Sudan University of Science & Technology

College of Engineering

School of mechanical engineering

Design and In Construction of Pico-hydro System For Generating Electricity

تصميم وتشييد منظومة كهرومائية صغيرة

A project Submitted In Partial Fulfillment for the Requirements of the Degree of B.Eng.(Honor) In Mechanical Engineering

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الآية

قال تعالى:

يَرَى اللهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ وَسَتُرَدُّونَ إِلَىٰ عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُمْ بِمَا
كُنتُمْ تَعْمَلُونَ}

صدق الله العظيم

التوبة: ١٠٥

DEDICATION

To those who were very caring, helping and encourage us for advancement and success

Our parents and family

To those who enlighten our way with knowledge since first steps of education

Our teachers

To those who we knew, spent with them all the moments, happy times and been touch with all meaning of friendship

Our friends and colleagues

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In the name of Allah, the Most Gracious, the Most Merciful. Praise to Him the Almighty that in His will and given strength, this final year project is in the right route of completion within the time period of two semesters.

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Also our special thanks go to our friends, family, and other parties that involved directly or indirectly during the progress of our project. Their endless support and motivation is what keep us going further.

Abstract

The energy production and transportation represents challenge to the decision maker and the designers of the rural areas. This challenge created an interest to produce electricity from any possible source available in the rural areas. One of the adopted and proven techniques is the Pico hydro power generation. This project is mainly about a Pico hydro power generation, in which a modified water turbine is installed in the new Pico hydro power generation.This project is done to reduce the dependency on the networks electrical supply.Generator is connected to the turbine to get the mechanical work to produce electricity. Suitable generator was selected as generators depend on the speed and torque provided to the shaft that connected generator and turbine.

الخلاصة

انتاج الطاقة و نقلها يمثل تحدي لمتخذي القرار و المصممين في المناطق الريفية و لذلك تم اللجوء لاستخدام مصادر متاحة في تلك المناطق لإنتاج الكهرباء عوضا عن نقلها من مصادرها الاصلية و ذلك لتلافي تكاليف النقل . واحدة من هذه المصادر المتاحة في تلك المناطق مياه الانهار و التي يكن استخدامها لتوليد الطاقة الكهربائية عن طريق منظومة صغيرة. هذه المنظومة هي عبارة عن توربين موصل لتحويل الطاقة الحركية الي طاقة كهربية.

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List of Abbreviations

kilowatt………………...……………..……..…………………………….kw

megawatt……………………..……..…...……………..…..………mw

Alternative Current …………………...………………………….……….AC

meter………………………………..…………...……….……………….m

liter ………..………………………………………….....…..……………….l

volt….. ………………………………………………..…..………………….v

Polyvinyl Chloride ……………………………………………………...… PVC

millimeter ………………………………………………………...…………....mm

centimeter ………………………………………………………………………cm

revolution per minute …………………………………………………….rpm

mill amber …………………..…………………………………...……..….. ma

Second ……………………………………………………………...……………….S

watt……………………………………………………………………..………. w

atmosphere …………………………………...………………………….……..atm

mega Pascal …………………………………………………...……………mpa

yield stress…………………………….…………………………….……….......σ_y

allowable stress ………………………..………………………………......σ_{allow}

CHAPTER ONE

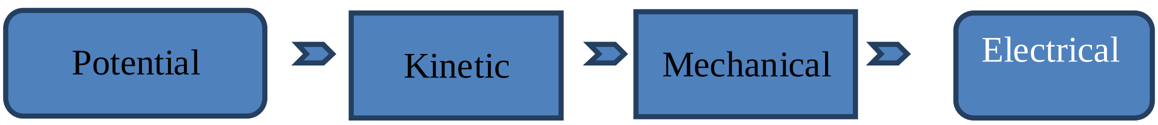
INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Project Background:

Hydroelectricity is type of power generation that used water as the working fluid in producing electricity. Energy from the hydroelectric power is renewable and can be found almost all around the world. Hydroelectricity is generated by using hydropower which is through the use of gravitational force of flowing water. Depending on the head of water, which mean the different of height of the water, the amount of energy that can be converted is based on the value of the head. In other words, the higher the head of water, the higher the potential energy of the water thus higher energy can be converted into electrical energy. Following are the energy conversion flow :-



How the energy is converted? The potential energy is based on the water head that is available at certain places. By building the dam at that place, the amount of water head can be increased. This means that the amounts of the potential energy will also increasing. The potential energy is then converted into the kinetic energy when the water arrived at the turbine.

The turbine is used to utilize the water flow and energy and converted the flow and energy into kinetic energy. The water that arrive at the turbine will rotate the turbine and will produce mechanical works. The turbine is rotating as the result of water flowing into the turbine blades. If the amount of water rotated the turbine is increase, the amount of energy converted is also increases. Same cases with the water flow rate. If the water flow rate that arrived at the turbine blade is fast, the rotational of the turbine is also increased. Turbine convert kinetic energy into mechanical energy and the mechanical energy is then used by generator to produce electrical energy.[1]

1.2 Problem statement:

Often, small and isolated communities are without electricity even in countries with extensive grid electrification. Despite the high demand for electrification, grid connection of small communities remains unattractive to utilities due to the relatively low power consumption. Additionally, other sources of energy such as oil and gas are too costly. There is a need for household energy generator that will reduce cost and produce electricity. Since remote areas are located near moving sources of water such as rivers and waterfalls, hydro power is the viable of renewable energy that can be implemented. Unfortunately, dams are very expensive to build and causing problems for animals that used to live there. In order to reduce cost and to minimize the impact on the environment, the small-hydropower system is proposed. This project aims to design a pico hydro turbine which can produce electricity for household consumption in small and isolated communities.

1.3 Objectives:

1- To determine appropriate features and specification to be used for Pico hydro system.

2- Fabrication the system.

3- To analysis the performance of the proposed Pico hydro system.

1.4 Scope of Study:

Scope of study is focusing on what is need to be focused on in order for the project to flow in the right ways. Following are the scope of study that is done in making this project:

- Renewable energy – Pico hydroelectric .
- Selection and fabrication of suitable power generation to be used with modified water turbine .
- Installation of hydropower system .
- Electronic component and transmission.
- Proving that this modified water turbine can be used for real life power generation application (full scale).

CHAPTER TWO

THEORETICAL BACKGROUD AND LITERATURE REVIEW

CHAPTER TWO

THEORETICAL BACKGROUD AND LITERATURE REVIEW

2.1 Introduction:

The Pico hydro is hydro power with a maximum electrical output of five kilowatts (5kW). Hydro power system of this size benefit in terms of cost and simplicity from different approaches in the design, planning and installation than those which are applied to larger hydro power. Recent innovations in Pico-hydro technology have made it an economic source of power even in some of the world's poorest and most inaccessible places. It is also a versatile power source. AC electricity can be produced enabling standard electrical appliances to be used. Common examples of devices which can be powered by Pico-hydro are light bulbs, radio and televisions. . Normally, Pico-hydro power system is found at rural or hilly area. Figure 1 shows an example of typical Pico hydro system applications at hilly area. This system will operate using upper water reservoir which is a few meter high from ground. From the reservoir, water flows downhill through the piping system. This downhill distance is called "head" and it allows the water to accelerate for prime moving system. Thus, the turbine will rotate the alternator to produce electricity. However, this research is conducted to show the potential of consuming water distributed to houses at town area as an alternative of renewable energy source.[2]

