Cape Peninsula University of Technology

DESIGN AND ANALYSIS OF A MICRO-HYDRO DISTRIBUTED POWER SYSTEM

by

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Dissertation

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Supervisor: **Prof MTE Kahn**

Bellville

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DECLARATION

I, Muster Thivhileli Madavha, declare that the contents of this dissertation represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed  **Date 10 July 2023**

ABSTRACT

Micro-Hydro Distributed Power System is a renewable energy power plant. This dissertation comprises four (4) chapters: Chapter 1 provides general Micro-hydro Distributed Power System information, Chapter 2 provides project modelling and analysis, Chapter 3 provides off the shelve designs for Micro-hydro Distributed Power Systems, and Chapter 4 provides project construction, conclusions and recommendations.

The purpose of this study is to improve the standard way of producing electricity in a micro-hydropower plant through introducing a more efficient method into a micro-hydropower plant's current conventional method of electricity production. The aim of bringing this Micro-hydro Distributed Power System is to achieve greater results in comparison to those attained with a standard micro-hydro power plant, without the need to depend on rainfall and instead using two naturally occurring resources that can be stored: air and water. Storage tanks will be filled with water from existing dams or river runoff, and solar compressors will provide the air. which will produce electricity year-round at a higher rate than the current micro-hydropower, which is dependent on rainfall.

The Micro-hydro Distributed Power System is a hydropower plant that generates electricity by compressing fluid into the system with compressed air. Because the entire power system is dependent on working pressure and how power is generated using two major renewable sources, water and air, the system is designed and analyzed in CAD design software, and the results are calculated to ensure the design is sufficiently durable to withstand the pressure. The Micro-hydro Distributed Power System operates on the same principle as hydropower plants; the system converts H-Head(m) into pressure, which is then used in the formula (P=gh) to calculate the system's power. The main difference between Micro-hydro Distributed Power Systems and normal hydropower is the use of H-Head(m), in this system the H-Head(m) is converted inside the pipeline to find pressure as actual Head on standard hydropower plants. This research was conducted theoretically and not practically.

Theoretically, the findings of this study show that the power to be produced based on calculations is significantly higher than anticipated prior to the start of the research; the power input needed for the Micro-hydro Distributed Power System based on the compressor system's rated power is 11KW in order to produce the 13 bars of pressure necessary to compress fluid for maximum power output. The compressor system generates 398.3 MW of electricity at 13 bars, but at a high water flow rate of 391.907 L/s. The fact that this water is recycled and pumped back into the tank is a significant benefit of the Micro-hydro Distributed Power System. Without compressed air, water does not flow and cannot be pumped back into the system.

The system uses the same principle as a standard hydropower plant when it comes to water entering the turbines, the difference is that in the Micro-hydro Distributed Power System Head(m) is not considered but converted into pressure for using it in hydropower formulas to find power and other useful calculations in the hydropower plant, since it manipulates pressure through the pipelines.

This system will help in the addition of electricity in hydro power, and during the draught season this system can produce electricity since the plant uses circulation of water. The reaserch about this system is still continueing to better the system interm of its design and the power it can produce.

Keywords: micro-hydropower plant, hydropower, air compressor, solar pv, h-head(m), water consumption.

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DEDICATION

To

My Baba Steyn Madavha, Mma Musoliwa Murovhi-Madavha, Sylvia Da-Gama, My wife Sisanda Madavha, Lisa Rendani Madavha and my late Grandpa, Frank Mathakha Madavha and late Grandma, Gertrude Murovhi.

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Nomenclature

Table 1 Nomenclature

SYMBOLS/ Acronyms	**MEANING**	**units**
C	Air requirement of demand	m^3/s
Cap	Cap = Compressor capacity	m^3/s
CO_2	Cabon Dioxide	µmol/mol
K	Kilo	10^3
M	Mega	10^6
P	Pressure	Kpa
P1	P1 = Initial tank pressure (Compressor discharge pressure)	Kpa
P2	P2 = minimum tank pressure (Pressure required at the output of tank to operate compressed air devices)	Kpa
Pa	Pa = Absolute atmospheric pressure, given in	Kpa
P_{power}	Power	W or (MW)
P_s	Static Pressure	Kpa
P_t	Total Pressure	Kpa
q	Dynamic pressure	Kpa
t	Time interval in minutes during which compressed air demand will occur	s
V	Velocity	m/s
W	Watt	$Kg.m^2.s^{-3}$

Abbreviations

CAD	Computer Aided Design
COTS	Commercial off-the-shelve Components
DERs	Distributed Energy Resources
FDC	Flow Duration Curve
LDC	Least Developed Country
MHDPS	Micro-hydro Distributed Power System
P&ID	Piping and Instrumentation Diagram
PHS	Pumped Hydro Storage
PV	Photovoltaic
RE	Renewable Energy
SHPs	Small-scale hydro plants

CHAPTER 1: Micro-hydro Distributed Power System General Information

1.1 Introduction

The utilization of air and water to power the turbine has many advantages because these two renewable sources boost system efficiency and the water is recycled. The goal of this dissertation is to investigate energy generation utilizing water and air, and then to create a miniature model that may be used in this process.

The MHDPS, as mentioned above, will benefit both people and the environment. It is commonly recognized that micro-hydropower plants may be operated well, supply clean energy from upstream rivers without a reservoir to power the turbine, and are relatively inexpensive to build and maintain (Nasir, 2014). What makes such hydropower facilities are distinctive because they do not waste water. Instead, the air pressure is employed to spin the turbine after being used to pump water back into storage tanks. Since the conventional style pump consumes a lot of electricity, redesigning it to use a renewable energy source to operate the turbine indicates that the output electric power may be more cost-effective than the conventional hydropower facilities that employ electric pumps. The MHDPS benefits from this usage of pressurised air since it is now able to regulate the amount of power the turbine generates. The amount of air pressure that is injected into the water tanks determines the power output.

With two reservoirs a 16 MW hydropower capacity is produced, and is a typical Pump-Hydro plant that has a 16 MW pump power capacity at a 200 m fall height(Eliseu & Castro, 2019). Since the pump in this system uses the generated energy at the tested 200-meter range, it serves well as a storage system. Water is used as a clean and sustainable energy storage medium in pumped hydro storage (PHS). This storage system does not require any chemical substances and utilizes two reservoirs at different heights to store energy (Mousavi *et al.*, 2020). The Pumped Hydro-Power Plant uses electricity to pump back water for reuse, whereas the MHDPS operates on the principle of working with pressure. This distinguishes the MHDPS from the PHS. The compressors in the MHDPS are primarily powered by solar energy.

1.1.1 Problem Statement

Everyone needs electricity as a source of energy to run their home or office appliances. Saving lives is made possible by hospitals and other medical facilities having a steady supply of electricity. Sub-Saharan African and LDC countries still struggle to produce enough electricity, but these regions do have abundant rainfall and large rivers (WHO, 2009). The answer to this electricity shortage won't be found in all forms of electricity. Some electrical energy sources could have a negative impact on climate change as a result of global warming, which is bad for our planet.
Early 1800s saw the invention of hydropower plants, and improvements have been made over the last 200 years. Both small- and large-scale hydropower plants are currently being constructed. Due to environmental changes, large-scale hydropower plants run the risk of not being able to generate electricity if there is a draught.

It is urgently necessary to find a solution that will allow a micro-hydropower plant to overcome its production and design inefficiencies. This study focuses on learning how to efficiently combine water and air in pressure tanks before sending that mixture to the turbine and generator at high speed or controlled pressure.

1.1.2 Background of problem

Hydropower and hydroelectric power facilities have been around for a long time. Unfortunately, because of climate change, their life expectancy has been reduced, and locations that used to have high level rainy seasons now have less rain, resulting in low levels of dams, making the continuous production of energy from these dams impossible..

Clean energy from upstream rivers can be produced by the micro-hydro power plant, which can be constructed to operate more effectively. As previously indicated, these "run-of-river" plants only need a little amount of reservoir or stored water to power the turbine(Nasir, 2014).

Micro-hydro power plants are dependable and efficient at producing green electricity. They can deliver 5KW to 100KW of electricity, and small hydropower plants can deliver up to 10MW (Nasir, 2014). Unfortunately, due to climate change, rainy seasons are no longer predictable around the world, and these power plants depend on a steady flow of water from rivers or dams.

1.1.3 Significance of problem

The concept of using air and water to create energy has yet to be thoroughly investigated, making the proposed MHDPS unique. African countries face energy challenges, particularly in terms of clean energy, due to frequent blackouts and load-shedding. In this day and age, everyone is reliant on energy, and power outages affect both private residences and industries.

This research effort will seek to produce a clean energy source that will improve the environment, attract investors, and provide job possibilities.

1.1.4 Delineation of the research

This research will not cover the following issues.

- Solar system design
- Compressor design
- Turbine design

It will, however, go over the usage of air and solar energy to power the compressor and a commercial-off-the-shelf turbine.

1.1.5 Literature Review

The principle of hydropower is based on the use of water dropping from a specific height and flowing water with kinetic and potential energy linked with it. The use of a turbine or water wheel to transform the energy in falling or flowing water into mechanical energy is known as hydropower. An electric generator then converts this energy into electricity (Pasalli & Rehiara, 2014).

Micro hydropower technologies can be considered as one of the ideal options to recover energy and boost energy sustain-\sability in water distribution networks. Using a hydraulic gradient, this device captures the kinetic energy of moving water and transforms it into electrical power. The key element of an MHP system for generating electricity from water flow is the turbine. Turbines come in a variety of types, such as Kaplan, Francis, Bulb, Pelton, Turgo, Crossflow, and Pumps-as-Turbines (PATs). a variety of research employing Pelton turbines to recover energy from water delivery networks (Hamlehdar et al., 2022).

In terms of creating clean electricity, micro-hydro power plants are both efficient and dependable. They can produce electricity ranging from 5KW to 100KW, with small hydropower facilities producing up to 10MW (Nasir, 2014), The large-scale hydropower facility can generate up to 80 TMW of energy. Hydropower facilities are critical for present and future electricity networks because they generate electricity without producing CO2, and hydro reservoirs give considerable operational flexibility (Jahns et al., 2020). One of the most well-established renewable energy sources, hydropower powers both large and small power plants and accounts for more than 16% of global electricity usage (Gagliano et al., 2014). In truth, hydropower plants produce electricity in a method that is highly good for the environment. The dams built for these facilities not only benefit people, but also the many different types of fish and plants that inhabit there. The enhanced hydropower system can produce more electricity with less water by using a solar compressor (whose energy source is the sun) with an improved design that will boost pressure.

Due to rising population demand, as well as issues brought on by the usage of fossil fuels, such as greenhouse gas emissions and climate change, energy supply is currently one of the main concerns of societies. In order to address the energy crisis and environmental issues associated with non-renewable energies, energy recovery together with renewable energy systems can be alternate energy solutions (Hamlehdar et al., 2022). Small-scale hydro plants (SHPs) offer an alternative to electric grid extension that serves widely dispersed communities as an effective power supplement in urban areas with few environmental difficulties, especially for the areas that are still not connected to the primary grid (Eshra et al., 2021).

Despite the fact that many renewable energy sources have negative effects, hydropower is still by far the most popular. But, in recent years, other renewable energy sources, such wind and photovoltaic (PV), have had significantly faster growth (Eliseu & Castro, 2019). Moreover, the MHDPS uses a PV solar compressor to pump pressure throughout the system. Hybridizing renewable energy sources is essential for a reliable energy supply. Yet, there are numerous optimization frameworks, including deterministic, stochastic (heuristic), and hybrid, that can be used to combine energy systems in the best way possible. Due to its clear advantage over deterministic approaches, stochastic methods have been used extensively in the optimization of energy systems (Nyeche & Diemuodeke, 2020).

More results will be attained through the introduction of an MHDPS without an electric pump. With two reservoirs and a normal tested hydropower capacity of 16 MW, the pump power capacity is also 16 MW at a fall height of 200m (Eliseu & Castro, 2019), already the pump is consuming the produced energy at that tested 200m. A PHS is a clean and sustainable energy storage system that uses water to store energy. This storage system does not require any chemical substances and can store energy in a wide range of capacities. It requires two reservoirs of different heights (Mousavi et al., 2020). The micro-distributed unit differs from the pump-hydro in that it uses reservoirs of the same height only to store water and control pressure that is mixed with air pressure from solar compressors, as opposed to using reservoirs of different heights.

Because of the use of hydropower plants in China, it was discovered that CO_2 emission reduction has exceeded 70%. Hydropower plants are environmentally friendly because they do not emit CO_2, but rather they reduce the CO_2 which is deposited in the environment (Liu et al., 2019). Using renewable energy sources may help to minimize CO_2 emissions (Crespo Chacón et al., 2020). It has not yet been done to switch to a type of hydropower plant that uses very little water and produces electricity equivalent to a conventional hydropower plant by mixing water and air. The use of various solutions and combinations of pipes and storage tanks in hydropower plant continuous improvement has been examined to determine the most practical solutions (Hatata & Saad, 2019). Several design options must be taken into account when seeking to create a successful micro-hydro power plant, these design considerations are (Pasalli & Rehiara, 2014):

- Flow duration curve (FDC)
- Flow rate measurement
- Weir and open channel
- Trash rock design
- Penstock design
- Head measurement
- Turbine power
- Turbine speed
- Turbine selection

Only a few of the aforementioned options for a micro-distributed power system must be taken into account since pressure from the compressor eliminates the majority of the aforementioned options. Flow duration curve (FDC), flow rate measurement, turbine power, speed, and selection, as well as pipe design and pipe selection for better flow, are the factors to be taken into account.

The diagram bellow is the study done on the new form of connecting generator into a pipe line, below diagram is the indication that the use of mounting generator into a pipe line can have a positive impact on microhydro power generation.

