gaps, and highlight areas for future investigation. By examining a range of academic works, it seeks to establish a foundation for understanding the complexities and nuances of pico hydro and irrigation systems. Through the exploration of key themes, theoretical frameworks, and empirical findings, this review aims to contribute to the ongoing discourse surrounding these projects.

Scholars have long examined pico hydro and irrigation systems, offering varied perspectives and insights into their multifaceted nature. Early studies by other researchers established the fundamental principles and conceptual frameworks that subsequent research has built upon. Recent scholarship has further explored various aspects of pico hydro and irrigation systems, analyzing their implications across different contexts and disciplines. By synthesizing these works, this literature review aims to elucidate the evolution of thought and highlight emerging trends within the field.

A prominent theme in the literature is the significance of renewable energy, which is essential for understanding pico hydro and irrigation systems. Researchers have examined the intricate relationship between renewable energy and pico hydro systems, revealing how small-scale implementations can be beneficial for specific projects. Additionally, studies have emphasized the importance of these initiatives.

This review aims to synthesize current research on the integration of pico hydro and irrigation systems. It will investigate the technical feasibility, economic viability, and environmental benefits of this approach. Furthermore, the review will identify potential challenges and knowledge gaps, paving the way for further research and development in this promising sustainable irrigation strategy.

2.2 Background Study

Through an extensive review of existing literature, this background study aims to consolidate current knowledge, identify barriers, and guide future research and implementation efforts. The goal is to maximize the potential benefits of this innovative technology for sustainable agriculture as well as rural and domestic development globally.

2.2.1 Irrigation System

In broad terms, irrigation refers to the artificial provision of water to supplement or replace natural rainfall for agricultural purposes. Throughout history, particularly in the Near East region, irrigation has held immense significance, being integral to the sustenance and development of civilizations. The utilization of water resources for irrigation played a pivotal role in the rise and, at times, the decline of various societies in the region, contributing to economic prosperity, social cohesion, and military strength [8].

These early practices laid the groundwork for modern water management technologies not only locally but also globally. The historical legacy and lessons gleaned from ancient irrigation systems offer valuable insights for the sustainable stewardship of water resources in contemporary times and for future generations [9].

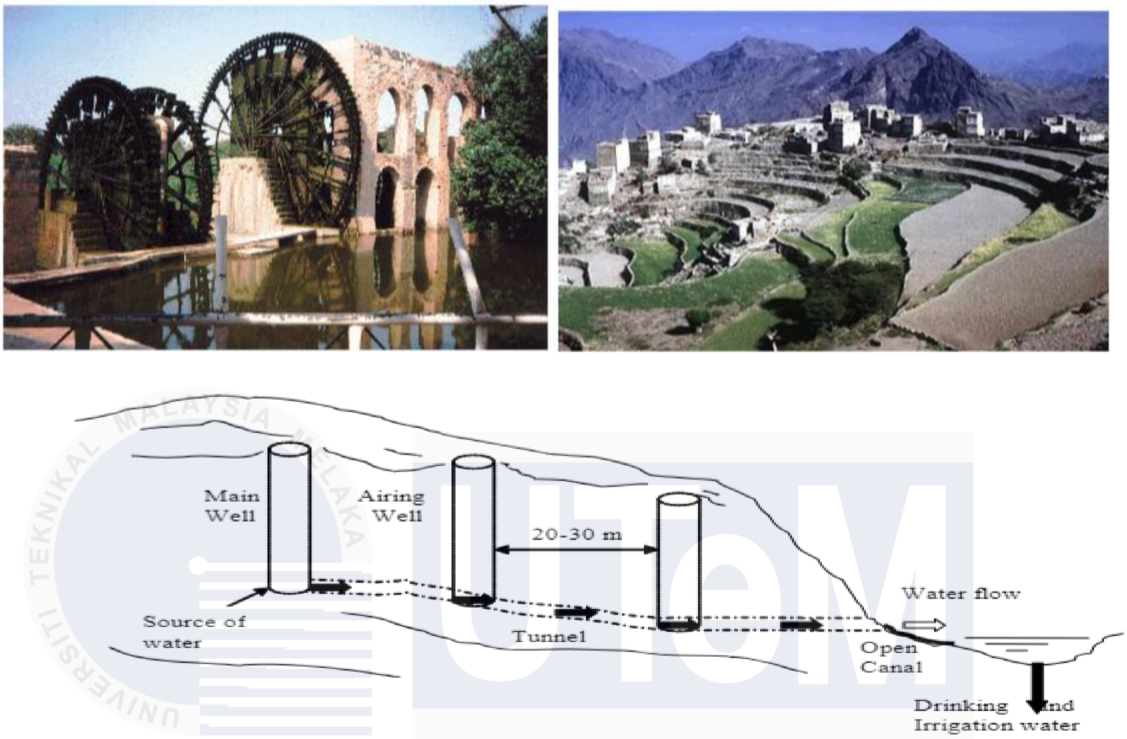


Figure 2.1 Ancient irrigation system

2.2.2 History Of Irrigation System

The Near East region, particularly Egypt and Mesopotamia, boasts a rich history of water management dating back to 5500-2000 B.C. Evidence suggests these early civilizations developed sophisticated (for their time) water diversion structures and irrigation schemes as early as 5000 B.C. [10]. These methods were honed over time and adopted by surrounding regions like North Africa and the Mediterranean.

Many references credit the Near East, particularly Egypt and Mesopotamia, as the birthplace of major civilizations built on irrigated agriculture [10]. These societies recognized the critical role of water management in crop cultivation and food security. Their pioneering efforts in harnessing water resources for irrigation laid the foundation for the success of the region's most prominent civilizations.

Anthropological studies reveal that irrigated agriculture emerged in the Near East around 5000 B.C. in Egypt, coinciding with the beginnings of agriculture itself. Early Egyptians constructed large, flat basins along the Nile to cultivate crops. During floods, water naturally flowed into these basins, where it was stored in the fields for 40-60 days [11]. This relatively simple and passive technique relied on the Nile's flood patterns but enabled the production of winter crops. The system was later improved, leading to the development of basin irrigation, a productive adaptation that capitalized on the river's natural rise and fall. Farmers built networks of earthen banks, both parallel and perpendicular to the river, to create basins of varying sizes.

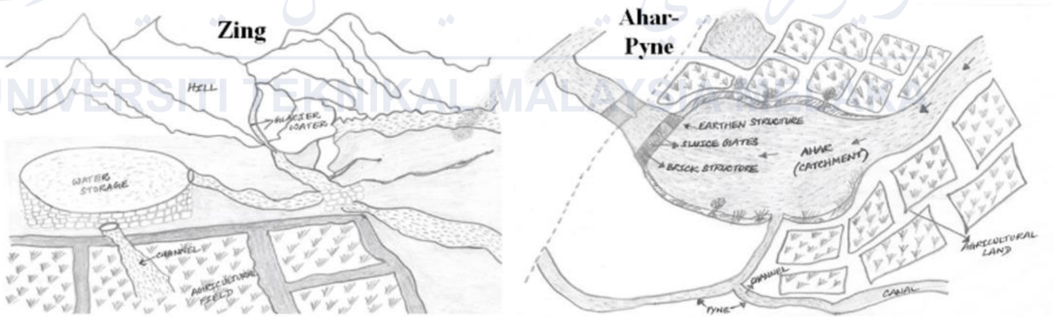


Figure 2.2 Irrigation landscape

2.2.3 Method of Irrigation

The way water is delivered to farmland, known as the irrigation method, significantly impacts the amount of water lost in the field and therefore the efficiency of irrigation. Choosing the right method is crucial for sustainable irrigation projects, especially regarding water use and management [12]. There are three main irrigation methods: surface, sprinkler, and drip. Each has advantages and disadvantages that depend on various factors. These factors include soil type, land slope, crop variety, climate, water availability and quality, and investment costs. Considering these factors is essential for selecting the most suitable irrigation method for a specific situation[13].

2.2.3.1 Surface Irrigation

Surface irrigation, a time-tested method dating back millennia, relies on gravity to distribute water across fields. Also known as gravity irrigation, it utilizes furrows, floods, or basins to wet the land and encourage water infiltration into the soil [8]. Surface irrigation encompasses furrow, border strip, and basin methods.

Historically, it has been the dominant irrigation method globally. While efficiency in water application may be lower compared to other techniques due to limitations in controlling water depth, surface irrigation boasts significantly lower initial costs and energy requirements than pressurized systems. This makes it an attractive option for developing countries, low-value crops, and large fields.

For situations where water source levels permit, dikes (levees) constructed with soil plugs can be used for water level control. Terraced rice paddies exemplify this approach, where flooding or precise water level management is achieved within individual fields. In some instances, water may be pumped or even lifted manually or with animal power to reach the desired field level.

Figure 2.3 Surface irrigation

2.2.3.2 Micro Irrigation

Micro-irrigation, also known as localized, low-volume, or trickle irrigation, delivers water through a pressurized network of pipes in a controlled pattern. Unlike traditional methods, it applies small amounts of water directly to individual plants or their surroundings. This category encompasses various techniques, including traditional drip irrigation with emitters, subsurface drip irrigation (SDI), micro-sprayers, micro-sprinklers, and mini-bubbler irrigation [14].

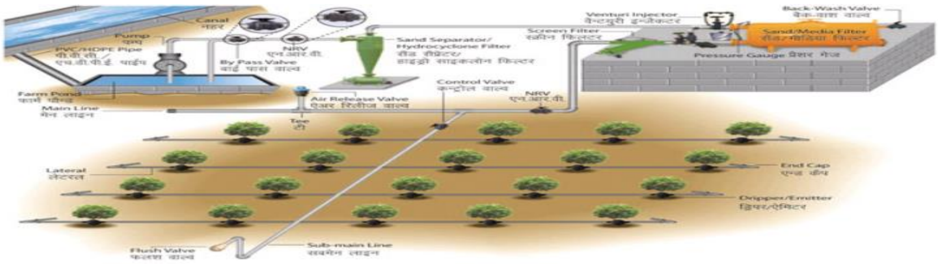


Figure 2.4 Micro irrigation

2.2.3.3 Sprinkler Irrigation

Sprinkler irrigation, also known as overhead irrigation, distributes water through high-pressure sprinklers or guns positioned at central locations within the field. A fixed system with sprinklers, sprays, or guns mounted on permanent risers is often called a solid-set irrigation system.

For larger coverage areas, high-pressure rotating sprinklers called rotors are employed. These rotors utilize ball drives, gear drives, or impact mechanisms for rotation, and can be designed for full or partial circular patterns. Guns share similarities with rotors but operate at significantly higher pressures (275-900 kPa) and flow rates (3-76 L/s) with larger nozzle diameters (10-50 mm). Their applications extend beyond irrigation to industrial uses like dust control and logging [15].

Figure 2.5 Sprinkler irrigation

2.2.4 Comparison of Irrigation System

Modern irrigation, often synonymous with sprinkler and drip methods, is the go-to choice for cultivating new desert lands with typical sandy soil. This is because these methods excel in such conditions. In contrast, traditional or flood irrigation remains the dominant method in established agricultural areas, particularly valleys and deltas, where clay soil is common. A key difference between the two approaches is pressurization. Modern irrigation utilizes pressurized systems that pump water through pipe networks, whereas flood irrigation relies on gravity to distribute water [16]

Item	Flood irrigation	Sprinkler irrigation		Drip irrigation
		Hand-move	Fixed	
Soil type	Heavy clay to medium	Light sandy to medium	Light sandy to medium	Light sandy to heavy clay
Suitable location	Valley and Delta	Desert land	Desert land	Desert, valley, and Delta land
Land leveling	Required	Not required	Not required	Not required
System costs	Low	Medium	Above medium	Above medium
High wind	Not affected	Affected with possible spacing control	Affected	Not affected
Labor & effort	High	medium	Low	Low
Irrigation efficiency	Low 50%	Medium 65%	Above medium 75%	High 85%
Suitable crops	Most crops	Except long crops and trees	Except trees	Trees, vegetables, and row crops
Irrigation water salinity	Up to 1100 ppm	Up to 800 ppm	Up to 800 ppm	Up to 1750 ppm
Required pressure	None	3-4 bar	3 – 4 bar	1 – 2 bar
Maintenance	Low	Medium	Below medium	Above medium
Fertilizers injection	Not used	Possible	Possible	preferable

Figure 2.6 Irrigation comparison

2.2.5 Pico Hydro

Pico hydro refers to a very small-scale hydropower system with a maximum electrical output of approximately four kilowatts (4 kW). This technique is particularly effective for providing electricity to off-grid, remote, and isolated areas experiencing energy shortages [17]. A standard pico hydro generator includes an electrical converting system, batteries, and safety equipment, allowing it to be installed on residential water pipelines [18]. The environmental impact of pico hydro generation is minimal since it does not involve large dams, and the systems can be managed and maintained by the end user. The pico hydro generator has been tested in practical applications using a Pelton turbine design, which harnesses high-pressure water flow from the main tank. The speed of the turbine and alternator is determined by the water pressure [19].

2.2.6 History of Pico Hydro

Hydropower plants are clean energy sources that convert the potential energy of water into electricity. After generating power, the water remains available for irrigation and other uses. The first instance of using moving water to produce electricity was a waterwheel on the Fox River in Wisconsin in 1882. Globally, hydropower is the most extensively used renewable energy source, accounting for 19% of the world's electricity from both large and small plants. The water turbine, developed in the nineteenth century, was extensively used for industrial power before the advent of electrical grids [17].

Today, water turbines are primarily employed for hydroelectric power generation. In Malaysia, the use of hydropower for electricity generation began in July 1900 with the construction of a small hydroelectric plant on the Sempam River bank near Raub, Pahang, by the Raub-Australian gold mining company. However, it wasn't until the 1970s that hydropower was commercially available for domestic electricity use in Malaysia. Although Malaysia has successfully utilized large and small-scale hydropower for electricity generation, no efforts have been made to exploit micro or pico hydropower systems. Fully harnessing this potential could generate clean energy, offering a viable solution to energy supply issues in remote and hilly areas where extending the grid system is not economically feasible.

Hydro generator	Capacity	Feeding
Large	More than 100 MW	National power grid
Small	Up to 25 MW	National power grid
Mini	Below 1 MW	Micro power grid
Micro	Between 6 and 100 kW	Small community or remote industrial areas
Pico	Up to 5 kW	Domestic and small commercial loads

Figure 2.7 Hydro power classification

2.2.7 Principle of Pico Hydro

Each type of turbine possesses distinct characteristics, particularly regarding its suitability for varying heads and water volumes. The Crossflow turbine is widely applicable and highly tolerant of debris in water. Pico turbines, often homemade, typically take the form of waterwheels or propeller turbines. The concept of pressurized pipes over high heads is not commonly practiced, possibly due to the need to alter the landscape to channel water towards a deep drop, which may not be immediately apparent. Providing informative materials could help increase awareness of such possibilities[20] .

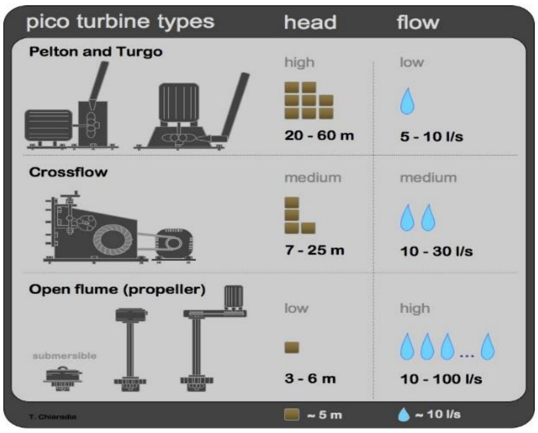


Figure 2.8 Pico turbine type

Table 2.1 Advantages and disadvantages of hydro

Advantages	Disadvantages
The most economical technical option for autonomous power supply.	Preliminary assessment of site-specific power output is necessary.
Utilizes clean, sustainable renewable energy sources.	Basic understanding of hydro installation specific to the site is needed.
Dependable with a long lifespan due to sturdy mechanical methods.	All expenses are upfront investments.
Requires minimal ongoing expenses, unlike batteries in photovoltaic systems.	Typically involves shared connections, necessitating community-driven operation, management, and water resource utilization.

2.2.8 Construction of Pico Hydro

Pico hydro systems are hydroelectric setups on a small scale, usually producing less than 4 kW of electricity. These systems are well-matched for isolated regions without access to conventional energy grids. Their main benefit lies in their capacity to convert the motion energy of water into renewable power, suitable for diverse purposes like running irrigation systems. Establishing a pico hydro system requires several essential stages, each pivotal in guaranteeing effective and dependable performance.

2.2.8.1 Penstock pipe

The penstock pipe is a crucial component in the construction of a pico-hydro system, as its function is to transport high-pressure water for turbine rotation. It's essential that the penstock has a sufficient pressure rating, as the pipe walls need to be thick enough to endure the maximum water pressure and prevent the risk of pipe bursting [21].

This is due to the fact that the water pressure within the penstock is determined by the head, where a higher head results in increased pressure. Consequently, un-plasticized polyvinyl chloride (uPVC) piping, depicted in Figure 2, will be utilized for the penstock due to its cost-effectiveness and lower maintenance requirements. Compared to mild steel and HPDE pipes, uPVC exhibits advantages in terms of friction, weight, corrosion resistance, and cost. Additionally, a nozzle is necessary to maximize pressure and achieve high water speed to drive the turbine [21].

Figure 2.9 Penstock pipe

2.2.8.2 Electrical Circuit

The pico-hydro system produces an AC output using the induction generator. Hence, a bridge rectifier is necessary to transform the AC output into DC output, enabling connection to DC appliances like DC motors, batteries, or LED lights.

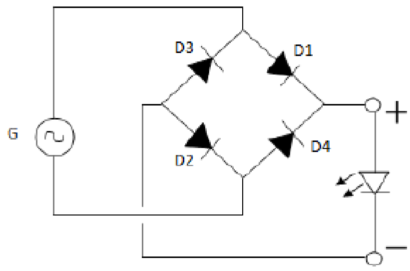


Figure 2.10 Electrical circuit

2.2.8.3 Generator

A generator is a device utilized to convert the rotational energy generated by a water turbine into electrical energy, albeit with a reduction in efficiency at this stage. An AC induction generator, as depicted in Figure 5, has been engineered in which voltage is generated by altering the magnetic field with the movement of the magnet [22]. The generator design comprises two main parts: the stator, composed of coil wire, and the rotor, comprised of pole magnets.