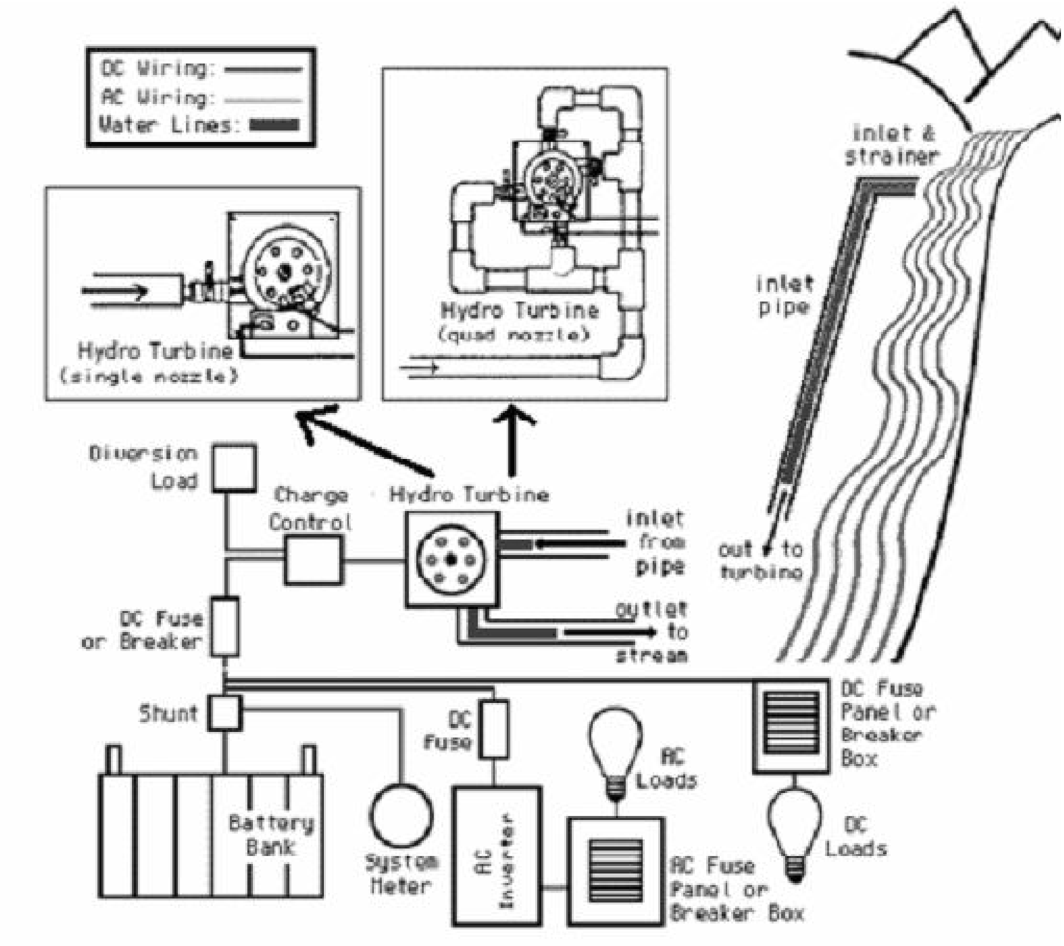


Fig 1. Example of Pico-hydro power system applications at rural area

The water flow inside the pipelines has potential of kinetic energy to spin small scale generator turbine for electricity generation. Therefore, this project has been done to show the additional use of consuming water distributed to houses for electrical power generation instead of routine activities such as bathe, laundry and dish wash. The electricity can be generated at the same time those usual activities are done without extra charge on the water bill consumption. The main function of the system is to store the generated power by means of battery charging for future use particularly during electricity blackout .

2.2 Main Components of Pico Hydro System:

- Water source.
- Penstock.
- Nozzle.
- Turbine.
- Generator.
- Transmission lines.

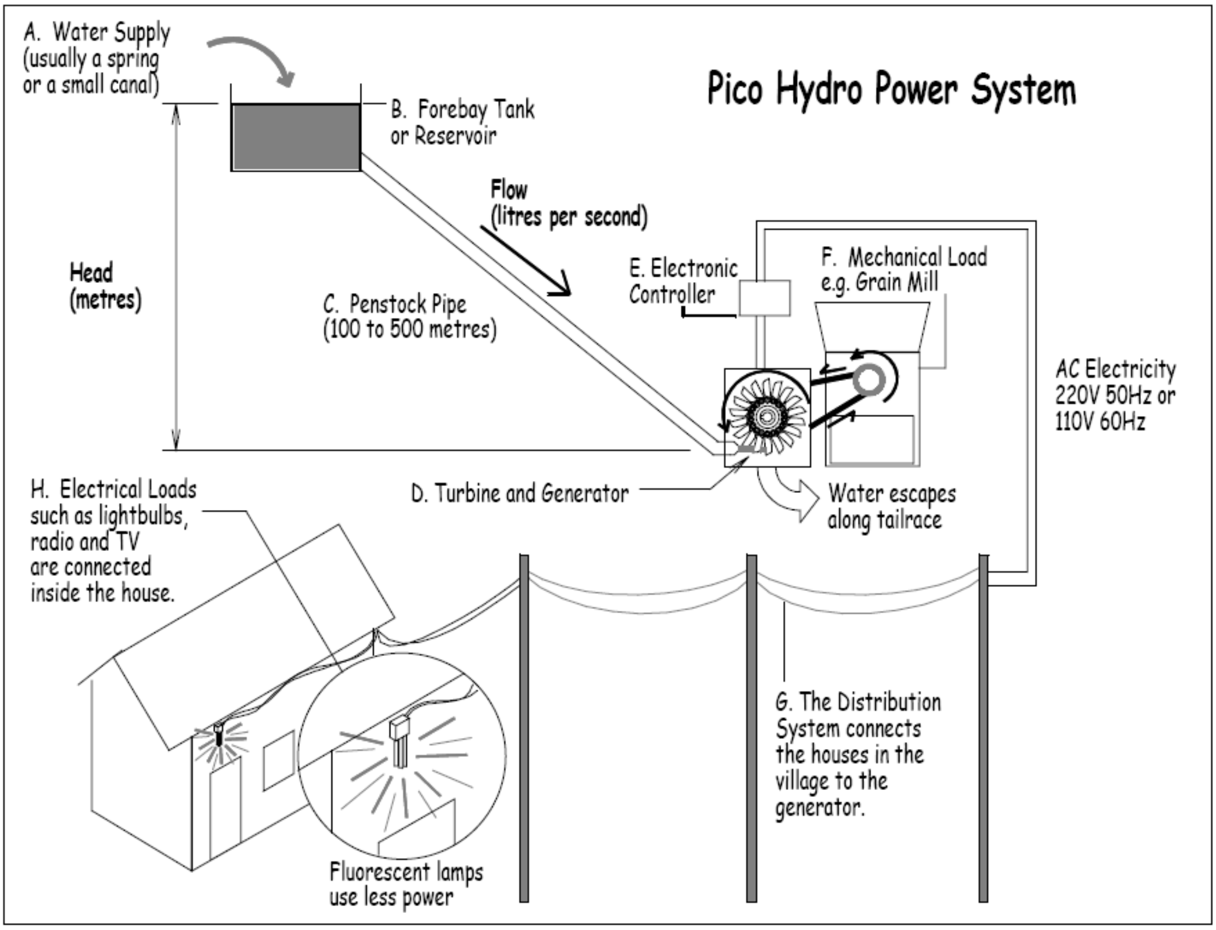


Fig 2. Pico Hydro System Components.

2.3 Classification of hydro-electric power plants:

Classification of hydro power based on the power development by the plant:[3]

1) Large hydro power plant. (>100MW)

2) Medium hydro power plant. (15-100MW)

3) Small hydro power plant. (1-15MW)

4) Mini hydro power plant. (>100KW)

5) Micro hydro power plant. (5-100KW)

6) Pico hydro power Plant. (<5KW)

Classification according to the availability of head:

1) Low head power plant. (<10m)
2) Medium head power plant. (10-50m)
3)High head power plant. (>50m)

Classification according to the nature of load:

1) Base load power plant.
2) Peak load power plant.

Classification according to quantity of water available:

1) Storage type plants.
2) Pump storage plant.

2.4 Pico hydro system planning:

There are many factors that determine the feasibility and achievability of the system. This includes:

- The amount of power available from the water flow inside the pipelines. This depends on the water pressure, amount of water available and friction losses in the pipelines.
- The turbine type and availability of required generator type and capacity.
- The types and capacity of electrical loads to be supplied by the Pico-hydro system.
- The cost of developing the project and operating the system.
-

A. Power Estimation:

In general, the feasibility of the proposed Pico-hydro system is based on the following potential input and output power equation:

$$P_{in} = H \times Q \times g \quad (1)$$

$$P_{out} = H \times Q \times g \times \eta \quad (2)$$

Where,

Pin = Input power (Hydro power)

Pout = Output power (Generator output)

H = Head (meter)

Q = Water flow rate (liter/second)

g = gravity (9.81 m/s2)

η = efficiency

Based on the equation (1) and (2), both head and water flow rate are very important parameters in hydro power system.

Head is a measure of falling water at turbine, i.e. vertical distance from the top of the penstock to the turbine at the bottom. Conversely, water flow rate is the amount of water flows within one second. Normally, water flow available is more than needed since the flows for Pico-hydro are small. Thus, it is important to measure the head carefully because the greater head, the greater power and the higher speed of the turbine rotation.

Basically, power produced by a hydro power system is converted from one form to another; some is lost at each stage as illustrated in Figure 3. It is noted in the figure that the first stage of loss is the power loss in penstock. For the proposed Pico-hydro system, this is referred to the friction loss in the pipelines. Before the losses in the pipelines are taken into account, the drop is referred as the gross head and after losses have been subtracted it is called the net head. In this research project, both equations (1) and (2) have already considered the friction loss, and thus the net head is used.

