DEVELOPMENT OF MICRO-HYDROELECTRIC GENERATION SYSTEM FROM WATER PIPELINE

By

VIRGÍLIO LEITÃO MUANDO

FINAL PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfilment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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Dr. Taib B. Ibrahim
Project Supervisor

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May 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Virgílio Leitão Muando

ABSTRACT

Utility water is normally stored in enormous tanks placed at certain height from the ground for distribution. This water, when exiting the tank, develops an increasing kinetic energy as it goes through the pipeline to its end usage. The kinetic energy that builds up is not being completely used. The research presented in this report focuses on harvesting energy from water in main pipelines (1), developing a micro-hydroelectric generation system from main pipeline (2) and conducting dynamic tests for the system (3). Numerous cost-effective and practical ideas are discussed with the aim of meeting different reliable power system dynamic characteristics such as frequency and voltage stability. A pumped-storage pico hydro generation scheme using a permanent magnet synchronous generator (PMSG) is assembled as a platform for conducting dynamic tests of the system. Issues regarding grid-connected and off-grid generation as well as reliability of the sustainable generation are addressed according to the results summarized from experiments and tests.

ACKNOWLEDGEMENTS

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Lastly I would like to thank my family, for always being there for me and inspiring motivation in me. To all those who direct or indirectly played a role in the success of my studies, including friends, MyMoz members, lecturers, and technicians, thank you!

"I know I can do it, but I don't have to. However, if I choose to do it then I will do it in the best way it could ever be done." – **Virgílio Leitão Muando**

"Explain it to me in a way that my non-technical wife would understand!" – **Martinus Beumer**

(Sasol Technology – Sastech Senior Electrical Engineer, Internship Supervisor)

In

Loving Memory of My

Late Father

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LIST OF ABBREVIATIONS

AC – Alternating Current

DC – Direct Current

DG – Distributed Generation

FYP – Final Year Project

kW – Kilowatts

MW – Megawatts

PM – Permanent Magnet

PMHG – Permanent Magnet Hydro Generator

PMSG – Permanent Magnet Synchronous Generator

PV – Photovoltaic

PVC – Polyvinyl Chloride

PWM – Pulse-width Modulation

RCBO – Residual Current Circuit Breaker with Overload Protection

RCD – Residual Current Devices

SLI – Starting, Lighting and ignition

TNB – Tenaga Nasional Berhad

CHAPTER 1
INTRODUCTION

1.1 Project Background

Hydro power generation is a clean, environmentally benign and renewable source of energy. Turbines convert water stored potential energy into mechanical rotary energy, which in turn is converted to electrical energy by generators coupled with turbines. Hydro power stations have distinct classification according to their generated electrical power. Large scale hydropower stations generate more than 100MW, medium scale generate stations generate between 15 and 100MW and small scale stations range from 1 to 15MW of electricity production to feed electrical grids. Other than those three, there are also mini-hydro stations (100kW – 1MW), micro stations (5kW-100kW) and pico-scaled hydro generations (less than 5kW) that serve different purposes. A study shown by Paish [1], reveals that although hydro potential was first implemented in the 19 century, up to today, less than one fourth of this potential is used worldwide. However, as electricity demands increase, there is an increase in electricity generation. A common practice nowadays is the Distributed Generation. There are many reasons in favor of this practice. Generating electricity in small scales to either individual purposes or to feed a utility grid is encouraged by utility companies as it compensates for long distance transmission losses, thus avoiding system overload. Small, micro hydro power plants are commonly designed to operate in parallel with the grid in order to obtain the economic benefit and enhancing the power capacity as to maintain the uninterruptible supply mode that could possibly be affected by the demand of electricity [2]. Other reasons as for why generating hydro power in micro scale include the facts that they are ecological friendly and they are within an acceptable generating costs without producing greenhouse gases and harmful pollution [3].

Hydroelectricity is a field that has been explored for more than a century. It has existed for a long enough time to be considered as a reliable source of electricity generation. 16% of the world's electricity production is hydroelectricity; that accounts for about 92% of the world's total renewable energy supply.

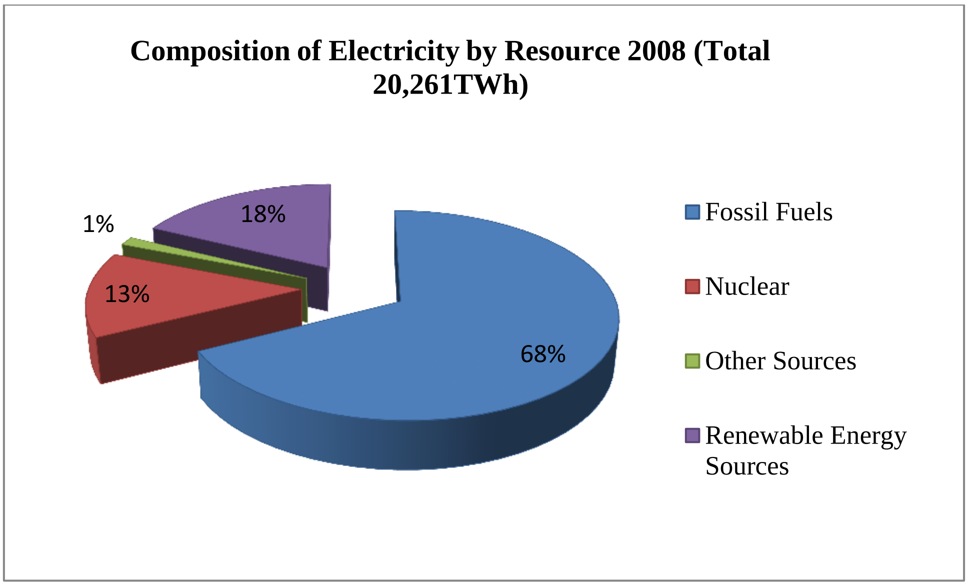


Figure 1: The world's electricity generation

Hydroelectricity has been an option of choice over the years due to its low greenhouse gas emissions and low maintenance costs. This is what makes it a sustainable generation for electricity. However, in some cases it destroys ecological system due to dam construction as discussed in chapter 2, below.

1.2 Problem Statement

Water is used in everyday activities. The same water delivered through pipelines has got a promising potential energy as it is stored in enormous storage tanks and containers elevated from the ground. Buildings are designed to hold a water tank at the top level in order to supply the building's water usage needs. That water gains kinetic energy as it descends to its end usage or application. This energy is not being totally utilized.

The kinetic energy it carries can be harvested without flow interruption and converted into electrical energy by installing turbines and generators in strategic locations along the pipeline. The present study is intended to show how this unused energy can be used in form of micro hydroelectric generation scheme. The development of the discussed system should be optimized in order to be both economically viable and environmental friendly. To meet this criterion, the system should at least produce enough electricity to auto-sustain the water system including pumping the water up to the storage tank.

1.3 Objectives

The objectives of this research-based project are as follows:

a) To harvest energy from water in main pipeline;
b) To develop micro hydro generation system from main pipeline and
c) To conduct dynamic test for the system.

1.4 Scope of Study

This is a research- and prototype-based project. Hence a very objective research is performed as the project takes place. A prototype in smaller scale (pico-scale) hydro generation is constructed and operated for a complete detailed technical and feasibility study on the system.

Using a single-phase submersible permanent magnet synchronous generator is coupled with an induction motor to serve as the prime mover in order to conduct dynamic tests. The purpose of the tests is to determine the electrical properties under both load and no-load conditions of the AC generator.

Data analysis shall be performed with the ultimate goal of determining the best power control modules to stabilize the output frequency and voltage. Different control methods are employed for experiment purposes.

A fully functional pico hydro generation scheme using water as prime mover is to be assembled and dynamic tests are run to determine the performance of the power system. Stability is an essential factor when electrical power is discussed; therefore, frequency and voltage shall be monitored and adjusted to suit the application under load condition.

CHAPTER 2
LITERATURE REVIEW

2.1 Previous Technologies

Various technologies are available to generate electricity from water's potential and kinetic energy. Up to date these technologies are divided in three categories: the conventional (dams) method, run-of-the-river and pumped-storage method [4]. They all use water energy in order to rotate the hydro turbine which in turn rotates the generator rotor.

2.1.1 Conventional (Dams) Method

Dams are strategically constructed along rivers to store water. The stored water accumulates to a certain height designed to have a desired potential energy. The distance vertical distance between the water gate to the turbine is called head [5]. The higher the head the greater the potential energy, *U*.

$$U = mgh \tag{1}$$

Having maximized the potential energy, *U*, hence mechanical energy of water, the energy that the water carries at the turbine level is more kinetic, *K*, than potential, *U*.

$$K = \frac{mv^2}{2} \tag{2}$$

The mechanical energy $E_{mechanical}$ the water carries is seen as constant through the principle of conservation of energy. As water loses its height, going down the penstock it experiences an increase in kinetic energy and a decreasing potential energy according to equation *(3)*.

$$E_{mechanical} = U + K \tag{3}$$

However, suitable turbines are chosen to withstand the water pressure. A pipe called penstock carries water from the dam (intake) to the turbine. The produced power is as well proportional to the flow in the penstock.

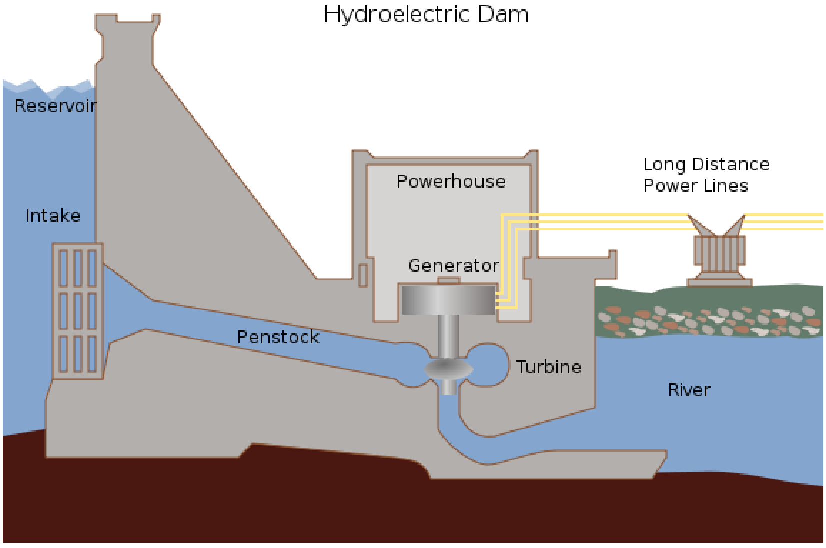


Figure 2: A hydroelectric dam scheme

This method of generation allows massive power generation; on the other hand, it has harming ecological side-effects as wild lives need to be relocated to widen the reservoir area. The biggest hydroelectric power plants employ this method of generation scheme. However, there are different ways of harvesting high amount of electricity employing methods that are less environmentally damaging such as low head, run-of-river hydroelectric technologies [6].