Figure 2.11 Pico hydro generator

2.2.8.4 Pelton Turbine

The Pelton turbine is a type of hydraulic turbine propelled by the force of water jets striking its buckets [23]. In this project, it is recommended to utilize the Pelton turbine for the pico-hydro system due to its suitability for situations with high head and low flow rates of water . However, Alexander and Giddens suggest that the Pelton turbine is versatile, as it can be employed in both high head and low head scenarios. The turbine typically consists of buckets affixed to a circular disk, and water jets with high velocity are directed onto these buckets to drive the turbine's rotation. The crucial aspect in designing the Pelton turbine lies in determining the number of buckets on the disk.

Figure 2.12 Pelton turbine

2.2.9 Pico hydro in domestic use

Pico hydro systems serve as valuable assets in residential environments, providing households with a dependable and eco-friendly source of electricity, particularly in rural areas where access to the main power grid is limited. These systems are capable of powering essential household devices such as lighting, mobile phone chargers, radios, and small electronic gadgets. By harnessing the energy from nearby streams or rivers, pico hydro offers off-grid households a sustainable and renewable energy solution, reducing dependence on costly and environmentally harmful alternatives such as kerosene lamps or diesel generators [24].

Furthermore, the integration of pico hydro systems at the household level promotes environmental sustainability by curbing carbon emissions and addressing deforestation linked to traditional energy sources like firewood and charcoal. By tapping into the energy of flowing water, these systems provide a renewable option that minimizes ecological impact and contributes to local conservation endeavors. Additionally, the cost-effectiveness and adaptability of pico hydro technology ensure its accessibility to households of diverse socio-economic backgrounds, empowering communities to manage their energy requirements and enhance their resilience to environmental and economic adversities.

The power available in water at height is given by a similar equation [17][20]:

$$\boldsymbol{P = Q \times g \times h} \tag{2.1}$$

Where; P = power in watts

Q = discharge of water in kg/s (this is also mass per unit time)

g = acceleration due to gravity (m/s^2)

h = head (m)

Figure 2.13 Pico hydro connected in domestic area

2.3 Summary of previous research on related project

A summary of previous research on a related project typically involves a comprehensive overview of existing studies and findings relevant to the topic at hand. By compiling this information, you can provide a comprehensive summary that encapsulates the breadth and depth of previous research on a related project, setting the stage for understanding current and future directions in the field.

2.3.1 Exploration and advancement areas within pico-hydro power

Extensive research is underway globally to explore various alternatives and renewable energy sources. Pico-hydro power stands out among these options due to its reputation as the most cost-effective renewable energy solution, especially for providing electricity in rural areas and tapping into extremely low head and flow streams as small as 1 meter and 1 liter per second, respectively. This review delves into the research and development aspects of pico-hydro and the factors influencing the success of implementing such schemes in rural regions [25].

These factors are anticipated to drive the demand for pico-hydro in rural energy markets. Many researchers and experts agree that customs duties imposed on pico-hydro components pose a significant barrier to the widespread adoption of renewable energy, as they increase initial costs by up to 40%. Despite this challenge, the future of the pico-hydro market appears promising due to the abundant availability of low head and flow hydroelectric sites in less developed nations. In the forthcoming years, technology is expected to play a pivotal role in providing lighting to homes in remote communities, with energy sourced from domestic water supplies.

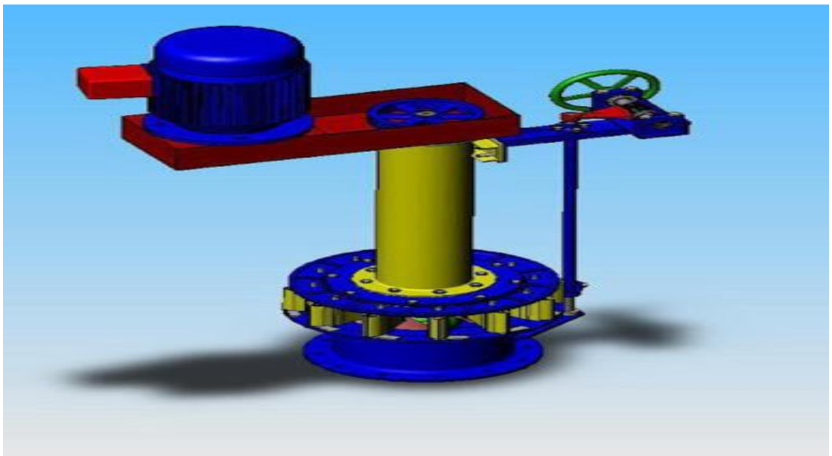


Figure 2.14 Sample of hydro generator

2.3.2 Identifying the best techno-economic energy management approach for solar photovoltaic water pumping irrigation systems

This study introduces a water pumping photovoltaic system (WPPVS) equipped with a water storage tank to supply freshwater for drip irrigation in Farafra oasis, Egypt. A multi-objective K-means clustering approach based on a non-sorting genetic algorithm is employed to minimize both the probability of water supply loss and the total annual costs, encompassing capital and operational expenses. Given the variability of water flow rates, a techno-economic energy coordination is devised, with specific attention devoted to averting water pump vibrations. Economic viability is assessed by comparing tomato crop yields to the total cost of the drip irrigation system[5].

A sensitivity analysis is conducted for dynamic head, crop prices, and interest and inflation rates. At a dynamic head of 6 meters, the findings reveal that the optimal design of the WPPVS pumps 10220 cubic meters of water for irrigation through the devised energy coordination, compared to 18575 cubic meters with pump vibration, resulting in a 45% reduction in pumped water. This highlights its impact on reducing pumped water across all dynamic head values. Additionally, the vibration avoidance strategy enables the pump to operate at lower dynamic heads above the water threshold level in the well, which is unattainable in the presence of vibrations.

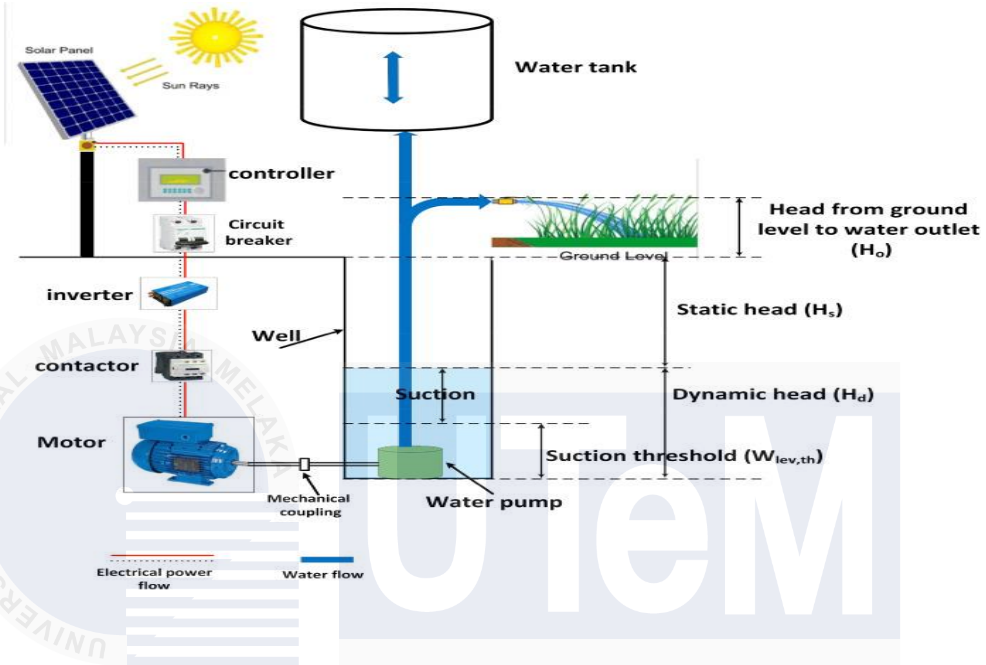


Figure 2.15 Solar Irrigation System

2.3.3 Incorporating small hydro turbines into the current water conduit of a power plant reliant on irrigation – An examination of a specific scenario

Hydro energy stands out as one of the most abundant and beneficial renewable energy resources worldwide. In reservoirs utilized for irrigation purposes, the transfer of water from agriculture to hydroelectric power is crucial. Balancing between irrigation needs and power generation is key to maximizing societal benefits. Typically, hydro turbines employed in irrigation-based setups favor reaction type turbines, particularly suitable for low to medium head and high discharge rates through irrigation canals [26].

However, challenges arise when water release through irrigation gates is reduced, impacting flora, fauna, and drinking water availability. The operational limitations of reaction type hydro turbines during lower release periods restrict energy extraction, leading to cavitation, noise, vibration, and potential equipment failure. This results in considerable generation losses for the power units.

To address this issue, a pilot study was conducted at the Dhom irrigation-dependent hydroelectric plant in Mahagenco, Satara, Maharashtra. The study aimed to harness untapped water energy during lower release and flood scenarios from reservoirs. Proposed modifications to the existing penstock section at the main inlet valve were suggested.

This paper advocates for the integration of small hydro turbines into the current water conduit of irrigation-dependent hydro power plants to capture unused energy. Incorporating inline hydro power units into the existing water conductor system could yield an additional 2.592 million units of energy per year. Additionally, increasing the plant's capacity factor from 0.315 to 0.463 is achievable. The surplus power generated can be utilized for internal loads within the power house.

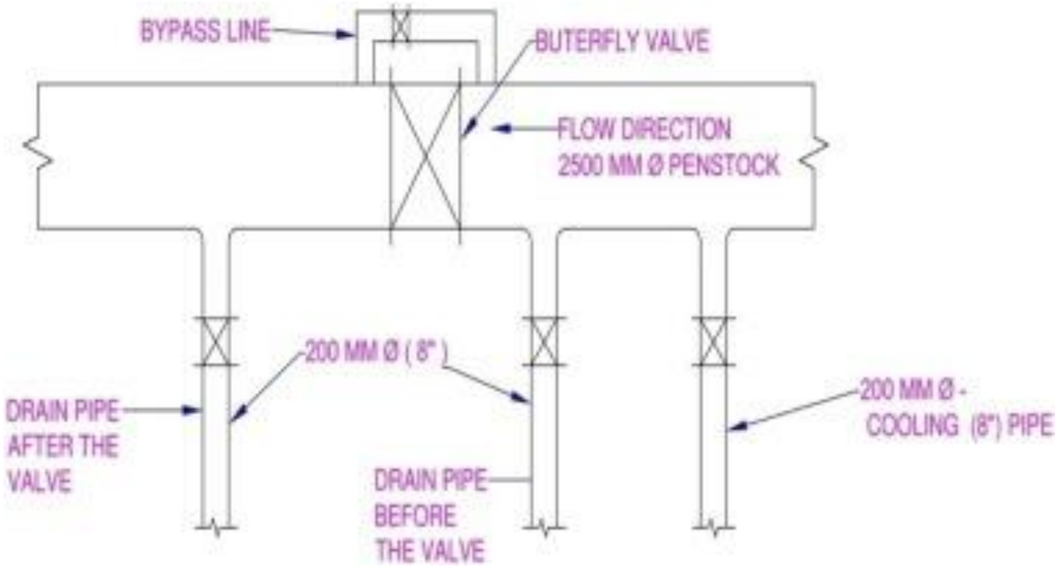


Figure 2.16 Hydro through pipe

2.3.4 Assessment of micro-pumped hydro energy storage on a continental scale using agricultural reservoirs

The shift towards low-carbon power systems demands cost-effective energy storage options. This research presents the inaugural continental-scale evaluation of micro-pumped hydro energy storage, advocating the use of agricultural reservoirs, known as farm dams, to substantially reduce construction expenses. Australia serves as a representative case study for similar arid and temperate regions globally [24].

A survey of Australia's 1.7 million farm dams revealed 30,295 promising pumped hydro sites, configured in dam-to-dam and dam-to-river reservoir setups. These sites typically feature nearby reservoirs with significant head height and discharge capacity. A benchmark comparison between a representative micro-pumped hydro site and a commercially available lithium-ion battery for a solar-powered irrigation system demonstrated that, despite lower discharge efficiency, pumped hydro storage proved 30% cheaper for larger single-cycle loads, attributed to its ample storage capacity. Leveraging existing farm dams, micro-pumped hydro energy storage has the potential to facilitate the adoption of reliable, low-carbon power systems in agricultural areas.

Wind and solar photovoltaics (PV) are leading the charge in decarbonizing electricity generation in various regions worldwide, such as China, Europe, and the United States. However, the increasing share of these intermittent sources underscores the need for innovative energy storage solutions to ensure a dependable and economical power supply.

Decentralized energy systems will play a pivotal role in this transition, given that distributed PV installations accounted for 22% of renewable capacity additions in 2022, with the number of household units projected to quadruple from 25 to 100 million by 2030. Consequently, distributed energy storage will be indispensable for this burgeoning sector.

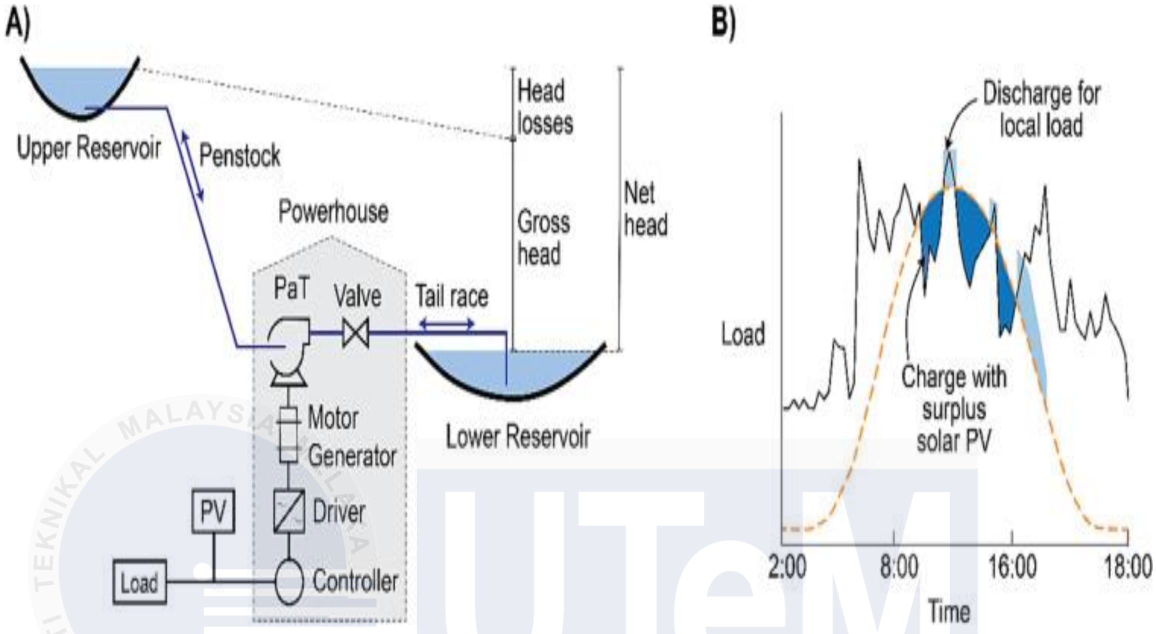


Figure 2.17 Reservoir

2.3.5 Creating a hybrid intelligent irrigation system using both hydro and solar energy sources

The advancement of Oman's agriculture sector holds significant importance for the country's economy. Central to agricultural progress is the efficient utilization and conservation of water resources, given Oman's abundance of solar radiation, which is among the highest globally [12].

These factors present substantial potential for modernizing and establishing a sustainable irrigation model. Leveraging modern technologies, particularly Fourth Industrial Revolution technologies like Artificial Intelligence and the Internet of Things, can effectively address this challenge. This paper introduces the development and implementation of an intelligent irrigation system powered by Oman's falaj (hydro) and solar energy. The system aims to optimize falaj water usage, minimize wastage, and harness the readily available renewable energy from falaj and solar sources.

The first component involves constructing a hybrid power generation system utilizing a turgo-hydro generator and PV panels. The energy produced by this hybrid system charges batteries for storage. The second component focuses on developing a cost-effective intelligent irrigation system. This system design incorporates an Arduino-based controller, sensors, transmitters, receivers, and other wireless subsystems. These sensors measure variables such as temperature, humidity, and moisture in the cultivation area, transmitting the data to the Blynk IoT platform for analysis and control.

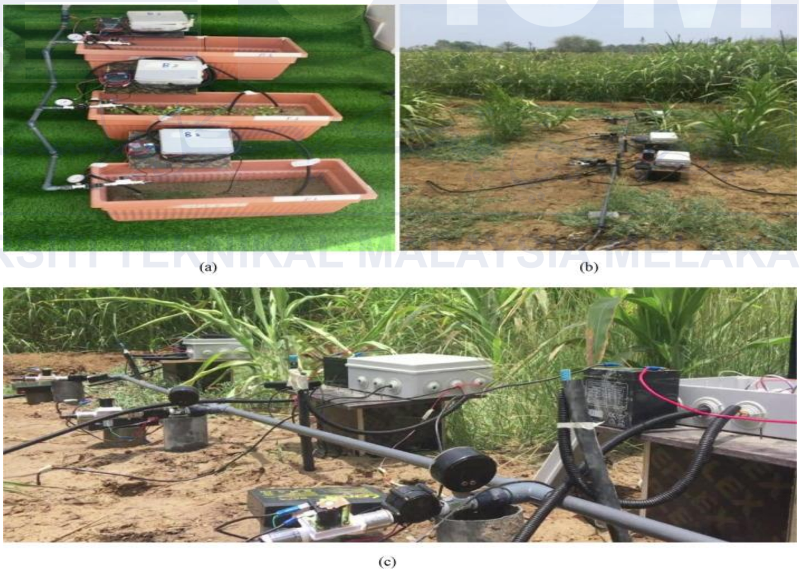


Figure 2.18 Falaj Hydro And Irrigation Experiment

2.3.6 An evaluation of a Pelton turbine's performance within a rainwater harvesting framework for generating micro hydro-power in urban environments

Hydroelectric power represents a sustainable and renewable method of energy production, typically employed on a large scale. However, there is ongoing exploration into its viability at smaller, micro scales, which could offer reduced installation and maintenance costs. This study aims to evaluate the performance of a micro hydro power station integrated into a rainwater harvesting system, focusing on optimizing turbine geometry to maximize efficiency. The project proposes diverse hydraulic heads to harness potential energy for electricity generation in urban settings [25].

For a case study, the system was implemented at an industrial facility in the Toluca Metropolitan Zone, Mexico. A methodology was devised to: A) establish hydraulic configurations based on precipitation patterns and generator operational needs; B) evaluate efficiency metrics by varying key geometric parameters using Computational Fluid Dynamics (CFD); C) validate the prototype via a 3D model. Given the rainwater harvesting system's nature, a Pelton turbine was chosen. Subsequently, hydraulic specifications such as turbine size, conduit pipe number and diameter, nozzles, valves, and gates were defined. Additionally, CFD analysis was conducted to examine fluid dynamics within the turbine and refine its geometry. Through numerical modeling, system efficiency was estimated by adjusting a coefficient based on inlet and outlet velocities, achieving efficiencies of up to 81.13%.