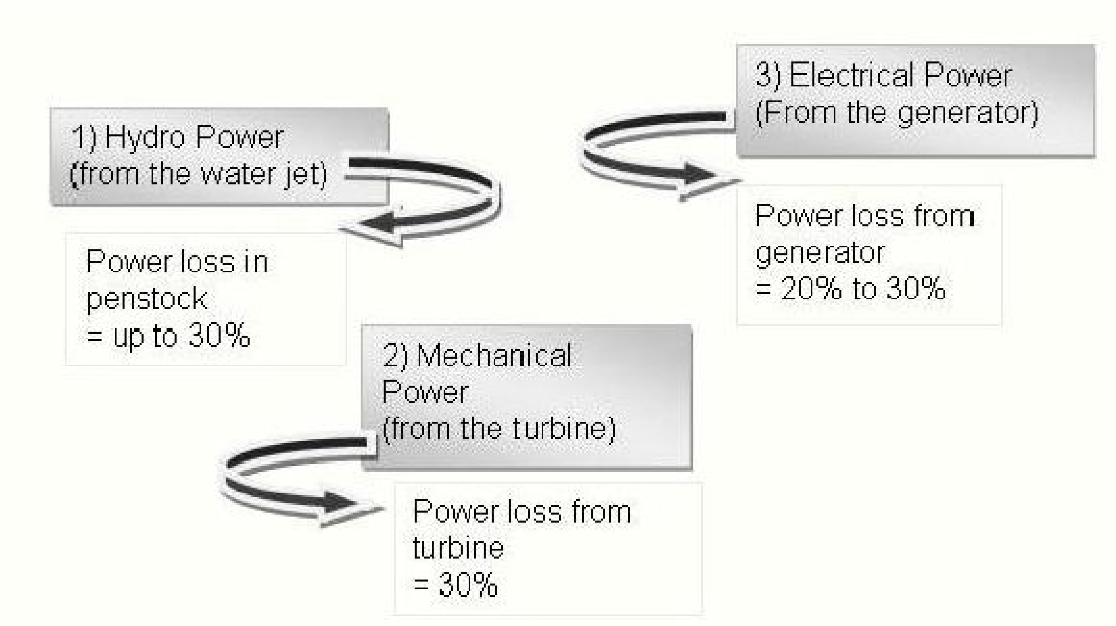


Fig 3. Power loss during the conversion from hydro power to electricity

For the proposed Pico-hydro system, the biggest loss usually occurs when the power in the water pipeline is converted into rotating, mechanical power by hitting the turbine blades, i.e. 30% of the total hydro power going out from the nozzle. A further 20% to 30% will be lost in the generator when the mechanical power is converted to electricity. Thus, the rule of thumb for efficiency to estimate the potential output power is normally 50%.

B. Head Measurement:

When determining head (falling water), gross or "static" head and net or "dynamic" head must be considered. Gross head is the vertical distance between the top of the penstock and the point where the water hits the turbine. Net head is gross head minus the pressure or head losses due to friction and turbulence in the penstock. These head losses depend on the type, diameter, and length of the penstock piping, and the number of bends or elbows. Gross head can be used to estimate power availability and determine general feasibility, but net head is used to calculate the actual power available.

C. Water Flow Rate Measurement:

The most simple of flow measurement for small streams is the bucket method. Therefore, this method has been used due to the capacity of the proposed hydro power system is significantly small. Throughout this method, the flow rate of the distributed water is diverted into a bucket or barrel and the time it takes for the container to fill is recorded. The volume of the container is known and the flow rate is simply obtained by dividing this volume by the filling time. For example, the flow rate of water that filled 20 liters bucket within one minute is 20 liters per minute or 0.333 l/s. This is repeated several times to give more consistent and accurate measurement.

2.5 Literature Review:

Pico hydro is a small water power which is used for hydro electricity generation up to 5kW. It was named “Pico” by Nigel Smith (2005) because to differentiate with micro, mini and larger hydro power. Widely used in rural communities, Pico hydro is the lowest-cost technology for electrical generation. The main parts of the system consist of intake from stream or river, pipe, water turbine, electrical generator, electronic controller and electrical distribution system.

Many places like Vietnam, Indonesia and Kenya already used this technology to generate small scale electricity for local used. A very small „Pico-hydro" power system had been installed in Central Province, Kenya by The Eastern Africa office of the Intermediate Technology Development Group (ITDG-Ed) to accommodate two remote communities on the slopes of Mount Kenya. Over 200 homes provided with light and power points from this project. This project has won Ashden Awards for Sustainable Energy.

Fig 4. Power house for a Pico-hydro power generation in Kenya (Photo from Martin Wright/Ashden Awards, 2004)

Fig 5. Clearing the canal for Pico hydro power generation (Photo from Martin Wright/Ashden Awards, 2004)

In Vietnam Pico hydro system is sold on the markets in Hanoi and other northern province cities by local electrical shop. These Pico hydro systems which are brought from China seem to be exported with formal paper.[4]

Case Study 1: Community Pico Hydro in Sub-Saharan Africa. Site: Kathamba, Kirinyaga District kenya

Length of penstock : 158 m

Diameter of penstock: 110 mm (PVC pipe)

Net Head : 28 m

Flow into turbine : 8.4 l / *s*

Turbine generator efficiency: 48%.

This case study describes a Pico hydro plant using a Pelton turbine directly-coupled to an induction generator which has an electrical output of 1.1kW. The water source is a small spring with a flow rate of at least 5l/s during 90% of the year and has never been known to run completely dry. Approximately 80m³ of storage has been provided at the intake to ensure that the turbine can be kept running for long periods. There are 65 households within a 550m radius of the turbine house and these are all being connected to the generator using a single-phase distribution system and insulated copper conductors. Each house has a 230V supply which is sufficient for one or two energy-saving lamps and a radio.[5]

Case study 2: Community Pico Hydro in Sub-Saharan Africa: Site: Thima, Kirinyaga District, Kenya

Below are the details of Pico hydro system:-

Length of penstock : 158 m

Diameter of penstock: 110 mm (PVC pipe)

Net Head : 18 m

Flow into turbine : 28 l / *s*

Turbine generator efficiency: 45%.

This case study describes a Pico hydro plant using a 'pump-as-turbine' directly-coupled to an induction motor as generator which has an electrical output of 2.2kW. The water source is the Rutui River which has a flow rate of more than 100l/s during 90% of the year. The minimum flow, measured after an unusually long period of dry weather, was 84 l/s. There are around 160 households within a 900m radius of the turbine house and 110 of these are being connected to the generator using a single-phase distribution system with insulated copper conductors. Each house has a 230V supply which is sufficient for one or two energy-saving lamps and radio.[5]

Case study 3: Community Pico Hydro in Culbone

Site: Culbone, Exmoor, Devon

Below are the details of Pico hydro system:-

System type: Pelton Turbine

Power output**:** 4.5 kW

Typical Generation: 24 MWh p.a.

Design Conditions: H = 50.00 m, Q = 0.016 m3/s

Pico Energy have commissioned a 4.5 kW scheme in the Exmoor National Park. The challenging site is located in a remote wooded valley on the North coast of Exmoor in the hamlet of Culbone which is famous for having the smallest church in England. The hydro power system works independently of the National Grid and provides power and heating for local residents.[6]

Pico Energy have worked with the client from initial proposal to gain approval from the National Park and to ensure the scheme has minimal impact on the picturesque location. The building work was carried out by contractors under close supervision from Pico Energy. The 'off-grid' generator control panel has been connected to the existing inverter and battery bank, replacing an old diesel generator as the power source. In addition to providing AC power directly to the house, the hydro generator also maintains the battery charge. If the maximum electrical load temporarily exceeds the generator capacity, then the batteries supply the shortfall via the inverter. In this way a peak load of up to 8 kW can be accommodated for short periods.

The stainless steel Pelton turbine system used for this installation was designed, manufactured and installed by Pico Energy Ltd. In addition to providing supplying all loads with renewable electricity the client receives the Feed-in Tariff on all electricity consumed.

CHAPTER THRER
DESIGN OF PICO HYDRO POWER SYSTEM
(METHODOLOGY)

CHAPTER THREE

DESIGN OF PICO HYDRO POWER SYSTEM (METHODOLOGY)

3.1 Project activities :

i. Information gathering:

Research of entire hydro power systems .

Research of Pico hydro power system .

Previous study in Pico hydro generation .

Research on suitable turbine and specification .

ii. Main components in the Pico hydro power generation consist of:

Reservoir.

Turbine .

Generator.