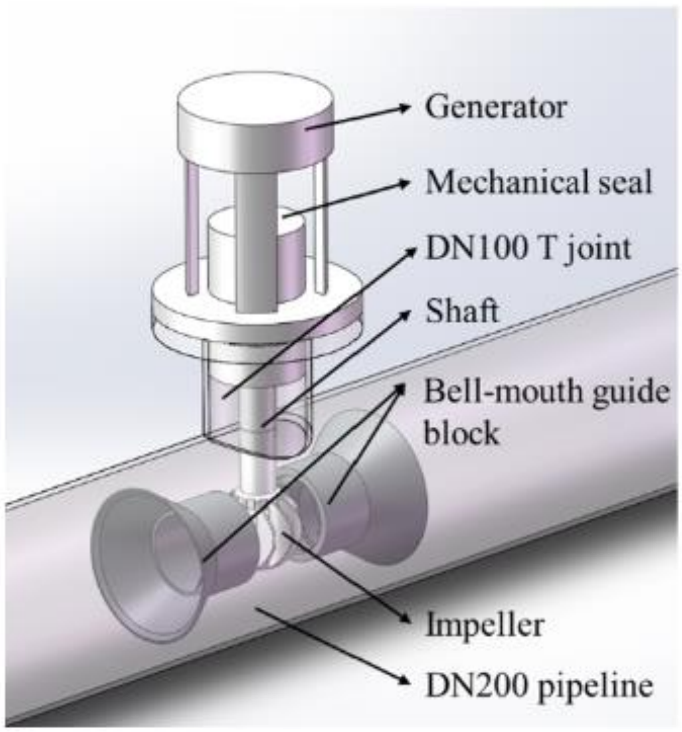

Figure 1 Water turbine scheme (Yao et al., 2023)

Figure 1 shows a built-in vertical axis water turbine that can harvest energy while regulating water flow. A design concept for a bidirectional crossflow water turbine is suggested in order to accomplish the necessary performance specified above, and its schematic representation is illustrated in Figure 1. There is a T joint (DN 100) which is integrated to an existing water pipeline (DN 200), and then the\simpeller and generator are installed through a DN100 flange. According to Figure 1, an impeller shaft and generator shaft are coupled by a shaft coupling, allowing the mechanical torque created by the water's kinetic energy to be transferred to the generator via the shaft and coupling. The control unit rectifies the electrical energy produced by the generator, which is then stored in the energy storage system [13]. Figure 1 is an indication of how turbines in c are installed or how they work.

Compressors are used widely globally, machines such as grinders and even drillers that previously utilized electricity, now are designed to use air as their source of energy. The process of the pump will use less electricity thanks to a redesign that prevents the input from being equal to the output and uses air from the solar compressor to create pressure. Most types of auxiliary power plants and small and medium-sized turbo aircraft engines use centrifugal compressors because of their small size, simple, compact design, and high single-stage pressure ratio. The optimal design of a centrifugal compressor with high-pressure ratio and deficiency in air equipment tool has been the pursuing target of compressor designers for decades (Tang et al., 2020).

From one point to another on microhydro power, flow is transferred by pipes. The direction of flow is from the lower hydraulic head to the upper hydraulic head. In our simulation, it is assumed that every pipe is always filled (Hamlehdar et al., 2022). In micro-hydro distributed power system pressure is transfered from one point to another using water.

Although some of the engineering products that result from system improvement may turn out to be the opposite of what was anticipated, this improvement has been classified as having a positive impact on technology. In comparison to the current hydropower system, the proposed MHDPS should be a new hydro type power system that offers superior output while requiring less energy to produce electricity. The traditional hydropower system requires a large amount of water to be available from a dam in an elevated position that should be full or have a high head (H), or if runoff water is used, the river should be flowing at a high speed, in order to produce the same amount of electricity. The advancement of technology and decrease in the price of electronic energy devices has led to an increase in micro-grid analyses. Due to this procedure, distributed energy resources (DERs) can now be integrated into the microgrid using a flexible architecture.

The advantages of a micro-hydropower plant over the same size wind, wave and/or solar power plants are (Nasir, 2014):

- High efficiency of 70% to 90%, making it by far the best energy technology available.
- High capacity factors of over 50% as opposed to solar power plants' 10% and wind power plants' 30%.
- Power output is at its highest in the winter; there is a slow rate of change; the output power varies only gradually from day to day and not from minute to minute.Power output is maximum in winter.

Many approaches for cost estimation have been developed as a result of the wide variability in the potential costs of hydropower schemes (at all scales) and, in particular, the dearth of costing information for mini- and micro-hydropower (Butchers et al., 2022). The extraction, delivery, and treatment procedures in the water business consumed 4% of the world's electricity in 2014, making it one of the most energy-intensive industries in recent years (Crespo Chacón et al., 2020). Micro-hydropower has the potential to significantly advance the fields of renewable energy and irrigation sustainability.

Many nations are exploring alternative energy sources due to the rising global energy demand, climate change, the negative environmental effects of conventional fuels, and the principles of sustainable development. To enhance human well-being, prevent environmental illnesses, and protect the environment, they work to develop technology, regulations, rules, and principles. The ideal solutions for these nations to take into account are energy efficiency and renewable sources of energy. Within a pipe-line, water and energy are inextricably linked. The pumping of water uses a significant amount of energy, however the kinetic and potential energy contained in the flow of water can be used to generate an interesting quantity of energy and water distribution methods (Berrada et al., 2019).

Considering the possibilities that the flow can be laminar flow. Poiseuille Equation is also an equation I have applied in my calculation, the reason I used Poiseuille Equation is because even at low Reynolds numbers ($Re \geq 1$) Poiseuille flow greatly deviates from the real fluid behavior in fractures of varied aperture. Poiseuille flow using the average aperture of the fracture produces results that are reasonably accurate. And due to its simplicity Poiseuille flow is frequently used to describe flow and has several physical assumptions and restrictions but does not preserve energy. (Gee & Gracie, 2022).

1.1.6 Research Question

The research question and secondary questions are:

- How much electricity can efficiently be created using a micro-hydro distributed power system by using stored water and compressed air to drive a turbine generator?
- Can such a system be built in a modular format cost-effectively?
- Can such a system be built in a modern drawing CAD design?

1.1.7 Aim and Objectives

The construction of a MHDPS uses two main natural sources, water and air, to create high pressure and uses that pressure to drive a turbine to generate electricity and, also, uses solar PV for energy to power the air compressor.

1.1.8 Research Design and Methodology

As previously mentioned, the MHDPS generates electricity primarily from two sources: air and water. To create a balance that can produce the desired pressure to generate electricity, these two sources must be distributed evenly, below is a figure 2, a simple flow chart of the system.

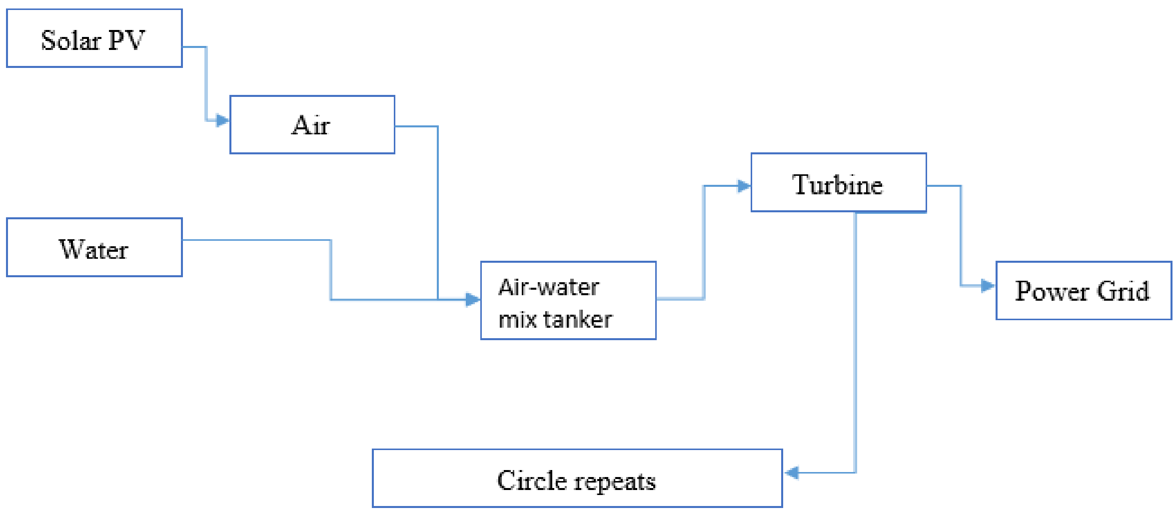

Figure 2: A simple flow chart

The MHDPS is a producer of renewable energy, using solar panels to power the air compressor. The pumps are not powered by electricity; instead, they are air-powered by compressed air that is sent to them as system waste. Additionally, components available from retailers will be used to construct the pumps i.e commercial-off-the-shelf components (COTS). Due to the use of less expensive local building materials, this procedure will make the power plant:

- Cheaper to build; and
- Simpler to assemble.

Before construction begins, all necessary calculations will have been made to demonstrate the viability of the MHDPS. The following design criteria will be taken into account:

- How much water a reservoir requires (reservoir capacity calculations).

- The required air pressure to fill the water tank.
- The turbine calculation used to determine which type of turbine can withstand the applied water pressure.
- The use of water pipes with less friction.
- How much electricity the MHDPS will produce from each turbine/generator load combination.

1.1.8.1 Comparison of the existing hydropower plant with Micro-hydro Distributed Power System

Figure 3 below delineates how different the above two power generating methods are before the distribution of electricity to the grid.

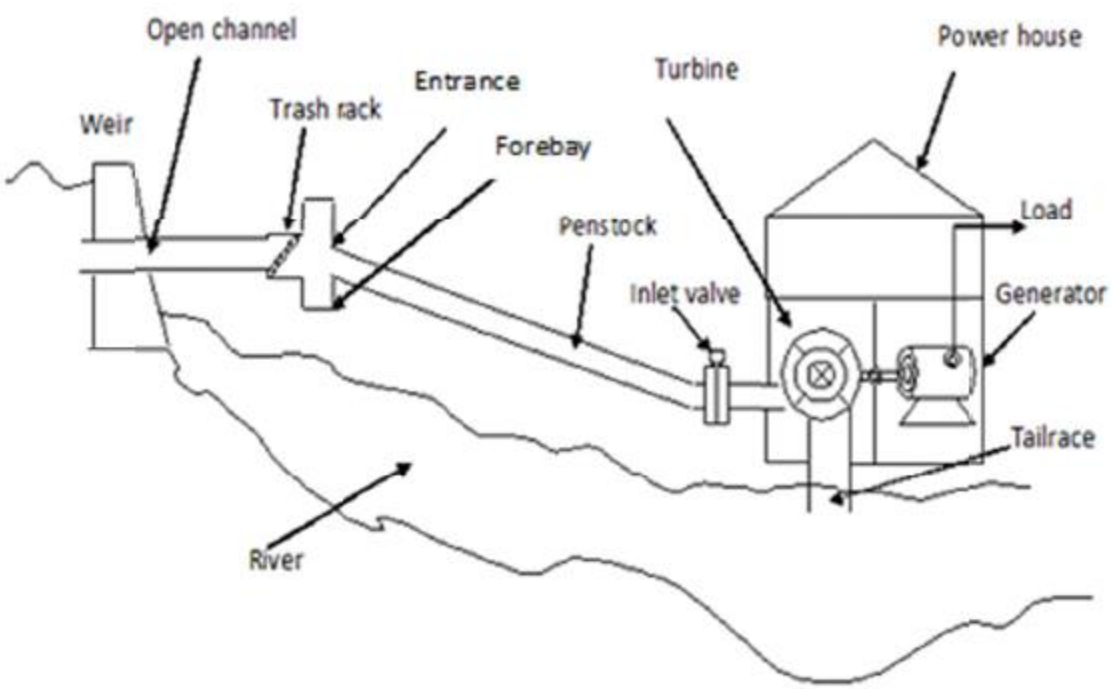

Figure 3 Schematic diagram of micro-hydro power plant (Nasir, 2014).

Unlike the MHDPS, which forces water through to the turbine at a higher speed after being pressurized by air, the existing hydropower plant allows water to flow directly from the river or running stream to the turbine.

1.1.9 Chapter 1 Summary

This chapter focuses upon the working principles of Micro-hydro Distributed Power System (MHDPS) which uses two natural resources (mainly air and water) to drive the turbines. This chapter also provides general information on how the air which is created by the rotor screw compressor is kept in the air storage tank and then used to pressurize water and also to pump this water back to the system as well as draw water from runoff streams or dams. The Micro-hydro Distributed Power System (MHDPS) references its working principles from the standard hydropower plant. The differences between the MHDPS and the standard hydropower are clearly outlined in this chapter. The MHDPS does not use H-height for gravitational pressure ($P=\rho gh$), instead, H-is converted to pressure as detailed in Chapters 2 and 3 below.

The objective of this chapter is to show innovative ways for improving micro-hydropower generation through the use of new methods of creating energy that employ only two main sources (air and water) as the primary power generating source. This section also classifies which components had to be specially designed and others that could be purchased, i.e., solar energy, compressor, and turbine

CHAPTER 2: Modeling and Analysis

2.1 Introduction

This chapter delineates the entire design of the Micro-hydro Distributed Power System (MHDPS) and the theoretical calculations relating to how much power the system provides, and the design components that will mainly be used together with the following Commercial off-the-shelve Components COTS:

- Solar energy
- Compressor
- Turbine

The main purpose of this chapter (as mentioned above) is to afford details of how the MHDPS is designed, from Piping and Instrumentation Diagram (P&ID) to the 3D model, and to provide the general calculations in terms of how it works and how much electrical power the system generates. P&ID in this section is the first process that was followed when it comes to the design between the structural design(3D model). All codes in *Table 2. P&ID Used symbols* (see 2.1.1 P&ID Drawing object and code below) are coded based on the formation of how air and water pipes are connected, from *Figure 3 P&ID Layout of Micro-Hydro Distributed Power System* (see 2.1.2 below) and in Table 3 the codes K-002 and K-003 are the release valves, these valves are in the form of a tank shape that is the same shape as in the 3D drawing, the reason for them taking this shape, and not as a valve symbol, is that they are customized valves and are designed from the vessel shape and to fit the design. The following computerized valves in the P&ID are operated with a manual valve, when the computer is not functioning, the computer valve will be open and manual valves can be opened and closed manualy:

Table 2 Description of computerised valve

Valve name in the design	Functionality
COM-CV-1	To release air valve and close air valve from compressor on the P&ID
AIR-T1-CV-2	To release air valve and close air valve from tank 1 on the P&ID
AIR-T1-CV-3	To release air valve and close air valve from tank 2 on the P&ID
MIX-T3-CV-2	To release air valve and close air valve to the air water mixing tank on the P&ID
MIX-T3-CV-3	To release air valve and close air valve to the air water mixing tank on the P&ID

The above valves are planned to be computerized due to the manual valve next to them. The MHDPS theoretically proved to be producing much more power compared to what was expected from the proposal owing to the 13 bar maximum air pressure from the compressor producing approximately 50MW(50.7MW). The 13 bar air pressure is produced at 11kw solar power or considering a solar system that will be operating specifically for the compressor in which it will be needing 11KW.