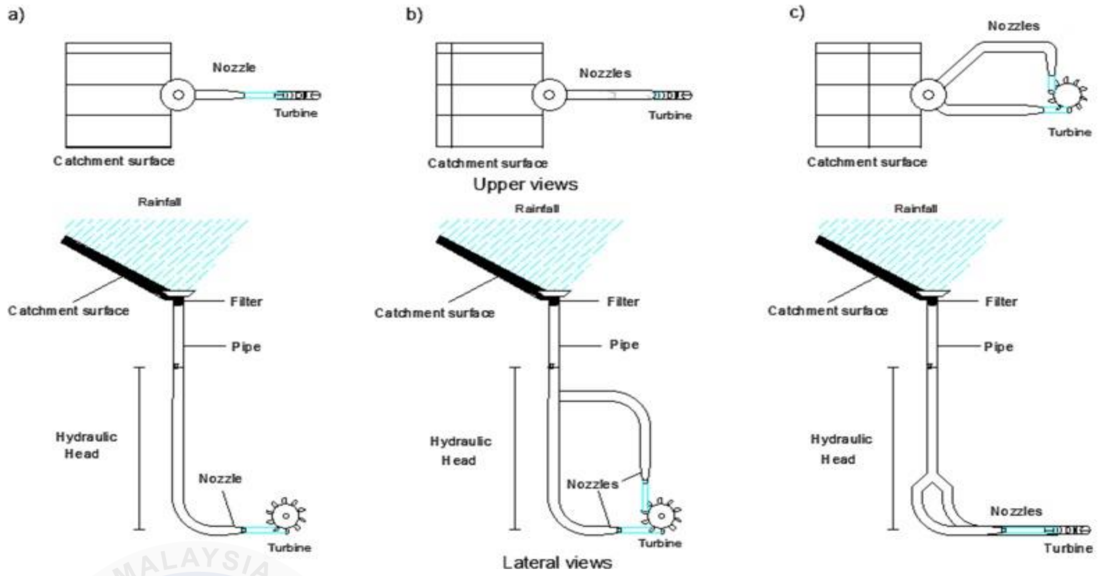


Figure 2.19 Rainwater Hydro

2.3.7 Developing an IoT-based smart irrigation system featuring data fusion and a self-sustaining wide-area network

Water is a crucial resource with significant impacts on human communities, yet optimizing irrigation practices for conservation remains a challenge. This study introduces an intelligent irrigation system that combines a data fusion model with a long-range (LoRa) network to enhance watering schedules. The data fusion model employs a long short-term memory (LSTM) network to forecast watering needs by integrating diverse data sources like historical weather patterns, user irrigation logs, weather predictions, and real-time sensor data [9].

A self-sustaining wide-area network is deployed using LoRa technology, comprising a gateway and two node types: valve nodes and sensing nodes. These nodes operate autonomously, powered by waterflow-based energy generation, ensuring maintenance-free operation throughout their lifecycle.

A cloud-based platform is developed to manage the network, control intelligent irrigation, and provide a mobile application interface. Through a case study on landscape watering, the system demonstrates significant water-saving benefits, achieving an average efficiency of 94.74% compared to conventional manual irrigation methods. Water resources, vital for sustaining life, are unequally distributed across time and space, with agriculture being the primary consumer of water, supporting human society's foundations.

Figure 2.20 IoT Based irrigation system

2.3.8 Utilizing hydro-turbines in water transmission pipelines to capture energy: A case study conducted in western Saudi Arabia

Pressurized water transmission lines often lose significant energy through pressure control mechanisms. This dissipated energy presents an opportunity for recovery by installing hydro-turbines at high-pressure points, thereby generating power and reducing CO2 emissions. This study simulated an existing water pipe under various velocity conditions, revealing substantial energy potential that could be harnessed using Pelton turbines. The approach involved identifying residual pressure locations within the system and assessing the power available for extraction.

Subsequently, the pipeline underwent redesigning with incremental increases in allowable velocity, ranging from 1 to 2.5 m/s. The most suitable turbine was then selected for each residual pressure location, estimating the potential power output. A financial and environmental evaluation of this solution was conducted, indicating a 2.74% reduction in total system cost by adopting a maximum velocity of 2 m/s. Optimization measures enabled the installation of hydro-power plants with a combined capacity of 5,751 kW and an energy payback period of 9.46 years [27]. Additionally, an estimated annual reduction of 35,295 tons of CO2 emissions was observed.

Harnessing kinetic energy from pipelines presents a renewable energy source by utilizing residual pressure from energy dissipating devices. With the adoption of appropriate hydroelectric technology like hydro-turbines, the water management sector can transition from intensive and non-renewable practices to sustainable energy utilization.

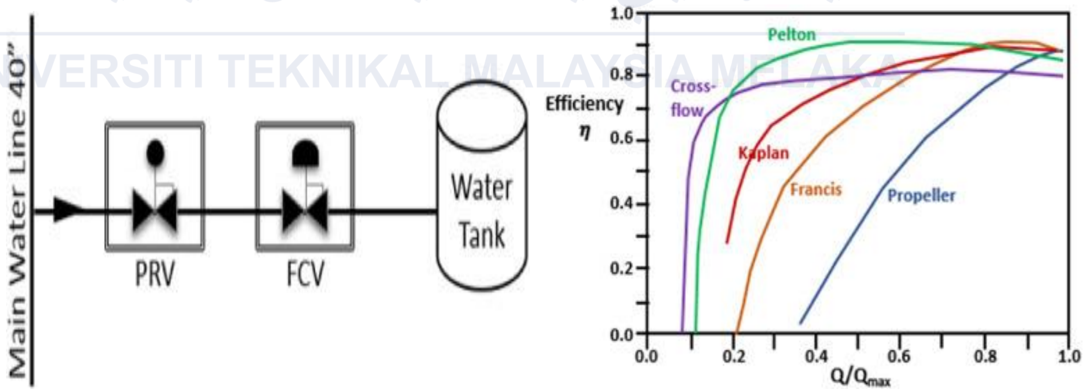


Figure 2.21Water Transmission Pipeline

2.3.9 Utilizing pico-hydro power generated from wastewater for automated street light management via IoT sensors in smart urban areas

The concept of generating free energy through a Pico-hydro-power plant utilizing treated sewage water is implemented and monitored using internet-of-things (IoT) sensors to efficiently control streetlights, CCTV cameras, and traffic lights during daylight hours.

To ensure uninterrupted power supply, two power monitoring schemes are employed through IoT devices and a cloud-based platform. Direct power supply is prioritized as the primary option, with battery energy storage (BES) serving as a secondary means of energy management. The BES is charged during periods of excess water availability or when the connected load is minimal.

This approach leverages waste-to-energy (WtE) conversion to contribute to the smart city's energy needs while also ensuring proper water quality monitoring to mitigate the risk of contaminated water and environmental pollution. Overall, this proposed scheme offers a solution for decentralized energy production, providing free energy for various smart city applications.

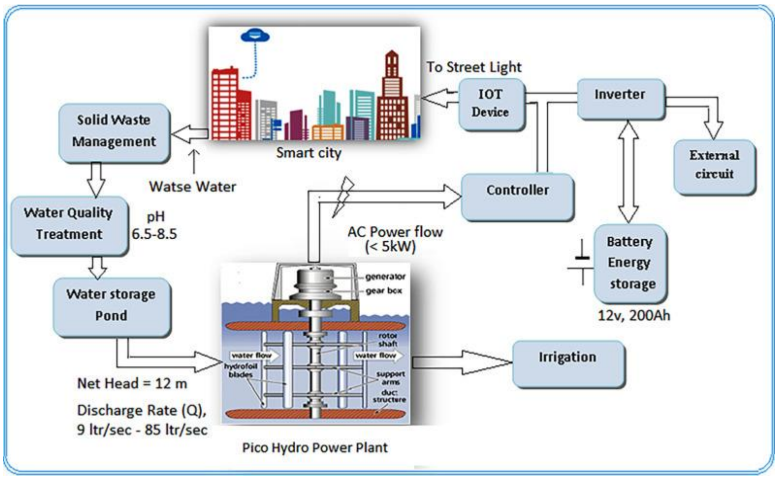


Figure 2.22 Pico-Hydro For Automatic Street Light

2.3.10 Development and creation of an in-line turbine for recovering pico hydro energy from treated sewage water distribution lines

The ongoing global demand for electricity and the imperative to produce clean energy with minimal carbon dioxide emissions have driven innovation in energy generation methods. In this study, the focus is on harnessing pico hydro power, wherein a hydro turbine is designed and fabricated for installation within an existing pipeline system to generate electricity. The turbine is specifically engineered to be seamlessly integrated inline with the pipeline, ensuring no loss of mass flow rate [4].

The key concept involves placing this turbine at the outlet of an overhead tank, allowing for the extraction of energy from the high-pressure water flow that would otherwise go unused. To demonstrate this approach, an overhead tank containing sewage treated water with a head of 14 meters and a discharge rate of 9 liters per second is selected. An impulse turbine, custom-developed for this application, is installed within the tank, and experiments are conducted to quantify the electricity generated. Results indicate that, with a flow rate of 8 liters per second, the turbine can generate a maximum electrical power output of 212 watts. This highlights the potential of this method for decentralized generation of clean energy.

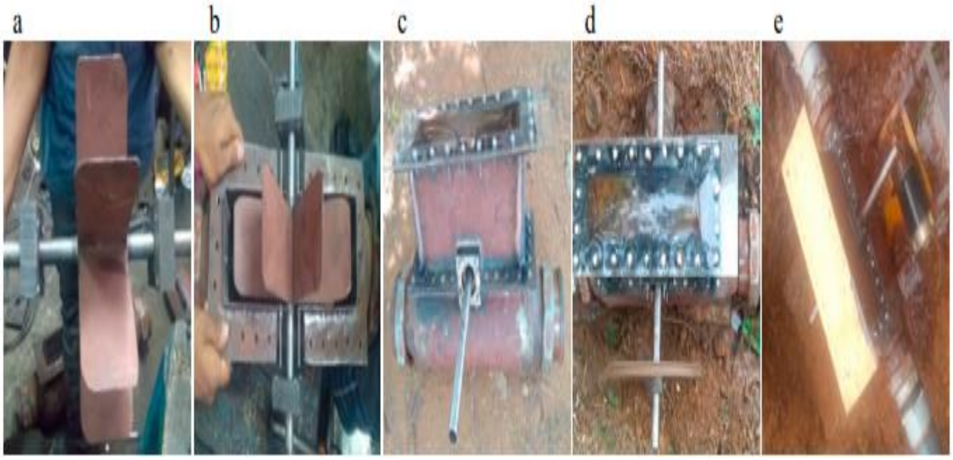


Figure 2.23 Construction of Pico Hydro In Treated Sewage Water

2.3.11 Utilizing pico-hydropower turbines for energy recuperation in a commercial establishment

Minimizing energy consumption in both systems and buildings is essential to combatting climate change. This paper seeks to fill the knowledge gap regarding pico-hydropower systems (<5 kW), which have been identified as an underutilized resource within the water industry. Through a literature review and multivariate analysis, the study aims to identify a suitable pico-hydro turbine for integration into a coral reef aquarium system at a government-owned facility [22].

The literature review highlights untapped potential, knowledge gaps, and the global assessment of small hydropower for energy recovery, alongside a lack of available data hindering the adoption of small hydropower technologies. The study identifies that a propeller-based pico-hydro turbine could recover approximately 10% of the energy expended in pumping water through a filtration system. With an available head of 2.3 meters and a water flow rate of 90 L/s, the turbine achieved a power output of up to 1.124 kW. Furthermore, the project demonstrated economic viability, offering both financial and non-financial benefits throughout the product's life cycle.

Despite the promising results, there remains a scarcity of case studies on energy recovery through small hydropower in scientific literature. However, an increasing number of researchers recognize the potential of this renewable energy technology to mitigate global greenhouse gas emissions and contribute to achieving the UN Sustainable Development Goals, particularly in providing affordable clean energy and addressing climate change. This study sheds light on opportunities to extract value from waste through the innovative application of hydropower within the water industry.

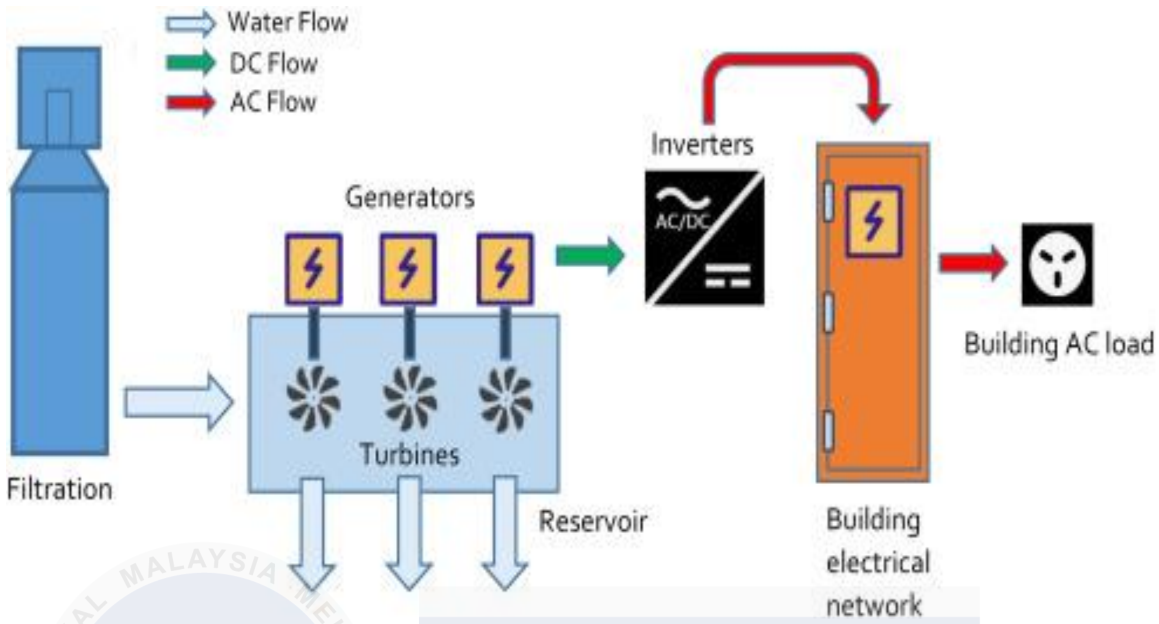


Figure 2.24 Commercial Building Pico-Hydro

2.3.12 Assessment of the design and operational efficiency of a micro hydropower facility within a pressurized irrigation network

Agriculture stands as one of the most energy-demanding sectors within the European Union, especially in rural areas where electric infrastructure is often lacking. To address this challenge, there's a growing interest in on-site energy generation, particularly in harnessing excess pressures within large pressurized irrigation networks for micro hydropower production. Pump-as-turbines have emerged as a cost-effective solution for this purpose, utilizing the surplus pressure in pipe networks to generate energy [8].

This paper outlines a methodology for designing a micro hydropower generation plant on an agricultural farm and examines the anticipated benefits of its implementation. These projected benefits were then compared with the actual performance of the plant during the 2019 irrigation season. The primary objective of the plant was to replace a diesel generator supplying energy to the farm. The excess pressure within the pipe network ranged from 0m to nearly 60m. The nominal power of the pump-as-turbine was chosen to meet the farm's maximum energy requirements.

The projected operational time of the plant was estimated at up to 3199 hours, mainly concentrated between April and September. Anticipated annual savings amounted to approximately €2950 and 11 metric tons of equivalent CO_2 emissions. The measured results revealed an actual operating time of 2443 hours, spanning from May to September, with no data available for April due to a non-operational monitoring system. Based on this operational time, the savings were calculated at €2258 and 8.4 metric tons of equivalent CO_2 emissions. Considering the theoretical irrigation time for April, the savings increased to approximately €2434 and 9.1 metric tons of equivalent CO_2 emissions. The return on investment for the installation was projected to be recovered in less than ten years.

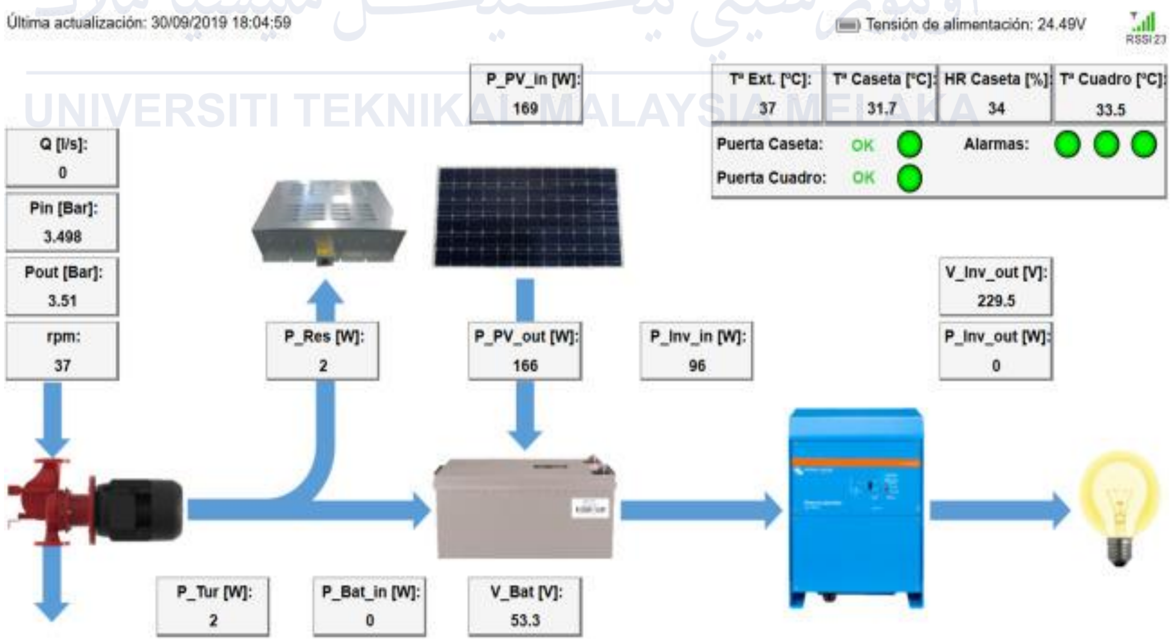


Figure 2.25 Design of Pico-Hydro Plant and Irrigation

2.4 Comparison of previous work by others

Table 2.2 Literature review

No	Title	Authors	Remark
1	Exploration and advancement areas within pico-hydro power	A.A._Lahimer, Alghoul, M. A., Sopian, K., Amin, N., Asim, N., & Fadhel, M. I.	cost-effective solution for rural electrification rural area cause the price to spike up to 40% easy accessibility to households.
2	Unified creation of a photovoltaic power generation facility with pumped hydro storage and irrigation capabilities in the Uhuelem-Amoncha community in Africa	Uchenna Godswill_Onu	Helping a community to have access to electricity Providing irrigation and water supply
3	Incorporating small hydro turbines into the current water conduit of a power plant reliant on irrigation – An examination of a specific scenario	M._Kurulekar, Kumar, K., Joshi, S., & Kulkarni, A.	challenge of allocating water between irrigation and power generation. Lower water level cause limitation on the generator
4	Assessment of micro-pumped hydro energy storage on a continental scale using agricultural reservoirs	Nicholas Gilmore, Gilmore, N., Britz, T., Maartensson, E., Orbegoso-Jordan, C., Schröder, S., & Malerba, M. E.	Agricultural reservoirs reduce micro-pumped hydro construction costs. Micro hydro pump match well with solar
5	Creating a hybrid intelligent irrigation system using both hydro and solar energy sources	Khadersab Adamsab	Utilizing the local canal Focus on efficient water usage to reduce wastage.
6	An evaluation of the potential for hydrogen production, irrigation, and job creation in a hybrid energy system tailored for tropical climates – Utilizing HOMER software, Shannon entropy, and TOPSIS methodologies	Agyekum, E. B., Ampah, J. D., Afrane, S., Adebayo, T. S., & Agbozo, E.	Optimization of hybrid power system for electricity and hydrogen production.