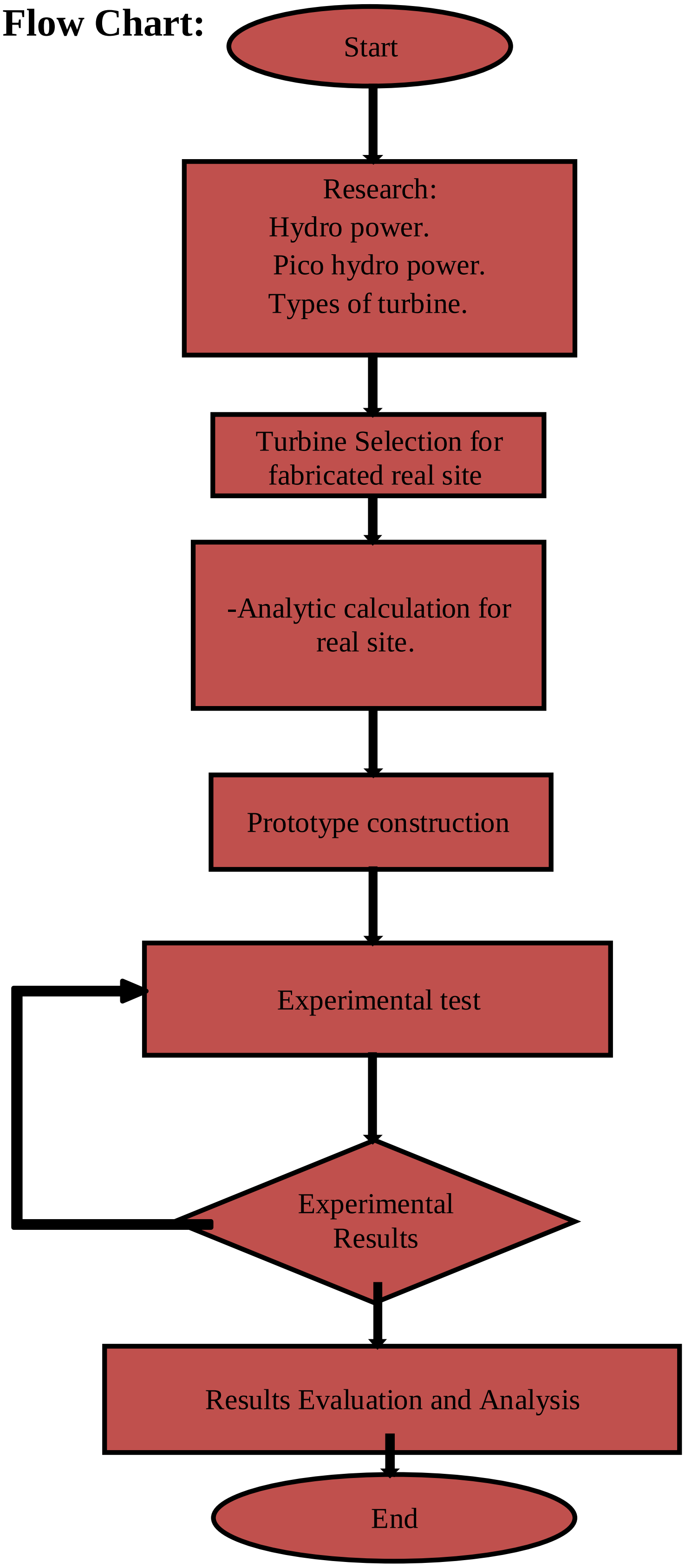
iii. Model fabrication :

Fabrication of water source , turbine and generator for real site.

Construct of small prototype for testing.

iv. Testing

3.2 Project Flow Chart:



3.3 Design Process:

i. Approximate power consumption for household per day:

The need of hydro power in rural areas is identified based on the research done.

ii. Definition stage:

The practical limitation has been set up. Then the approximate power consumption is in a day is calculated in order to estimate the power output required. The Pico hydropower output will be finalized as to meet the average power demand in remote areas. Design will encompassed the mechanical compartment of the Pico hydro turbine only.

iii. Preliminary design stage:

During the preliminary design stage, several sketches of the alternativeassemblies were done.

iv. Detailed design stage :

Constraints

In order to design hydro turbine, power output limitation has been set up. Whenever a constraint is applied, the solution possibilities are reduced.

Product requirement

To determine the specifications of product, searches have been done through existing product, journals and other sources to identify the driving technology of the product such as power, materials, weight and others. Product requirements includes:

- Performance parameter (force, speed, torque)
- Required features
- Desired features
- Size
- Weight
- Cost
- Environment
- Maintenance requirements
- Expected life

Material selection analysis

Selection of material is done based on the product requirements. The analysis is done using decision matrix to ensure selection of the best material for the design. All weighted criteria will be evaluated on each materials and the best material will be chosen.

Mathematical Model

With a tentative design direction, a specific mathematical model of the Pico hydro turbine system was established in order to perform analysis.

3.4 Methodology Of Mathematical Model :

- Approximate Power Consumption for Household per day .
- Hydro turbine design
  - Some preliminary designs of Pico hydro power turbine prepared , then suitable one is selected . Basically the design consists of penstock, wheel and generator . gears are auxiliary tools.
- Constraint
  - It has been set up to ensure meet the power demand..
- Product Requirements
  - Desired criteria has been weighted by percentage, The criteria are performance, cost, reliability, weight and safety.
- Material Selection Analysis
  - Decision matrix table are used in this analysis for wheel and shaft.

3.5 Hydro power design:

Below is the preliminary design of the Pico hydro turbine. This serve as the first concept of the design before proceed to the next stage in the design process.

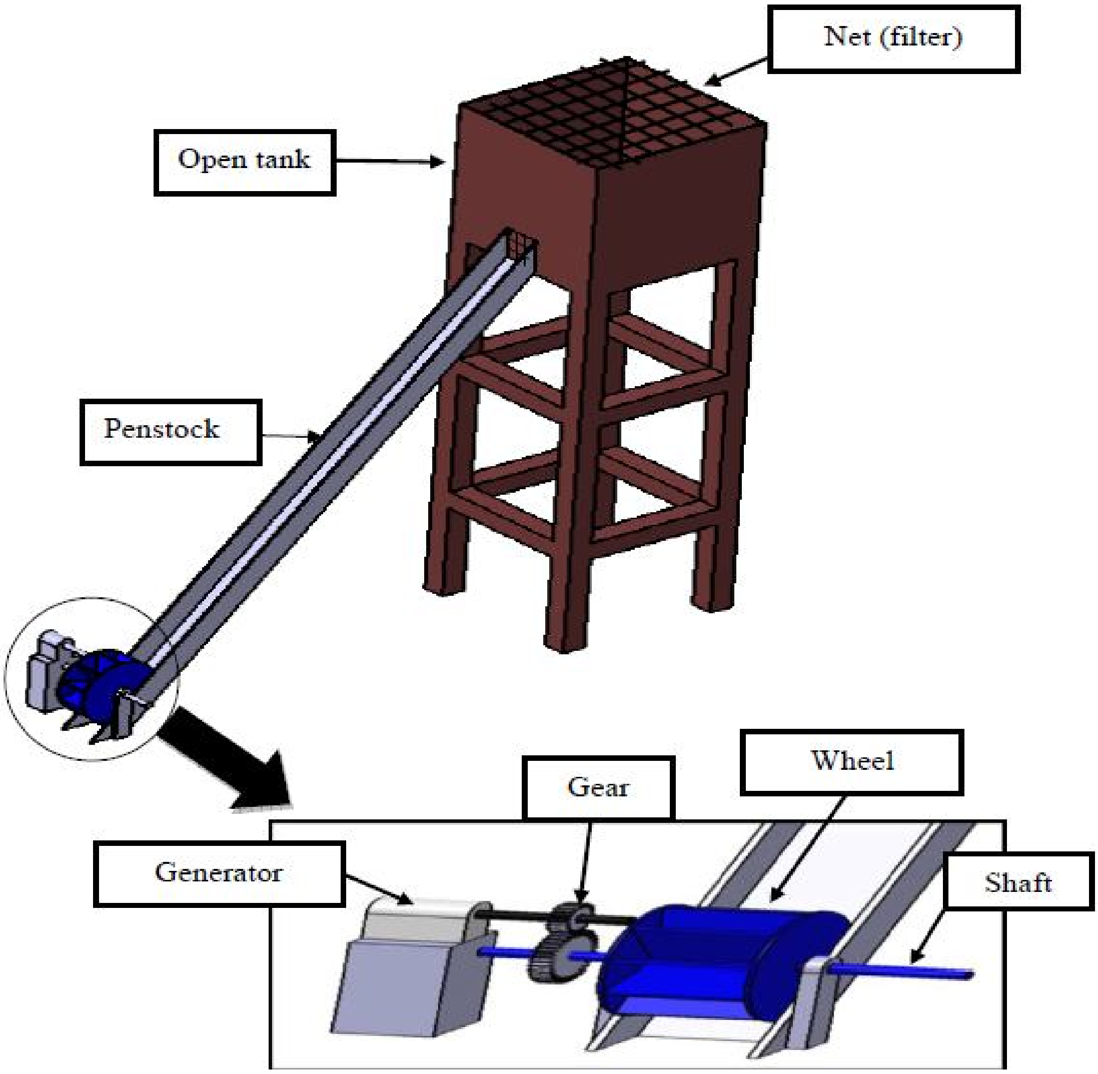


Fig 6. shows the labeled drawing for Pico hydro turbine design. Basically the design consists of an open tank, penstock, wheel and generator

3.5.1 Principle of operation

The design will be installed near the waterfall as the water will be directly diverted into reservoir by a canal. The function of a net is to filter all the debris before entering the reservoir, thus only clean water will flow in the penstock. The force of falling water pushing against the wheel, thus cause the wheel to rotates. The kinetic energy from the rotating wheel then is converted into mechanical energy.