The existence of the air tank in the system always will provide air at a higher pressure when needed, the reason for this being that the air tank will allow air pressure to be built up. The air tank can store air at a higher pressure than is necessary for the MHDPS and creates favorably high pressure when it is needed (Evans, 2021). From the 3D drawing, it can be seen that air goes back to the air tank with the option to drain as soon as it as completed pumping water back into the system. The air that pumps the water back is the same air that gets extracted from the water-air tank mixture. In the P&ID this air has the option of passing through the dryer, as indicated by F-001, then back to the K-001 of the air tank as shown in *Fig 6.*

The design of the MHDPS is analyzed through the design software and calculations based upon the working process of the sources to be used. All components in this chapter are designed and modified to work specifically for the MHDPS, for example, the vessels in Figures 6 to 10 (below) have been in existence for many years but for this system are modified to fit components inside them, such as the release valve in Figure 7.

The designs are also simulated to test their strength since this system works with pressure throughout the production of generating power. Maximum hydropower output depends entirely upon how much flow and the head are available at the site where the power plant is situated (Renewables First, 2015b). The MHDPS depends entirely upon air pressure and it is this pressure that determines this flow. From the maximum pressure of 13 Bar that the compressor can provide, 50.7 MW of power will be produced, based upon theoretical calculations.

2.1.1 P&ID Drawing object and code

Table 3. P&ID Used symbols

Object	CODE
Air Dryer	F-001
Air Pump	P-001
Air Tank Storage	K-001
Air Tank Storage	K-007
Check Valve	HA-104
Check Valve	HA-109
Check Valve	HA-110
Compressor	V-001
Computerised Valve	COM-CV-1
Computerised Valve	AIR-T1-CV-2
Computerised Valve	AIR-T1-CV-3
Computerised Valve	MIX-T3-CV-2
Computerised Valve	MIX-T3-CV-3
Main Water Storage	K-005
Realease Valve Vessel	K-002
Realease Valve Vessel	K-003
Turbine	WATER-CV-2
Water-Air Tank Mix	K-004
Water-Air Tank Mix	K-006

2.1.2 P&ID Layout

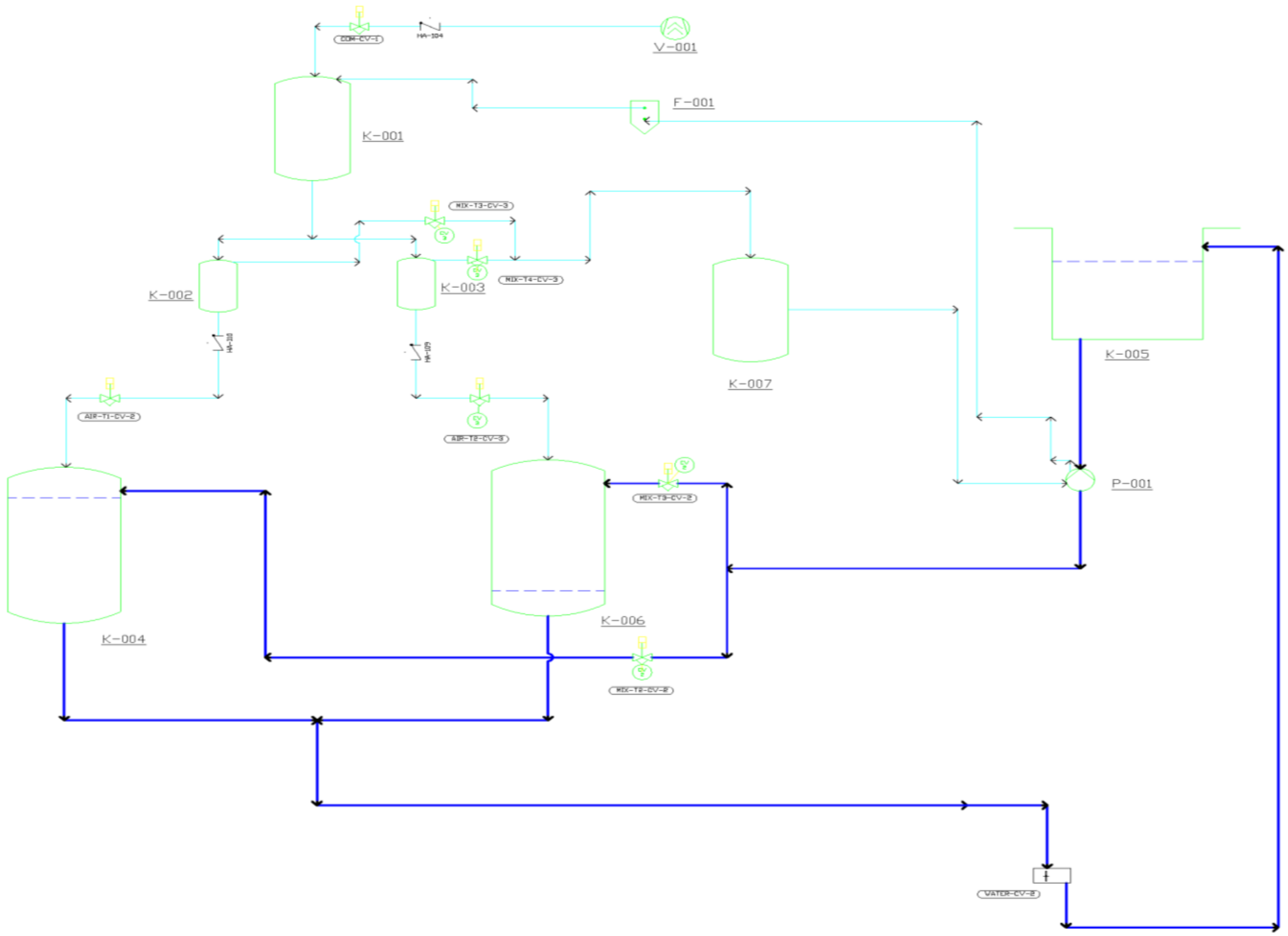

Figure 4. P&ID Layout of Micro-Hydro Distributed Power System

2.1.3 Project 3D View

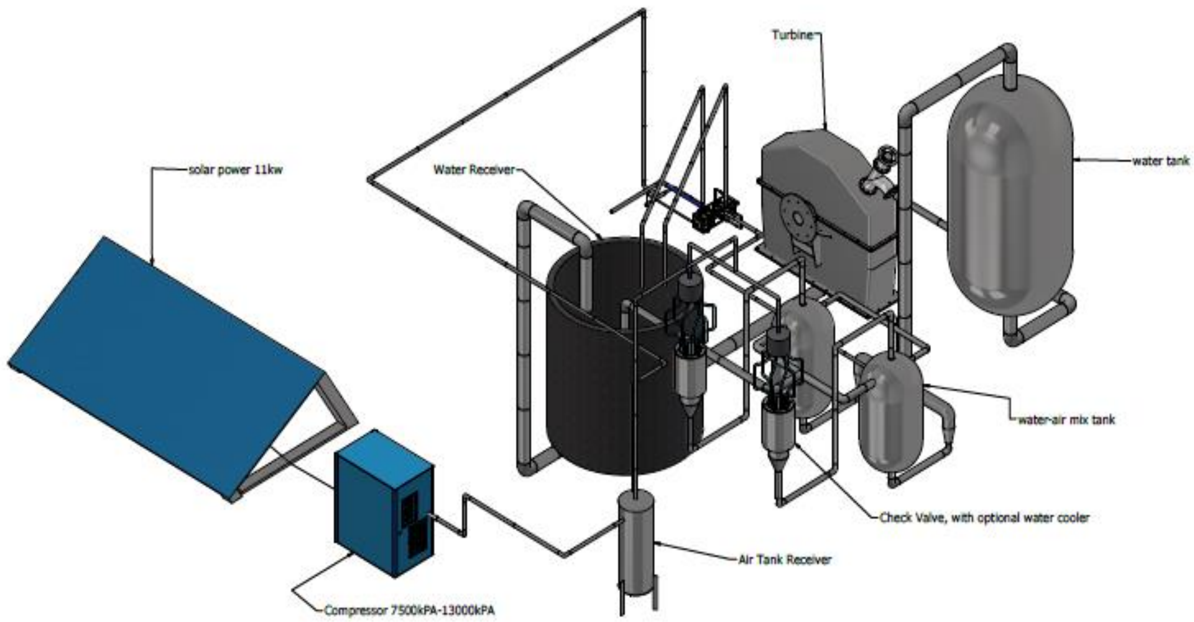

Figure 5. 3D View of Micro-hydro Distributed Power system (MHDPS)

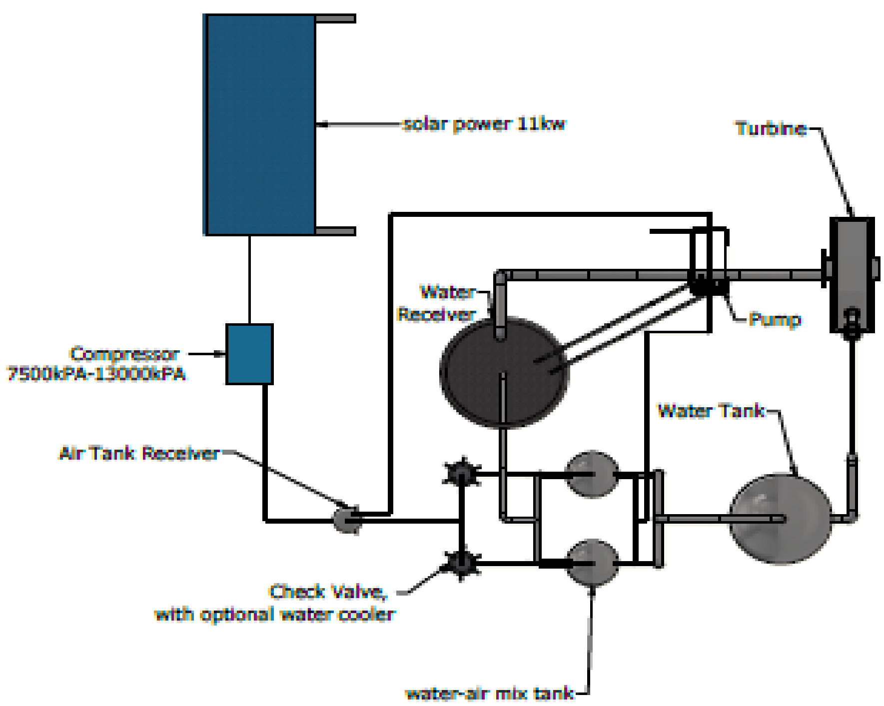

Figure 6. Top View of Micro-hydro Distributed Power system.

2.2.1 Air Tank storage

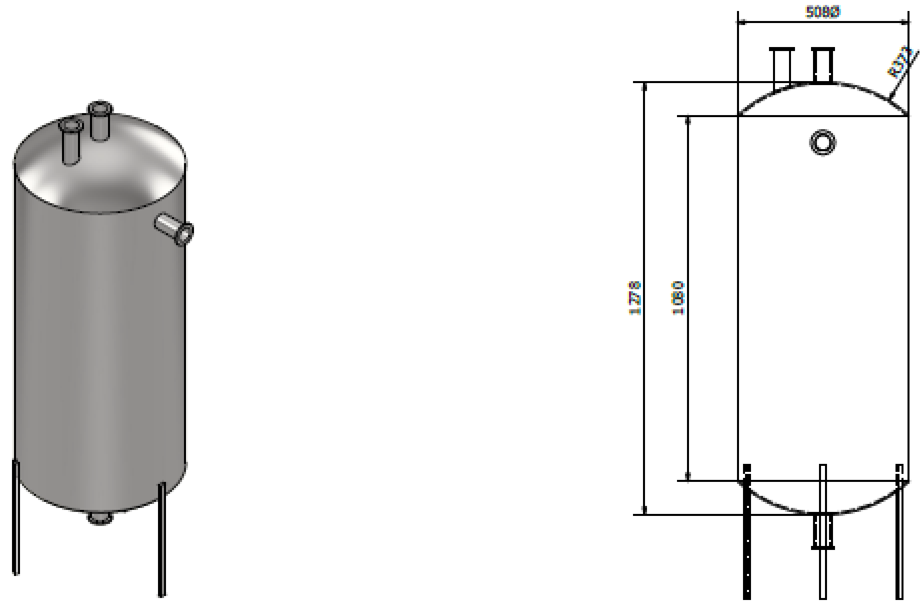

Figure 7. Air Tank Receiver

This air tank is an air receiver, it accepts air from the pumps and compressor and discharges the air to the check valve. The air tank is used to store air at a higher pressure than what is needed for the MHDPS and creates a favourably high pressure when it is needed for the system (Evans, 2021).

<u>Air tank receiver capacity calculations – Figure 6</u>

V = Volume of receiver tank in m^3

t = Time interval in minutes during which compressed air demand will occur

C = Air requirement of demand in m^3/s

Cap = Compressor capacity in m^3/s

Pa = Absolute atmospheric pressure, given in KPA

P1 = Initial tank pressure (compressor discharge pressure) in KPA

P2 = minimum tank pressure (pressure required at the output of tank to operate compressed air devices) in KPA

For the chosen off-the-shelf compressor GA 11 with its design capacities load.