7	An evaluation of a Pelton turbine's performance within a rainwater harvesting framework for generating micro hydro-power in urban environments	Miguel Ángel_Zamora-Juárez_, Ortiz, C. R. F., Guerra-Cobián, V. H., López-Rebollar, B. M., Alarcón, I. G., & García-Pulido, D.	A turbine that is install in rainwater tank to produce electricity Focusing on height and length of the bucket
8	Assessing the viability of combining photovoltaic and mechanical storage systems for irrigation in remote regions: Streamlining, energy administration, and multi-criteria decision-making	Bashri A.A._Yousef, Amjad, R., Alajami, N. A., & Rezk, H.	System combines PV panels, different DG sizes, flywheel, and batteries for energy production/storage.
9	Developing an IoT-based smart irrigation system featuring data fusion and a self-sustaining wide-area network	Li_Gong, Yan, J., Chen, Y., An, J., Li, H., Zheng, L., & Zou, Z.	The data fusion method is explored to analysis multi-source heterogeneous data. An intelligent irrigation model is proposed to facilitate various IoT application scenarios.
10	Utilizing hydro-turbines in water transmission pipelines to capture energy: A case study conducted in western Saudi Arabia	Youssef Itani, Soliman, M., & Kahil, M.	Residual pressures are exploited by adding hydro-turbines to recover energy. Energy is affected by pipe design, and optimization reflects on system’s cost. Carbon footprint can be reduced by installing hydro-turbines in transmission pipes.
11	Assessing pesticide water fluctuation and prioritization: Initial measures to enhance water management tactics in hydro-agricultural irrigation zones	Júnia_Alves-Ferreira	Prevention of pesticide is the main topic instead of Hydro and irrigation Irrigation systems can spread contamination further

12	Examining trade-offs and synergies between hydropower generation and irrigation expansion in the Abbay River Basin, Ethiopia	Andargachew Melke_Alemu	The combined benefits derived from hydropower and irrigation outweigh the benefits of pursuing a single objective. river basin is potential source for hydropower production and irrigation development.
13	Evaluation of energy audits and environmental consequences across the entire life cycle of barley cultivation under various irrigation methods	Ali_Kaab, Khanali, M., Shadamanfar, S., & Jalalvand, M.	Energy audit was surveyed for barley production with different irrigation systems. Drip irrigation systems were found to have lower greenhouse gas emissions. Drip irrigation is the most efficient system in terms of water usage.
14	Identifying the best techno-economic energy management approach for solar photovoltaic water pumping irrigation systems	Ahmed_Elnozahy, Abdel-Salam, M., & Abo-Elyousr, F. K.	Study the water pumping PV systems for irrigation and how weather information affects water consumption. Modelling the cost analysis of the system parameters based on a vibration avoidance algorithm.
15	Determining the most appropriate existing irrigation dams for the implementation of small hydropower projects in Turkey using a GIS-Fuzzy logic tool	Serhat_Kucukali, Bayatı, O. A., & Maraş, H. H.	There's growing interest in using existing irrigation dams for small hydropower Converting irrigation dams to hydropower offers benefits like

			reduced investment and guaranteed water discharge. The study proposes a method to assess potential dam sites using GIS and fuzzy logic.
16	Utilizing pico-hydro power generated from wastewater for automated street light management via IoT sensors in smart urban areas: An economic evaluation	Tapas_Ch. Singh, Rao, K. S., Rajesh, P., & Prasad, G.	The article proposes generating free energy for a smart city using a pico-hydropower plant powered by treated sewage water. The system uses internet-of-things (IoT) sensors to monitor power generation and control street lights, CCTV, and traffic lights.
17	Development and creation of an in-line turbine for recovering pico hydro energy from treated sewage water distribution lines	Joel_Titus	The design allows installing the turbine within existing pipelines without disrupting water flow. The system harnesses energy from flowing treated sewage water, minimizing waste.
18	Practical examination of turbine and generator effectiveness within a pico hydro system	Ibadullah_Safdar, Sultan, S., Raza, H. A., Umer, M., & Ali, M.	The research explores how batteries and inverters affect turbine and generator efficiency. Small-scale hydropower offers a clean and reliable renewable energy source.

19	Utilizing pico-hydropower turbines for energy recuperation in a commercial establishment: A case study conducted in Australia	Sascha Thyer & White, T.	The study explores using pico-hydropower in water treatment systems to recover energy and reduce greenhouse gas emissions. Research finds a lack of information on pico-hydro applications in water treatment facilities. The study demonstrates successful implementation of a propeller turbine in a coral reef aquarium, achieving 10% energy recovery.
20	Assessment of the design and operational efficiency of a micro hydropower facility within a pressurized irrigation network: Practical implementation on a farm in Southern Spain	Miguel Crespo_Chacón	Electricity was brought to remote places with no access to grid connection. Diesel energy source was fully replaced by micro hydropower technology. Solar and micro hydro hybrid solution was used for self-consumption.

2.5 Summary

The literature review on pico hydro-powered irrigation systems presents a comprehensive synthesis of existing literature, research, and initiatives concerning this innovative technology. It explores the historical background of irrigation systems and the evolution of hydroelectric power generation, tracing the emergence of pico hydro systems as a sustainable energy solution for rural communities grappling with water scarcity and dependence on fossil fuels. By examining the significance of irrigation in agriculture, the review highlights the limitations of traditional methods and investigates the principles and components of pico hydro systems, emphasizing their suitability for small-scale, off-grid applications and reliance on the kinetic energy of flowing water. Additionally, it scrutinizes case studies and pilot projects worldwide, showcasing successful deployments of pico hydro-powered irrigation systems in various settings and identifying key factors contributing to project success, such as community engagement, technical proficiency, and access to funding. Furthermore, the review addresses obstacles and hurdles to adoption, including regulatory complexities and technical constraints, emphasizing the importance of interdisciplinary cooperation, stakeholder participation, and knowledge exchange in promoting sustainable agricultural practices and addressing global water and energy dilemmas.

2.6 Formula

$$\boldsymbol{P = Q \times g \times h} \tag{2.1}$$

CHAPTER 3

METHODOLOGY

3.1 Introduction

The methodology chapter introduces how a research study is conducted, outlining the chosen approach, procedures, and techniques. It starts by explaining the research design and philosophical underpinnings guiding the study. This brief overview also previews key components like component details, quotations, flowcharts, and project progression. Overall, it sets the stage for a detailed exploration of the methodology's key elements.

3.2 Methodology

The methodology for implementing a pico hydro-powered irrigation system begins with a meticulous process of site selection, taking into account factors such as water availability, terrain, and proximity to the fields. This initial step ensures that the chosen location is well-suited for harnessing hydro power and efficiently distributing water to the agricultural areas. Through site surveys and feasibility studies, a thorough assessment of these factors is conducted to inform decision-making accurately [28].

Once the site is determined, the design phase ensues, wherein the required flow rate, elevation difference, and selection of system components like turbines, piping, and irrigation infrastructure are finalized. Rigorous calculations and engineering assessments are undertaken to ensure that the design meets the specific irrigation requirements of the area while maximizing energy utilization and minimizing expenses.

Following the design phase, installation takes place, involving the setup of the hydro turbine, piping network, and irrigation apparatus as per the design specifications. Skilled labor and appropriate equipment are pivotal during this stage to ensure the system's proper and safe installation. Moreover, community engagement and local insights may contribute significantly to the installation process, fostering a sense of ownership and sustainability.

Subsequently, testing, calibration, and ongoing monitoring become imperative to validate the system's performance and address any potential issues that arise. Regular maintenance and periodic adjustments are carried out to enhance the system's efficiency and reliability over time. Community training initiatives may also be implemented to equip local users with the necessary knowledge and skills to operate and maintain the system effectively. Throughout the methodology, emphasis is placed on sustainability, environmental considerations, and social inclusivity to ensure the enduring success and resilience of the pico hydro-powered irrigation system [29].

3.2.1 General Flowchart

A general report flowchart outlines the systematic process of report creation, beginning with identifying the report's objectives and scope. It progresses through conducting research, gathering and analyzing data, and drawing conclusions. An outline is created to organize the content, followed by drafting the report.

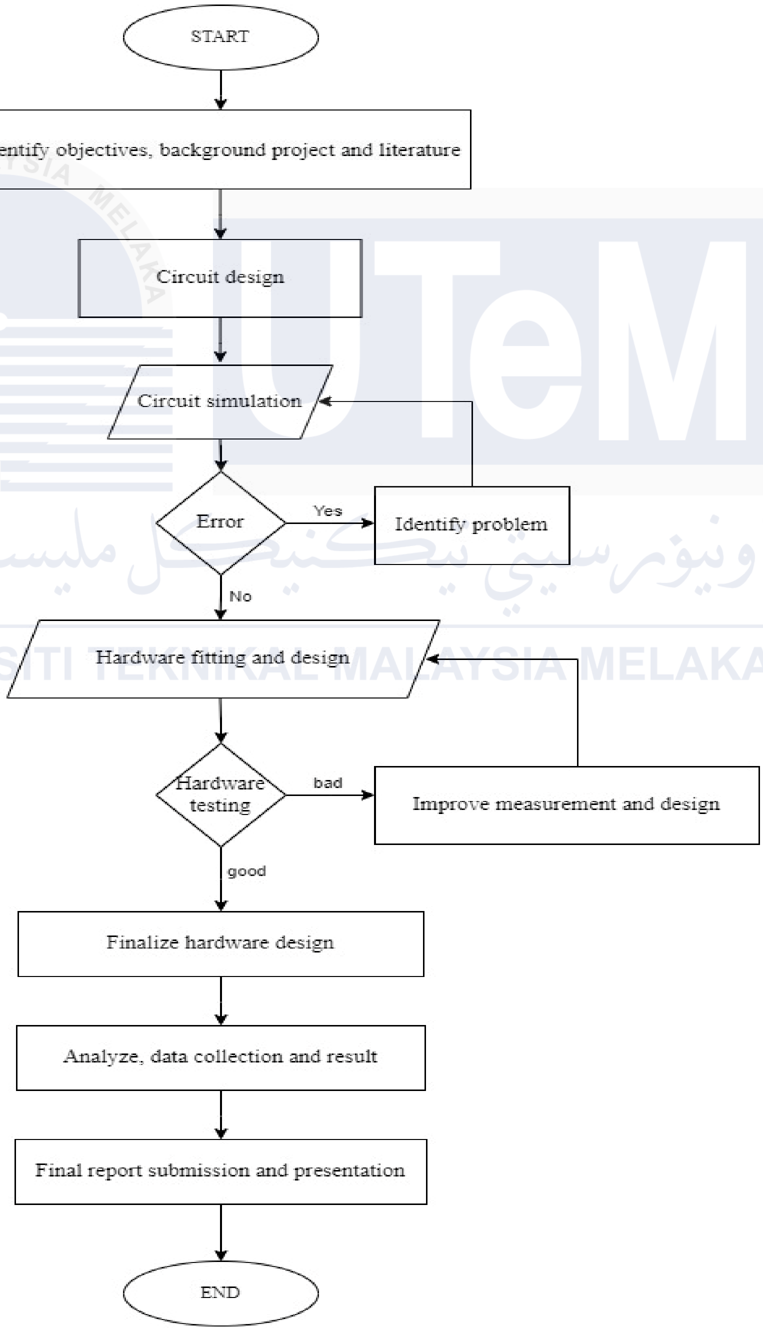


Figure 3.1 General Flowchart

3.2.2 Project flowchart

A project flowchart illustrates a pico hydro-powered irrigation system that automates water delivery based on soil moisture levels. Water from a storage tank flows through a penstock pipe to a pico hydro turbine, generating renewable energy to power the system. A soil moisture sensor monitors conditions, if moisture is high, water is redirected to storage, conserving resources. If moisture is low, an irrigation valve opens, delivering water through the system to hydrate the soil. This sustainable design optimizes water usage and ensur eefficient irrigation.

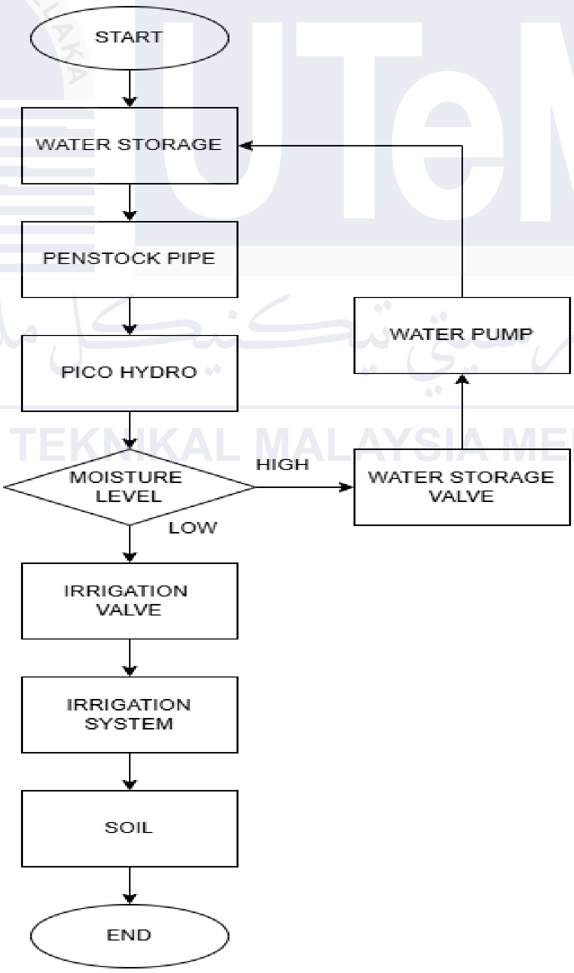


Figure 3.2 Project Flowchart

3.3 Project Architecture

Project architecture refers to the high-level design and structure of a project, outlining its key components, interactions, and dependencies. It provides a blueprint for how the project will be organized and executed, guiding the development process from conception to completion. This includes defining the project's scope, identifying major modules or components, specifying interfaces and interactions between them, and outlining the technologies and tools to be used. A well-defined project architecture enables efficient development and ensures that the final product meets the desired requirements and objectives.

This block diagram illustrates a pico hydro power plant, a small-scale system that harnesses moving water to generate electricity. Water diverted from a source travels through a channel and spins the turbine blades within the pico hydro unit. This mechanical rotation is then converted into electricity by the generator. Optionally, the water can be directed for irrigation after passing through the turbine.

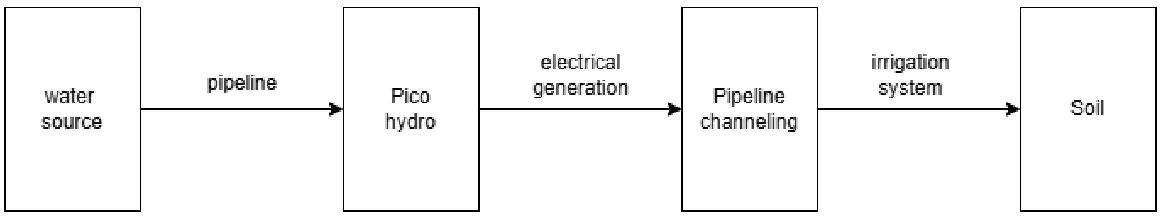
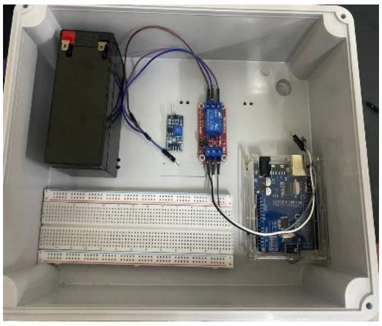
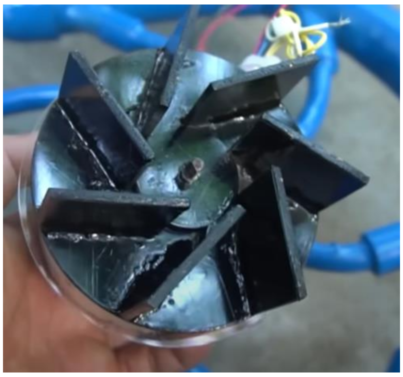


Figure 3.3 Project block diagram

3.3.1 Project components

Table 3.1 list of components use in this project

No	Component name	Applications	Descriptions
1	Hydro Generator  	A small-scale hydroelectric system designed to harness the power of flowing water from small streams or rivers to generate electricity.	These systems typically have a low power output, ranging from a few watts to a few kilowatts, making them suitable for powering off-grid applications in rural and remote areas.
2	PVC Pipe 	A complete design of piping can be turn into a water diversion for better water flows.	Pipes are cylindrical hollow structures typically made of metal, plastic, or other materials, designed to convey fluids, gases, or solids from one point to another.
3	Electrical Circuit 	Electrical circuits are used for power distribution, lighting and many other electrical related components.	An electrical circuit is a closed loop or pathway through which electrical current flows, consisting of interconnected components.