2.1.2 Run-of-river Method

Similarly, this method uses a river flow to rotate the turbines. River water under normal flow is deviated from the main course to run through turbines. They basically make use of smaller dams to ensure enough water enters the penstock so that the turbines will rotate at an acceptable speed [7]. This method can be better explained as a low head dam hydroelectric power station. They lessen the environmental impact compared to that of a conventional type hydro station [8]. Wijesinghe and Lai [8] mention that the shortage of places to build conventional-type hydro power plants lead the development of electricity generation to explore run-of-river technology.

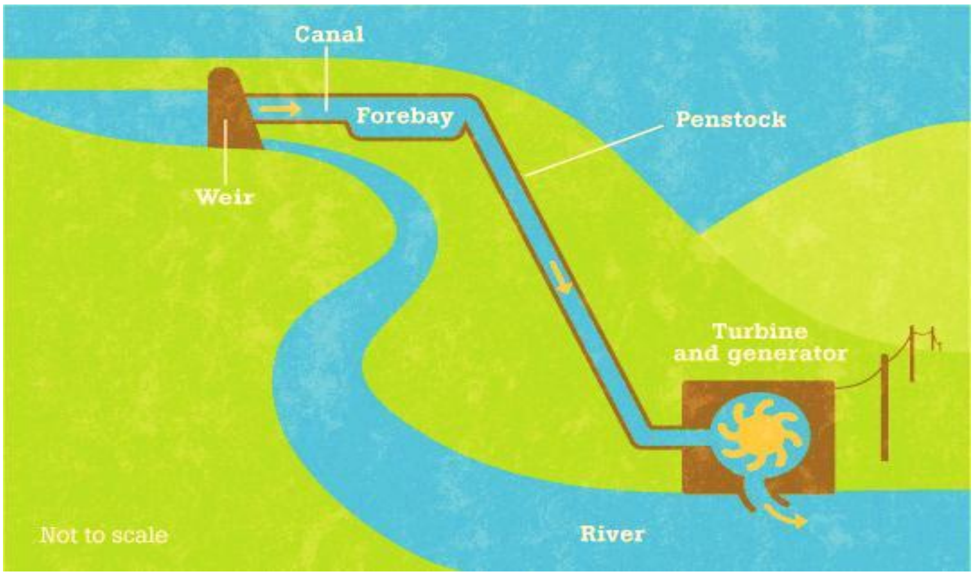


Figure 3: A low head run-of-river hydro generation scheme

Wang et al [3] uses the same concept to design micro generation scheme for rural Africa; however, in this case irrigation water was used instead of a river. The run-of-the-river, often referred as diversion technology allows power harvesting from very low heads. Other diversion type hydro generation do not require a dam, thus they become very cost efficient generations. Limitations concerning both types of technology mentioned above increase as rivers are not everywhere and electricity is needed everywhere.

2.1.3 Pumped-storage

A pumped-storage power station uses two reservoirs to store water. Typically an upper reservoir stores the water energy pumped from the lower reservoir. The two reservoirs are separated by elevations as per their names. As the water goes through a penstock from the upper reservoir to the lower, it passes through the turbine thus generating electricity and this water is then pumped back to the upper reservoir [9]. This is an arrangement often done in places with no river nearby. In times of lower electricity demand the excess electricity is used to pump water to the upper reservoir and when the demand increases the generating station covers the load as its upper reservoir is full. Allen [10] discusses different arrangements for a pumped storage hydro station including conventional pumped-storage, underground pumped-storage, single stage and double stage underground pumped-storage.

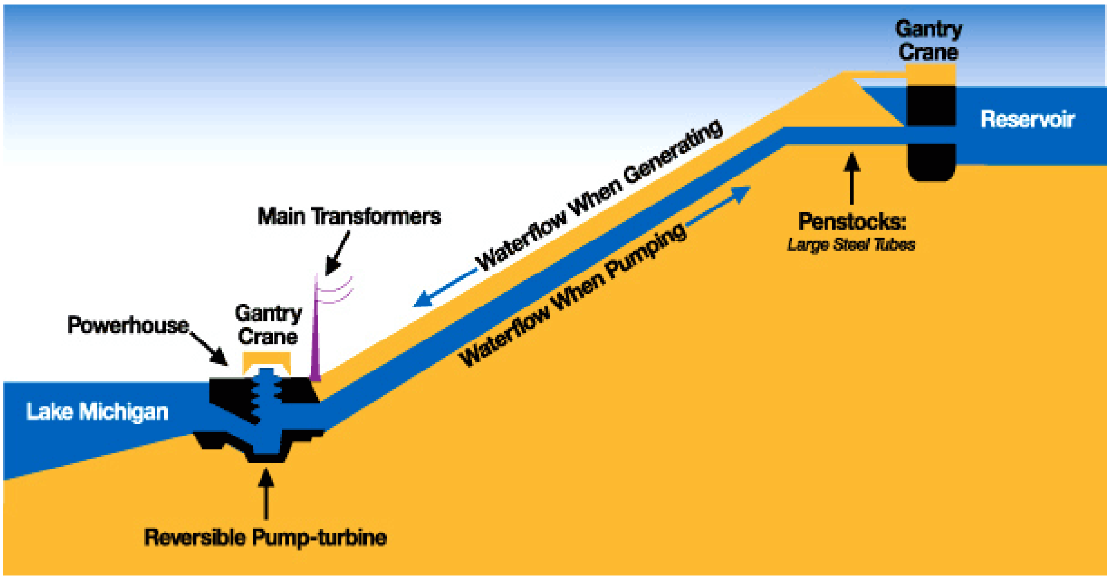


Figure 4: General arrangement of a pumped-storage hydroelectric generation plant

In most cases the water is provided by rain, be it a river running bear-by or not. This generation scheme is very dynamic as it needs an extended weather research. There is a need in knowing the flexibility of weather changes per year and the load supplied by the plant so that an operational philosophy is designed to detail aspects such as when should the water be pumped from the lower to upper storage so that the demand will be met [11]. According to a research carried out by Cochran, Isles and Pope in [12], pumped-storage hydroelectric scheme used to be the most widely used and best-developed technology of storing electrical energy.

This type of technology allows a limited power generation as per pound or reservoir size. There are many incentives to build this type of power plants including its cost effectiveness since they do not require a dam. This technology explores the head height without a need of a dam. Other reasons go beyond economical comfort, the ecological and environmental benefits of pumped-storage makes it a good technology to invest in.

According to the [1], the mechanical power delivered to the hydro turbine is proportional to the pressure head and volume flow rate in the following formulation:

$$P = \rho \eta g Q H \qquad \text{in } W \tag{4}$$

Where P is the power delivered to the turbine, η is the hydraulic efficiency of the turbine, Q is the volume flow rate passing through the penstock or flowing through the penstock *(m^3/s)*, g is the gravity constant, *$9.81 m/s^2$* and H is the head height *(m)*. Having the density of water to be assumed *$1000 kg/m^3$*, then equation *(4)* is simplified into *(5)*.

$$P = \eta g Q H \quad \text{in } kW \qquad (5)$$

In a nutshell, the power delivered by a fixed turbine can be manipulated by the head height of the reservoir. This is the ultimate reason of the proposed design.

2.2 Proposed Design

The design proposed in this report is explained below and advantages and disadvantages as compared to other available designs are discussed per sections. A final design scheme shall be shown after the design explanation.

2.2.1 Reservoir

It was earlier discussed the disadvantages of having dams to serve as reservoir. Micro scale hydroelectric generation needs no dam to maximize its electricity production. However, there is still a need for a reservoir. Looking at building designs, there are tanks that supply utility water to the building. This water is normally stored at the building's highest level. This practice is still true for cases where the utility water is distributed to a village or a slightly smaller area. Water is stored at high levels so that its pressure will build up as it goes, through pipeline, to its end usage. Intercepting the water as it descends creates an opportunity for an appropriate head height. Therefore, this project will use utility water tank as reservoir and the common pipeline as its penstock in a fully vertical position. Applying the penstock in a vertical position shortens its length for the same height compared to a conventional arrangement. Furthermore, this enables the full energy conversion of the dropping water with less friction along the penstock. This way the head is maximized with less usage of resource and no much modification should be made to the existing utility system.

2.2.2 Turbine

Hydro turbines are found in two major divisions: reaction turbines and impulse turbines. The former derive power from pressure drop across the turbine and they are totally immersed in water. They could be found in different designs: Propeller, Francis and Kaplan. The latter convert kinetic energy of water jet hitting buckets, without pressure drop across the turbine. These are found in the following designs:

Pelton, Turgo and crossflow. The above mentioned designs can be summarized in figure 5.

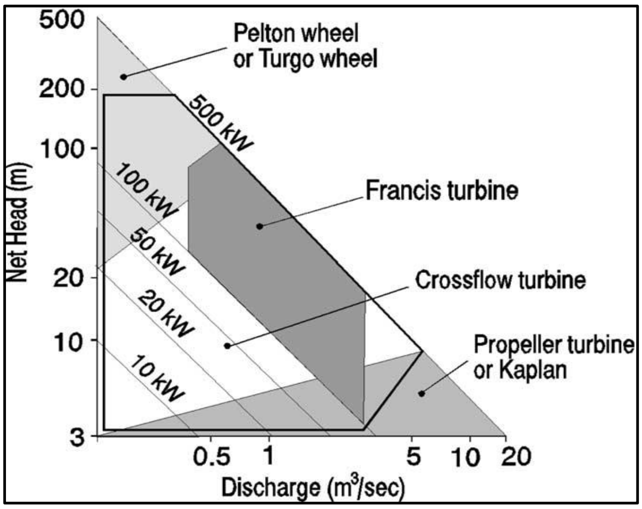


Figure 5: Head versus flow of small hydro turbines

Figure 5, above, shows that Propeller and Kaplan are the most suitable turbines for low-head small power generation. A head of *2-5m* (low-head) is considered in this project. Hence, the prototype discussed ahead, uses a low head propeller turbine.