Table 4. Technical Specification (AtlasCopco, 2018b).

Compressor Type GA 11	Max. Working Pressure				Capacity FAD			Installed motor power		Noise level	Weight	
	Workplace		WorkPlace Full feature								Workplace	WorkPlace Full feature
	bar	KPA	bar	KPA	l/s	m^3/h	cfm	KW	hp	dB(A)	kg	kg
	7.5	751.5	7.3	724	35.8	128.9	75.9	11	15	63	410	455
	8.5	800	8.3	827.4	33.8	121.7	71.7	11	15	63	410	455
	10	999.7	9.8	972.2	30.3	109.1	64.2	11	15	63	410	455
	13	1303.1	12.8	1275.5	25.2	907	53.4	11	15	63	410	455

Bar 1=100kpa

If the compressor is to be operated for 5 minutes, since the MHDPS does not require a compressor to be operated 24/7, but only when it is necessary to recover lost air, due to the following aspects:

- Blasting of pipes,
- Lost air in pumps,
- Air which is deliberately flushed out,
- Loss of air in pipes during the process of pumping in the pipes and the check valves, and
- Any leakage which might have occurred.

The 5 minutes chosen is for sample calculation to show how much, at that given time, the volume flow air receiver capacity will hold if the receiving pressure from the compressor in Table 4 below is to be 724 KPA (P2) and the initial pressure (P1) needed in the check valve, or to be pushed to the air tank mixture, is twice or 1200 KPA.

$$V = \left(\frac{5(75.9)x101.3}{1200-724}\right) \quad 1$$

V= 80.76m^3

Although pressure will vary, the volume calculated is an indication of the design storage capacity for running the compressor at a maximum of its capacity at 13 bars (13000KPA) The volume the tank will hold is based upon the design strength simulated in the model. The chosen compressor is designed to operate from 724KPA to 13000 KPA. If an event suddenly occurs which causes the pressure to drop the check Valve will not be operational, the air stored at that specific time in the air receiver will help support the demand required by the other check valve (Marshall & Scales, 2021).

2.2.2 Release Valve

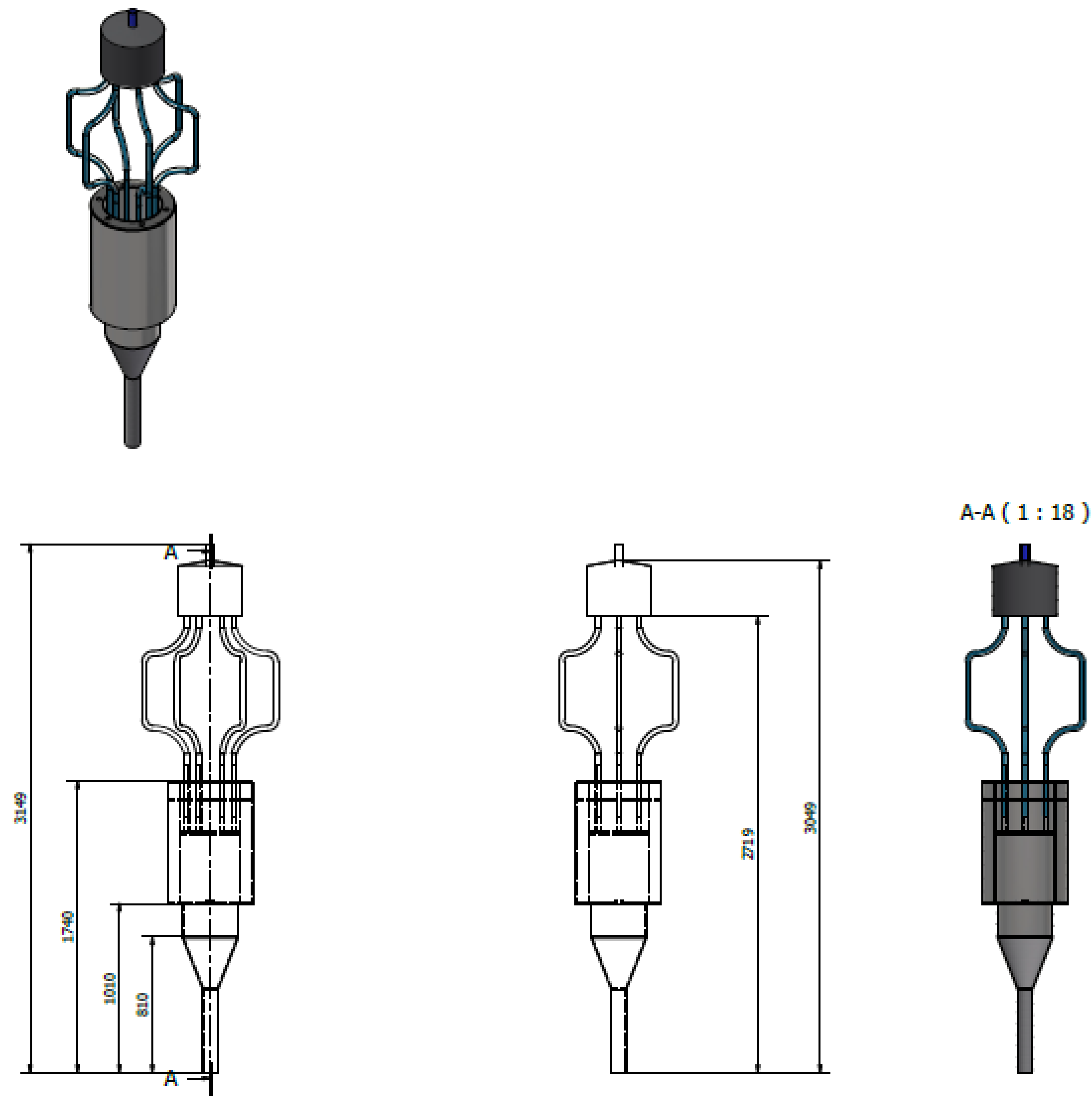

Figure 8. Release Valve

This valve is a customized release valve, designed only to allow air to pass through it and will not allow air to flow back, or to reverse pressure. At a certain pressure the release valve releases air to the other tank and when the pressure reaches its maximum operational point, the air then goes to release valve 2 to complete the same process as at release valve 1. Figure 8 is a schematic diagram of how the release valves work.

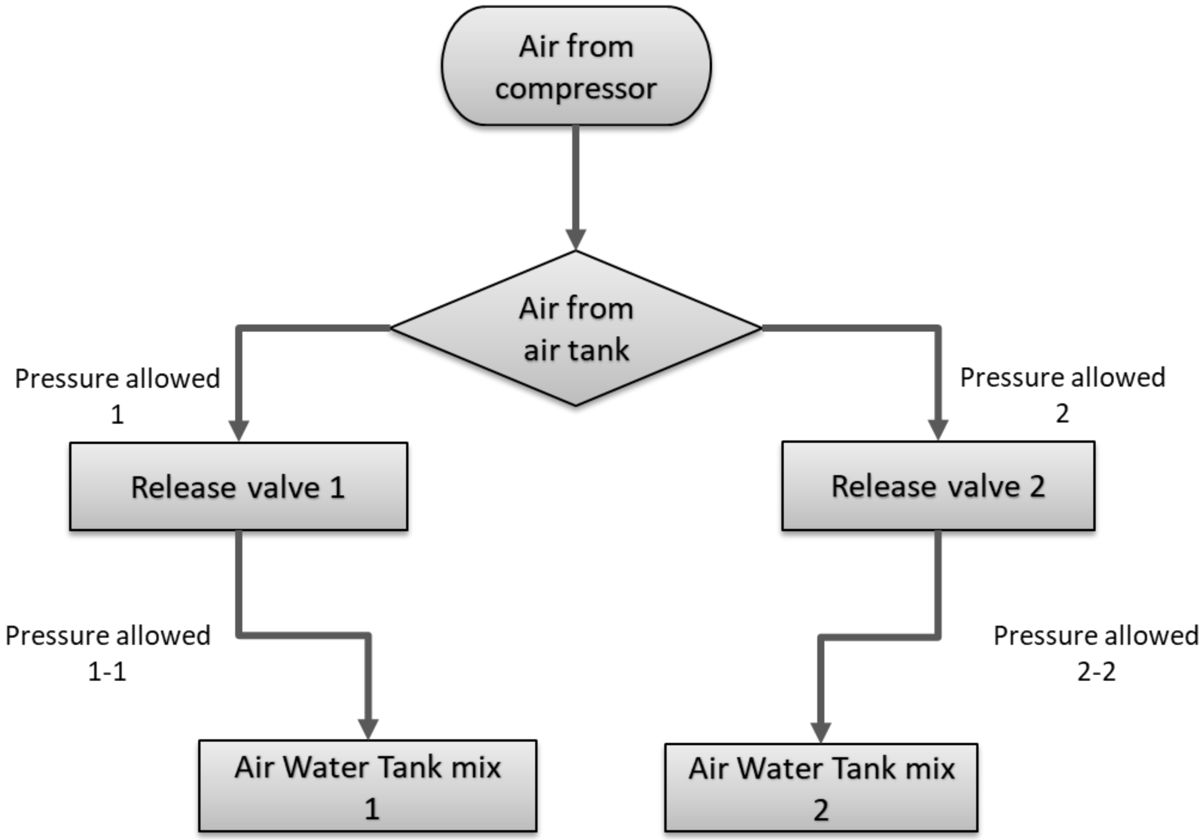

Figure 9. Schematic workflow of air-to-air water tank mixer

The label “Pressure allowed” in Figure 8 above indicates that the valve allowing pressure is open, as shown by yes (green) and when the required pressure is reached, it closes that main release valve 1 and opens release valve 2.

The main purpose of the release valve for the MHDPS is to allow and reject the air needed to the mix tank and to allow or reject the air (pressure) needed on release valve 1, since this release valve does not work simultaneously wih release value 2. If release valve 1 is working and needs 3000 Kpa, release valve 2 will not work during that time. As soon as release valve 1 has acquired the allowed pressure of 3000 KPA then the release valve 2 will repeat the process that with release valve 1. Before release valve 1, there is a computerized valve that allows the change of pressure to be directed to a single line on release valve 1, this process is termed the “breathing method”.

Table 5. Pressure Release work process

Working pressure on a pipeline to Release Valve 1	3bar 0bar	3bar 0bar	Working pressure on a pipeline to Release Valve 2
Pressure allowed 1	yes no	no yes	Pressure allowed 2
Pressure allowed 1-1	yes no	no yes	Pressure allowed 2-2

2.2.3 Air-water Tank Mixture

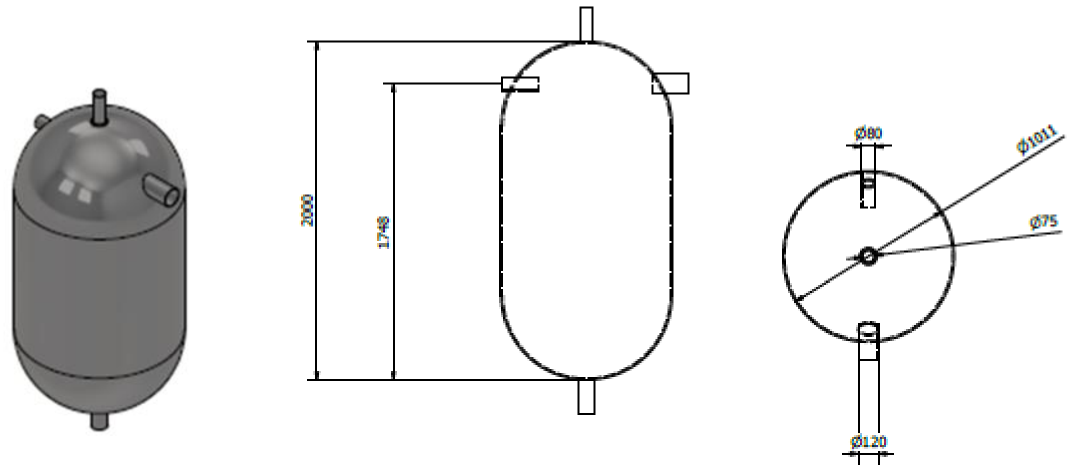

Figure 10. Air-Water Tank Mixture

The air-water tank allows air to build up as it creates high pressure, the reason for the two air-water tanks is to allow each tank to clear and for the water which will be pumped into the tank to be pumped in without a push back pressure which will make the water fill in process slow. The principle of this "breathing method" is that as one release valve releases, the other release valve is engaged in filling the tanks.

Theoretically the pressure will always be the same as per a single release valve, with the assumption that in the process of the working release valve there are no pressure losses which are due to:

- Leakage of a pipeline.
- Valve leakage
- Friction losses
- And other minor unplanned losses which might occur.

2.2.4 Main Pressurized Water Storage

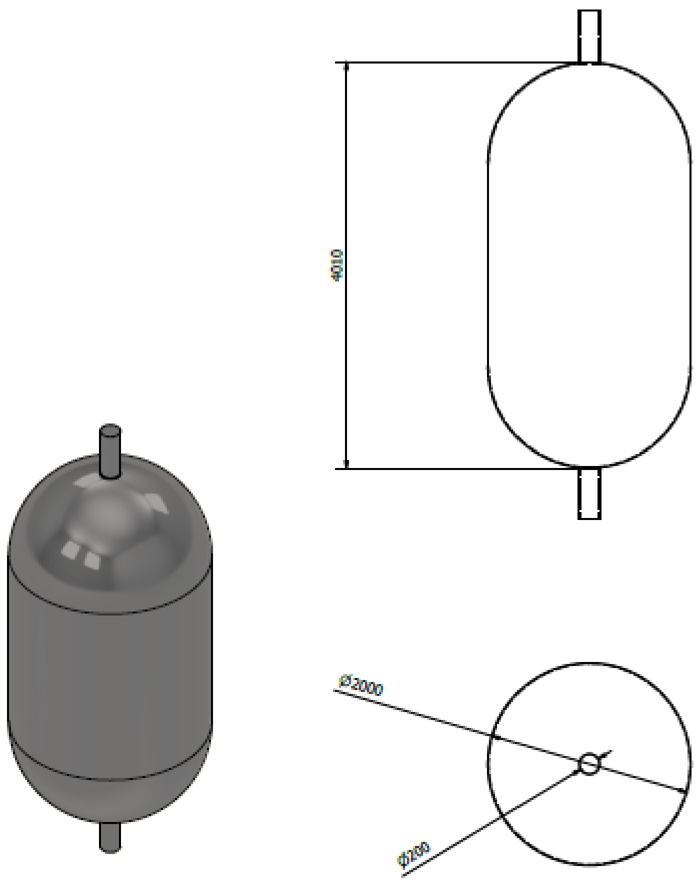

Figure 11. Water Reservoir with high pressurized water

The main pressurized tank is the last component in the process of this MHDPS, which discharges the pressure created by the air-water tank. The water enters the tank at high pressure, which is then directed to the turbine.