4	Turbine 	Turbine are used for power generations typically related to hydro and wind.	turbine is a rotary mechanical device that converts energy from a fluid flow into mechanical energy or work, typically by means of blades or vanes mounted on a shaft.
5	Water Storage 	Water storage tanks are used to store water and provide faster access to a water supply, it is also the main storage and supply of raw resource for this project.	Water storage involves storing water for various purposes, such as household use, agriculture, and rainwater harvesting.
6	Solenoid Valve 	A solenoid valve is an electronically controlled valve that manages the flow of liquids or gases within a system.	Solenoid valve control the flow of water for the irrigation and water storage.
7	Water Pump 	A water pump is a mechanical device to increase pressure for the water storage system.	to move water from one location to another by creating pressure or increasing flow.

3.3.2 Component quotations

Table 3.2 quotation for this project

No	Component name	Description	Quantity	Price
1	Hydro Generator	RM 32.22 / unit	1	RM 32.22
2	PVC Pipe	RM 0.90 / meter	12	RM 10.80
3	Poly Pipe	RM 0.60 / meter	1	RM 0.60
4	Jumper	RM 3.44 / set	3	RM 10.32
5	Solenoid Valve	RM 19.80 / unit	2	RM 39.60
6	Water Pump	RM 27.61 / unit	1	RM 27.61
7	Water Storage	RM 23.90 / unit	2	RM 47.80
8	Soil Moisture Sensor	RM 3.90 / unit	4	RM 15.60
9	Arduino Uno	RM 42.90 / unit	1	RM 42.90
10	Arduino Relay	RM 3.90 / unit	2	RM 7.80
11	8 Hole Dripper (Sprinkler)	RM 0.16 / unit	10	RM1.60
12	Soil Basket	RM 19.90 / unit	1	RM 19.90
13	Pipe Connector	RM 0.40 / unit	15	RM 6.00
14	Junction Box	RM 16.90 / unit	1	RM 16.90
			TOTAL	RM 280.55

3.4 Project design

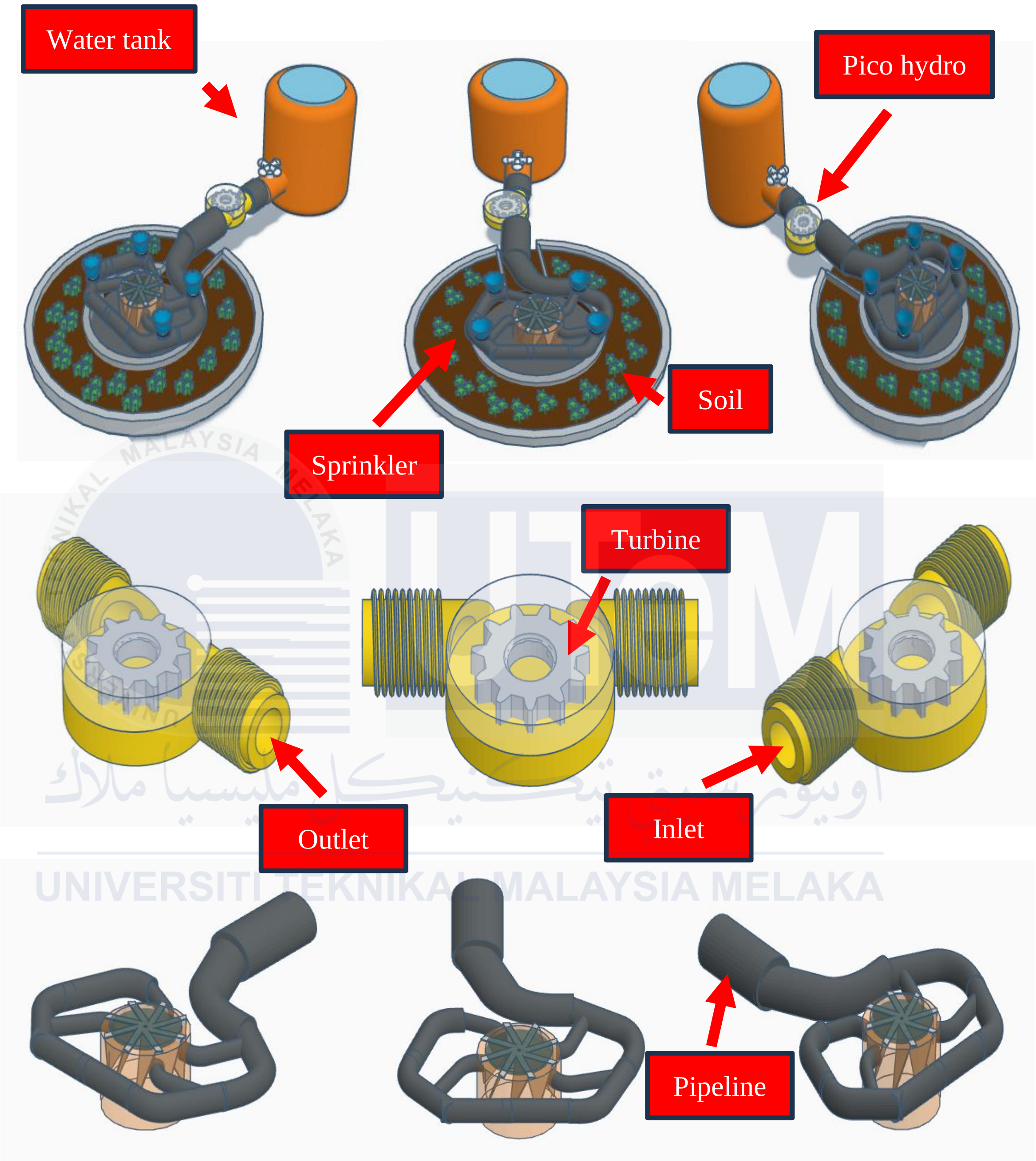


Figure 3.4 initial project design

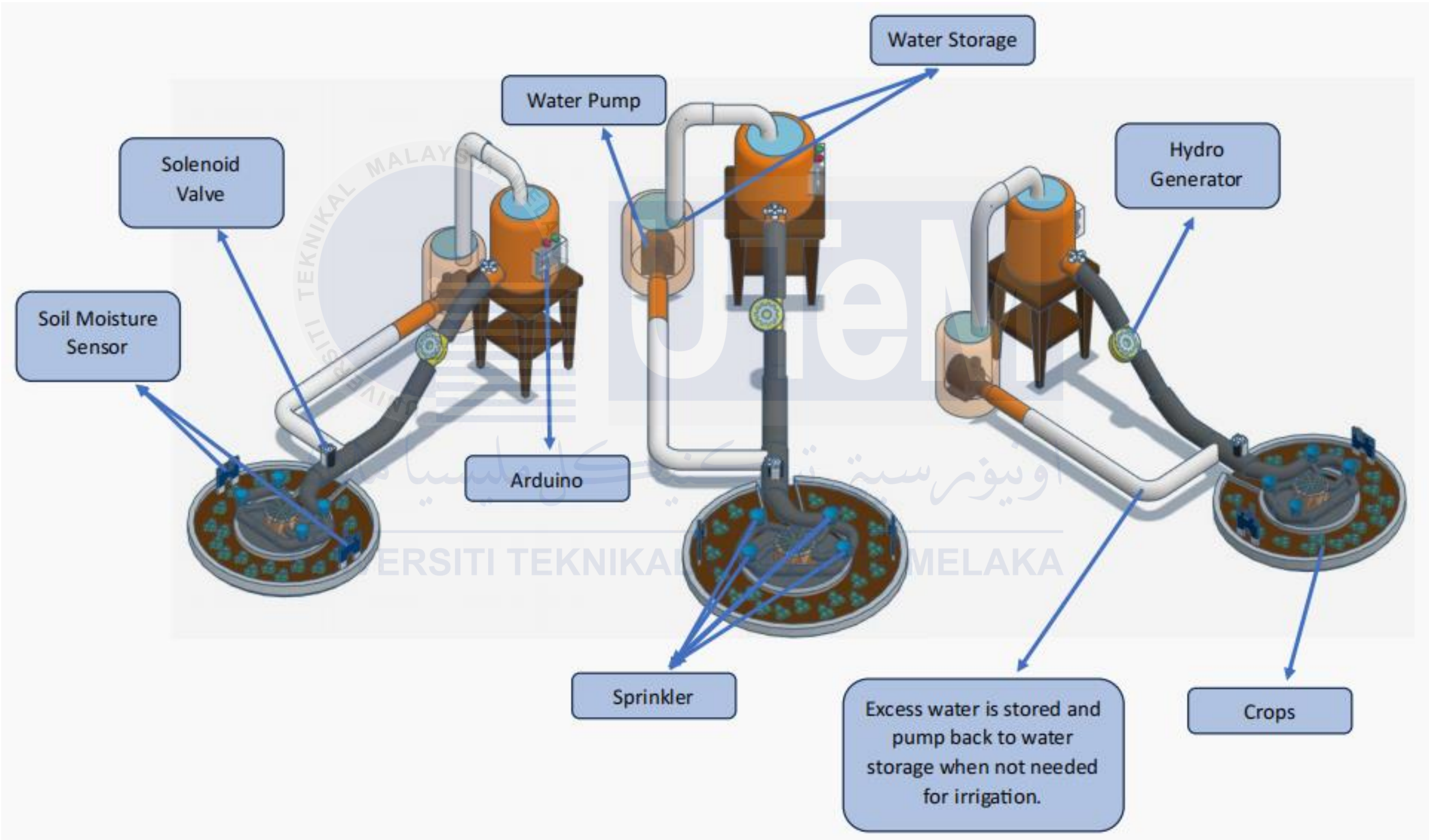


Figure 3.5 full project design

3.5 Hardware Methodology

Hardware analysis is the process of evaluating and assessing the physical components of a system to ensure they meet the requirements for functionality, efficiency, reliability, and compatibility. It involves examining how each piece of hardware operates individually and as part of the overall system, focusing on design, performance, durability, and integration.

In the context of “Pico Hydro Powered Irrigation System” hardware analysis includes identifying and selecting appropriate components, such as sensors, pico hydro generator, controllers, waterflow, power, moisture and pipeline based on system requirements. It also involves studying the materials, energy consumption, cost-effectiveness, and maintenance needs of the hardware.

The goal of hardware analysis is to optimize the performance of a system, minimize potential issues, and ensure that the selected components work together seamlessly to achieve the desired output. It is commonly applied in fields like electronics, automation, renewable energy systems, and industrial design.

3.5.1 Electrical Design

This electrical design represents an automated irrigation system powered by a pico hydro generator, integrating key components such as an Arduino microcontroller, sensors, relays, and solenoid valve and water pump. The system is start up by a pico hydro generator which is then assist by 12V battery for smoother performance on valve and water pump. The Arduino serves as the central controller, processing input signals from the soil moisture sensor and managing the overall operation of the system. The soil moisture sensor continuously monitors the moisture levels in the soil, sending data to the Arduino. If the moisture level falls below a predefined threshold, the Arduino activates a relay to power the valve, ensuring water is delivered to the soil.

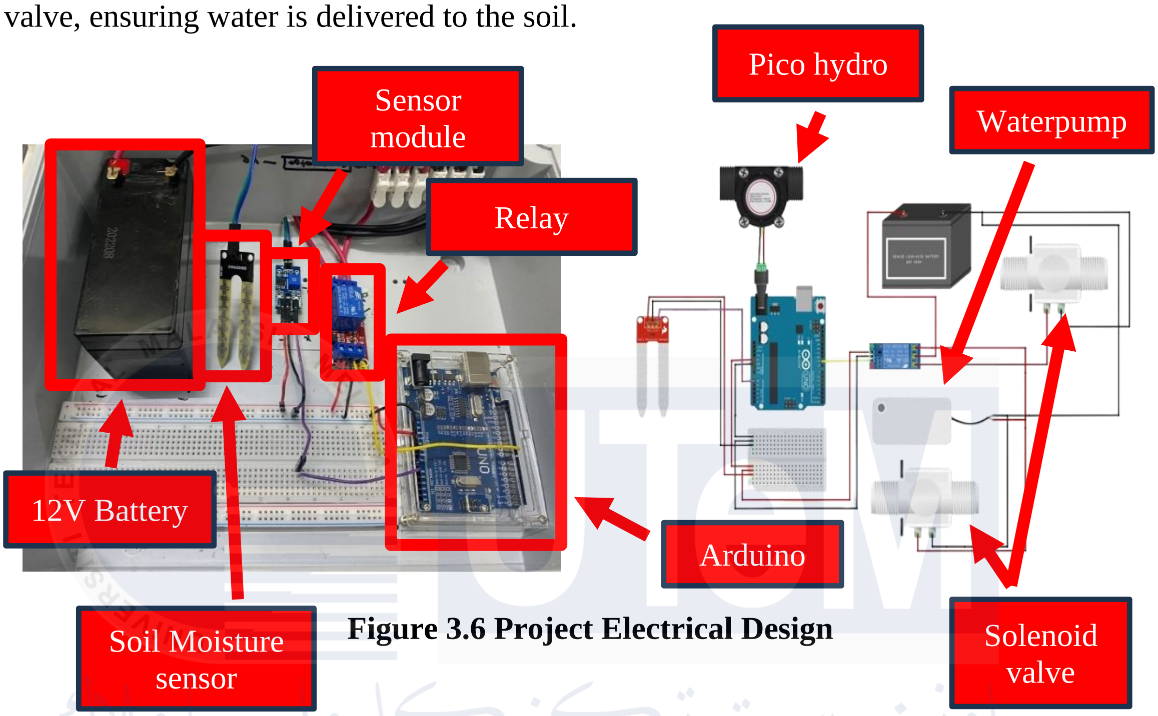


Figure 3.6 Project Electrical Design

3.5.2 Voltage, Current and Power methodology

The analysis for voltage and current involves measuring voltage and current across different penstock sizes using multimeter. Voltage is recorded by connecting the multimeter in parallel to the circuit, while current is measured by connecting the multimeter in series. These measurements allow for observing the relationship between penstock size and electrical parameters. The data shows how both voltage and current vary with different sizes, providing a basis for understanding the energy generation potential of the system.

For power is calculated using the voltage and current measurements obtained from previous voltage and current readings. The formula "$P = VI$" is applied to derive power values for each penstock size. This method emphasizes the combined effect of voltage and current on the power output and highlights the scalability of energy generation with penstock dimensions.

$$P = V \times I$$

$$P = Power\ (W)$$

$$V = Voltage\ (V)$$

$$I = Current\ (A) \tag{3.1}$$

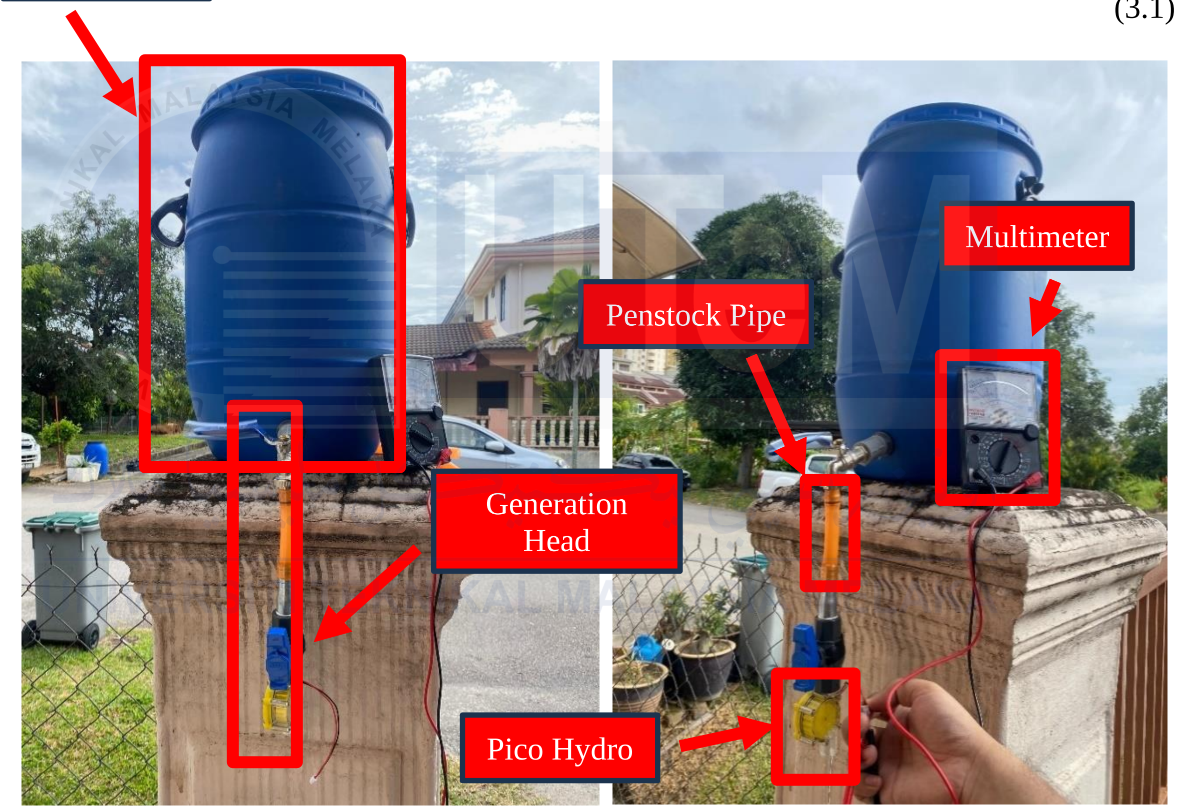


Figure 3.7 Measuring voltage and current

3.5.3 Moisture sensor placement

Sensor placement focuses on moisture detection using a moisture sensor connected to an Arduino IDE plotter. The sensor is placed in different conditions fully submerged, in humid soil, in dry soil, and outside the soil and resistance readings are recorded. The data categorizes moisture levels into predefined ranges based on the resistance values, offering clear distinctions between various soil moisture states.