2.2.3 Electrical Power Stabilizers

The output power needs to be reliable for utilization. In this case, electrical power stabilization is defined by the system voltage and frequency. The process of using power electronics to control the AC frequency is called frequency regeneration. This method is suggested by Wang et al. [3].

The unstable AC voltage is rectified by a rectifier circuit, then the output of this is interfaced by a DC link to the inverter circuit, which in turn it converts the power into a stable 50Hz AC to supply normal electrical appliances. Frequency regeneration is normally used to control the speed of inductions and synchronous machines. Generally, by applying it one can design the module to output any electric grid frequency either (50Hz or 60Hz) and voltage, normally by means of pulse width modulation. This is further discussed in methodology section.

A battery bank is used to compensate the power rectified in case the turbine runs slow including when it stops. The characteristics of the bank can vary in the data collected from utility water usage. The prototype presented in this report highlights the battery specifications and the results shown emphasize the need of a power stabilizer module.

This shall be discussed in chapter 3, below.

2.2.4 Generator

The development of power electronics allows a variety of generator for choice. Nowadays variable speed generators can be used to produce mains at the standard of either 50Hz or 60Hz [1]. This is possible through a frequency regeneration process discussed in [3]. There are different frequency and voltage controllers discussed by Singh et al. [13], Colak [14] and by Ahshan and others [15] which employ power electronics techniques.

According to Wang [3]

> The employed generators of micro hydro power plants may be self-exited induction generators, synchronous generators with field excitation or permanent-magnet generators. With the fast development of manufactured power semiconductor devices, the generated power from micro hydro power plants can easily be converted to stable power sources with excellent power quality to meet the requirements of commercial loads using novel power converters and inverters. (p. 2)

Using permanent magnet synchronous generators for small generations has got its rich advantages: they do not require an additional DC supply for excitation; they also refrain from the application of slip rings which makes them simpler and literally maintenance free. Another advantage is that they do not require condensers in order to maintain the power factor as in induction generators, and being for micro scale generation, the economic burden on large permanent magnets is neglected. Synchronous machines have an advantage over induction machines in this particular application since the prime mover (water), in this project, is not intended to be controlled at a very high accuracy (water flow and level). Synchronous machines generate electricity at variable speed and do not depend on their synchronous speed as it is in induction generators. Theoretically, induction generators only generate electricity when their rotor speed is above that of the machine’s synchronous speed, else they act as motors.

CHAPTER 3
METHODOLOGY

This is a research- and prototype-based project. Therefore at the end, a prototype that simulates the research is going to be constructed. The project involves the following phases: research, experiments, data analysis, prototype design, assembly, test, conclusion and recommendations. A pico-scale hydroelectric generation scheme shall be constructed as the project prototype.

3.1 Research

An extensive research or literature review on hydroelectric power generation systems was carried out prior to any other project work. From the forms of hydroelectric generation available nowadays it is important to look at the options that minimize disadvantages while maximizing advantages – system optimization. This is done to ensure a new design that optimizes the previous technology is designed and developed.

3.2 Experiments and Data Analysis

Prior to this important step, a literature review is conducted in order to better understand the hydroelectric power generation and the pros and cons for each technology available. Afterwards, experiments in laboratory are performed. The generator is coupled with a motor to serve as prime mover in order to deliver torque and speed to the generator shaft. Data gathered from the experiments will be processed and studied in order to determine the best parameters of modules to be assembled in the system. These modules will determine the reliability of the power generation system. As per the present phase, laboratory experiments on generator, power control have been conducted to ensure the design suits the application.

3.3 Assembly and Tests

After the system scheme is defined, in the previous step, it is assembled to use water as prime mover, as discussed earlier. This allows a complete prototype dynamic test and tuning of the system to achieve the desired performance. This is graphically shown in section 3.4, below with the aids of a flow chart.

The project is due to be completed in eight (8) months, equivalent to two semesters of study. The project is scheduled as per Gant charts in section 3.5, below.

3.4 Project Flow Chart

All the project steps and phases are illustrated in the following flow chart, in figure 6, below.

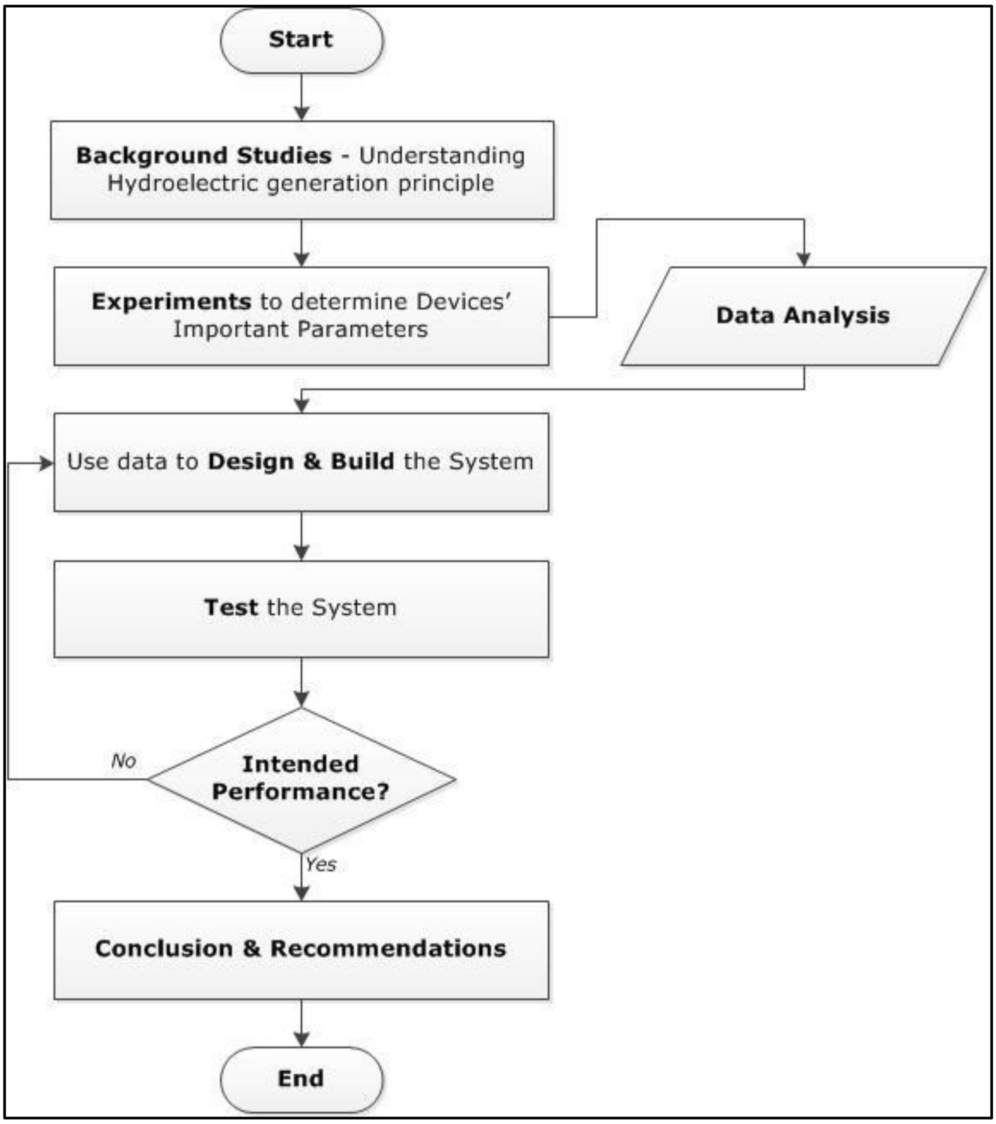
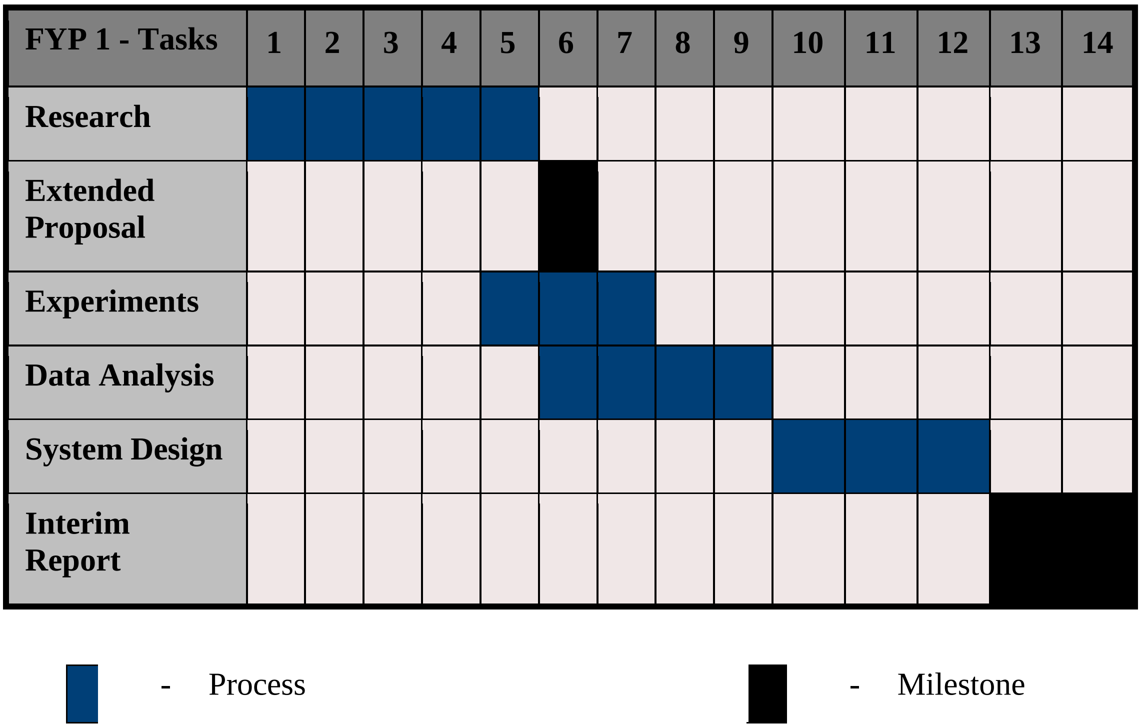


Figure 6: Project Flowchart

3.5 Project Gant Chart

The project is subdivided into two stages, namely, FYP 1 and FYP 2. In the first half of the project, the schedule of project activities was arranged as per bar chart in table 1, below.