2.2.5 Main water reservoir

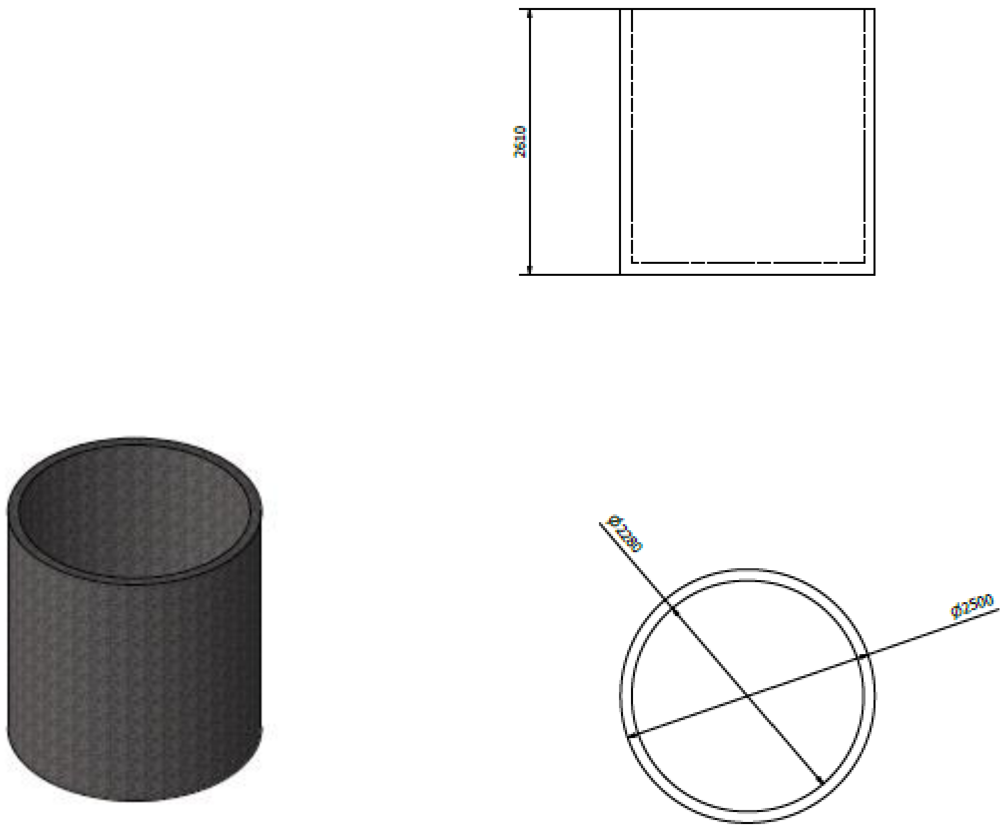

Figure 12. Main Reseivoir

The water reservoir collects water from the river or borehole or any other open-source water supply available at the site of the power generation plant. The turbines also ‘throw’ water into the reservoir and if it not needed, the water from the turbine is flushed back into the river or drain.

2.2.6 Pump

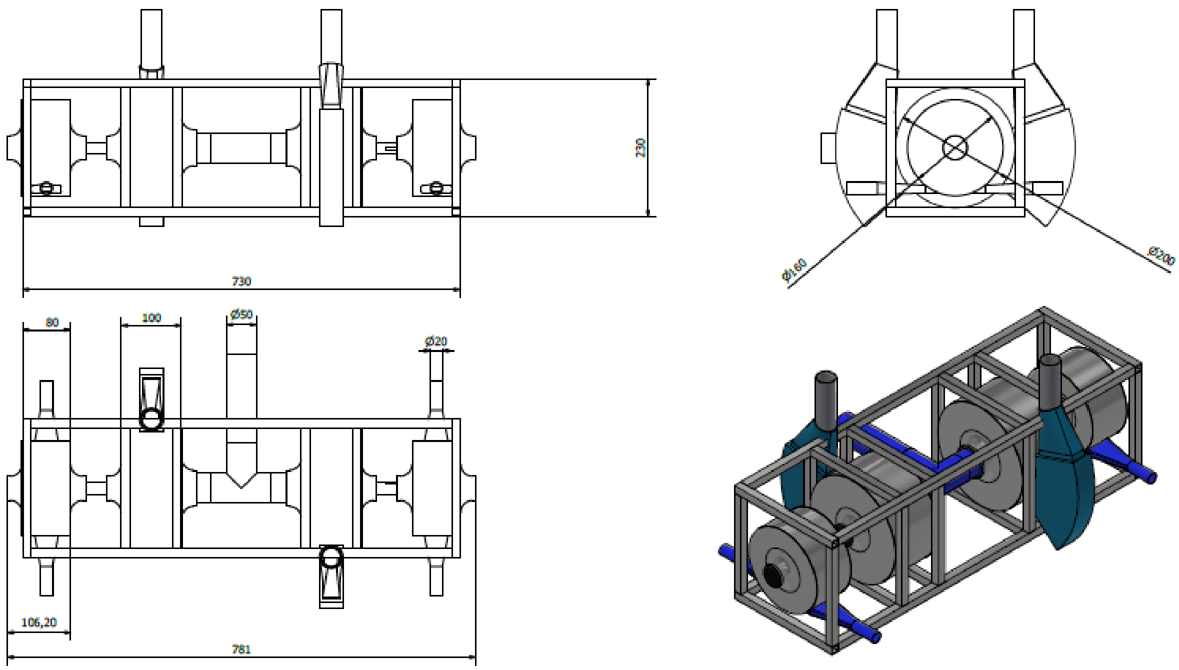

Figure 13. Main Pump View

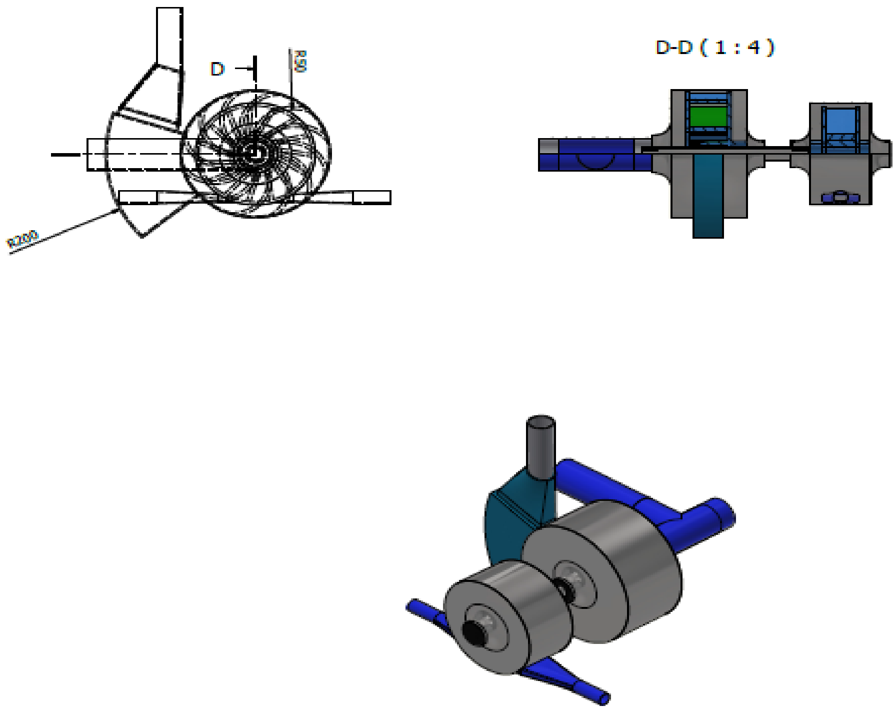

Figure 14. Pump Section, front, side, and isometric view

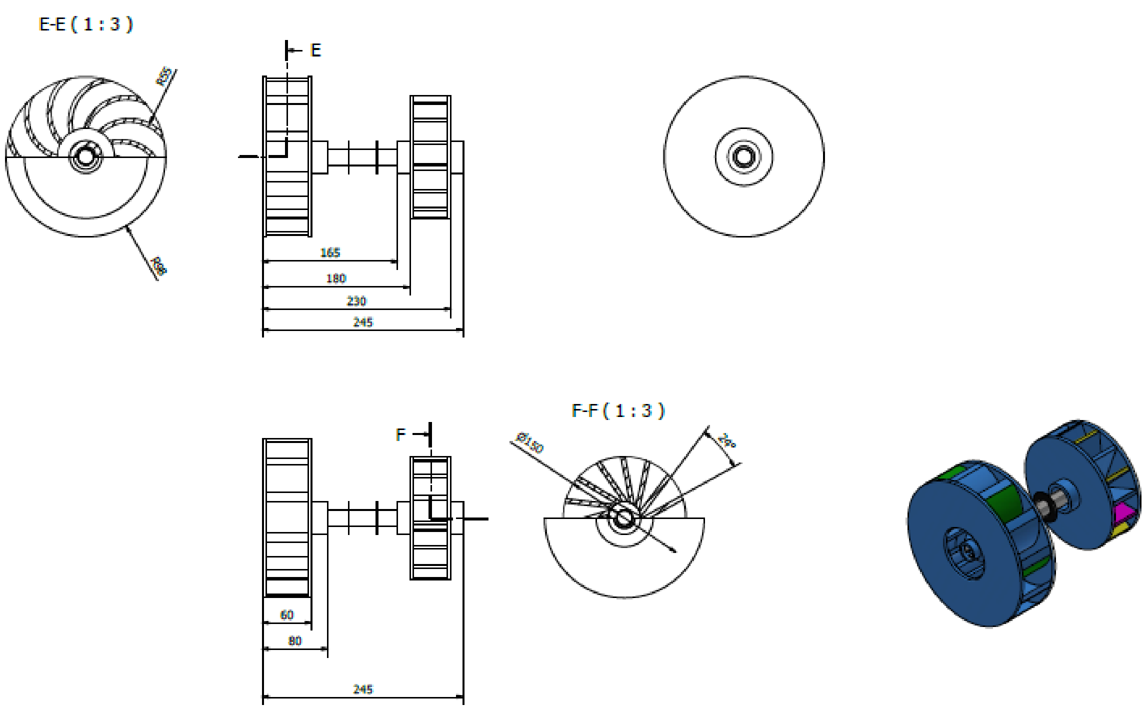

Figure 15. Impellers, front, side, sectioning, and isometric view

This pump is custom made for the MHDPS, it uses air, from the air-water tank mix which has been previously ustilized. The pumps are also responsible for pumping water into the air-water tank. There is also an optional pipeline for use when the pressure from the air-water tank is not meeting the required pressure to pump water into the tanks. This optional pipeline runs from the main compressor tank.
The pump blades are made of hard plastic, and are printed from a 3D printer.

The water pump vanes are centrifugal vanes, and the calculations and angles of the vanes are from centrifugal vanes. They are designed to bend or curve inwards to have a greater output flow rate, the more air that pushes the other side of axial vanes, the more water that is pumped.

2.2.6.1 Water impeller

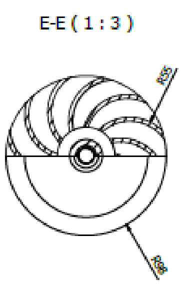

Figure 16. Water impeller, sectioning view

The water impeller is in a circular bend shape, water does not create a vortex while being pumped into the plant.

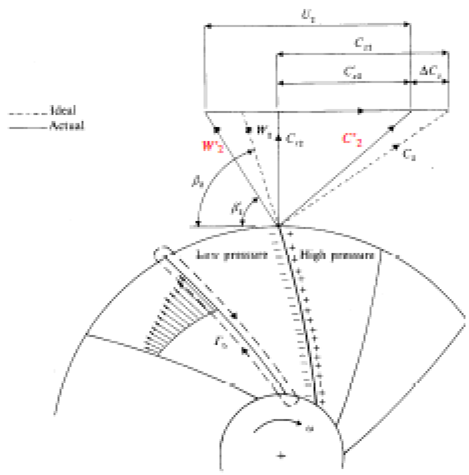

Figure 17. Slip and velocity distribution in centrifugal pump impeller blade (Arsu, 2001).

<u>Slip</u>

Ideally, fluid would leave the impeller at the same angle as the exit angle of the blade. In practice, due to pressure differences across the blades, the exit velocity W_2 is swept backward to W'_2. This reduces C_{x2} to C'_{x2}.

The ratio of C'_{x2}/C_{x2} is called the slip factor σ_s. In radial-bladed impellers where $C_{x2}=U_2$ this simplifies to (Fawkes, 2015):

$\sigma_s = C'_{x2}/U_2$ “ 2

The slip factor applies also to the centrifugal forward-facing vanes. Centrifugal vanes have been in existence since 1851 and, since then, there has been an improvement from the curved vanes to centrifugal vanes that belong to a wide group called Turbo-Machine (Amirfazli, 2009).