Meanwhile, the function of the generator is to convert the mechanical energy produced by the turbine into electrical energy. The generator is connected to the wheel by shafts and gear so when the wheel rotates, causes the generator to rotate also. The gear is designed to transmit motion from the turbine shaft to load shaft (generator) in order toavoid damage of the generator if overloading.

3.6 Prototype Model

Construct a small prototype model for testing and discussing purpose .

Preliminary designs have been prepared , this design is chosen depends on cost and availability of materials.

3.6.1 Methodology Of Prototype Model :

Eight plastic spoons are used to work s turbine. All spoons have same length which represent to turbine radius and angles between them is 45°.

Fig 7. The Turbine

Smooth engine's valve of small car is used as a shaft to transmit power between the turbine and the generator. To connect the turbine and the shaft copper connector is used.

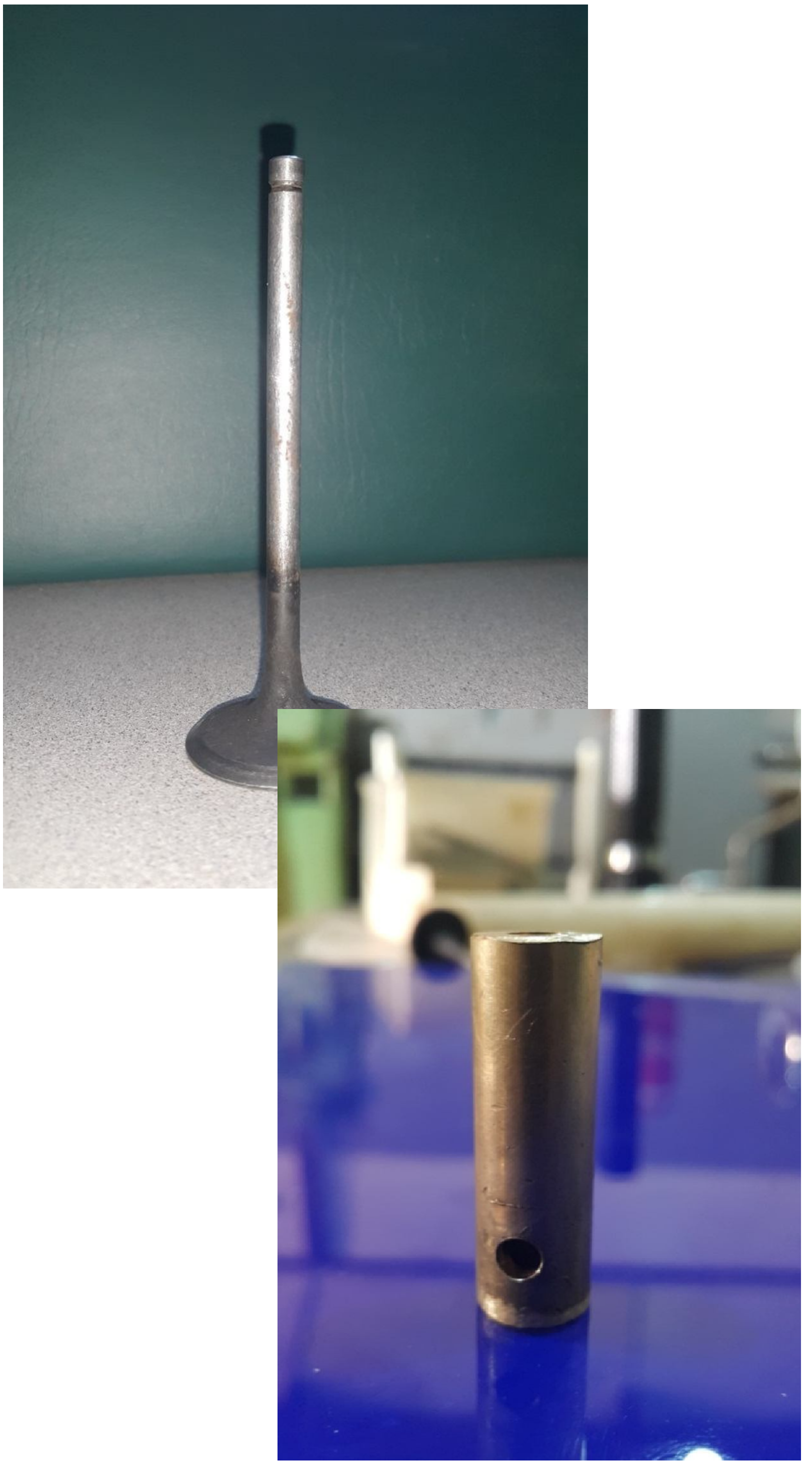


Fig 8.The Shaft and The Connector

The generator has been brought and it has these specifications:

- DC 6V

- Output Power: 1.1 watt
- Rated Speed: 170RPM
- Rated Current: 340mA
- Rated Torque: 35mN.m
- Shaft Diameter: 6mm
- Sample Application: lightweight mechanism such as: bank note machine, handling machine, educational robot, etc.

Fig 9.The Generator

Elbow (1 cm) is used as a nozzle and penstock together. Small bucket is as a water reservoir to simulate the real site. Another bucket is used to fix the turbine and to save water for using it again to represent the main idea of the Pico hydro power system [Renewable energy].

Multi readings table is used to give 4 different readings for experiment. The 4 readings is (38.5, 55.5, 84.6 and 102.8)cm.

Fig 10.Multi readings table

Firstly experiment had been done with 12.5 cm turbine's radius, but was not success. The hydro power wasn't enough to move the turbine.

Another experiment was done with 15.5 cm turbine's radius it was success. Flow rate is calculated by using known volume(1.5L) and stop watch. Stop watch readings had taken three time for more exact results.

$$Q = \frac{V}{t}$$

Hydro power and velocity had been calculated

$P_W = \rho g Q H$

$V = \frac{Q}{A}$

The voltage had been taken by using voltmeter and then output power calculated

Output power = I * V

Then, The turbine efficiency was calculated

$$\text{Turbine efficiency} = \frac{\text{Output Power}}{\text{Hydro Power}}$$

Finally, The angular velocity, shaft speed and torque had been calculated

ω= TSR * v/r

where,

TSR= Tip speed ratio

Tip Speed Ratio(TSR) is the ratio of the speed of the blade at the its tip and the speed of the river water. Tip Speed Ratio is very important in the water turbine blade[7]. If the rotor of the turbine spins too slowly, most of the water will pass straight through the gap between the blades, therefore giving it no power. But if the rotor spins too fast, the blades will blur and act like a solid wall to the water. That is the reason why TSR plays an important role to get the maximum power output. [8]

$$N = \omega * 60 / 2\pi$$

Where,

N = Shaft speed

3.7 Approximate Power Consumption for Household per day:

First of all the approximate power consumption for household per day is calculated (refer table 1). Assume normal village house comprises of a living room, 3 bedrooms and a kitchen.

Table (1) Average power consumption

Appliance	Watts	Units	Total watts
Lighting	6 W	5	30 W
Fan	2 W	5	10 W
Refrigerator	47.5 W	1	47.5 W
Ironing	100 W	1	100 W
Cooking Purpose	100 W	1	100 W
Entertainment	10 W	1	10 W
TOTAL			**297.5 W**

Based on table (1) the average power consumption for household per day is297.5 W.

For small communities (3 houses) , the average power consumption is :297.5 *3 = 892.5 W

Total power demand is 892.5 W which is approximately 1kW. Thus, the Picohydro turbine is designed to produce 1kW power.

3.8 Constraint:

It has been set up in designing hydro turbine .the power output of Pico hydro turbine must be between 0.9 KW to 5KW to ensure meet power demand.

3.9 Product Requirements:

Below is the table of desired criteria with its weighted percentage.

Table (2) Product Criteria and Weight

NO.	Criteria	Weighted percentage
1	Cost	25
2	Reliability	30
3	Weight	5
4	Safety	5
5	Performance	35
	Total	100

The most desirable criteria would be performance. This is followed by cost. Pico hydropower should cost less since it is designed for community in remote areas. Next is reliability where the product can perform its intended function satisfactorily without failure at given age. Since this design is based on water, thus the reliability of the product is one of the most important criteria that have to be considered. The leastdesired criteria are weight and safety.

3.10 Material Selection Analysis:

Material selection will be based on product's requirement and function of eachcomponent. Decision matrix[12] table are used in this analysis. The following steps show the process of choosing the best material for each component.