Table 1: FYP 1 Gant/bar chart



The second half of this project is scheduled for completion of the project. The commissioning phase is included in Tests phase, shown in table 2, below.

Table 2: FYP 2 Gant/bar chart

FYP 2 - Tasks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Assembly															
Prog. Report															
Tests															
Pre-SEDEX															
Tech. Paper															
Final Report															
VIVA															

- Process - Milestone

3.6 Design and Concept

From section 2, above, the design of the prototype follows that of a pumped-storage hydroelectric scheme. A three-meter head separates the storage tank and the turbine or turbo-generator set. The penstock is a vertical pipe designed in order to maximize the power harvested from the water.

The power delivered to the turbine increases as the water flow increases as per equation *(5)* above; the water flow increases when the water velocity inside the pipe increases, as per equation *(6)*, below.

$$Q = VA \quad \text{in } m^3/s \tag{6}$$

where A is the circular area of the pipeline/penstock and V the velocity of water flowing.

Knowing that the kinetic energy developed by the water inside the pipe is given by *(2)* which implies that the power delivered to the turbine is directly proportional to the kinetic energy the water carries. Thus, kinetic energy, K, increases at its maximum rate if potential energy, U, decreases at its maximum rate according to equation (3)

From the knowledge that mechanical energy is constant, a vertical pipe makes the potential energy decrease the fastest with the least friction as it loses its height at maximum rate. Therefore, the designs implemented for prototype used a vertical penstock.

A manually operated control valve is located between the storage tank and the turbo-generator to simulate variable flow versus power generation.

The hydroelectric scheme, in figure 7, below, features a vertical penstock which maximizes the kinetic energy delivered to the turbine, which means that the energy is harvested at its maximum with a low head turbine.

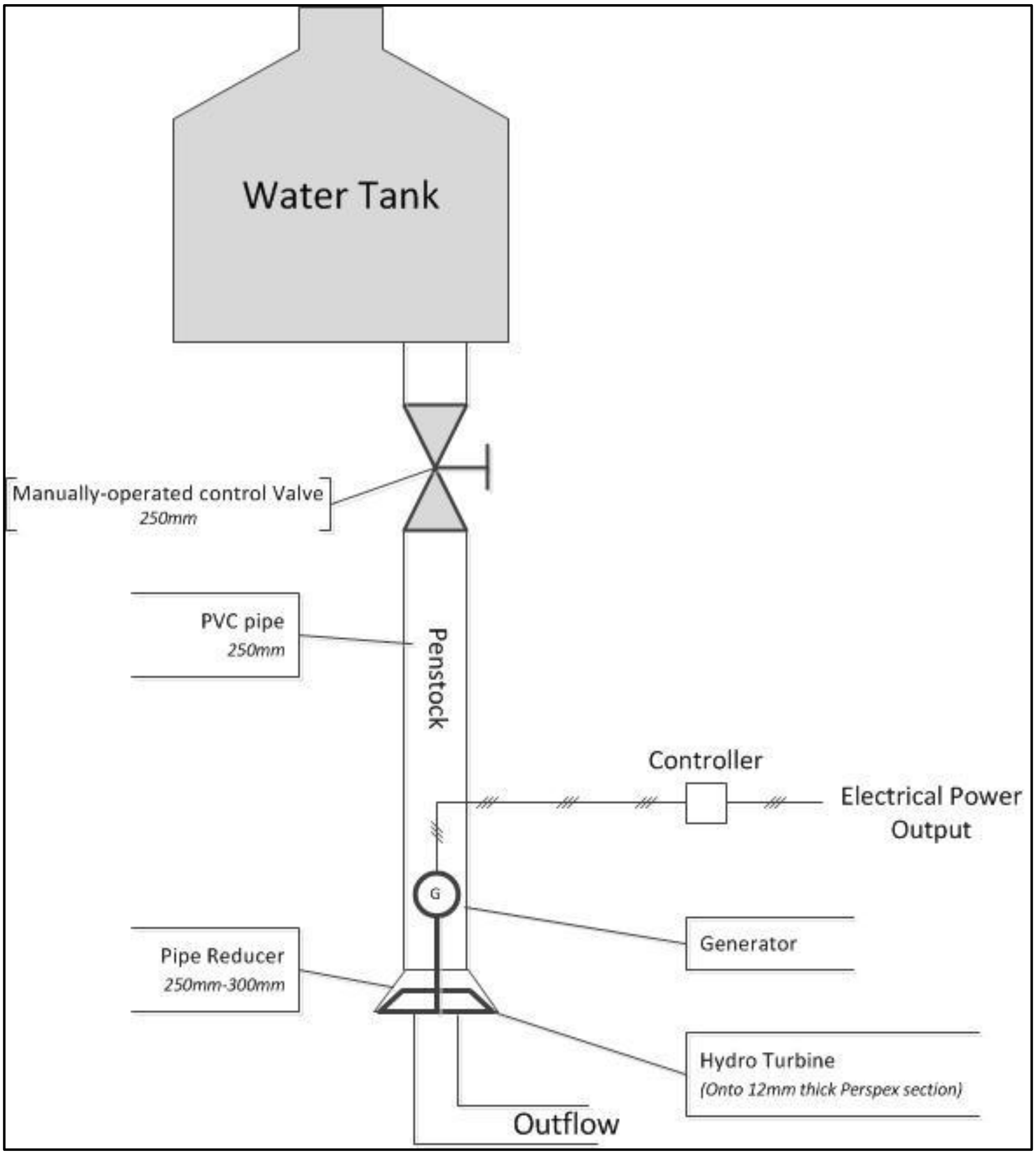


Figure 7: Proposed scheme for the project (not drawn to scale)

The scheme proposed is compatible to be used in an existing pipeline system. Another module to be discussed in this section is the power controller. Power controller stabilizes the output power to a steady level of voltage, frequency and power. A power controller (rectifier) converts the unstable AC power into an unstable

DC power. The DC is then supplied to batteries installed for back up and it is also connected to an inverter. The inverter converts the stable (due to battery) DC power into a stable AC power. This AC power can then supply the load.

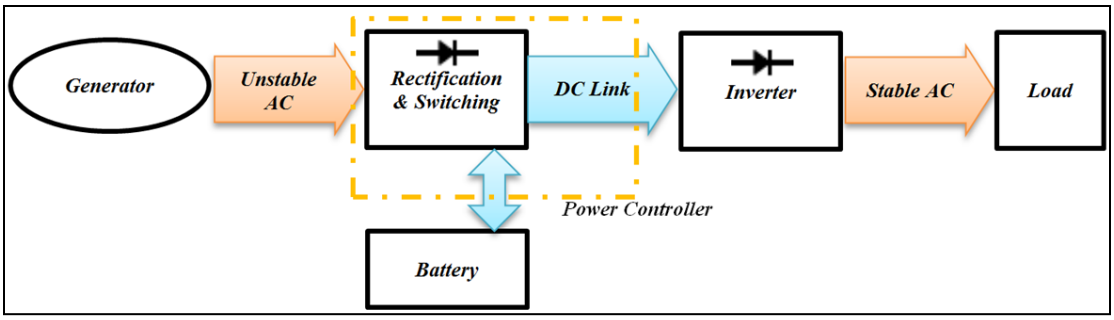


Figure 8: Block diagram for electrical power stabilization

The power controller needs to be able to do the switching of both outputs: the battery bank and the output power. The power converter receives an AC signal with a varying frequency and voltage to stabilize. In a simpler design, the controller features components shown in figure 9, below.

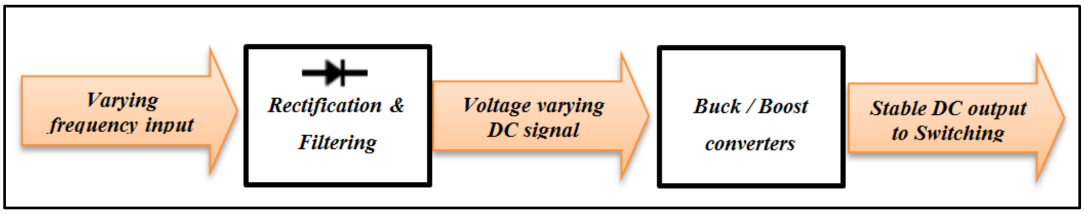


Figure 9: Block diagram for AC-DC conversion

The conversion happens inside of the power converter. The inverter does not have to have a buck/boost converter since the battery is there to ensure a continuous 24 V, 500W DC signal is input to it. Therefore the inverter design can be a simple PWM inverter available in the market.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Experimental Results

4.1.1 Testing Setup

Experiments on the permanent magnet generator were performed using a motor as prime mover the results in table 3, below, were obtained. These are preliminary results for design purpose. The system's parameters are expected to change depending on the load and control systems employed. Since the system is intended to be economically viable, it shall not have a governor to control its frequency. Instead, it uses a power controller (equipped with a power rectifier) to convert the AC signal generated at the output of the generator into DC signal as suggested in chapter 3, above. This, in turn, is converted into AC, by the means of a power inverter installed at the output of the controller. Therefore, the system will be stable; however, the power output by the generator shall oscillate as the prime move (water flow) oscillates. By achieving this state, the system is reliable to be installed as an on- and off-grid system.