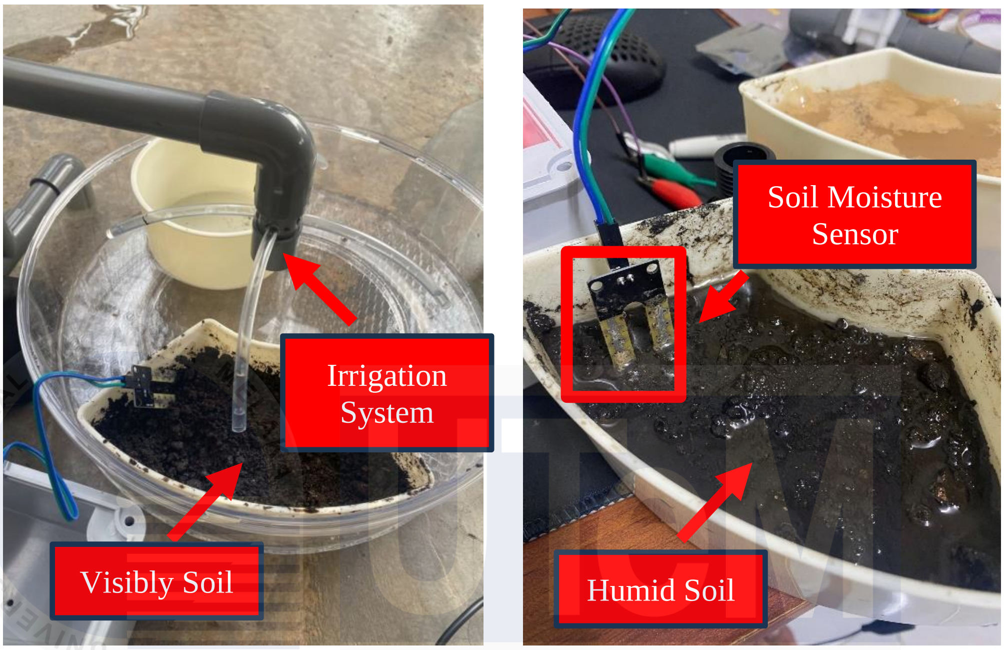


Figure 3.8 Moisture sensor placement

3.5.4 Flowrate meter

This method measured the flow rate of water through a pipeline at different valve opening angles. A flow rate meter connected to the pipeline records the speed of water flow in meters per second for each angle tested, ranging from 15° to 90°. The data demonstrates a strong positive correlation between valve angle and flow rate, showing that wider openings significantly enhance water flow. This relationship underscores the importance of valve control in regulating water flow and optimizing the performance of water-based systems, such as irrigation or hydroelectric setups.

Figure 3.9 Flowrate readings

3.5.5 Voltage on different valve angle

This experiment investigates the voltage generation of a pico hydro generator as the valve angle is adjusted. Using a multimeter, voltage readings are captured at different angles, revealing that voltage generation begins only when the valve angle exceeds 60° and peaks at 90°. This finding highlights the critical role of flow rate in enabling power generation. This method identify sufficient water flow, controlled by the valve angle, is essential to overcoming the threshold for effective electricity production. The analysis reinforces the dependency of pico hydro systems on optimal water dynamics for achieving maximum energy output.

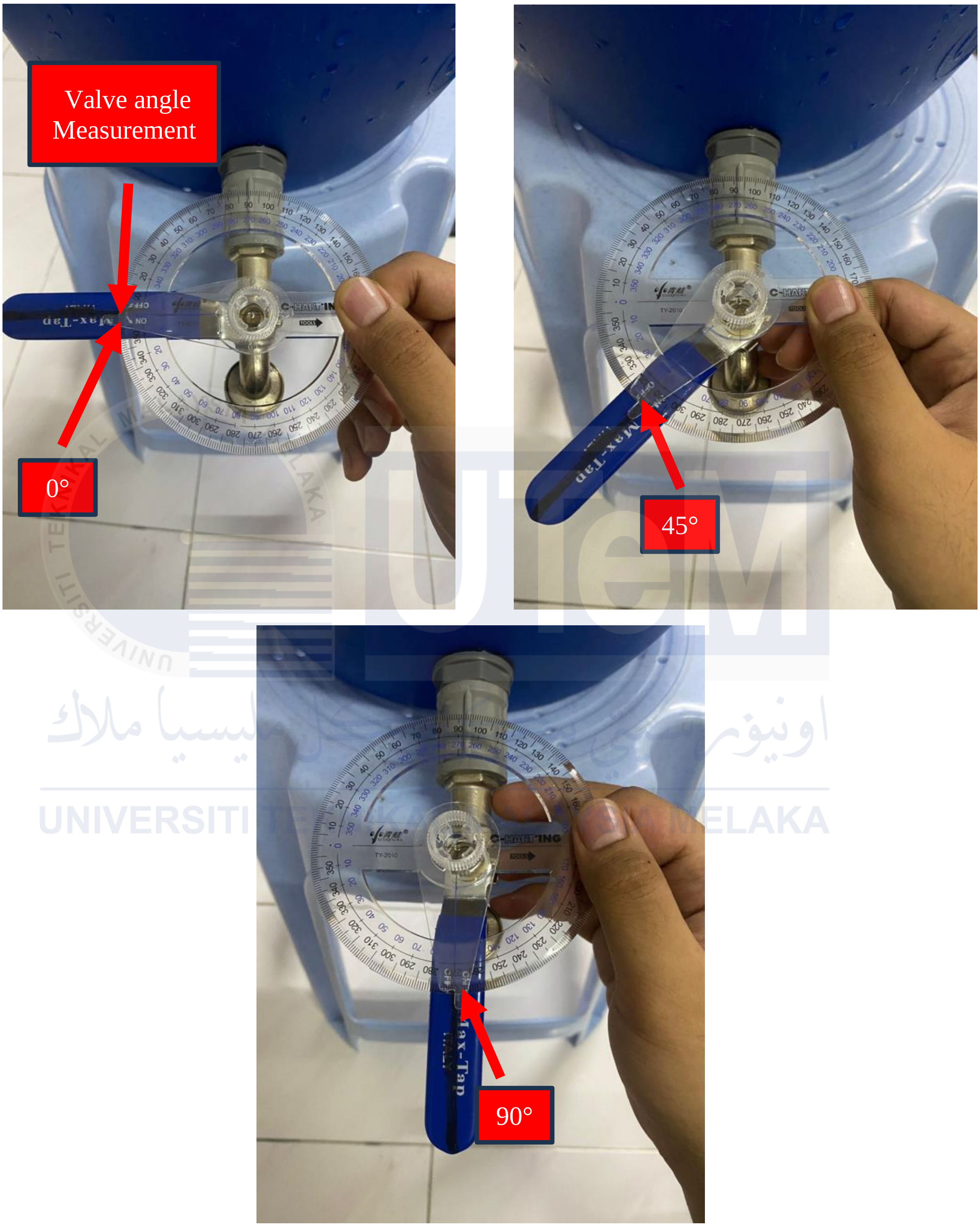


Figure 3.10 Valve angle

3.5.6 Full hardware assembly

The hardware assembly of a pico hydro-powered irrigation system integrates mechanical, electrical, and structural components to achieve energy generation and automated water distribution. At its core, the system consists of a water reservoir, typically elevated, to create gravitational potential energy, enabling water to flow through pipes under pressure. This flow can pass through a small turbine to generate electricity while also being directed to irrigation outlets for watering plants.

The assembly includes a network of pipes, valves to control water flow, and a plant basin for irrigation. The system also incorporates electronics such as sensors, microcontrollers, and water distribution. Structural elements, like stands or frames, provide stability and maintain the required height for water flow. This setup ensures efficient use of water and renewable energy, making it ideal for small-scale sustainable agriculture.

Figure 3.11 Full Hardware Assembly

3.6 Gantt chart

Table 3.3 Gantt chart

TASK	PSM 1														PSM 2													
WEEKS	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Briefing for PSM 1 by JK, PSM, FTKEE																												
Project Title confirmation and Registration																												
Briefing with Supervisor																												
Study the project background																												
Drafting chapter 1 : Introduction																												
Task progress evaluation 1																												
Drafting chapter 2 : Literature Review																												
Table of Summary Literature Review																												
Drafting chapter 3 : Methodology																												
Work on the Software/Hardware																												
First Draft Submission to Supervisor																												
Task progress evaluation 2																												
Submission Report to the Panel																												
Presentation of BDP1																												
Drafting Chapter 4 : Analyze Data And Result																												
Data Analyza And Result																												
Record The Result																												
Drafting Chapter 5 : Conclusion And Recommendation																												
Compiling Chapter 4 and Chapter 5																												
Submit Latest Report To Supervisor																												
Finalize The Report																												
Presentation of BDP2																												

3.7 Summary

The methodology outlined for the Pico Hydro Powered Irrigation System provides a robust framework for integrating hardware and experimental analysis to optimize performance. By carefully measuring voltage, current, and power across different penstock sizes, the study highlights the correlation between physical system components and energy generation potential. The placement and calibration of moisture sensors contribute to precise soil moisture monitoring, enabling efficient irrigation practices tailored to varying soil conditions. Furthermore, the assessment of flow rate and valve angle effects emphasizes the importance of controlled water dynamics in maximizing both irrigation efficiency and energy output. Together, these methodologies ensure that the system operates cohesively, meeting the dual objectives of water management and renewable energy generation.

For future work, several avenues can be explored to enhance the system's functionality and impact. Advanced automation techniques, such as integrating IoT for real-time monitoring and remote control, can further improve efficiency and user convenience. Additionally, experimenting with alternative turbine designs or incorporating energy storage solutions could optimize power availability and scalability. Expanding the system's application to include hybrid renewable setups or larger-scale irrigation networks could also enhance its versatility and environmental benefits. These efforts would contribute to the continued refinement of sustainable agricultural technologies, addressing the growing demand for innovative solutions in water and energy management.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter presents the preliminary results and analysis of this study, focusing on the effectiveness and practicality of the proposed solution. This chapter evaluates key performance metrics, examining how well the system meets its intended goals under various conditions. The initial findings provide insights into the system's operational efficiency, reliability, and potential areas for improvement. Through detailed analysis, this chapter aims to identify critical factors that influence overall performance and to lay the groundwork for more comprehensive future studies. This chapter sets the stage for understanding the system's capabilities and limitations, guiding further refinement and optimization efforts.

4.2 Preliminary Results and Analysis

The preliminary results and analysis present the investigation into the ability and state of a pico-hydro powered irrigation system using harvested rainwater. The task systematically evaluates the system's key performance metrics, including power output, efficiency, and reliability under various operational conditions. Additionally, we analyze the impact of the generated power on the irrigation system's functionality, focusing on water flow rates, irrigation coverage, and overall system efficiency. The initial findings provide insights into the operational strengths and limitations of the pico-hydro system, highlighting critical factors that influence its performance in agricultural settings. These insights form a foundation for further detailed studies, aiming to optimize the design and operation of pico-hydro powered irrigation systems to support sustainable agricultural practices and enhance the livelihoods of farmers in resource-constrained regions.

4.2.1 TinkerCAD simulation using Arduino

TinkerCAD simulation depicts a circuit designed to measure soil moisture. An Arduino Uno board supplies power to a soil moisture sensor with two probes inserted into the soil. As the moisture content changes, the resistance between the probes fluctuates. The Arduino reads this resistance and converts it to a moisture level value. This setup allows you to monitor soil moisture and potentially trigger actions like an LED indicator or send data for further analysis.

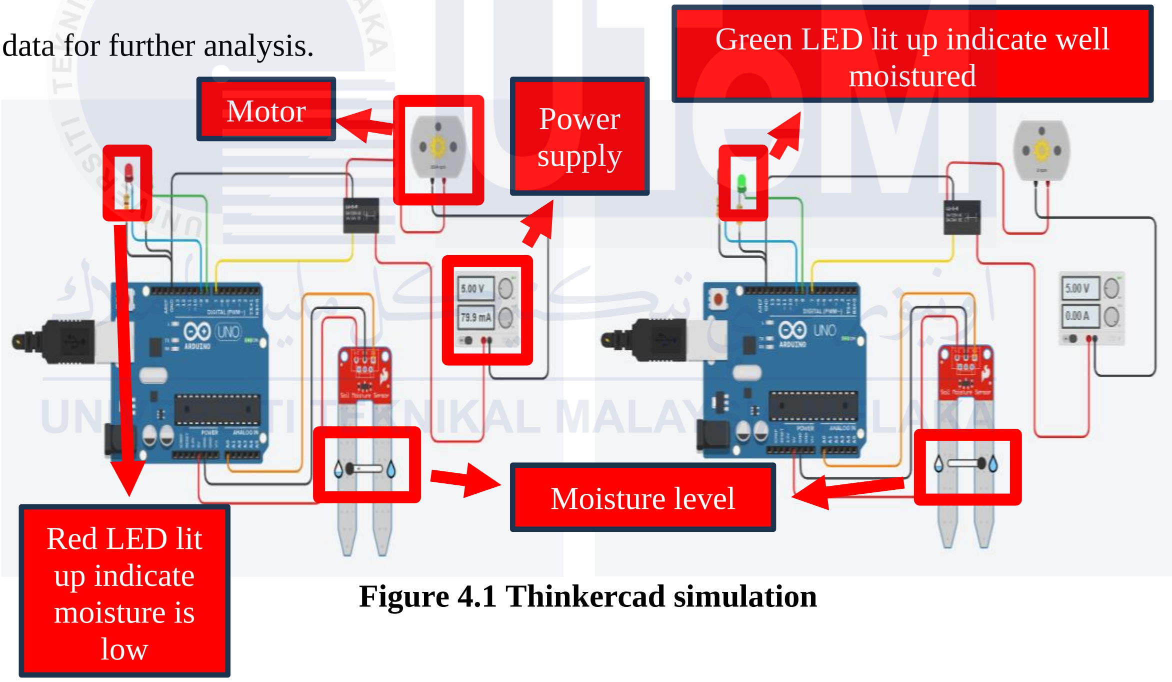


Figure 4.1 Thinkercad simulation

Table 4.1 Simulation content

Component	Application
Soil moisture sensor	To determine the moisture level in the soil.
Power supply	To supply motor for watering system.
LED	To indicate high and low moisture level.
Arduino	Control system.
Motor	Act as a valve.

4.3 Hardware Analysis

The hardware analysis for the pico hydro-powered irrigation system focuses on evaluating each component's functionality, compatibility, and performance to ensure the system operates efficiently and reliably. At the core of the system is the pico hydro generator, which converts the kinetic energy of flowing water into electrical energy. 12V battery acts as a a support for consistent operation even during fluctuations in water flow. The Arduino microcontroller serves as the central control unit, processing data from the soil moisture sensor and managing the operation of the water pump and solenoid valves through relays. The soil moisture sensor is critical for monitoring the soil's moisture levels and must be accurate, durable, and resistant to environmental conditions like water and soil exposure. The water pump draws water from the source, and its flow rate and energy efficiency must align with the irrigation needs and the system's energy limitations. Solenoid valves play a key role in directing water to specific irrigation zones, requiring durability and efficient operation at the system’s voltage. Relays are used to control the high-power devices, ensuring safe and reliable switching between components. Additionally, wiring and connectors must support appropriate current ratings and be waterproof to withstand outdoor conditions. Protective enclosures and stable mounting structures are also necessary to protect sensitive components and ensure system longevity. By carefully analyzing and selecting hardware components based on their compatibility and sustainability, the system can achieve its goal of providing efficient, automated irrigation powered entirely by renewable energy.

4.3.1 Voltage and current measurement

The results collected during this analysis provide critical insights into the performance of the pico hydro system and its related components. Each set of results illustrates the relationship between system design variables and their output performance, offering a comprehensive foundation for optimization and future developments.

Table 4.2 The Result of Voltage Reading Obtained from Different Penstock Length

Penstock length	Voltage (V)			
	Reading 1	Reading 2	Reading 3	Average
10 cm	3.8	4.8	4.6	4.4
20 cm	4.8	4.8	4.8	4.8
30 cm	5	5.1	5	5.03
40 cm	5.2	5.2	5.2	5.2
60 cm	5.3	5.4	5.4	5.36
80 cm	5.6	5.6	5.6	5.6

Table 4.3 The Result of Current Reading Obtained from Different Penstock Length

Penstock length	Current (mA)			
	Reading 1	Reading 2	Reading 3	Average
10 cm	2	4	4	3.33
20 cm	2.5	6.5	6.5	5.17
30 cm	10	11	11	10.67
40 cm	12	12.5	12.5	12.17
60 cm	13	14	14	13.67
80 cm	15.3	16	16	15.77

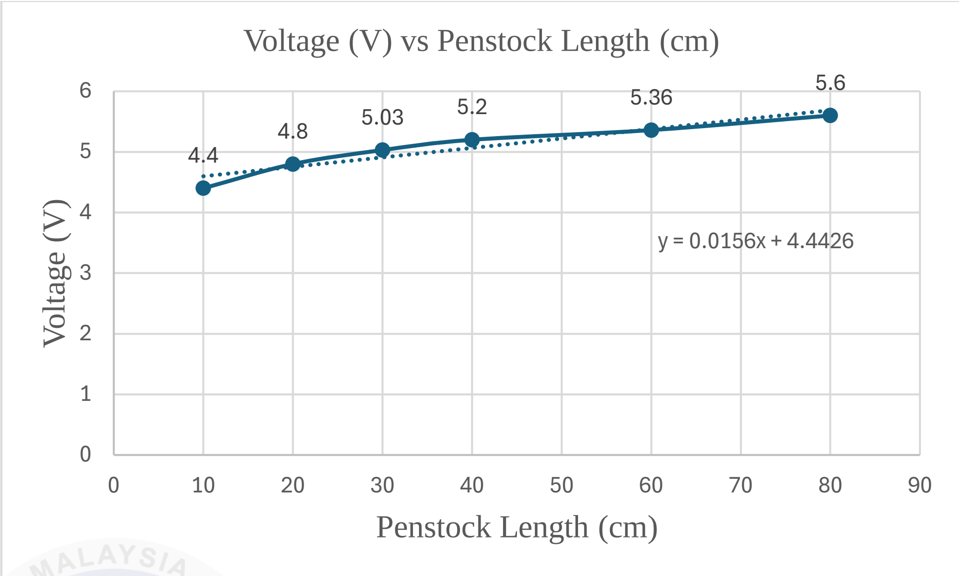


Figure 4.2 Graph of Voltage vs Penstock Length

Based on the graph we obtain the equation :

$$\boldsymbol{y = 0.0156x + 4.4426} \tag{4.1}$$

y = Voltage (V)

x = Penstock length (cm)

To find the necessary penstock length for 12V:

$$\boldsymbol{y = 0.0156x + 4.4426}$$

$$12V = 0.0156(x) + 4.4426$$

$$x = \frac{12V - 4.4426}{0.0156}$$

$$x = 484.45cm$$

Hence the necessary penstock length is : $484.45cm$

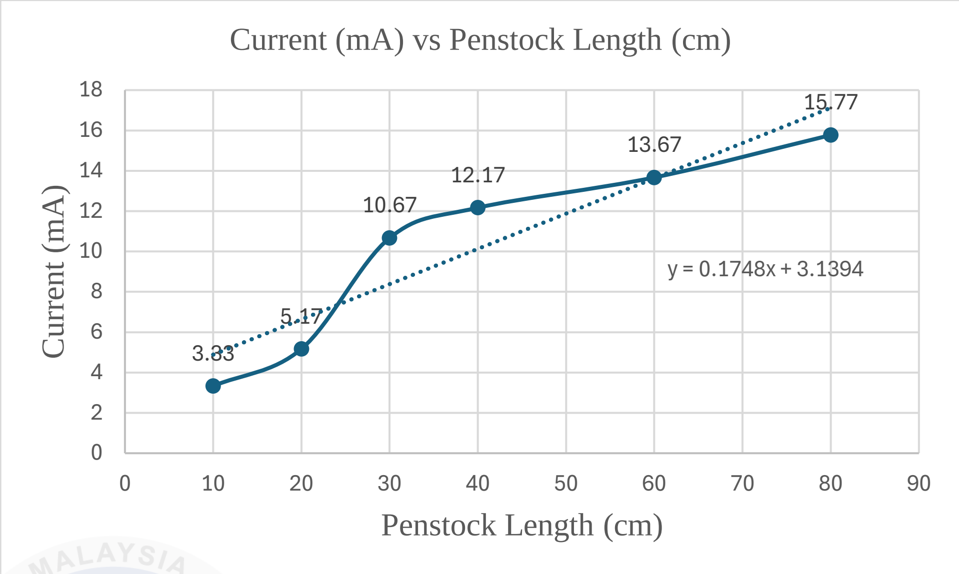


Figure 4.3 Graph of Current vs Penstock Length

Based on the graph we obtain the equation :

$$\boldsymbol{y = 0.1748(x) + 3.1394} \quad (4.2)$$

y = Current (mA)

x = Penstock length (cm)

To find the necessary penstock length for 600mA:

$$\boldsymbol{y = 0.1748(x) + 3.1394}$$

$$600 = 0.1748(x) + 3.1394$$

$$x = \frac{600 - 3.1394}{0.1748}$$

$$x = 3414.53cm$$

Hence the necessary penstock length is : $3414.53cm$

The voltage readings measured across penstocks of varying sizes indicate a clear trend of increasing voltage output with larger penstocks. For instance, the voltage starts at an average of 4.4 V for a 10 cm penstock and steadily rises to 5.6 V for an 80 cm penstock. This result is consistent with the expectation that larger penstocks allow for higher water flow, which drives the pico hydro generator more effectively.