Table (3) Rating for Evaluation

5- point scale	Description
0	Inadequate
1	Weak
2	Satisfactory
3	Good
4	Excellent

a) Wheel:

Table (4) Decision Matrix for Wheel Material

		Material			
Design Criterion	**Weight Factor**	**Mild Steel**		**Stainless Steel**	
		Score	**Rating**	**Score**	**Rating**
Reliability	0.30	3	0.90	4	1.20
Ease of fabrication	0.28	4	1.12	1	0.28
Cost	0.25	3	0.75	1	0.25
Weight	0.05	2	0.10	2	0.10
Availability	0.12	4	0.48	4	0.48
Total	1.00		**3.35**		2.31

Table (4) shows that mild steel scored higher point compared to stainless steel. Mild steels are stiff and strong. Welding mild steels requires that special precautions be taken. However, welding mild steel presents far fewer problems than welding stainless steels. Stainless steels corrosion resistance is better than mild still, however the use of protective coating may increase the mild steel corrosion resistance. Other than that, mild steel is easily available and less in cost.

b) Shaft:

Table (5) Decision matrix for Shaft

		Material			
Design Criterion	**Weight Factor**	**Stainless Steel**		**Aluminum**	
		Score	**Rating**	**Score**	**Rating**
Reliability	0.30	4	1.20	2	0.60
Ease of fabrication	0.28	2	0.56	3	0.84
Cost	0.25	3	0.75	2	0.50
Weight	0.05	2	0.10	3	0.15
Availability	0.12	4	0.48	4	0.48
Total	1.00		**3.09**		2.57

Table (5) shows that stainless steel scored higher point compared to aluminum.Stainless steel is better for shaft material because of its high modulus of elasticity.Besides, stainless steel also has a great corrosion resistance in oxidizing environments. Aluminum is generally less strong compared to stainless steel. Other than that, aluminum is relatively high cost compared to steel of the same strength.

For other components, the chosen materials are

Tank – Aluminum

Penstock – Aluminum

3.11 Mathematical Model:

3.11.1 Hydro power design

Table (6) Technical Summary of the Pico Hydro turbine

power output required	1Kw
Water source	Waterfall with average flow rate between 200-500 l/s
Net head	3.5 m
ow into turbine	139.95 l/s

3.11.2 Hydro power calculation

From Bernoulli's equation

$$\frac{P_1}{\rho g}+\frac{V_1^{\,2}}{2g}+H_1=\frac{P_2}{\rho g}+\frac{V_2^{\,2}}{2g}+H_2$$

Since it is an open system, P_1=P_2=P atm

V_1= 0, H_2 = 0

$V_2=\sqrt{2gH_1}$

$$V_2 = \sqrt{2 * 9.81\left(\frac{m}{s^2}\right) * 3.5(m)}$$

V_2= 8.28674 m/s =8.3 m/s

The flow of water in a penstock, Q = VA

= 8.3 m/s (0.15* 0.11) m^2

= 0.13695 m^3/s = 136.95 l/s

Flow rate of waterfall in Sudan ranges from approximately 200 l/s to 500 l/s. [information has been taken from Sudanese Dams Corporation] Thus, flow rate at the canal, Qc is always greater than flow rate at the penstock, Q. This will ensure continuous flow of water at the penstock.

Hydropower, Pw =ρgQH

= $(1000 kg/m^3)(9.81\ m/s^2)(0.13695\ m^3/s)(3.5m)$ = 4702 watt

3.11.3 Turbine design

3.11.3.1 Blade design

Material: mild steel

Material Properties:- σ *y* = 250*Mpa*

Based on typical building beam design, a typical factor of safety with respect to yielding in tension is 1.67.[10]

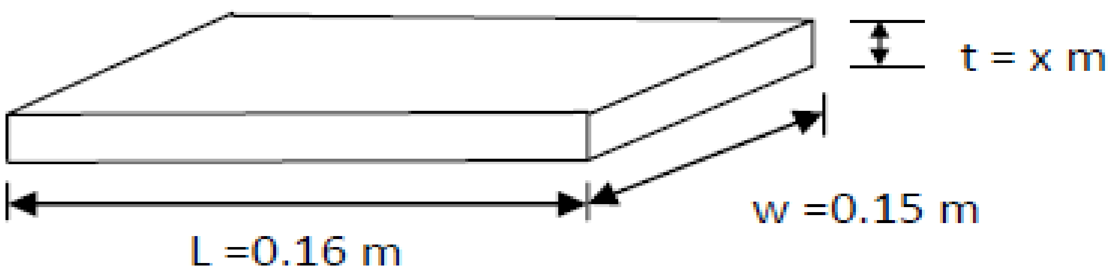


Fig 11:Blade design

To design a beam to resist bending stress, the required section modulus, S is calculated:

$$S = \frac{M_{max}}{\sigma_{allow}}$$

$$\sigma_{allow} = \frac{\sigma_y}{n}$$

Because the flow of water inside the penstock is static, there is no acceleration, thus the pressure distribution is hydrostatic.

Z= .11 m

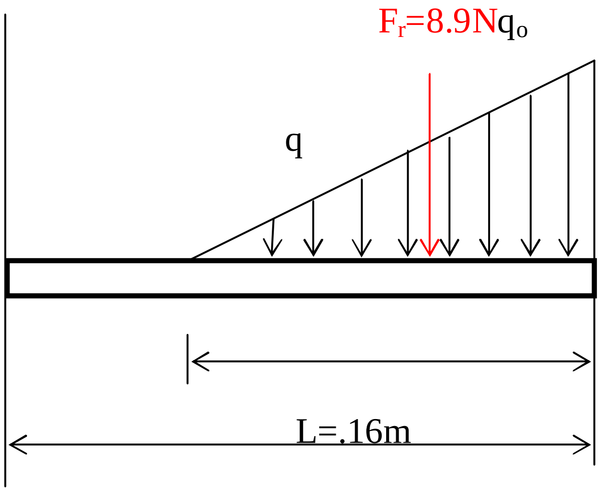


Fig 12:Hydrostatic force on blade

- Hydrostatic pressure, P $=\rho_w gz$

$=1000kg/m^3 (9.81m/s^2)(0.11m)$

$=1079.1Pa$

- Intensity of the load, w, =bP

  =(0.15m)(1079.1Pa)

  =161.85N /m

- Magnitude of resultant force, F_R= area of triangle

  $=\frac{1}{2}(0.11)(161.85\text{N/m})$

  = 8.9N

Line of action passes through the centroid of triangle. Hence

- Q_0

$$q_o = \frac{qL}{x}$$

$$= \frac{161.85\ \text{N/m}(0.16\text{m})}{0.11\text{m}}$$

= 235.418N /m

- M_{max}

$$M_{max} = \frac{q_o L^2}{6}$$

$$= \frac{161.85\ \text{N/m}(0.16^2\text{m})}{6}$$

= 1.00445N.m

Section Modulus, S $= \frac{1.00445\text{Nm}}{150 * 10^6\text{Pa}} = 6.696 * 10^{-7} m$

$$S = \frac{bh^2}{6}$$

$$h^2 = \frac{6.696 * 10^{-7}(6)}{0.15}$$

$$h = 0.52\text{cm}$$

Minimum thickness of the blade, h = 0.52 cm.

Thus chosen thickness of the blade, t = 1cm.

3.11.3.2 Wheel Design

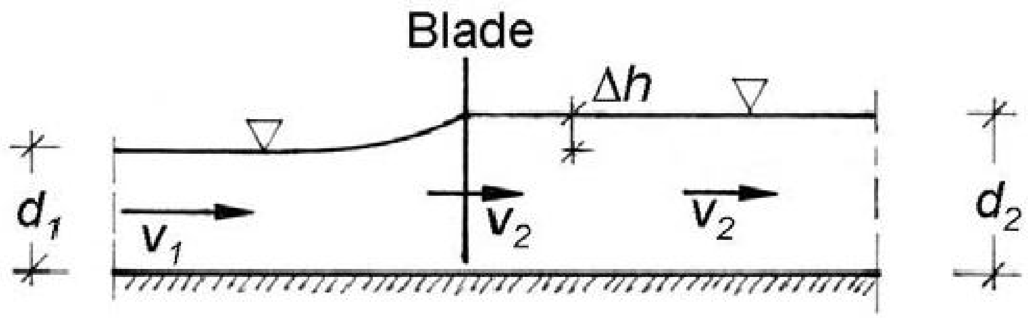


Fig 13:Subcritical Flow in channel

Based on the assumptions for the theory of the subcritical stream wheel, with the flow being obstructed by a blade of depth d ≈ t, the power is generated by the momentum exchange between flow and blade, leading to a higher water level in front and behind of the blade. [10]

The power P is then given as:

$$P = \rho_w b d_2 v_2 (v_1 - v_2)^2$$

The power maximum occurs for $v_2 = 0.5\ v_1$;

Assume d_2=0.18m,

$P = (1000\ kg/m^3)(0.15m)(0.18m)(4.15m/s)(8.3m/s - 4.15m/s)^2$

= 1929.78 watt.

Thus mechanical power output,P_m=1929.78 watt.

3.11.3.3 Shaft Design

Material: stainless steel.