A three-phase squirrel cage motor is coupled with the turbine shaft, which in turn, is directly coupled to the generator shaft. Enough current (about $I_{ph} = 0.9\ A\ to\ 1.2\ A$) at $V_{ph} = 90\ V, f = 50\ Hz$ is supplied to the motor connected in wye configuration.

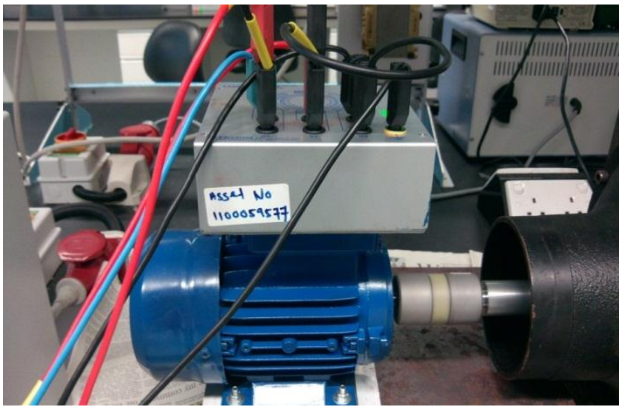


Figure 10: The squirrel cage 0.23kW motor used for experiment

The shaft speed were recorded though measurements using the tachometer. The voltage and frequency were monitored using digital multimeters as the voltage supplied at the input terminals of the induction motor is changed to allow shaft speed change. Since it is a submersible generator, it is then coupled with the turbine as close as possible to avoid generator over heating as water level in the pound/storage tank decreases. Like a submersible pump, this generator has to be properly sealed to protect the inner parts from water short circuit possibly provoked by leaking.

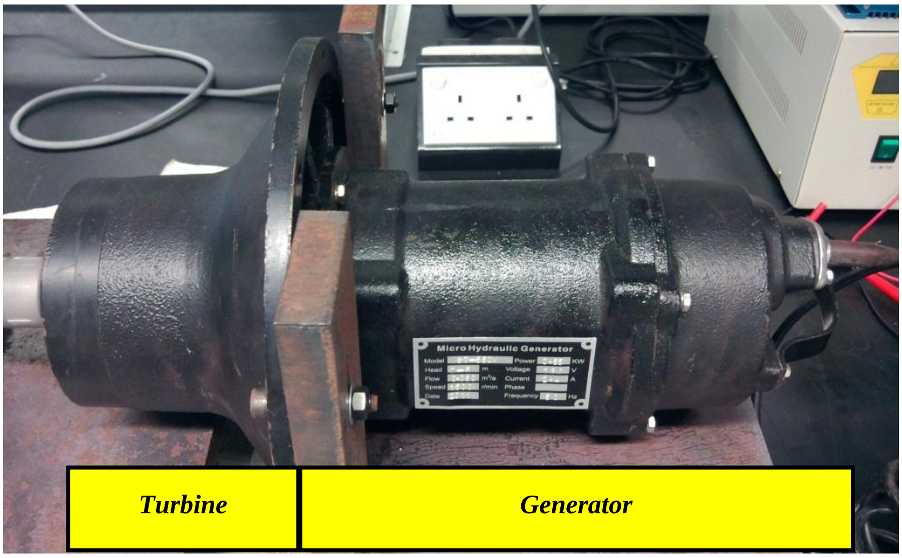


Figure 11: The turbine and generator for prototype

As a submersible generator, it is not advisable to keep the generator in the water for days while shutdown due to moisture that may build up in the windings, which may lead to short circuit the next time the generator is started. This safety measure is implemented due to the fact that the generator does not have an internal heater to keep the temperature above 28 degrees inside so that all the moisture will be absorbed. However, moisture absorbers like silica gel could be used as good solutions for moisture inside the generator.

Figure 12: Digital Multimeters monitoring the "No Load" voltage and frequency

The complete laboratory Open Circuit (OC) test setup is composed by a squirrel cage motor, the PMSG, multimeters and a tachometer.

Figure 13: The complete setup for generator test in Electrical Machines Laboratory

4.1.2 Experimental Test Results

For the experimental different runs/speed of the generator, the results are compiled in table 3. The variation of speed in a PMSG is seen as proportional to the output frequency and voltage.

Table 3: Generator characteristics under no-load condition

Generator speed (*rpm*)	**Output AC Voltage (*V*)**	**Output Frequency (*Hz*)**
1168.4	220.03	38.98
1208.8	230.00	40.25
1264.0	240.04	42.07
1481.4	280.18	49.00
1491.4	283.14	50.00
1494.6	283.34	50.00
1495.6	283.79	50.00
1496.0	283.54	50.00
1499.0	284.13	50.00
1505.4	283.04	50.00
1534.5	290.08	51.00
1590.4	300.00	53.09
1592.6	300.00	53.09

Plotting for voltage and frequency, the results are seen as in figures 14 and 15, below.

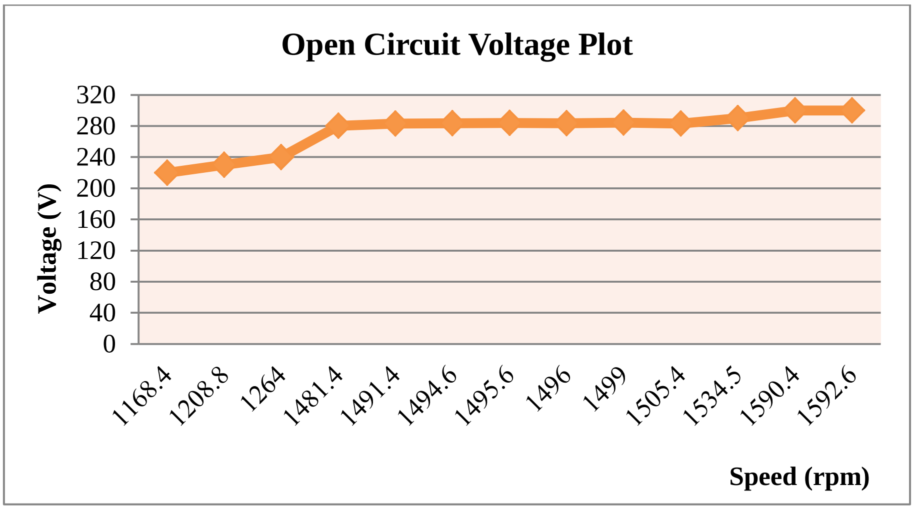


Figure 14: Variable speed Open Circuit (OC) test

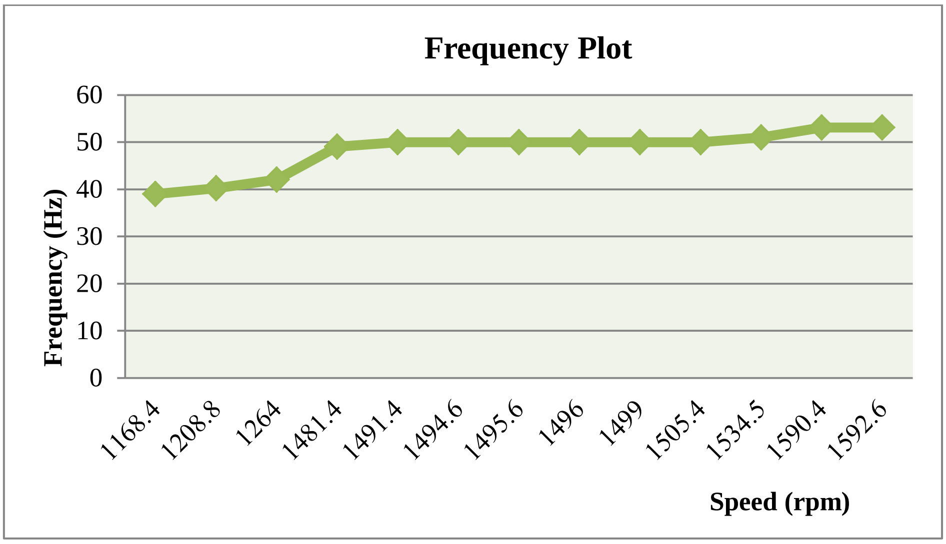


Figure 15: Variable speed Open Circuit (OC) test

From the OC test it concluded that slight rotor speed variation has great impacts in output frequency and voltage of the system. Frequency is crucial in a network it cannot deviate much from the system frequency. By rule of thumb in TNB, Malaysian largest electric utility company, it is common practice to keep the frequency at a tolerance of ±2% of nominal system frequency and ±5% of nominal system voltage. The graphs seen above show that both voltage and frequency oscillate far outside the allowable range. In power plants, that can be controlled by a governor (frequency controller) and a variable excitation circuitry (voltage controller). However, this is intended to be a simple and less costly system.

The system turbo-generator is characterized by the parameters given in table 4, below.

Table 4: Generator and Turbine Ratings and Specifications

Parameter	**Value**
Model	*ST-550W*
Head	*2 – 5 m*
Flow	*0.050* m^3/s
Speed	*1500 rpm*
Power	*0.55 kW*
Voltage	*230 V*
Current	*2.4 A*
Phase	*Single Phase*
Frequency	*50 Hz*

4.2 Power Controller

Being it hydro turbine with very simple and basic control mechanisms, the water flow varies, this influences the turbine speed and hence the generator frequency varies. Like electricity supplied by the utility companies, water supply follows the variation of flow according to peak times for consumption and times where the system goes partly idle. In fact, the concept of electricity resembles the concept of water distribution, where the flow increases as the demand gets higher. In the real application of the project simulated here, the water flow rate is expected to change with respect to time. This is the reason that a manually operated control valve is installed in the pipeline that carries the water through the turbine so that variable water flow can be simulated.

The system is also meant to be cost effective, therefore having to install a frequency governing system in every generator will deviate the project from its objectives and commercial value. On the other hand, a generation system with varying frequency is not desired. The frequency needs to be controlled and kept at a given set-point ± 2%, 50Hz in this case and a voltage of ±5% of 220V. The best way to achieve good results is to install a frequency regeneration system within the generation system.

The power controller unit of this project does the rectification process from different inputs and allows a DC output. It also has got a battery charging unit integrated which charges a battery that stores the power for “idle” hours. To reinstate the frequency back to the system forces the need of an inverter system. A Pulse-Width Modulation (PWM) inverter allows some of the best inverting techniques available in the market.