Similarly, the current measurements display a proportional increase with penstock size. At a 10 cm penstock, the current averages 3.33 mA, while at an 80 cm penstock, it reaches 15.77 mA. The correlation between penstock size, water flow, and electrical output is evident, demonstrating the importance of scaling the system dimensions to achieve higher energy yields. These findings suggest that by optimizing the size of the penstock, the pico hydro system can be made more efficient and suitable for larger-scale applications.

4.3.2 Power Output

Power output, calculated using the formula "$P = V \times I$" reflects the combined effect of voltage and current. The results show a gradual increase in power with penstock size, starting at 0.02 W for the 10cm penstock and reaching a peak of 0.09 W for the 80cm penstock. This incremental improvement underscores the significance of system design in achieving higher energy efficiency. While the power output is modest in this prototype setup, the trend suggests substantial potential for improvement in scaled-up models with better water flow management and enhanced turbine designs.

Table 4.4 The Result of Power Reading Obtained from Different Penstock length

Sizing	Power (W)			
	Reading 1	Reading 2	Reading 3	Average
10 cm	7.6m	0.02	0.02	0.02
20 cm	0.01	0.02	0.02	0.02
30 cm	0.05	0.06	0.06	0.06
40 cm	0.06	0.07	0.07	0.07
60 cm	0.07	0.08	0.08	0.08
80 cm	0.09	0.09	0.09	0.09

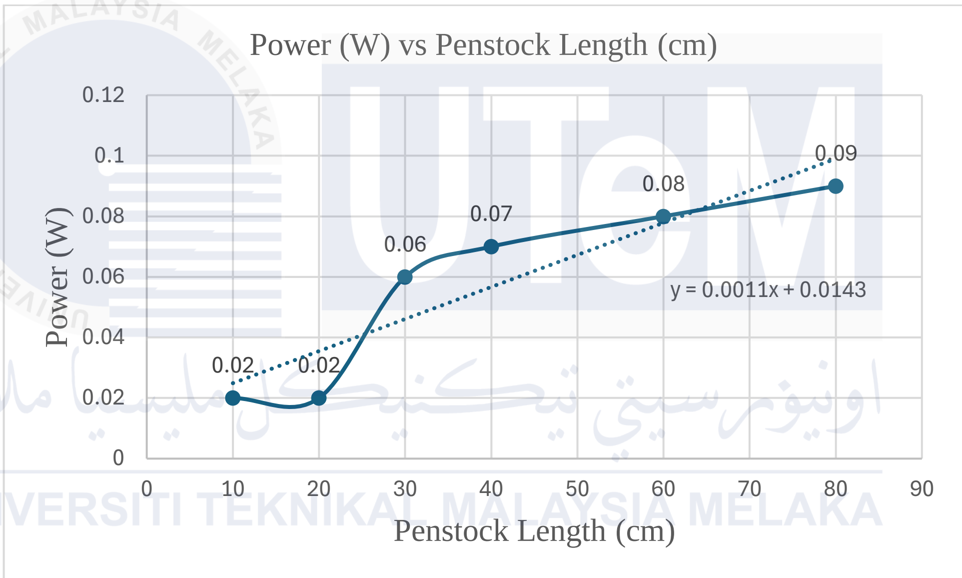


Figure 4.4 Graph of Power vs Penstock Length

Based on the graph we obtain the equation :

$$\boldsymbol{y = 0.0012(x) + 0.01}$$

(4.3)

y = Power (W)

x = Penstock length (cm)

To find the necessary penstock length for 8W:

$$\boldsymbol{y = 0.0012(x) + 0.01}$$

$$8 = 0.0012(x) + 0.01$$

$$x = \frac{8 - 0.01}{0.0012}$$

$$x = 6658.33cm$$

Hence the necessary penstock length is : $6658.33cm$

4.3.3 Moisture sensor performance

The moisture sensor readings provide valuable data for monitoring soil moisture under various conditions. When fully submerged, the sensor recorded the lowest resistance, averaging 424 Ω, indicative of maximum moisture content. In humid soil, the resistance increased to an average of 554 Ω, while dry soil showed significantly higher resistance at 901 Ω. When the sensor was not in soil, resistance peaked at 1018 Ω, indicating a disconnected or dry state.

Table 4.5 The Result of Moisture Sensor Reading Obtained from Different Sensor Placement

Placement	Ohm (Ω)			
	Reading 1	Reading 2	Reading 3	Average
Fully submerge	418	426	428	424
In Humid soil	587	562	513	554
In dry soil	840	920	943	901
Not in soil	1010	1022	1023	1018

Table 4.6 Summary of moisture readings

1000 > above	Not in soil / Disconnected
600 >= 1000	In dry soil
450 >= 600	In humid soil
below < 450	Fully submerge

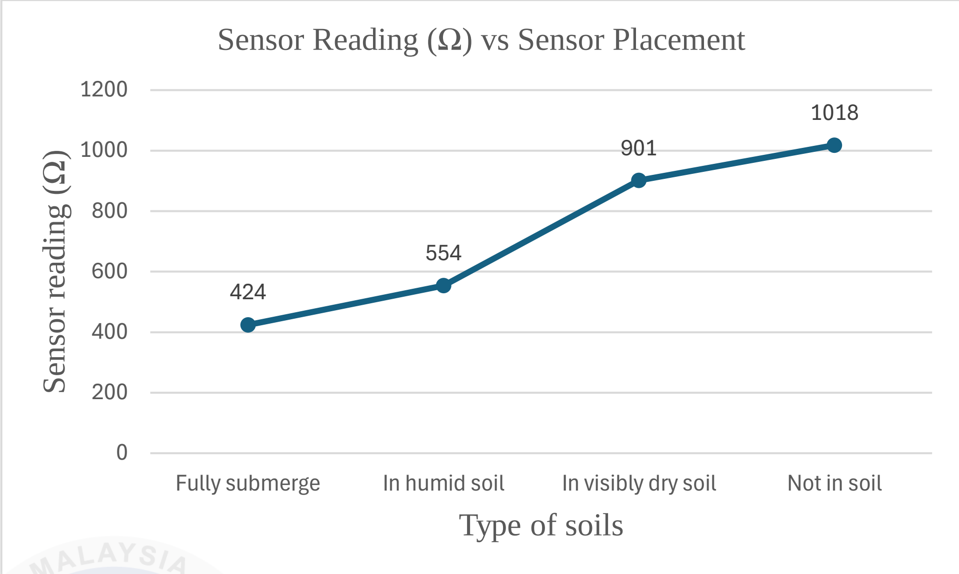


Figure 4.5 Graph Sensor Readings vs Sensor Placement

These resistance ranges allow for the categorization of soil conditions, enabling the sensor to provide accurate real-time feedback. This capability is highly applicable in smart irrigation systems, where precise moisture monitoring can optimize water usage and enhance crop yields. The effectiveness of the sensor demonstrated here suggests its potential for broader agricultural and environmental monitoring applications.

4.3.4 Flow rate measurement

Flow rate readings reveal the impact of valve angle on water flow dynamics. At smaller valve angles, such as 15°, no measurable flow was recorded, indicating insufficient water pressure to generate movement. As the valve angle increased, the flow rate steadily rose, peaking at 0.92 m/s at a 90° angle. This strong correlation between valve angle and flow rate highlights the importance of precise valve control for optimizing system performance.

Table 4.7 The Result of Flow Rate Reading Based on Different Valve Angle

Valve Angle	Meter per second (m/s)			
	Reading 1	Reading 2	Reading 3	Average
15°	0	0	0	0
30°	0.09	0.12	0.11	0.08
45°	0.37	0.32	0.39	0.36
60°	0.75	0.75	0.77	0.76
75°	0.82	0.82	0.84	0.83
90°	0.92	0.90	0.93	0.92

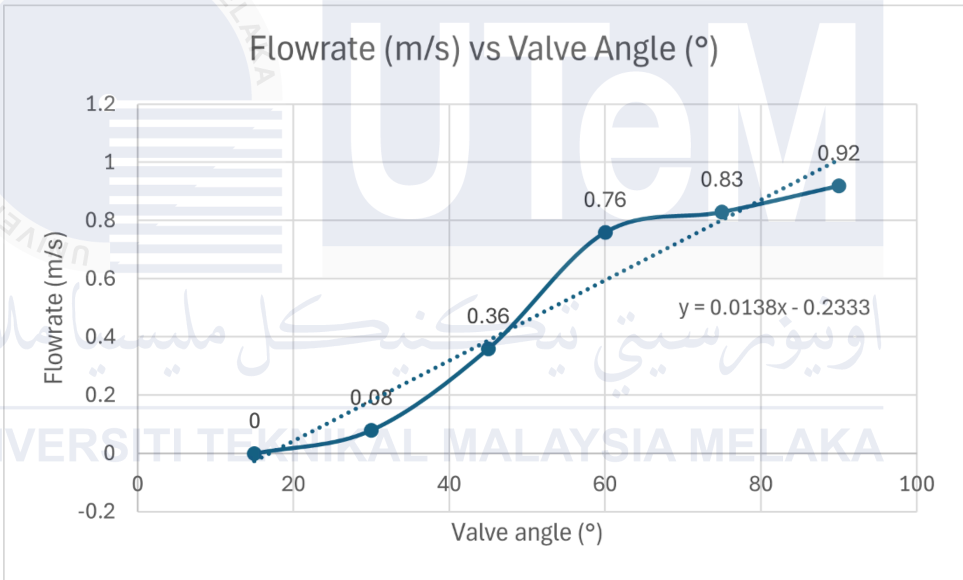


Figure 4.6 Graph of flowrate vs valve angle

Based on the graph we obtain the equation :

$$\boldsymbol{y = 0.0138(x) - 0.2333} \tag{4.4}$$

y = flowrate (m/s)

x = valve angle (°)

To find the necessary valve angle for 3m/s :

$$\boldsymbol{y = 0.0138(x) - 0.2333}$$

$$3 = 0.0138(x) - 0.2333$$

$$x = \frac{3 + 0.2333}{0.0138}$$

$$x = 234.30°$$

Hence the necessary valve angle is : $234.30°$

The findings suggest that the pico hydro system can be fine-tuned by implementing automated or adjustable valves to maintain optimal flow rates, ensuring consistent energy generation while minimizing water wastage.

4.3.5 Voltage generation and valve angle

Voltage generation measurements align closely with the flow rate data, as both depend on water movement through the system. At valve angles below 60°, no significant voltage was recorded. Once the valve angle exceeded 60°, voltage generation became noticeable, with an average of 0.31 V. The voltage reached its peak of 5.17 V at a 90° valve angle, demonstrating that adequate water flow is critical for energy production.

Table 4.8 The Result of Voltage Based on Different Valve Angle

Valve Angle	Voltage (V)			
	Reading 1	Reading 2	Reading 3	Average
15°	0	0	0	0
30°	0	0	0	0
45°	0	0	0	0
60°	0.29	0.31	0.33	0.07
75°	1.2	1.25	1.25	0.08
90°	4.67	5.21	5.17	0.09

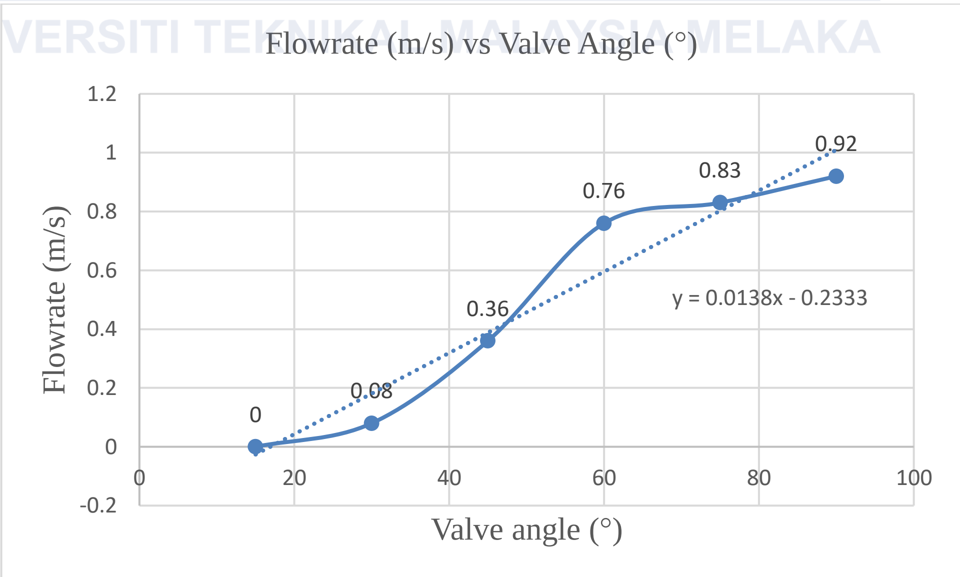


Figure 4.7 Graph of voltage vs valve angle

Based on the graph we obtain the equation :

$$\boldsymbol{y = 0.0553(x) - 1.8133} \tag{4.5}$$

y = Voltage (V)

x = Valve angle (°)

To find the necessary valve angle for 12V:

$$\boldsymbol{y = 0.0553(x) - 1.8133}$$

$$12 = 0.0553(x) - 1.8133$$

$$x = \frac{12 + 1.8133}{0.0553}$$

$$x = 249.79°$$

Hence the necessary valve angle is : 249.79°

This dependency on flow rate emphasizes the need for robust control mechanisms to regulate water movement efficiently. By optimizing these controls, the pico hydro system can achieve consistent and reliable power generation, making it more suitable for real-world applications.

4.3.6 Soil saturation and absorption

The soil saturation study highlights variations in water absorption rates and retention capacities among different soil types. Compost soil exhibited the highest water retention, taking an average of 60.6 seconds to reach saturation. Red soil followed with an average time of 31.7 seconds, while normal soil took approximately 28 seconds. Sand, known for its low retention capacity, saturated the fastest, with an average time of 10.3 seconds.

Table 4.9 The Result of Time Taken for Soil to Reach Required Moisture Level Based on Different Type of Soil

Type of Soil	Time (s)			
	Reading 1	Reading 2	Reading 3	Average
Sand	7	13	11	10.3
Normal Soil	25	32	27	28
Red Soil	32	28	35	31.7
Compost Soil	67	56	59	60.6

Table 4.10 Calculated time taken using formula ($T = \frac{W}{Ka}$)

Type of soil	Water Retention (mL)	Absorption Rate (mL/s)	Time (s)
Normal soil	90 – 120	6	15 – 20
Fertilize Soil	150 – 210	4	37.5 – 52.5
Red Soil	60 – 90	3	20 – 30
Sand	15 – 30	15	1 – 2

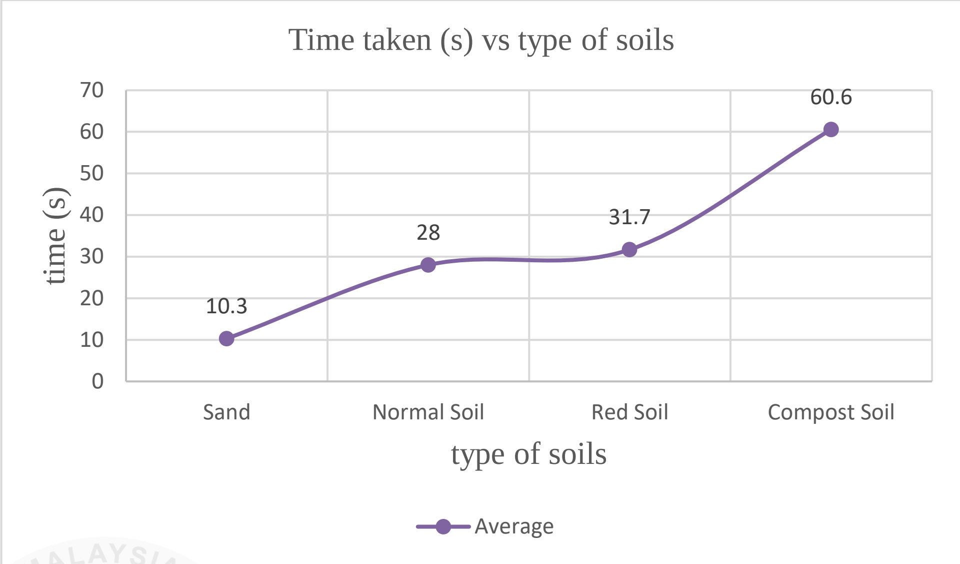


Figure 4.8 Graph of time taken vs type of soils

These results are crucial for designing effective irrigation systems. Soils with higher retention capacities, such as compost, require slower water delivery to avoid runoff, while sandy soils benefit from rapid water application. This analysis provides actionable insights into tailoring irrigation practices for different soil types to maximize water efficiency and plant growth.

$$T = \frac{W}{Ka} \tag{4.6}$$

$T = Time$

$W = Water\ Retention$

$Ka = Absorption\ Rate$

4.4 Overall insight based on results and analysist

The results obtained demonstrate the critical relationship between system design variables and performance outputs. Penstock size, valve angle, and water flow all play pivotal roles in determining the energy generation capacity of the pico hydro system. The moisture sensor effectively categorizes soil moisture levels, offering applications in precision agriculture and environmental management. Finally, the soil saturation data provides guidance for developing irrigation strategies that conserve water and enhance efficiency.