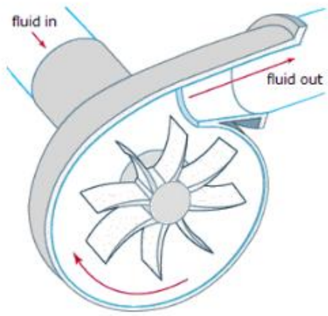

Figure 18. Wermac Schematic centrifugal pump (Werner Sölken, n.d.).

Centrifugal pumps are highly efficienct, require a low power consumption and are proven to have less maintenance cost (Werner Sölken, n.d.).

2.2.6.2 Air vanes

Air vanes are set at an angle, the angle of 24 degrees between them allows air to push directly to each axial vane. They are designed to contract all air coming from the compressor. As the air enters the air vanes chamber, the axial vanes are pushed with a direct positive facing which allows the shaft to rotate at high speed.

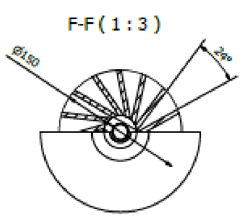

Figure 19. Air vanes

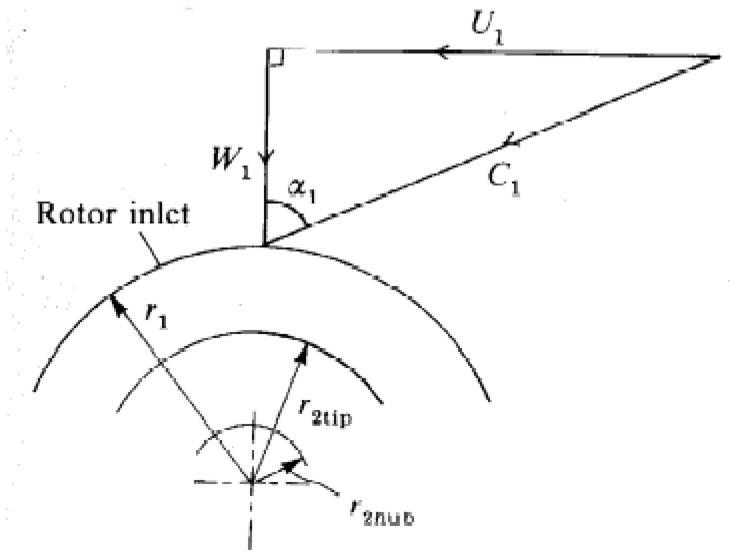

Figure 20. Velocity diagram for axial flow air impeller (90^0 inwards flow radial) (Sayers, 1990).

Reducing the angle of attack on air blades has been proven to be effective because it reduces stall. Since this MHDPS uses water and air, there will be wet air (moisture on-air) which will then make the blade stall. Creating an axial blade reduces stall because the blade also stalls if there is partial blockage or uneven flow in the diffuser. The 90^0 blades will not only reduce stall but will create a space to wash out blockage or uneven flow being created by moisture (Sayers, 1990).

2.3 Working Principle

- **Water to Reservoir Tank (Main water tank)**

Water is drawn from the river or nearby stream/dam to the first tank and, as water is passing through the air vanes, water is drawn by the water vanes to the reservoir tank. The reservoir tank is an open tank, and the pressure on top of the water is atmospheric pressure (101.323KPA).

- **Water to Air-water Tank Mixture**

Water is pumped again to the air-water tank mixture at a lower pressure and when check valve A is open, check valve B is closed, allowing water in at lower pressure. As soon as the water required is in the air-water tank mixture B, the pumps stop working on air-water tank mixture A, and moves to pump water at air-water tank mixture B, pumping water at the same rate and conditions as from air-water tank mixture A. This process is the working principles of the air-water tank mixture A and B.

2.4 Chapter 2 Summary

This chapter provides the design of the Micro-hydro Distributed Power System (MHDPS), from Piping and Instrumentation Diagram (P&ID) as used in table 3, to 3D model, and all components designed to fit within the system, the P&ID and 3D model are fitted with all the components and sources for the entire system. The following components are discussed in this chapter: air tank storage, release valve, water-air tank mix, main pressurized water storage, and main water reservoir to supply the system with water. Details of the related literature reviews have been included in their respective sections of this chapter. The details of three (3) (solar energy, compressor, and turbine) and their study are not included in this chapter but are referred to because the other components which are discussed are referenced to them.

The main purpose of this chapter is to provide information regarding how the MHDPS is designed, from the P&ID to the 3D model, and thus, specifies the general calculations relating to how it works and how much power can be generate from the system. P&ID in this section is the first process that was followed in relation to the design between the structural design(3D model). The maximum power generated from MHDPS 50.7MW, based upon the theoretical calculations.

CHAPTER 3: Off shelve designs for Micro-Hydro Distributed Power Systems

3.1 Introduction

The purpose of this chapter is to provide details of the off-the-shelf equipment, namely the solar energy, compressors, and turbines; As mentioned above, all these components are not modified and, thus, calculations relating to these components were not made. However, their specification from the manufacturer is considered because these have assisted the researcher in determining what components the MHDPS will need and how much solar energy the compressor will need to produce the required air pressure and how much power it will be capable of producing from the supplied pressure.

The selected GA-11 compressor is an oil-injector rotary screw compressor that has an input power of 11KW and has a different maximum working press which ranges from 7.5 Bar to 13 Bar. The main difference between a GA-11 compressor and a reciprocating (piston) compressor is the way the air is compressed. In a screw rotary compressor air is compressed by two helical screws meshing together to compress air, and in a piston air compressor, pistons are driven by a crankshaft to compress air (ChicagoPneumatic, 2021).
The solar energy to run the GA-11 compressor will have a rated power of not less than 11KW but from 12KW to 20KW. Solar panels will be brought in to produce the solar energy necessary to supply the 11KW maximum power needed by the compressor (which is why the proposed system is considered as an off-the-shelf one). From the Homer software it was simulated that a load requires 11KW, the results seem to be compatible with the battery storage and 20KW rated power solar panels. A Kaplan turbine is being used in the MHDPS and the main reason for selecting a Kaplan turbine is that it is a reaction turbine, which allows water to flow both in and out in the axial flow. What makes the Kaplan turbine effective during the demand for pressure is that the angle of the blades can be changed for different flow rates of water, thus, assuring maximum efficiency

(Jordan et al., 2020). In addition it has a proven 50.7MW of power, thus, making the Kaplan turbine the best choice for use within the proposed MHDPS.

3.1.1 Compressor

A compressor is an important conversion energy device and its efficiency directly affects the system's economy and efficiency (Guo et al., 2021). The most common types of compressors include (Guo et al., 2021):

- The displacement type in which there is a piston compressor.
- The dynamic type in which there are axial and centrifugal compressors.

Among various compressors, the multistage geared compressors are highly efficiency (Guo et al., 2021). Compressors were mainly found in industries that formerly used an electric motor to drive its mechanisms, i.e., grinding machines and other rotating objects, Currently, many machines drive their mechanisms with air pressure, such as the air grinding machine, which is being used in industries with the same degree of power and efficiency as the electric grinding machines.

Figure 21. GA-11 compressor courtesy of Atlas Corp. (AtlasCopco, 2018a).

Figure 22. GA-11 inside front and back compressor, courtesy of Atlas Corp. (AtlasCopco, 2018a).

The GA-11 compressor, as stated above, is an oil-injector rotary screw air compressor. Unlike the piston air compressor that has many moving parts, the rotary screw compressor only has two moving parts and operates at fairly low temperatures and has a good cooling integrated system (ChicagoPneumatic, 2021).

3.1.1.1 Features and benefits of GA-11 model oil injector screw rotary compressor (AtlasCopco, 2018a)

Superior performance

- State-of-the-art compression elements coupled with a maintenance-free gearbox,
- 100% continuous duty cycle,
- Motor and drive trains are greased for life to avoid improper re-greasing,
- Reduced electrical cubicle temperature doubles electrical component lifetime,
- Integrated dryer with heat exchanger,

- Integrated water separator for dry, quality air, and
- Best-in-class low noise levels.

Supreme energy efficiency

- IE4 efficiency rated motor,
- Free Air Delivery increased by 6-10%, and
- Power consumption reduced by 3-8%,

Quick installation & maintenance

- Delivered plug and play,
- Easy transportation, and
- The main components are easily accessible.

Compressor technical specification data.

Table 6. Technical Specification (AtlasCopco, 2018b).

Compressor Type GA 11	Max. Working Pressure				Capacity FAD			Installed motor power		Noise level	Weight	
	Workplace		WorkPlace Full feature								Workplace	WorkPlace Full feature
	bar	KPA	bar	KPA	l/s	m^3/h	cfm	KW	hp	dB(A)	kg	kg
	7.5	751.5	7.3	724	35.8	128.9	75.9	11	15	63	410	455

	8.5	800	8.3	827.4	33.8	121.7	71.7	11	15	63	410	455
	10	999.7	9.8	972.2	30.3	109.1	64.2	11	15	63	410	455
	13	1303.1	12.8	1275.5	25.2	907	53.4	11	15	63	410	455

Options

- Integrated filter,
- Dryer bypass,
- Motor thermistors,
- Anti-condensation heaters,
- Tropical thermostat,
- Freeze protection,
- Heavy-duty air inlet filter,
- Fan saver cycle,
- Compressor inlet pre-filter,
- Rain protection,
- Lifting device,
- NEMA 4 and NEMA 4X cubicle (NEMA enclosures are primarily intended for outdoor use and offer a superior level of protection from corrosion and extreme environments (NEMA-Enclosures, 2020)),
- EQi central control license for 4 or 6 machines (available on Elektronikon® Touch only),
- Food-grade oil,
- Roto-Xtend duty oil,
- Energy recovery,
- Modulating control,
- High ambient temperature versions (55°C for a pack, 50°C for FF), and
- Dryer save cycle

Reference Conditions

- Absolute inlet pressure 101.323kpa,
- Intake air temperature 20°C.

3.1.2 Solar Energy

The solar energy in the MHDPS is only used to power compressor; however, it is the “brain” of this particular plant. Without solar energy, the plant will not run because the compressor, its release valves and pumps are dependent upon solar energy.

Without solar energy, there will not be any air – this air is responsible for moving most of the MHDPS components. For instance, water needs to be pumped by air, and the valves need to be released and share pressure to mix the air tank. Solar energy is also the main component that makes the MHDPS work. If this system was to use electric pumps instead of air pumps, the high level of plant energy, which is the main objective of this research project, will be less than that produced with the use of solar energy. To obtain more energy from the proposed MHDPS, the air pumps, whose energy source is not electricity but air from compressors, will help to achieve the desired results.

3.1.2.1 Design solar energy

The solar energy used within the MHDPS must be able to provide 11KW to 25KW for the effective production of the desired air pressure at all times, for both air tanks and pumps. The air will be recycled during times when the system needs to be strained and the solar energy must meet the demand. The selected compressor needs a minimum of 11KW to produce 7 bars to 13 bars, solar energy between 11kw to 25kw will allow the power system to have excess energy which will also be used as a back-up to the system and for other electrical components the power system requires.

The Homer software program is the most popular tool for sub-national level planning energy distribution. This software has been extensively used in many studies to provide for a cost comparison of investment decisions (Abid et al., 2021). Homer reduces the complexity by producing the worldwide databases for solar PV radiation and the ability to design and choose industrially available components, and the option to model PHS as a storage type, together with other technologies (Yimen et al., 2018). The use of Homer software to simulate how much power can be extracted from the all-season climate was use to guage how much solar PV and storage was needed in the proposed MHDPS.

3.1.2.2 Solar energy simulation for micro-hydro distributed power system

Homer solar energy supply for the compressor:

Figure 23: Homer connection of solar for compressor only.

The aim of running the Homer test only for the solar compressor is because the solar power needed to operate the compressor is rated at 11kw. It, therefore, was best to run the Homer software programe to indicate how much power can be provided to the solar panels through sunlight to operate the compressor.

3.1.3 Turbine

The proposed MHDPS, as mentioned above, will install an COTS turbine. There are mainly two types of turbines namely (US Department of Energy, 2020):

- Impulse turbines
    - Pelton turbines
    - Crossflow turbines
- Reaction turbines
    - Propeller Turbine
        - Bulb Turbine
        - Straflo Turbine
        - Tube Turbine
        - Kaplan
    - Francis
    - Kinetic

The proposed MHDPS, as mentioned before, will run with a Kaplan turbine. As previously explained, the Kaplan turbine is a reaction turbine type that allows water to flow both in and out in the axial flow. Its major benefit is that during the demand for air pressure, the angle of the blades can be changed for maximum efficiency for different flow rates of water (Jordan et al., 2020).

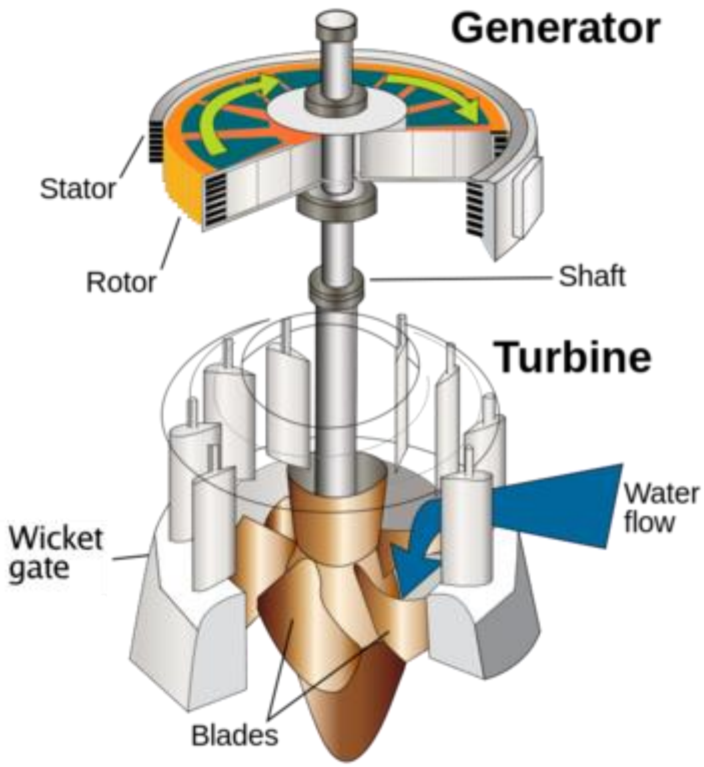

Figure 24. Kaplan turbine (Jordan et al., 2020).