The AC wind input (seen in the figure 16, below) is used for the AC hydro generator, battery terminals are bidirectional ends used to charge the battery bank and to draw power from batteries when the input power system is not coping with the demand. There are two DC output terminals available to supply the DC load, in this case to supply the inverter.

Figure 16: 600-W Advanced Wind/Solar Hybrid (Street Light) Power Controller

The controller also offers an additional function of setting up the turbine cutoff speed, for cases where the water flow is extremely low and damages to the generator are to be avoided due to low speed. More sophisticated systems may use the cutoff speed to stop the flow through the turbine and bypass it to the consumers; however simple systems may only use the cutoff speed for switching inside the controller. The battery charging is through aids of PWM with voltage limiting and current limiting optional setup.

The hybrid controller allows the rectification of as low input AC voltage as 20V to as high as 240V. As the power input to the hybrid controller raises, the input voltage is 'locked' to 24V and current increases rapidly. Part of the current is fed to the batteries and part of it is output. The hybrid controller also does the internal switching discussed in details in the Battery Bank section, below.

4.3 Battery Bank

A battery bank for storage purposes is required assuming variable availability of prime mover. The extra electricity that may be produced during peak time may be used during low water usage periods. In addition when the power generated by the AC generator oscillates very much, the battery bank is used to stabilize the output demand. The switching is provided by hybrid controller.

Many factors influence the battery bank capacity and types of batteries inside the bank. The availability of supply, supply outage, power demand, type of supply (grid tie, ON/OFF, OFF) are some of the deciding factors on the bank capacity.

For the present system, the prototype only requires a bank for demonstration purposes, therefore low Ampere-hour batteries can be considered. A 24VDC, 45A-h battery bank is used. The bank is made of 2 12VDC, 45A-h heavy-duty lead-acid automotive batteries normally used for starting, lighting and ignition (SLI) of small engines.

$$\text{Since} \quad P = V \times I \ \text{(DC)}$$
$$P = 24\,V \ \times 45\,A \cdot h$$
$$P = 1.08\,kW \cdot h$$

Therefore, *1.08kW* is how much the batteries can supply in an hour of generator outage due to maintenance or extremely low turbine speed.

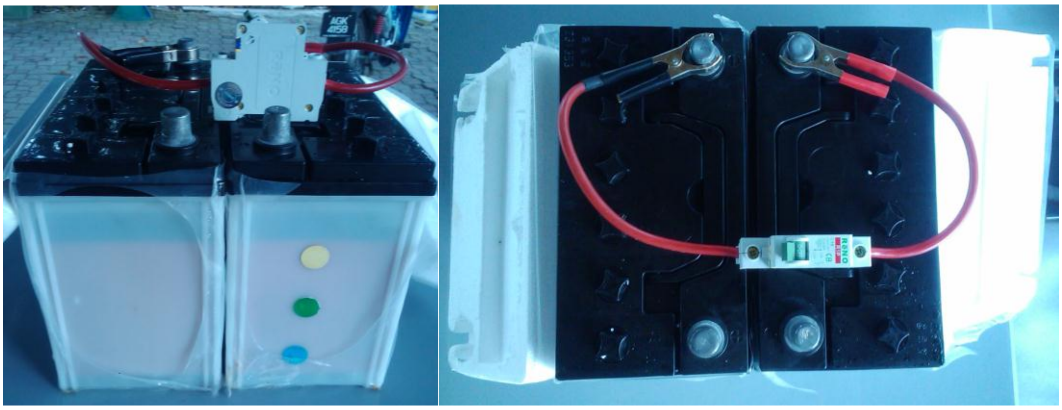


Figure 17: Lead-acid battery bank

For systems that draw more power or those that need electricity supply without interruption, a bank with a bigger capacity needs to be considered. Increasing renewable energy inputs to the controller also could be a solution for those cases. Photovoltaic (PV) input is provided by the controller. However these are exceptional cases where this system represents the primary electricity generation system. The prototype does in not intended to work as a primary system of generation. The controller is designed with a load dumping circuit which deviates or diverts the battery charging current as soon as the battery is fully charged to prevent the bank from overcharging. It supplies only enough current for the battery to maintain its charge so that the charge will not flow out from the batteries to the output while the generator is running at a speed that can cover the load.

4.4 Controller Module

The complete frequency regeneration module was assembled per specifications provided in table 5, below. It is composed by three main components: the hybrid power controller, the battery bank and the inverter.

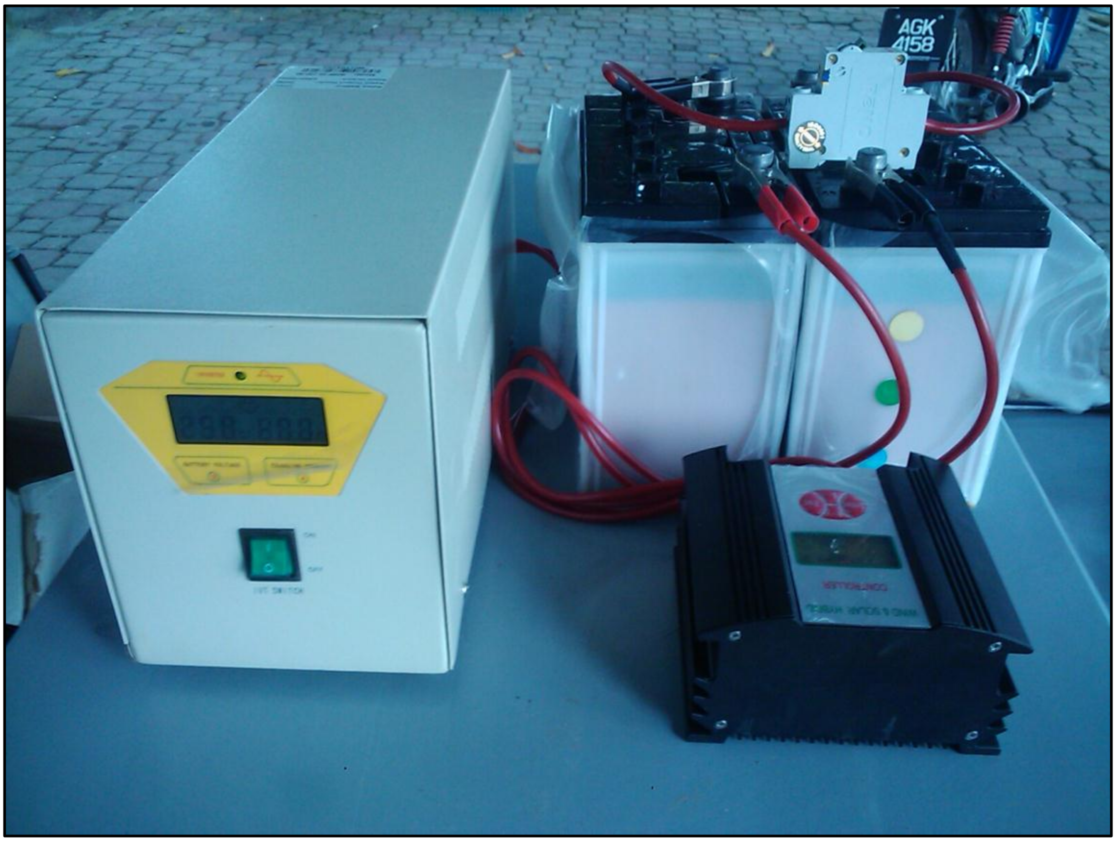


Figure 18: The controller module (frequency regeneration system)

The power controller, inverter and battery bank technical details are presented in table 5, below.

Table 5: Controller Inverter and Battery Bank Ratings

Parameter		Value
Controller	Input AC Voltage	*24-240 V*
	Output DC Voltage	*24 Vdc*
	AC Input Power	*600 W*
	DC Output Current (2 lines)	*10 A (each)*
	Control Mode	*PWM*
Inverter	Rated Input Voltage	*24 V*
	Rated Output Voltage	*220 V*
	Rated Output Frequency	*50 Hz*

Rated Battery Voltage	*24 V (2x12V)*
Rated Battery Amp-hours	*45 A-h*

The controller is equipped with a charging battery circuit which keeps the storage always fully charged whenever the generator is working. The battery also helps to pick up the load when the generator power drops due to decreasing flow. In this condition the overall system output is kept constant for as long as the storage holds. The controller also is capable of shutting off the output when the battery voltage drops below 22V to prevent damages.

4.5 Construction and Commissioning

The system was built as per the design. Both the turbine and generator are installed inside the vertical pipeline. PVC pipes and tank make were used to construct the system. A hand-operated control valve provides the open-loop control system to simulate variable flow. The mechanical stand that supports the system possesses strength to 'hold' a 300-gallon tank weight and the weight of the turbo-generator. The turbo-generator is installed inside the pipeline.

Figure 19: The system stand

Figure 20: the water tank installed onsite

Figure 21: Generator installation in the pipeline

The system features a ball valve, mentioned in chapter 3, above, that is manually operated to simulate variable water flow.

Figure 22: The manually-operated ball valve installed in the system

The water tank is fed by utility water for testing purposes only. The water goes through the turbine and is directed to the drainage system nearby. The generator is installed at the base inside the pipeline. The system was successfully commissioned and the testing phase was performed. Being it is a PMSG (constant excitation) the speed variation is proportional to terminal voltage and frequency. After running experiments and tests, the need for a frequency regeneration system is proved in order to stabilize the output power under constantly changing flow and a dynamic load. The controller allows an input voltage between 24V and 300V; this makes it suitable for variable voltage and frequency stabilization.

The complete system assembled does not deviate from the design proposed in this report.

Figure 23: The complete hydroelectric scheme

A load test was used to simulate the power system dynamics, and the results are compiled in section 4.6, below. It is composed by three fluorescent lamps that draw about 0.64 A at 220V.

Figure 24: The test load used in the testing phase

4.6 Test Results

After project commissioning began the testing phase. They system was tested for output voltage stability, output frequency stability and output power stability.

The control valve was adjusted to five different levels in order to simulate disturbances for both output voltage and frequency and finally plot the output characteristics. The load was switched ON and OFF, in given intervals to simulate output power disturbance to investigate the response of the system under different loading transients.