Together, these findings lay the groundwork for optimizing the pico hydro system and expanding its use in renewable energy and sustainable water management solutions. By addressing scalability and control mechanisms, this project has the potential to make significant contributions to clean energy and environmental conservation.

4.5 Summary

The findings from this project provide valuable insights into the performance of a pico hydro system and associated components, emphasizing the importance of system design variables such as penstock size, valve angle, and flow rate. Voltage and current measurements reveal a clear correlation between penstock size and electrical output, with larger penstocks significantly enhancing energy generation. Power output calculations further highlight the combined impact of voltage and current, demonstrating that optimized system dimensions can maximize energy efficiency, making the pico hydro setup more viable for practical applications.

The moisture sensor readings validate its effectiveness in accurately categorizing soil moisture levels under various conditions, offering potential for integration into precision agriculture systems. By enabling real-time soil monitoring, this sensor can contribute to water conservation and improved crop management practices. Additionally, the flow rate and voltage generation results underscore the critical role of valve control in maintaining sufficient water dynamics for energy production. The data shows that voltage generation begins only after surpassing a threshold flow rate, peaking when the valve angle reaches 90°, highlighting the dependency of the system on efficient water flow regulation.

The soil saturation study complements these findings by illustrating how different soil types absorb and retain water, providing actionable insights for designing tailored irrigation systems. Compost soil, with its high retention capacity, and sandy soil, with its rapid absorption rate, exemplify the variability that must be addressed for efficient water use in agricultural practices.

Overall, the project demonstrates the feasibility of pico hydro systems for small-scale energy generation, along with their potential integration into sustainable water management and agricultural solutions. Future improvements, such as enhanced turbine designs, automated flow control mechanisms, and scalable penstock configurations, could significantly increase the system's efficiency and expand its applicability. These results lay the foundation for advancing renewable energy technologies and contributing to global sustainability efforts.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

This chapter offers a concise synthesis of key findings and actionable insights for future research and implementation. It revisits research objectives, summarizes main findings, and discusses implications for practice, policy, and further research. By providing a comprehensive overview and guiding readers towards actionable steps, this chapter serves as a valuable resource for informing decision-making and shaping future research directions.

5.2 Conclusion

This project explores the development of a pico hydro-powered irrigation system. It starts by outlining the importance of irrigation in agriculture, highlighting the shift from historical methods to modern techniques. The project then identifies key challenges like water scarcity, inefficient traditional practices, and dependence on fossil fuels. To address these issues, the project aims to design, build, and assess a cost-effective and sustainable irrigation system powered by a pico hydro source. The project will focus on selecting a suitable site, designing the system, installing it, testing its functionality, and monitoring its performance. The ultimate goal is to improve agricultural productivity and water management practices in a specific rural or residential area.

The following section dives into existing research on pico hydro-powered irrigation systems. It explores the history of irrigation and the development of hydroelectric power generation. The review emphasizes the rise of pico hydro systems as a sustainable energy solution for remote communities struggling with water limitations and reliance on fossil fuels. It highlights the importance of irrigation for agriculture and the shortcomings of traditional methods. The suitability of pico hydro systems for small-scale, off-grid applications is also addressed. Additionally, the review examines successful case studies and pilot projects worldwide, identifying factors that contribute to project success. Challenges and barriers to adoption, such as regulations and technical limitations, are also explored. Finally, the review underscores the importance of collaboration between different disciplines and active community involvement in promoting sustainable agricultural practices and tackling global water and energy challenges.

Afterward, The methodology for developing the pico hydro-powered irrigation system integrates a detailed hardware and electrical design, along with robust data collection techniques, to evaluate and optimize system performance. The hardware analysis emphasized selecting appropriate components, such as the pico hydro generator, sensors, controllers, and pipelines, ensuring functionality, efficiency, and compatibility. This process accounted for material properties, energy consumption, cost-effectiveness, and maintenance requirements to create a cohesive and reliable system. The electrical design incorporated an Arduino microcontroller as the central unit, interfacing with the soil moisture sensor, relay, solenoid valve, and water pump. The pico hydro generator, supported by a 12V battery, provided energy for uninterrupted operation. Voltage and current measurements were performed using a multimeter connected to different penstock sizes, enabling the assessment of the system's energy generation potential. Power output was derived using the formula $P=V\times I$, revealing the interplay between voltage, current, and penstock dimensions. Moisture sensor placement experiments involved recording resistance values under varying soil conditions, such as fully submerged, humid, dry, and not in soil, providing precise moisture categorization. This methodology facilitated real-time monitoring, essential for effective irrigation management. The flow rate was measured using a flow meter, demonstrating a direct correlation between valve angle and water flow, with larger angles enabling higher rates. Voltage generation experiments confirmed that a valve angle exceeding 60° is necessary for energy production, with peak efficiency observed at 90°. This comprehensive methodology ensured a systematic approach to designing, testing, and optimizing the system. The findings highlight the critical role of component selection, precise measurements, and data-driven adjustments in achieving a high-performing, energy-efficient irrigation solution. These methods pave the way for scaling and enhancing the system for broader agricultural and environmental applications.

Lastly, the analysis of the pico hydro powered irrigation system has revealed significant insights into its performance and optimization potential. Both voltage and current outputs were shown to increase proportionally with penstock length, with voltage rising from 4.4V at 10 cm to 5.6V at 80 cm and current increasing from 3.33mA to 15.77mA, highlighting the importance of optimizing penstock dimensions to enhance water flow and energy generation. Similarly, power output followed a comparable trend, peaking at 0.09W for an 80 cm penstock, indicating substantial potential for higher performance in scaled-up systems with improved turbine designs. The moisture sensor demonstrated its capability to categorize soil moisture levels effectively, providing precise data for smart irrigation systems with resistance values ranging from 424Ω in saturated soil to 1018Ω when not in soil, enabling efficient water usage. Flow rate measurements further underscored the significance of valve angle control, with rates increasing from 0 m/s at 15° to 0.92 m/s at 90°, directly influencing voltage generation, which became significant at angles above 60° and peaked at 5.17V at 90°. Additionally, the soil saturation study revealed variations in water retention across soil types, with compost soil retaining the most water and sand the least, providing crucial insights for tailoring irrigation practices to soil-specific needs. Collectively, these findings highlight the critical role of system design and control mechanisms in achieving efficient and reliable operation, demonstrating the potential for integrating the pico hydro system with smart irrigation technologies to support sustainable water and energy management in agricultural applications. Future efforts should prioritize scaling up the system and refining its components to enhance performance and broaden its applicability to larger-scale operations.

5.3 Future Works

Future research on pico hydro-powered irrigation systems could focus on enhancing system efficiency and sustainability. This could involve fine-tuning sensor and actuator integration for more precise irrigation control and exploring additional renewable energy sources like solar or wind power to supplement hydroelectric generation. Additionally, studies could investigate the scalability of these systems to serve larger areas and assess their socio-economic impacts, including job creation and community resilience. Efforts to promote knowledge sharing and capacity building could also support widespread adoption.

The project can also be enchance by :

a) Adaptavity for different field layouts by including hybrid renewable setups.
b) Invest in research for low cost turbine development.
c) Involve with local community for the deployment of the system, so it can be tailored to meed the specific need and preferences of the users.
d) Intergrating IoT for real time monitoring and remote control.

5.4 Potential for commercialization

The potential for commercializing the pico hydro-powered irrigation system is significant, particularly in regions with abundant water resources and a need for sustainable agricultural practices. Its ability to generate power while automating irrigation offers a dual-purpose solution that is cost-effective and environmentally friendly. This system is especially suitable for rural or off-grid areas where access to electricity and water management technologies may be limited.

Key advantages include its reliance on renewable energy, low operational costs, and adaptability to different scales of agricultural operations. With further refinement, such as enhanced turbine design, improved energy storage, and integration with IoT for real-time monitoring, the system could appeal to small-scale farmers, agricultural cooperatives, and organizations promoting sustainable farming practices.

Ultimately, the system aligns with global efforts such as SDG's 2,7 and 11 to address zero hunger, affordable and clean energy and sustainable cities and communities which could attract interest from governments, NGOs, and sustainability-focused enterprises. By targeting markets with specific needs, such as developing countries or eco-conscious regions, this project has strong potential for commercialization and widespread adoption.

REFERENCES

[1] C. Cao *et al.*, "Coupling sprinkler freshwater irrigation with vegetable species selection as a sustainable approach for agricultural production in farmlands with a history of 50-year wastewater irrigation," *J Hazard Mater*, vol. 414, Jul. 2021, doi: 10.1016/j.jhazmat.2021.125576.

[2] E. B. Agyekum, J. D. Ampah, S. Afrane, T. S. Adebayo, and E. Agbozo, "A 3E, hydrogen production, irrigation, and employment potential assessment of a hybrid energy system for tropical weather conditions – Combination of HOMER software, shannon entropy, and TOPSIS," *Int J Hydrogen Energy*, vol. 47, no. 73, pp. 31073–31097, Aug. 2022, doi: 10.1016/j.ijhydene.2022.07.049.

[3] S. Sadic, E. Demir, and J. Crispim, "Towards a connected world: Collaborative networks as a tool to accomplish the SDGs," *Journal of Cleaner Production*, vol. 462. Elsevier Ltd, Jul. 10, 2024. doi: 10.1016/j.jclepro.2024.142726.

[4] J. Titus and B. Ayalur, "Design and fabrication of in-line turbine for pico hydro energy recovery in treated sewage water distribution line," in *Energy Procedia*, Elsevier Ltd, 2019, pp. 133–138. doi: 10.1016/j.egypro.2018.11.117.

[5] A. Elnozahy, M. Abdel-Salam, and F. K. Abo-Elyousr, "Optimal techno-economic energy coordination of solar PV water pumping irrigation systems," *Energy*, vol. 288, Feb. 2024, doi: 10.1016/j.energy.2023.129817.

[6] A. A. Alola, "Global urbanization and ruralization lessons of clean energy access gap," *Energy Policy*, vol. 188, May 2024, doi: 10.1016/j.enpol.2024.114101.

[7] H. Zainuddin, J. M. Lazi, M. Rubel Basar, and Z. Ibrahim, "Design and development of pico-hydro generation system for energy storage using consuming water distributed to houses," 2009. [Online]. Available: https://www.researchgate.net/publication/280688181

[8] M. C. Chacón, J. A. Rodríguez Díaz, J. G. Morillo, and A. McNabola, "Evaluation of the design and performance of a micro hydropower plant in a pressurised irrigation network: Real world application at farm-level in Southern Spain," *Renew Energy*, vol. 169, pp. 1106–1120, May 2021, doi: 10.1016/j.renene.2021.01.084.

[9] L. Gong *et al.*, "An IoT-based intelligent irrigation system with data fusion and a self-powered wide-area network," *J Ind Inf Integr*, vol. 29, Sep. 2022, doi: 10.1016/j.jii.2022.100367.

[10] S. Kucukali, O. Al Bayatı, and H. H. Maraş, "Finding the most suitable existing irrigation dams for small hydropower development in Turkey: A GIS-Fuzzy logic tool," *Renew Energy*, vol. 172, pp. 633–650, Jul. 2021, doi: 10.1016/j.renene.2021.03.049.

[11] B. A. A. Yousef, R. Amjad, N. A. Alajmi, and H. Rezk, “Feasibility of integrated photovoltaic and mechanical storage systems for irrigation purposes in remote areas: Optimization, energy management, and multicriteria decision-making,” *Case Studies in Thermal Engineering*, vol. 38, Oct. 2022, doi: 10.1016/j.csite.2022.102363.

[12] K. Adamsab, M. Saif, S. Saif, I. Khamis, and W. Talib, “Hybrid powered intelligent irrigation system using Oman Falaj and solar energy,” in *Materials Today: Proceedings*, Elsevier Ltd, 2019, pp. 260–264. doi: 10.1016/j.matpr.2020.09.033.

[13] M. Kurulekar, K. Kumar, S. Joshi, M. Kurulekar, and A. Kulkarni, “Integration of small hydro turbines into existing water conduit of an irrigation dependent power plant - A case study,” in *Materials Today: Proceedings*, Elsevier Ltd, 2020, pp. 6581–6586. doi: 10.1016/j.matpr.2021.04.061.

[14] S. M. Ismail, “Modern Irrigation Systems Operation and Maintenance,” 2017. [Online]. Available: https://www.researchgate.net/publication/318394690

[15] A. M. Alemu and Y. Seleshi, “Trade-off and synergy analysis between hydropower generation and irrigation development in the Abbay River Basin, Ethiopia,” *J Hydrol Reg Stud*, vol. 52, Apr. 2024, doi: 10.1016/j.ejrh.2024.101723.

[16] U. G. Onu, G. S. Silva, A. C. Zambroni de Souza, B. D. Bonatto, and V. B. Ferreira da Costa, “Integrated design of photovoltaic power generation plant with pumped hydro storage system and irrigation facility at the Uhuelem-Amoncha African community,” *Renew Energy*, vol. 198, pp. 1021–1031, Oct. 2022, doi: 10.1016/j.renene.2022.08.059.

[17] A. M. A. Haidar, M. F. M. Senan, A. Noman, and T. Radman, “Utilization of pico hydro generation in domestic and commercial loads,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1. Elsevier Ltd, pp. 518–524, 2012. doi: 10.1016/j.rser.2011.08.017.

[18] I. Safdar, S. Sultan, H. A. Raza, M. Umer, and M. Ali, “Empirical analysis of turbine and generator efficiency of a pico hydro system,” *Sustainable Energy Technologies and Assessments*, vol. 37, Feb. 2020, doi: 10.1016/j.seta.2019.100605.

[19] A. A. Lahimer, M. A. Alghoul, K. Sopian, N. Amin, N. Asim, and M. I. Fadhel, “Research and development aspects of pico-hydro power,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 8. pp. 5861–5878, Oct. 2012. doi: 10.1016/j.rser.2012.05.001.

[20] A. A. Lahimer, M. A. Alghoul, K. Sopian, N. Amin, N. Asim, and M. I. Fadhel, “Research and development aspects of pico-hydro power,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 8. pp. 5861–5878, Oct. 2012. doi: 10.1016/j.rser.2012.05.001.

[21] A. K. Yahya, W. N. W. A. Munim, and Z. Othman, “Pico-hydro power generation using dual pelton turbines and single generator,” in *Proceedings of the 2014 IEEE 8th International Power Engineering and Optimization Conference, PEOCO 2014*, IEEE Computer Society, 2014, pp. 579–584. doi: 10.1109/PEOCO.2014.6814495.

[22] A. M. A. Haidar, M. F. M. Senan, A. Noman, and T. Radman, “Utilization of pico hydro generation in domestic and commercial loads,” *Renewable and Sustainable Energy Reviews*, vol. 16, no. 1. Elsevier Ltd, pp. 518–524, 2012. doi: 10.1016/j.rser.2011.08.017.

[23] S. Thyer and T. White, “Energy recovery in a commercial building using pico-hydropower turbines: An Australian case study,” *Heliyon*, vol. 9, no. 6, Jun. 2023, doi: 10.1016/j.heliyon.2023.e16709.

[24] N. Gilmore, T. Britz, E. Maartensson, C. Orbegoso-Jordan, S. Schroder, and M. Malerba, “Continental-scale assessment of micro-pumped hydro energy storage using agricultural reservoirs,” *Appl Energy*, vol. 349, Nov. 2023, doi: 10.1016/j.apenergy.2023.121715.

[25] M. Á. Zamora-Juárez, C. R. Fonseca Ortiz, V. H. Guerra-Cobián, B. M. López-Rebollar, I. Gallego Alarcón, and D. García-Pulido, “Parametric assessment of a Pelton turbine within a rainwater harvesting system for micro hydro-power generation in urban zones,” *Energy for Sustainable Development*, vol. 73, pp. 101–115, Apr. 2023, doi: 10.1016/j.esd.2023.01.015.

[26] U. G. Onu, G. S. Silva, A. C. Zambroni de Souza, B. D. Bonatto, and V. B. Ferreira da Costa, “Integrated design of photovoltaic power generation plant with pumped hydro storage system and irrigation facility at the Uhuelem-Amoncha African community,” *Renew Energy*, vol. 198, pp. 1021–1031, Oct. 2022, doi: 10.1016/j.renene.2022.08.059.

[27] Y. Itani, M. R. Soliman, and M. Kahil, “Recovering energy by hydro-turbines application in water transmission pipelines: A case study west of Saudi Arabia,” *Energy*, vol. 211, Nov. 2020, doi: 10.1016/j.energy.2020.118613.

[28] J. Alves-Ferreira *et al.*, “Pesticide water variability and prioritization: The first steps towards improving water management strategies in irrigation hydro-agriculture areas,” *Science of the Total Environment*, vol. 917, Mar. 2024, doi: 10.1016/j.scitotenv.2024.170304.

[29] A. Kaab, M. Khanali, S. Shadamanfar, and M. Jalalvand, “Assessment of energy audit and environmental impacts throughout the life cycle of barley production under different irrigation systems,” *Environmental and Sustainability Indicators*, vol. 22, Jun. 2024, doi: 10.1016/j.indic.2024.100357.

[30] “Irrigation history and methods,” *SlideShare*, Jul. 22, 2020. https://www.slideshare.net/slideshow/irrigation-history-and-methods/237153016 (accessed Jun. 08, 2024).

[31] Ismail, S. M. (2020). Modern irrigation systems operation and maintenance. *ResearchGate*.https://www.researchgate.net/publication/318394690_Modern_Irrigation_Systems_Operation_and_Maintenance

[32] Awal mula dunia pertanian. Ensiklopedia Sejarah Dunia. Hancock, J., & Museum, T. O. T. B. (2024). https://www.worldhistory.org/trans/id/2-1886/awal-mula-dunia-pertanian/ (Hancock & Museum, 2024)

[33] United Nations, “The 17 Sustainable Development Goals,” *United Nations*. https://sdgs.un.org/goals

[34] Basar, M., Ahmad, A., Hasim, N., & Sopian, K. (2021). Introduction to the pico hydro power and the status of implementation in Malaysia. *Introduction to the Pico Hydro Power and the Status of Implementation in Malaysia*. https://doi.org/10.1109/scored.2011.6148751