Since the water in the MHDPS has to be in axial flow, the water will enter the turbine in radial flow. Kaplan's design is different to that of other turbines in that it allows water to first enter through radial then exit axial (Bright Hub Engineering, 2021). This process will not make the water turning the turbine lose pressure because the water in the line to the turbine is already pressure raised from the water-air tank mixture.

3.2 Discussion

Selecting an off-the-shelf GA-11 compressor which is an oil-injector rotary screw compressor will help produce sufficient air whenever the MHDPS requires it. As mentioned previously, oil-injector rotary screw compressors are fairly new inventions and use less electricity compared to older versions such as reciprocating compressors. Air needed for the system is only stored in the water-air mix tank and goes to the pump and back to the dryer to remix with new air for repeating the circle. The GA-11 compressor does not run throughout the entire production of electricity since the air is recycled.

The capacity of the selected energy is only sufficient to supply the compressor (see *Figure 23. Homer connection of solar for compressor only)* and is an example of how the load could be arranged to match the chosen solar power system. The load displayed in Figure 23 represents the consumption of 11kw of power that will be demanded when the compressor is running.

The turbine suggested for the proposed MHDPS is the Kaplan reaction turbine and was selected based on its characteristics compared to other turbines, and in particular, the fact that the angle of its blades can be adjusted to meet demands of this system. No calculations were made in relation to the Kaplan turbine because it is as an off-the-shelf component of the proposed MHDPS.

3.3 Chapter 3 summary

This chapter provides the general use of off-the-shelf sources and equipment (COTS) to be used on the MHDPS. The sources and equipment are solar energy, compressor and turbine; all these three sources/equipment are not designed or modified but will come as complete units and will be selected based on the desired capacity of the designed components described in Chapter 2 of this dissertation, for instance the air tank storage unit. This Chapter further details all the characteristics of the selected compressor GA-11, solar system on Homer with the assumed load to be 11.27KW from the 20 KW rated solar panels with battery storage and inventor, and the load on homer is taken as the compressor operating power of 11KW.

The use of various off-the-shelf equipment (solar energy panels, compressor and turbine) will help yield the best results at the lowest cost since all this equipment will be installed ready to be used. There will not be any buildings required to fit the design because the proposed MHDPS is devised to fit these three off-the-shelf components, thus, the cost of re-designing and re-fitting the standard micro-hydro power plant will be minimal.

CHAPTER 4: Results

4. Introduction

Maximum hydropower output depends entirely on how much flow and the head that are available at the power plant's site (Renewables First, 2015b). The proposed MHDPS depends entirely upon air pressure and this pressure determines the extent of the flow. The more pressure the air creates the stronger the flow and the greater the output power generated.

Pressure is converted to height since the proposed MHDPS uses pipes to transport water and air pressure, the pressure in this plant is taken to be the same as the normal height in the the standard hydropower plant. The reasons for this assumption is because, unlike the existing hydropower plant, the proposed MHDPS has only be designed theoretically and the hypothesis that air pressure can be created to a sufficient height to generate electricity is based upon the following calculations (Renewables First, 2015b):

P – Pressure

ρ – Density

g – Gravity

$$P = \rho g H \qquad (3)$$

4.1 Height

H_{net} is the gross head and head losses can be assumed to be 10% (Renewables First, 2015a). In the design for the proposed MHDPS, the height from the mix release tank 1 is included, however, not from both of the tanks, because they work alternatively but not simultaneously, (because when water-air mix tank 1 is at work, the other tank is filling the main reservoir tank with high pressured water (Renewables First, 2015a).

$$H_{net} = H_{gross} X0.9 \qquad (4)$$

Or

$$H = \frac{p}{\rho g} \quad 5$$

4.2 Efficiency

For a typical small hydropower system, the drive efficiency would be 95%, generator efficiency 93%, and turbine efficiency 85%. Therefore the overall system efficiency will be (Renewables First, 2015a):

$\eta_{\text{overall eff}} = \eta_{\text{Drive eff}} X\ \eta_{\text{Generator eff}} X\ \eta_{\text{Turbinel eff}}$ 6

=0.95X0.93X085

=0.75 or 75%

4.3 Flow rate

Assuming flow rate in the pipe is lamina flow, I have use the Poiseuille Equation to calculate the flow rate (stackexchange inc, 1993):

$$Q = \frac{\pi X D^4 \Delta P}{128 \mu \Delta X} \quad 7$$

Where

Q – Flow Rate

D – the pipe diameter

μ – is dynamic viscosity water under room temperature 8.9×10^{-4} Pa·s

ΔP – is the pressure difference between the two ends of the pipe

ΔX – the length of the pipe

Mass flow rate (ṁ) = l^{-1} or kg^{-1}

Therefore, the power output base on different heights will use the following formula:

$$P_{power} = \dot{m} X\ H_{net}\ X g\ X\ \eta_{overall\ eff} \quad 8$$

4.4 Velocity

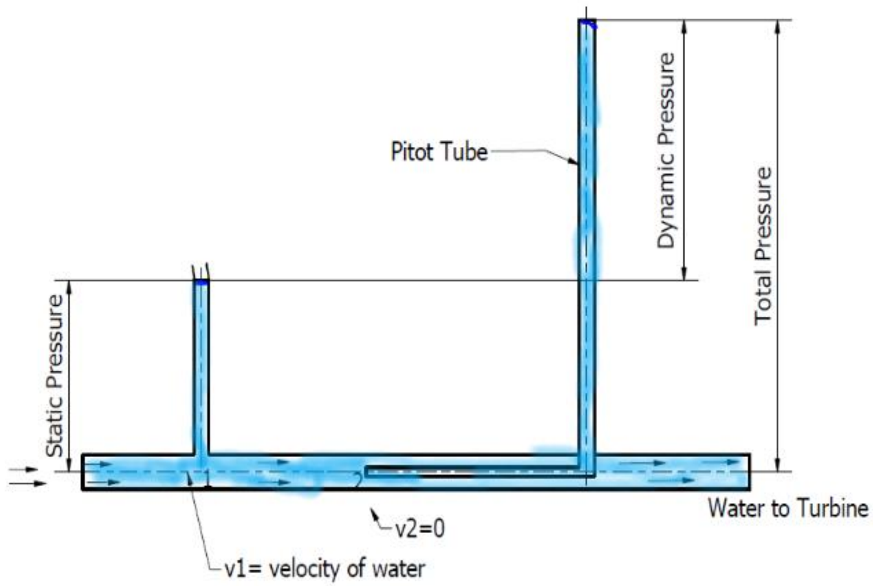

Figure 25. Velocity in the pipeline

Bernoulli's Equation

static pressure + dynamic pressure = total pressure

$$\frac{P1}{pg} + \frac{V1^2}{2g} + Z1 = \frac{P2}{pg} + \frac{V2^2}{2g} + Z2 \qquad 9$$

Z_1 and Z_2= 0

P1 =(Ps) (static pressure)

P2=(Pt) (total pressure)

$$\frac{P1}{pg} + \frac{V1^2}{2g} = \frac{P2}{pg} \quad 10$$

$$P1 + \rho\frac{V1^2}{2g} = P2 \quad 11$$

$$V1^2 = \frac{2(\mathrm{pt} - \mathrm{ps})}{\rho} \quad 12$$

4.5 Calculation summary

Static pressure

$$P_S = \frac{\rho x g x H}{1000} \quad 13$$

$$= \frac{1000x9.81x5.61}{1000}$$

= 55.0341 KPA

Total pressure

With pressure from compressor pushing down water

$P_T = Pcompressor + P_S$

$= 100+55.0341$

$= 155.0341$ KPA

Pressure in Height

$$H_{pressure} = \frac{P(compressor\ pressure)}{\rho x g}$$

$$= \frac{100}{1000x9.81}$$

$= 10.19368$m

Net pressure in height

$H_{net} = H_{pressure} + Hinitial$

$= 10.193+5.61$

$= 15.804$m

Pressure in a pipe line to turbine (P_{pipe})

$P_{pipe} = P_T - P_S$

$= 100 - 55.0341$

$= 44.9659$ KPA

Velocity in a Pipe line to turbine

$V1^2 = \frac{2(\text{pt}-\text{ps})}{\rho}$ 11

$= \sqrt{\frac{2(44.9659)}{1000}}$

= 9.48323 m/s

Assuming that the flow is laminar

$Q = \frac{\pi X D^4 \Delta P}{128 \mu \Delta X}$ 7

$= \frac{\pi X 0.1^4 44.9659\text{x}1000}{128x8.9\times10^{-4}\text{x } 5}$

= 0.0004911m^3/s = 0.4911L/s

Area of a Pipe

$A = \pi r^2$

$= \pi 0.05^2$

= 0.007854m^2

Volume flow rate.

Q = Area X V1

= 0.007854X9.48323X1000

= 74.48118 m^3/s

Power

$P_{power} = \dot{m} X\ H_{net}\ X g\ X\ \eta_{overall\ eff}$ 8

= 74.48118X9.81X15.8036X075

= 86603.341 W

4.6 Theoretically calculated data

Table 7. Theoretical calculation

P(kpa)	Ps	Ptotal (kpa)	g	P density	H pressure	H	Hnet	overal effec	q=pt-ps	velocity	volume flow(l/s)	power(W)	Power (MW)
0	55.0341	55.0341	9.81	1000	0	5.61	5.61	0.75	0	0	0	0	0
50	55.0341	105.0341	9.81	1000	5.09684	5.61	10.70684	0.75	0	0	0	0	0
100	55.0341	155.0341	9.81	1000	10.19368	5.61	15.80368	0.75	44.9659	9.483238	74.48118	8660.34155	0.00866
150	55.0341	205.0341	9.81	1000	15.29052	5.61	20.90052	0.75	94.9659	13.78157	108.2402	16644704.3	16.6447
200	55.0341	255.0341	9.81	1000	20.38736	5.61	25.99736	0.75	144.9659	17.02738	133.7328	25579810.5	25.57981
250	55.0341	305.0341	9.81	1000	25.4842	5.61	31.0942	0.75	194.9659	19.74669	155.0901	35480837.6	35.48084
300	55.0341	355.0341	9.81	1000	30.58104	5.61	36.19104	0.75	244.9659	22.1344	173.8432	46290196.8	46.2902
350	55.0341	405.0341	9.81	1000	35.67788	5.61	41.28788	0.75	294.9659	24.28851	190.7615	57948691.9	57.94869
400	55.0341	455.0341	9.81	1000	40.77472	5.61	46.38472	0.75	344.9659	26.26655	206.297	70404135.4	70.40414
450	55.0341	505.0341	9.81	1000	45.87156	5.61	51.48156	0.75	394.9659	28.10573	220.7419	83611621.6	83.61162
500	55.0341	555.0341	9.81	1000	50.9684	5.61	56.5784	0.75	444.9659	29.83172	234.2978	97532458.9	97.53246
550	55.0341	605.0341	9.81	1000	56.06524	5.61	61.67524	0.75	494.9659	31.46318	247.1113	112133050	112.133
600	55.0341	655.0341	9.81	1000	61.16208	5.61	66.77208	0.75	544.9659	33.01412	259.2923	127383951	127.384
650	55.0341	705.0341	9.81	1000	66.25892	5.61	71.86892	0.75	594.9659	34.49539	270.9261	143259128	143.2591
700	55.0341	755.0341	9.81	1000	71.35576	5.61	76.96576	0.75	644.9659	35.91562	282.0806	159735368	159.7354

750	55.0341	805.0341	9.81	1000	76.4526	5.61	82.0626	0.75	694.9659	37.28179	292.8105	176791820	176.7918
800	55.0341	855.0341	9.81	1000	81.54944	5.61	87.15944	0.75	744.9659	38.59963	303.1608	194409631	194.4096
850	55.0341	905.0341	9.81	1000	86.64628	5.61	92.25628	0.75	794.9659	39.87395	313.1693	212571646	212.5716
900	55.0341	955.0341	9.81	1000	91.74312	5.61	97.35312	0.75	844.9659	41.10878	322.8676	231262179	231.2622
950	55.0341	1005.034	9.81	1000	96.83996	5.61	102.45	0.75	894.9659	42.30759	332.283	250466810	250.4668
1000	55.0341	1055.034	9.81	1000	101.9368	5.61	107.5468	0.75	944.9659	43.47335	341.4389	270172230	270.1722
1050	55.0341	1105.034	9.81	1000	107.0336	5.61	112.6436	0.75	994.9659	44.60865	350.3555	290366106	290.3661
1100	55.0341	1155.034	9.81	1000	112.1305	5.61	117.7405	0.75	1044.966	45.71577	359.0508	311036967	311.037
1150	55.0341	1205.034	9.81	1000	117.2273	5.61	122.8373	0.75	1094.966	46.79671	367.5405	332174107	332.1741
1200	55.0341	1255.034	9.81	1000	122.3242	5.61	127.9342	0.75	1144.966	47.85323	375.8384	353767510	353.7675
1250	55.0341	1305.034	9.81	1000	127.421	5.61	133.031	0.75	1194.966	48.88693	383.957	375807773	375.8078
1300	55.0341	1355.034	9.81	1000	132.5178	5.61	138.1278	0.75	1244.966	49.89922	391.9075	398286050	398.286

4.7 Considering laminar flow in pipe line.

length of pipe	Q-flow rate	V-velocity	Power(W)	Power(MW)
5	0	0	0	0
5	0	0	0	0
5	4,9112E-07	6,25E-05	9,694392	0,074116
5	1,0372E-06	0,000132	27,0772	0,310518
5	1,5833E-06	0,000202	51,41314	0,786134
5	2,1294E-06	0,000271	82,7022	1,5807
5	2,6755E-06	0,000341	120,9444	2,773954
5	3,2216E-06	0,00041	166,1397	4,445634
5	3,7677E-06	0,00048	218,2881	6,675478
5	4,3138E-06	0,000549	277,3897	9,543224
5	4,8599E-06	0,000619	343,4444	13,12861
5	5,406E-06	0,000688	416,4522	17,51137
5	5,9521E-06	0,000758	496,4131	22,77125
5	6,4982E-06	0,000827	583,3272	28,98797
5	7,0443E-06	0,000897	677,1944	36,24129
5	7,5904E-06	0,000966	778,0147	44,61093
5	8,1365E-06	0,001036	885,7881	54,17664
5	8,6826E-06	0,001105	1000,515	65,01816
5	9,2287E-06	0,001175	1122,194	77,21521
5	9,7748E-06	0,001245	1250,827	90,84754
5	1,0321E-05	0,001314	1386,413	105,9949
5	1,0867E-05	0,001384	1528,952	122,737
5	1,1413E-05	0,001453	1678,444	141,1536
5	1,1959E-05	0,001523	1834,89	161,3244
5	1,2505E-05	0,001592	1998,288	183,3292
5	1,3051E-05	0,001662	2168,64	207,2477
5	1,3597E-05	0,001731	2345,944	233,1596

Finding power using Laminar flow vs using Benolli equations

Power (MW)	Power(MW)
398.286	233,1596

4.8 Graphs

The graphs are generated as per the data produced by calculations.