τ_{allow}= 100 Mpa

From previous calculation, Mechanical power

P_M= 1929.78 watt, 1929.78 Nm/s

P = Tω

where, P = power

T = torque

ω = angular velocity

$$\omega = \frac{v_2}{r}$$

where; v= velocity of the water .

r= radius of the wheel.

$= \frac{8.3\ m/s}{0.18\ m}$

= 46.1 rad/s

$P = T\omega$

$T = \frac{P}{\omega}$

$= \frac{1929.78 N.m/s}{46.1 rad/s} = 41.861$ N.m

By using the torsion formula, we can determine the size of the shaft's cross section.

Specifically the geometric parameter becomes;

Geometric parameter, $= \frac{J}{c} = \frac{T}{\tau allow}$

Where;

τ_{allow} =allowable shear stress in the shaft

T = resultant internal torque acting at the cross section

J = the polar moment of inertia of the cross sectional area

c = outer radius of the shaft

Since the shaft is tubular, $J = \frac{\pi(c^4)}{2}$

$$\frac{J}{c} = \frac{\pi}{2}\frac{c^4}{c} = \frac{T}{\tau_{allow}}$$

$$c^3 = \frac{2T}{\pi\tau_{allow}}$$

$$c = \sqrt[3]{\frac{2(41.861)}{\pi(100*10^6)}} = 0.644 \text{ cm}$$

Minimum diameter for shaft = 2*0.644 =1.288 = 1.3 cm

Chosen diameter for shaft = 2 cm

3.11.3.4 Gear Design

The gear in this turbine is designed to transmit motion from the turbine shaft to load shaft (generator) in order to avoid damage of the generator if overloading. The speed of the turbine shaft will depend on the site conditions and the type of generator used. A turbine shaft speed based on the number of generator poles should be used to calculate the speed ratio. The number of poles (usually 4 but sometimes 2, 6, 8 or 10) can be found on the information plate on the side of the generator.

Table (7) Generator shaft speeds for direct drive f = 50 Hz

Number of Poles	Design Speed of Turbine/ Generator Shaft (rpm)
2	3000
4	1500
6	1000
8	750
10	600

• Angular velocity of turbine shaft, *w1* = Angular velocity of the wheel

$= 46.1$ rad/s

$$= 46.1\frac{\text{rad}}{\text{sec}} * \frac{1\text{ rev}}{2\pi\text{ rad}} * \frac{60\text{ sec}}{1\text{ min}} = 440 \text{ rpm}$$

Assume number of poles = 10

• Speed ratio = turbine shaft rpm (w_1) / load shaft rpm (w_2)

$$=\frac{\omega_1}{\omega_2} = \frac{440}{600} = \frac{11}{15}$$

• Torque =9.55 H/n,

Where H= power

n = shaft speed

$$T= 9.55\frac{1929.78}{440}$$

=41.88Nm

• Horsepower = T*n/63025

$$=\frac{41.88(440)}{63025}$$

=0.2923HP

Gear Selection

Based on the horsepower, the diametral pitch of the gear is selected.Because this application involves general gearing, a pressure angle of $20^0$is used.an estimate of diametral pitch P_d= 24[11]

- $VR = \frac{440}{600} = \frac{11}{15}$
- $VR = \frac{\omega_1}{\omega_2} = \frac{N1}{N_2}$
- $N_2 = \frac{\omega_1}{\omega_2} N_1$

using

N1= 42 N2= 30.8

N1= 48   N2= 35.2

N1= 30   N2= 22

N1= 36   N2= 26.4

Thus, the smallest integer combination is 30 and 22

- Loading on spur gears

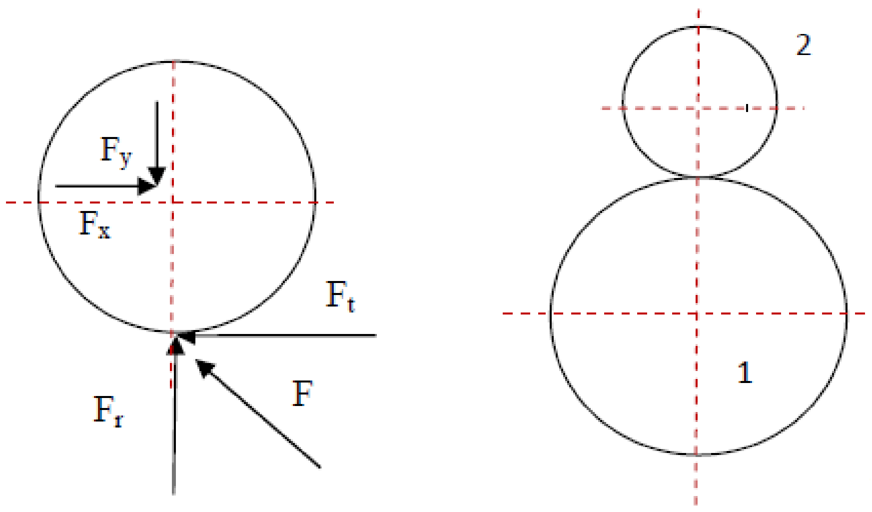


Fig. 14 Free Body Diagram of Gears

- The magnitude of tangential component:-

$F_t = 2\ P_d\ T_b\ /N_p$

$=(2 * 24 * 41.88)/36$

=55.84 N

- The radial component:-

$F_r = F_t\ \tan \varphi$

= 55.84 tan 20

=20.32 N

- The resultant force:-

$F = F_t / \cos \varphi$

= 55.84/cos 20

=59.42 N

Thus the resultant force acting on a shaft is **59.42 N**

3.11.3.5Turbine Efficiency

Turbine efficiency = $(P_m / P_W) * 100$

$$= \frac{1929.78}{4702} *100$$

=41%

The turbine efficiency is within the range of pico hydropower efficiency which is between 40%-50% .

Assume generator efficiency is 80%

Power output = 0.8 *1929.78 = 1543.824 W

CHAPTER FOUR

RESULT AND DISCUSSION

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Prototype Calculation:

Multi-readings table had been prepared for experiment. Known volume container (1500L) was used with stop watch to calculate the time for filling that volume. Time had been calculated 3 times for every individualreading and then mean had been taken to calculate flow rate.

Voltage and current had been calculated by using multi-meter for every individual reading .All experimental data in the table below.

Table (8) : The measured results for head, voltage and time

Head cm	Volt V	Time to discharge 1.5L (sec)		
		T_1	T_2	T3
38.5	2.7	10.81	10.91	10.59
55.5	2.9	10.80	10.93	10.62
84.6	3.5	10.95	10.27	11.10
102.8	4.2	10.86	11.13	11.25

4.1.1 Estimation of flow rate

The volume is constant (1.5L) $V=1.5 * 10^{-3}\ m^3$

$$T=\frac{T1+T2+T3}{3}$$

$$Q_{actual}=\frac{Volume}{T}$$

For H_1= 38.5cm

$Q_1 = 1.391 * 10^{-4}\ m^3\backslash s$

For $H_2 = 55.5cm$

$Q_2 = 1.393 * 10^{-4}\ m^3\backslash s$

For $H_3 = 84.6cm$

$Q_3 = 1.395 * 10^{-4}\ m^3\backslash s$

For $H_4 = 102.8cm$

$Q_4 = 1.395 * 10^{-4}\ m^3\backslash s$

The flow rate is approximately the same for every readings, the increase is very small. so the flow rate of hydro power system does not depend on the head between a nozzle and a turbine . It depends on sectional area , velocity and head of water in the bucket.

4.1.2 Estimation of the velocity

Diameter of nozzle = 1cm

Sectional Area = $\frac{\pi D2}{4} = \frac{\pi (0.01)2}{4} = 7.8598 * 10^{-5}$

Velocity' $V = \frac{Q}{A}$

$V_1 = 1.77\ m\backslash s$

$V_2 = 1.70\ m\backslash s$

$V_3 = 1.78\ m\backslash s$

$V_4 = 1.74\ m\backslash s$

4.1.3 Estimation of generated hydro power

$P_W = \rho gQH$ when $\rho g = 9810\ kN\backslash m$

$H_1 = 38.5cm$, $P_W = 0.526$ watt

H_2= 55.5cm, P_W = 0.758 watt

H_3=84.6cm, P_W = 1.156 watt

H_4= 102.8cm, P_W= 1.405 watt

When flow rate is constant , Hydro power increase with the head of hydro power system.

Q = constant

$P_W \alpha H$

4.1.4 Estimation of output power

Output power = I *V

H_1= 38.5cm, Output power = 0.297 W

H_2= 55.5cm, Output power = 0.319 W

H_3= 84.6cm, Output power= 0.385 W

H_4=102.8cm, Output power = 0.642 W

The output power increase with increase at the head, but massive increase in hydro power doesn't mean the same increase at the output because of turbine efficiency.