The first test was performed to the loaded circuit and output voltage and frequency were recorded in two different points, generator output and system output. The battery voltage was as well monitored.

The results are compiled in table 6, below.

Table 6: Output of the system at different % of valve opening

Valve opening	Generator output	System output	Battery Voltage	Battery status
0 %	0 V @ 0 Hz	219 V @ 50 Hz	24.58 V	Discharging
25 %	0 V @ 0 Hz	220 V @ 50 Hz	24.58 V	Discharging
50 %	138 V @ 27 Hz	221 V @ 50Hz	24.62 V	Charging
75 %	246 V @ 42.7 Hz	221 V @ 50 Hz	24.75 V	Charging
100 %	306 V @ 54 Hz	224 V @ 50.12 Hz	24.78 V	Charging

The results obtained can be further interpreted. Having the normal battery charge under load condition as 24.58 V for 0% and 25% valve opening the battery is discharging as the generator is idle. As soon as the generator starts its operation the voltage across the battery terminals raises as a sign of charging.

Being it a PMSG, the generator rotor needs a higher torque at the start; therefore, it only starts to rotate at about 40% of the valve opening. Once rotating, it does not stop unless the valve opening drops below 30%. The direct relationship between output power and rotor speed is observed in this system.

The output voltage at generator terminals and system terminals can be compared in figures 25 and 26, below.

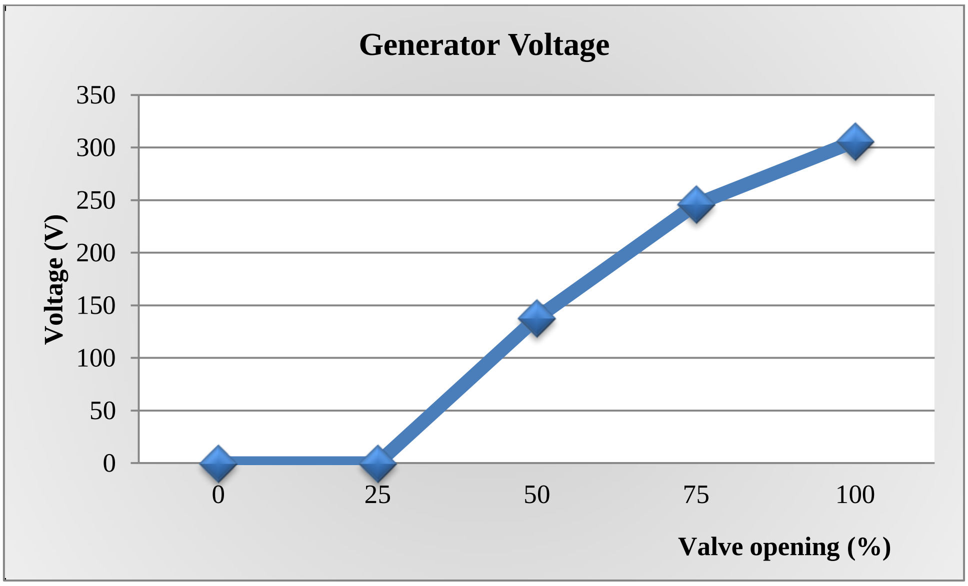


Figure 25: Generator terminal voltage at variable rotor speed

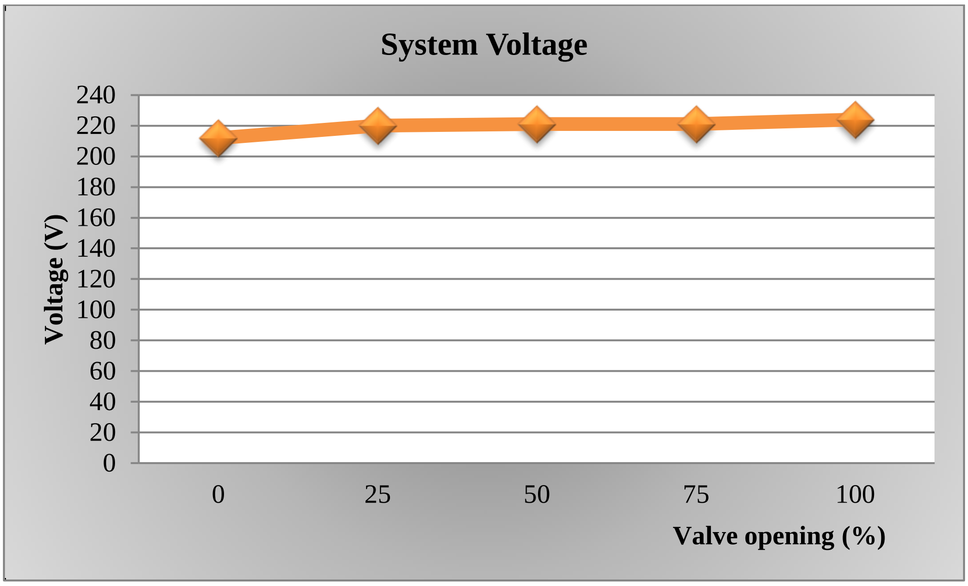


Figure 26: System voltage at variable rotor speed

As per results the system output voltage varies from 219 to 224 V for 0% to 100% valve opening. That is a satisfactory result as discussed earlier; the output voltage allowed tolerance is ±5% of nominal voltage. The inverter nominal voltage is 220 V. Hence

$$V_{tolerance} = \pm 0.05 \times 220\, V$$

$$V_{tolerance} = \pm 11\, V$$

Therefore,

$$209\, V \le V_{allowed} \le 231\, V$$

The frequency plot is shown in figures 27 and 28, below.

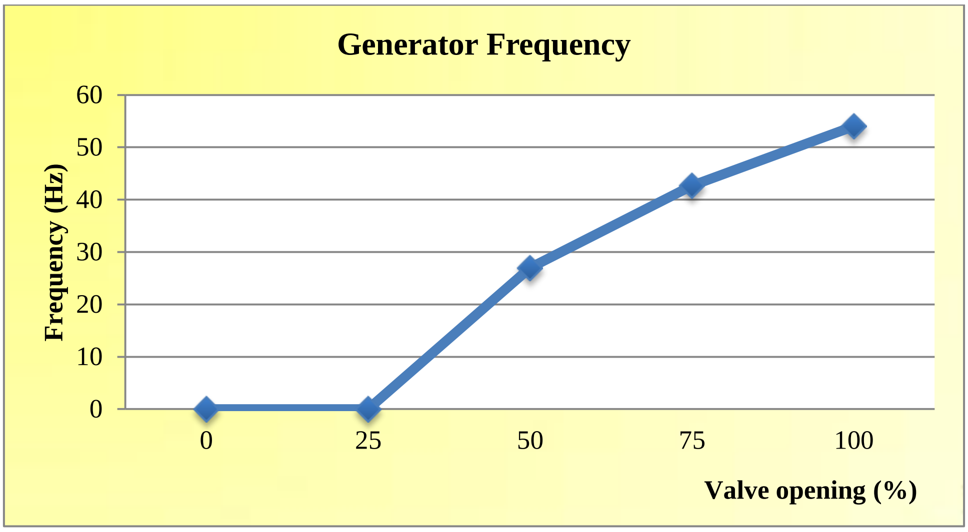


Figure 27: Generator output terminal frequency at variable rotor speed

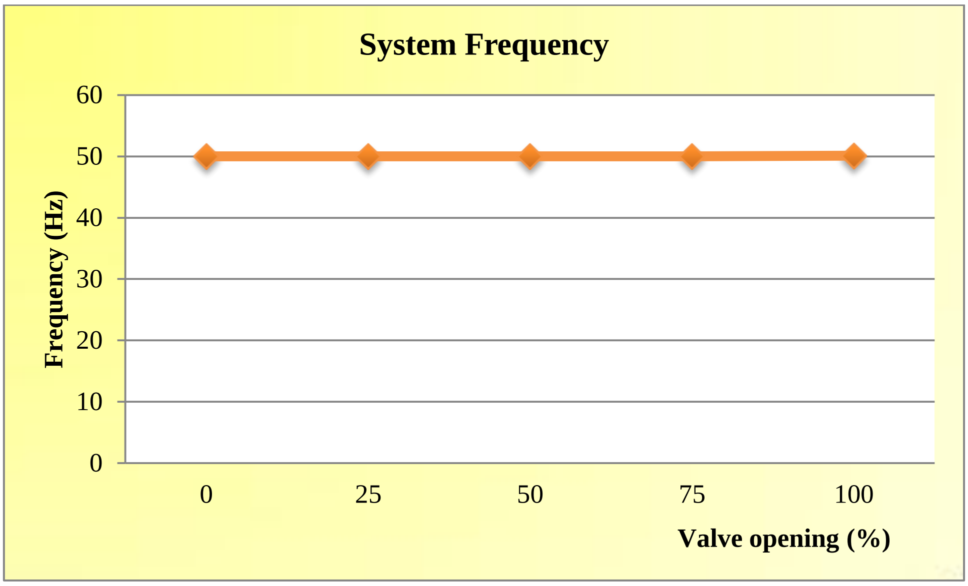


Figure 28: System output frequency at variable rotor speed

For frequency, as per results, it swings from 50 Hz to 50.12 Hz. The allowed output swing is ±2% of nominal voltage. The inverter nominal frequency is 50 Hz.

$$f_{tolerance} = \pm 0.02 \times 50\ Hz$$

$$f_{tolerance} = \pm 1\ Hz$$

Therefore,

$$49\ Hz \leq f_{allowed} \leq 51\ Hz$$

Both frequency and voltage are within the allowable limits. This step shows that frequency regeneration indeed stabilizes the frequency and voltage, in this case.

Lastly the power is tested for disturbances, thus increasing and removing the load to analyze the system response in transient.

This part was tested by adding a 140-W load to the 500-W system as a disturbance. The results could not be recorded as a graph, but it was observed in an analog multimeter. As the load was added to the system the multimeter pointer was observed to see the deviation from its steady-state value. The swing in the multimeter was observed to be between 215 to 225 V for loading and unloading respectively. As the system is loaded, the voltage drops and swings within a maximum transient period of 2 seconds it goes back to its steady-state value. When the system is unloaded the voltage goes up and down within the above limit for a transient period of no longer than 2 seconds and then it settles back to its steady state value.