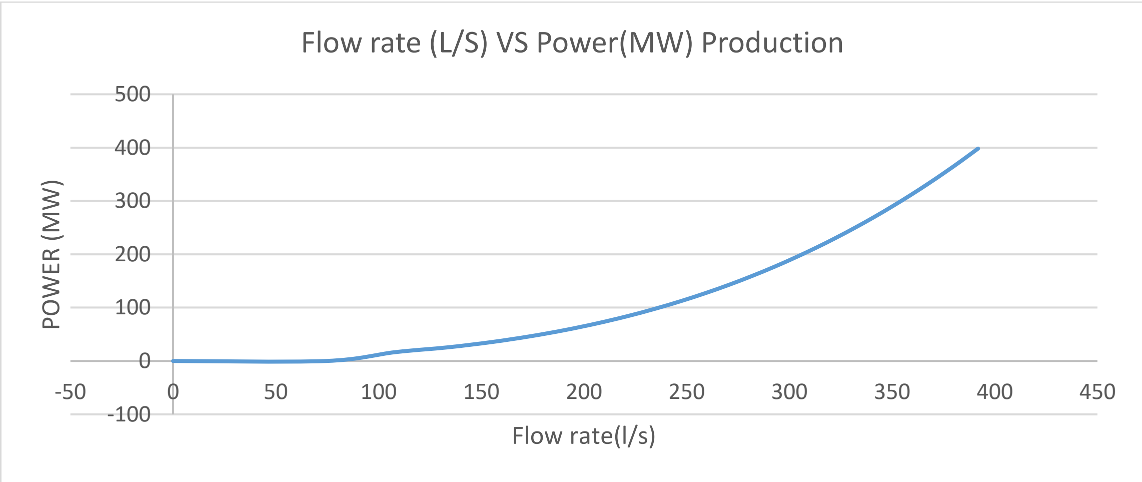

Figure 26. Flow rate vs power production

According to the calculation and graph presented, the greater the power output, the more water is needed in the system as the pressure increases in the air-water tank (air compressor filling the release valve). From 0L/s to 75L/s, as indicated in the graph, theoretically there is no power being generated due to Pressure P from Table 1 of the theoretical calculation being pressure from the compressor, Ps is static pressure and Pt is the total pressure inside the water-air mix tank, Table 9's theoretical calculation from the main table, the zeros(0) from dynamic pressure to Power.

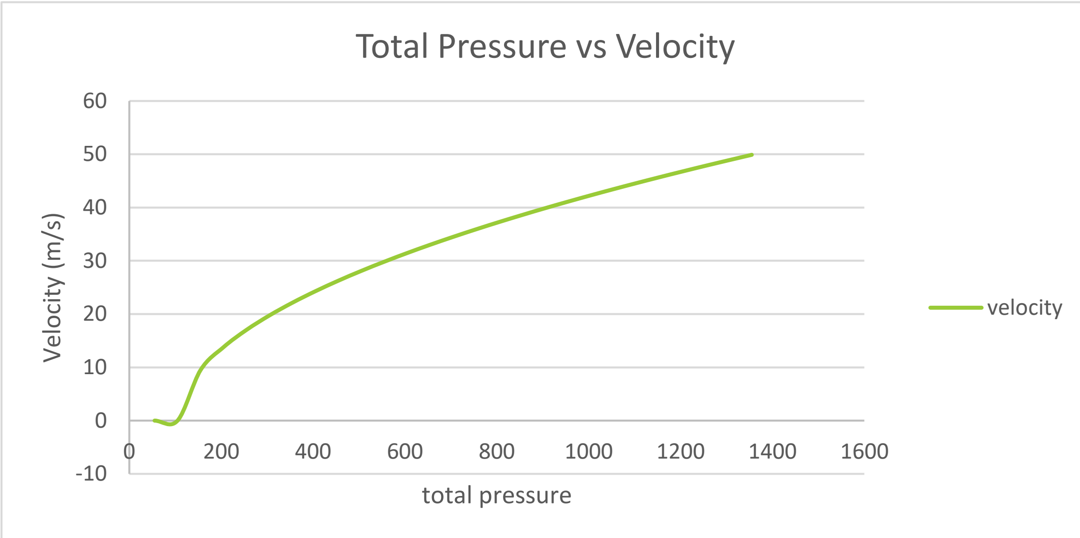

Figure 27. Total Pressure vs Velocity

The pressure created in the main pressurized water storage exits the tank at high speed to the turbine, and as the pressure increases the velocity of water increases, and more pressure is added the greater the flow rate.

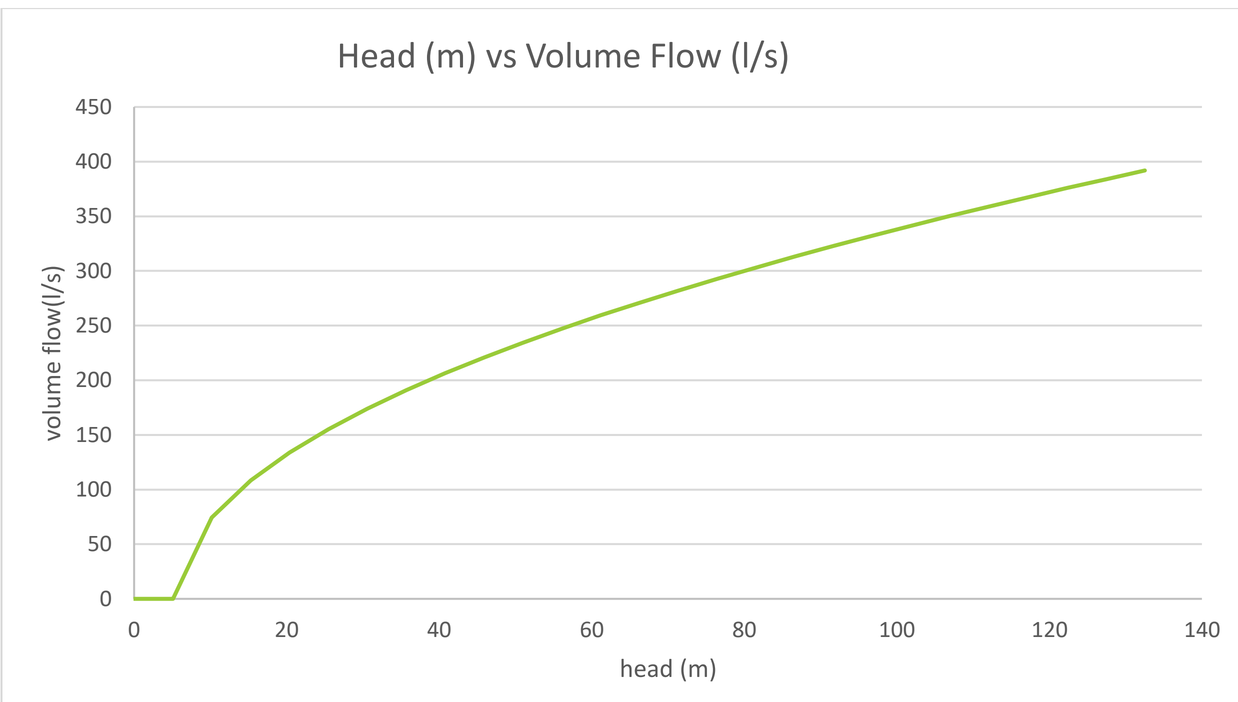

Figure 28. Head(m) vs volume flow (L/s)

This graph shows a pressure converted to a pressure head (m) from a hydro pressure ($P=\rho gH$) used to calculate the height. For instance, if 555.0341 KPA for this pressure the head is 50.9684m, the more head increases the more this power system uses or discharges water to the turbine.

4.9 Discussions of results.

The design for the proposed MHDPS is first constructed from P&ID, to determine the flow processes of water and air, which are the main variables for the working of the plant. All components to be used in the actual prototype are from the P&ID.

Calculations in ***Table 8*** have proven that the MHDPS will effectively produce power based on the amount of pressure being supplied.

Table 8 Pressure supplied by the compressor

P(kpa)	volume flow	power(W)	Power(MW)
0	0	0	0
50	0	0	0
100	74.48118	8660.34155	0.00866
150	108.2402	16644704.3	16.6447
200	133.7328	25579810.5	25.57981
250	155.0901	35480837.6	35.48084
300	173.8432	46290196.8	46.2902
350	190.7615	57948691.9	57.94869
400	206.297	70404135.4	70.40414
450	220.7419	83611621.6	83.61162
500	234.2978	97532458.9	97.53246

When looking at Table 9 below, the compressor running at 0-500kpa can have a much greater effect on the MHDPS, thus, approximately 98MW of power can be produced by compressing 13 bars of pressure in the air-water tank mixture.

The results based on the theoretical calculations prove that the MHFPS will produce more power than was original anticipate from the proposed research. Based upon the results findings, the more air (pressure) is available the greater the amount of electricity genderated. A 13 Bar compressor running from solar energy at 11KW, a MHDPS can produce 50MW (50.7MW). Although such theoretical calculations were produced without considering other pipe losses, the MHDPS will still yield good results as expected. This result is concluded from the 11KW power which the 13 Bar compressor will be consuming if not connected to the solar system for the production of 50MW power.

Table 9 Theoretical calculation from the main table

q=pt-ps	Velocity	mass flow	Power (W)	Power (MW)
0	0	0	0	0
0	0	0	0	0

Pressure P from Table 1's theoretical calculation is pressure from the compressor, Ps is static pressure and Pt is the total pressure inside the water-air mix tank. In Table 9's theoretical calculation from the main table, the zeros(0) from dynamic pressure to power, the reason being it is yielding negative value from when the compressor is at zero till 50kpa. It is assumed, that due to the negative velocity from 0 to 50kpa, there is no power being generated.

At 13 bars of the maximum working pressure of the compressor (1300Kpa), the MHDPS is producing about 398MW, this value is worked out without considering pipe loses and other friction losses, only generator, drive and turbine efficiency are considered for the calculations. The reason for not considering the pipe loses is due to the different pipes which can be used for this MHDPS, and the fact that other loses are expected to happen, which could occur due to the high pressure which might result in the blasting of pipes, leakage from pipes or defective valve. The general losses of pressure from pipes will not have very much effect on the output of the MHDPS.

4.10 Conclusions

An examination of the P&ID to the 3D model clearly shows how air is being manipulated into mixing with water vessels. All vessels are modified and, according to their calculations and working principles, they show strength. An observation of *Table 5. Theoretical calculations* (above), indicates that the more pressure is added to the water-air mix tank the more power is generated. Theoretically, as water is added to the MHDPS there is an increase in the generation of power, while the graphs in Figure 18. Water consumption vs power production (see above) likewise shows that the adding of water also increases the generation of energy. Although the MHDPS requires high pressure for the best results, the pressure from the compressor is not being created continuously while the generation of energy is taking place. By maintaining a standard pressure in the air receiver tank, the plant will generate the desired results needed at that time of generating energy, provided that the water is kept circulating, unlike the air pressure that requires being moved continually from one water-air mix tank to another (see *Table 4. Release work process,* above).

CHAPTER 5: Conclusion, and Recommendations

5.1 Conclusion

The design and analysis of the MHDPS was first designed from P&ID layout in which all the necessary valves are included to make the system run. Other P&ID components, such as the release valve. are concluded to be indicated by mini tanks and, then later on the 3D model, are designed and detailed according to where they will function. The symbols of the computerized valves are different from the manually operated valve, for instance, the check valve has no sticky pins and a head on top of it which, from the P&ID layout, is also an indication that is manually operated.

The MHDPS represents theoretical research undertaken with a design to support the theoretical results. It was proposed originally as falling under the category of the small hydropower plant, but due to the results obtained, it can be categorized as a large power plant. The only problem with the MHDPS is the amount of water it consumes while producing electricity, bearing in mind that the more the flow rate the greater the electricity generated. To solve the water crisis associated with the MHDPS, the design is designed to recycle water by using air pumps to drive the water back into the system. At 13 Bar pressure from an 11KW rated solar compressor, 398MW of electricity theoretically can be produced from the proposed MHDPS.

As stated and shown above 398MW is a theoretical calculation, and the efficiency of the generating stage is not calculated for the said MHDPS due to the research not being implemented practically. The overall efficiency used for this system is of a small hydropower plant that was used based upon the initially proposed idea that this system will be categorized as a small hydropower plant, based on the nature of the design and capacity of the source (solar energy for compressor, size of compressor and the amount of water needed to operate the envisaged MHDPS).

5.2 Recommendations

Based on my research I recommend that the use of compressor should be properly installed to minimize any losses that may occur, which will then affect the desired results when building the actual model. The highest possible level of accuracy was followed during both the calculation and designing of the P&ID to 3D model.

The use of pipes that ensure maximum flow and can hold as much pressure as is possible will minimize losses.

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