4.1.5 Turbine efficiency

Assume generator efficiency = 90 %

$$\text{Shaft power} = \frac{\text{Output Power}}{\text{generator efficiency}}$$

$$\text{Turbine efficiency}(\eta_T) = \frac{\text{Shaft power}}{\text{Water power}}$$

$H_1 = 38.5cm$, Shaft power= 0.330 W, $\eta_T = 62.7\%$

$H_2 = 55.5cm$, Shaft power= 0.354 W, $\eta_T = 46.7\%$

$H_3 = 84.6cm$, Shaft power= 0.428 W, $\eta_T = 37.0\%$

$H_4 = 102.8$ cm, Shaft power=0.513 W, $\eta_T = 36.5$ %

Hydro power increase with increase of a head, Meanwhile a turbine efficiency decrease, because the increase of hydro power less than the increase of output power.

4.1.6 Angular velocity, Shaft rpm and Torque

$$wQH = 0.5\ \rho\ Q\ _V$$

$$\eta_T = \frac{\text{Shaft power}}{0.5\ \rho\ Q\ V}$$

ω= TSR * v/r

where,

TSR= Tip speed ratio

$TSR = V_{water} / V_{blade} \approx 1$

ω_1= 15.31 rad/sec

ω_2= 17.29 rad/sec

ω_3= 19.9 rad/sec

ω_4= 21.2sec/sec

$N = \omega * 60 / 2\pi$

N_1= 146 r.p.m

N_2= 165 r.p.m

N_3= 190 r.p.m

N_4= 202 r.p.m

$T = P/\omega$

T_1= 0.020N.m

T_2= 0.021N.m

T_3= 0.022N.m

T_4= 0.024N.m

Obviously, increase at flow rate lead to increase at angular velocity, speed of the turbine and a torque.

Discussion:

For the real site design, output power is 1543.824 W . this result is expectable for that head . It covers the 3 houses power requirements that estimated approximately 1kw. The output power can increase by increase the flow rate which depends on area and velocity . we can increase velocity by increase the head leading to hydro power increase but we must take in the account friction in a penstock .

About prototype model results clearly we notice increase in flow rate leads to increase in hydro power, output power, angular velocity, shaft speed r.p.m and torque. Another factors involve in the design such as turbine efficiency and generator efficiency. Turbine efficiency increase by including all parameters in the design like angles, materials and use modified turbine.

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CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

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CONCLUSION AND RECOMMENDATION

5.1 Conclusion :

The design of the pico hydro turbine has been completed. The design is capable ofproducing electricity for small communities in remote area. To accomplish this project,structured design process had been successfully adhered to. As presented in chapter 4,the material selection has been done based on the product requirements. Themathematical model of the turbine has been designed. The project has enabled me to understand more on hydro power system and the design process. It can be concluded that this project is a success and completed withinagreed time frame.

5.2 Recommendation:

As for recommendation and future works, detail study and analysis of the mechanicalpower transmission component such as bearing and lubrication can be done. Detaildynamic and kinematic analysis should be done in order to ensure the reliability of thedesign. The design of the wheel should be improved in terms of the shape ormanufacturing process.

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APPENDIXES

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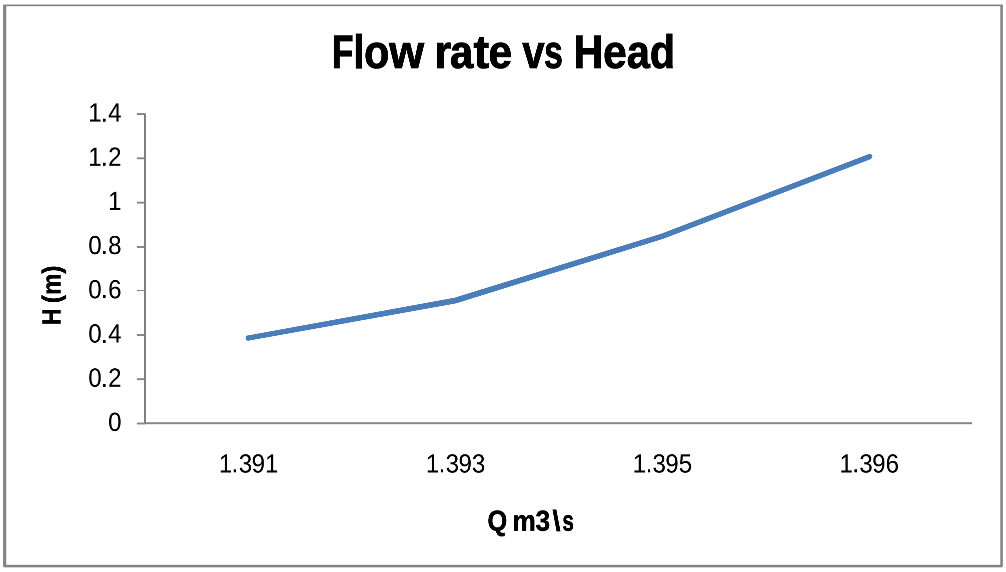
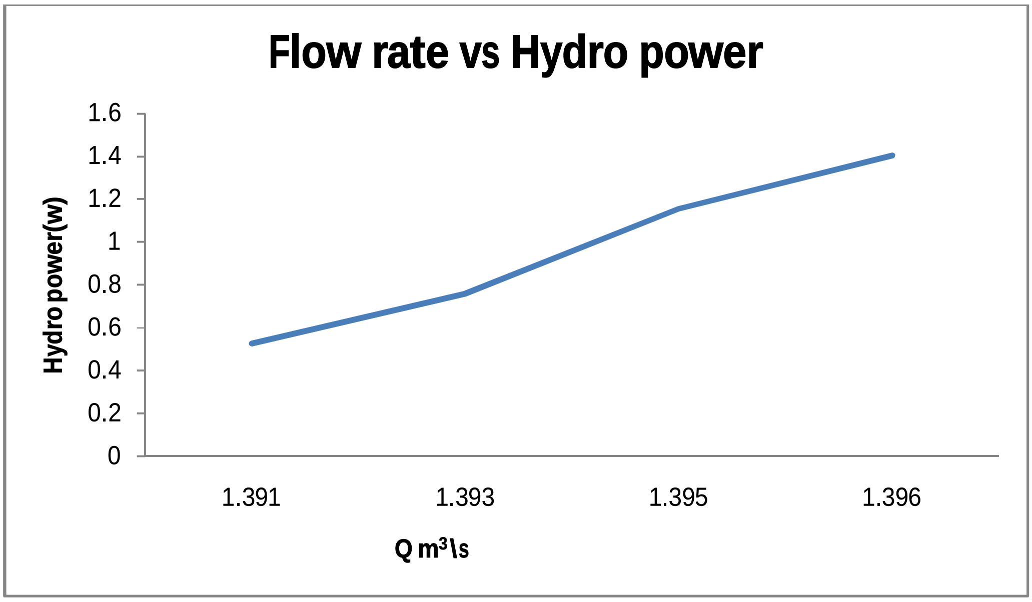
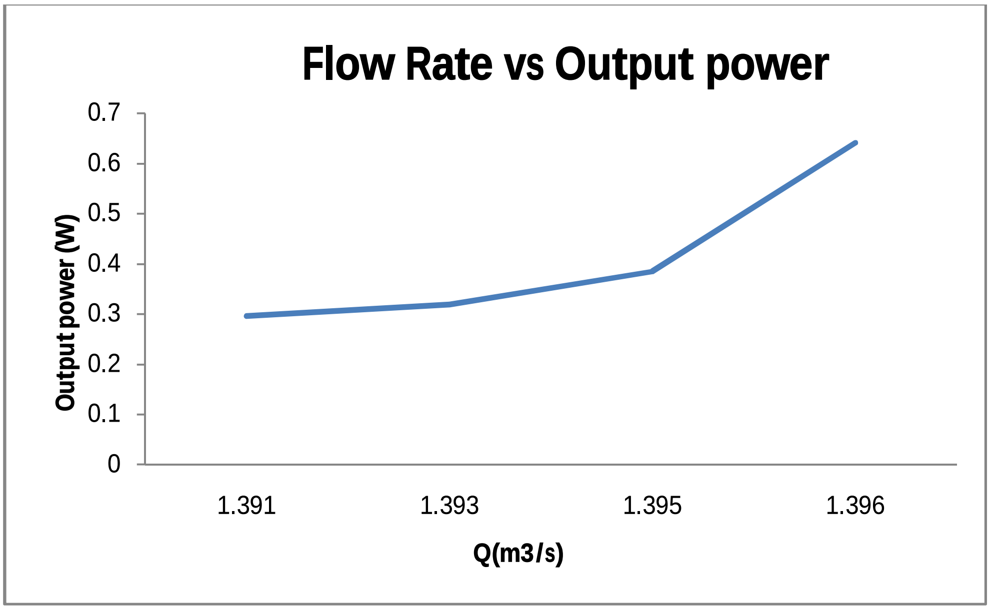


Appendix 1



Appendix 2


Flow Rate vs Output power
Output power (W)
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1.391
1.393
1.395
1.396
Q(m3/s)

Appendix 3