The normal and maximum swing that the analog multimeter could pick up is shown.

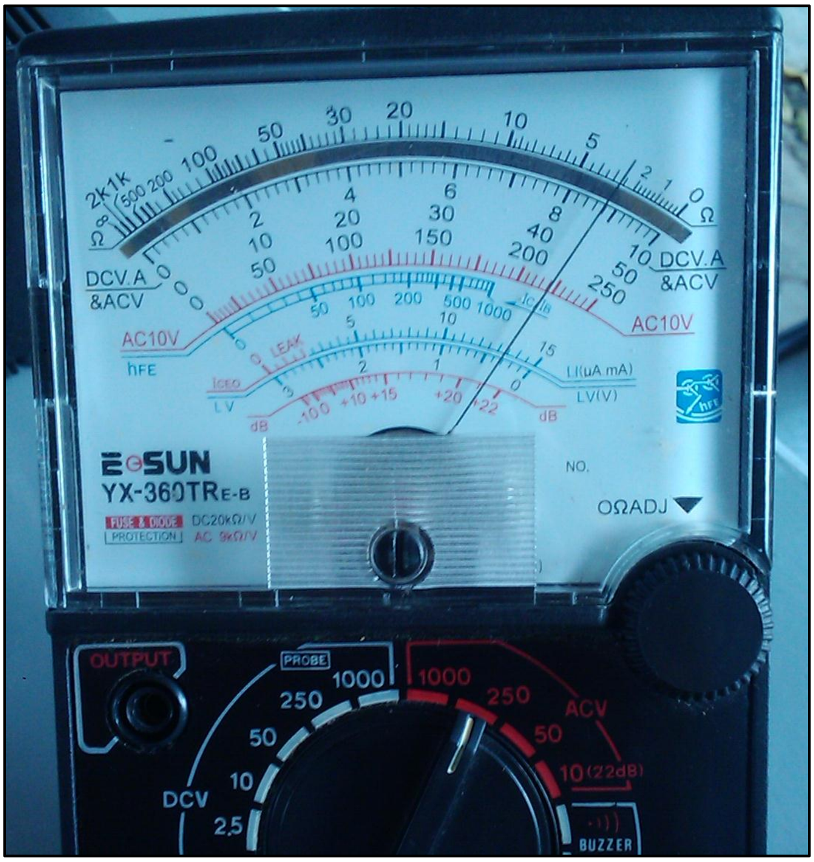


Figure 29: Analog multimeter showing steady-state value of loaded system voltage (220V), 250-V, Red scale

When the system is unloaded the pointer swings in the mentioned voltage limit then it settles back to its steady state value.

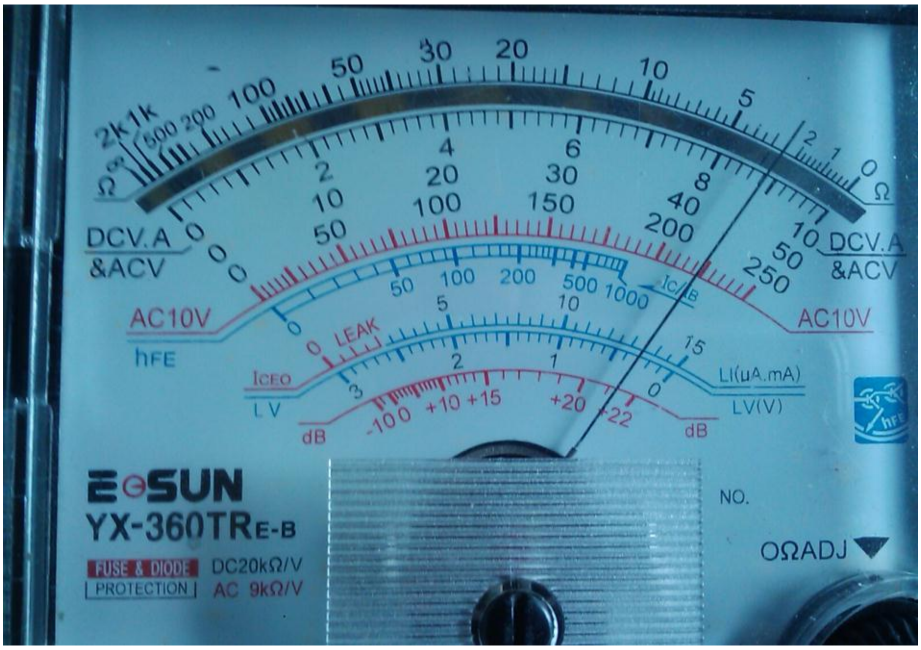


Figure 30: Analog multimeter showing maximum transient voltage at unloading action (225V), 250-V Red scale

Fluorescent lamps installed for test were purposely not connected to starting current limiting device so that a higher step power would be taken at once as the system is loaded. Fluorescent lamps are known to take high starting current therefore they would be the best choice for transient analysis as the system is loaded. The power drawn by the load is high enough to cause significant disturbance in the power system; however, that did not happen in this system due to the backup battery bank installed that allows power compensation.

The efficiency of the system, taking generator output as input power and maximum system output as output power is calculated below:

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \qquad (7)$$

$$\eta = \frac{500}{550} \times 100\%$$

$$\eta = 90.9\%$$

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This project presents a new development in hydroelectric power generation at micro scale. The development makes use of the pumped-storage technology as way of harvesting electric power from water tanks installed with the primary objective of supplying utility water to consumers. Having a water tank at a good height and using a penstock in a vertical position allows less friction to water descending through the turbine, more power transfer and less pipeline usage, hence less modifications to the actual utility water supply system.

Numerous advantages of using a pumped-storage technology were listed in the literature review, above. Added to that vast group of advantages is the fact that this development allows electricity to be harvested in systems that already exist with absolutely zero environmental harm and using the least material amount and equipment, which does not happen with the existing or currently used technologies.

Developments in hydroelectric power generation are encouraged it is one of the electric power generations that has the least ecological footprint as compared to fossil fuels and non-conventional (renewable) energy sources.

The systems developed in this project can be operated as ON/OFF grid system due to its amount of power generated and the non-expensive power controls. Less maintenance is expected from hydroelectric generation schemes. The system built as prototype was designed to feature almost maintenance-free equipment. The turbo-generator set is totally submersible, this allows the system to me installed in remote areas without any security risks as the pipeline does not present any sign of generator on the outside.

Generation under variable rotor speed is possible without a governor system. Like for a motor speed, power electronics recent developments enable generator's frequency and voltage manipulations for a stable micro power supply under variable rotor speed. Energy contained in water from storage tanks can be harvested in form of stable electricity supply. It can generate enough electricity to pump the water up to the storage tanks making the utility water supply independent from electric grids especially in rural areas where national grids do not cover.

Vertical penstock allows maximum energy conversion in a hydroelectric system. However in large system, the turbine may not be able to withstand high pressure that vertical penstocks deliver.

The development discussed in this paper shows that sustainable development in electricity generation can be maximized as this system is environmental/ecological-damage free and equally affordable.

Tying the micro system to the grid may be another way of stabilizing the voltage and frequency;

A battery bank, if needed, is recommended to stabilize the output power for cases where the system needs to keep supplying power constantly.

5.2 Recommendations

It is a hard task to control the system frequency and voltage in small schemes for power generation where there is no high precision prime mover control. For these types of systems a DC generator would be more economical due to the fact that it would lessen the amount of equipment installed in the scheme, which in turn would reduce maintenance costs.

The system can perform as great if it is grid-connected. Since in this case the grid would control the system frequency, it would leave only the power output as the only variable to be settled in the design. Simple switching procedure would have to be observed in this situation as the micro/mini-scaled power generating system would first need to be synchronized with the grid before the circuit breaker is enabled. And an anti-islanding circuit would have to be in place to avoid islanding in the grid when the utility supply is interrupted [16]. Furthermore, connecting the system to the grid (cutting the need for a battery bank) would mean locking the micro-generating scheme to the grid frequency, forcing the generator to act as a motor when the water flow is below the needed to achieve at least the synchronous speed. A diode would be required at the DC link to block power flow to the generator whenever its speed falls. Another way to do it is to apply a reverse power relay to prevent that power flowing back to the generator.

A cascaded generating scheme could be installed for cases where the water storage tank is placed at very high levels, where the height doubles or triples that of the turbine rated head. This would allow more power to be harvested in the existing pipeline system. A central controller unit could be used for more than one generator to save costs. A controller of higher power would be designed.

Reliable protection system needs to be in place, in order to operate the system in fault conditions. A circuit breaker and a simple leakage detection residual current device (RCD) should be added to increase protection. To lessen the number of components a residual current circuit breaker with overload protection (RCBO) can be used, because this integrates the function of the two protection devices discussed in this paragraph.

As discussed in chapter 4, above, the submersible generator used for prototype does not have an internal heater. When water gets low temperature while the generator is shutdown for maintenance, moisture may build up between the windings. Therefore, for larger scale systems, the generators to be installed should have heaters so that the application becomes more flexible. A submersible hydro-generator in this case has got numerous advantages comparing to a non-submersible one. From the electrical machine design point a permanent magnet submersible synchronous generator removes the need of excitation circuitry and is maintained at a cooled environment so that the installed permanent magnets would not permanently demagnetize due to high temperature.

A two valve system to bypass the turbine in cases the system needs to be taken out for maintenance can be developed for this case. However, the water from the prototype does not feed anything; the bypass system is not required here. In fact only one valve needs to be installed between the water tank and turbine/generator unit to ease maintenance and to simulate variable water flow with respect to the output power.

The system described in this report could be installed in existing pipelines. Obviously before that happens, a detailed analysis on the utility water supply system needs to be carried out. Not every water supply pipelines have the same diameter and flow. Those are some of the details that need to be studied in the design process prior to determining the type of equipment to be installed.

Future work on the development of this project could feature the design and construction of a higher power controller that allows more power conversion with an inverter integrated in a single module. A system that would require smaller battery bank would save up in the investment costs as batteries are costly. Therefore storing electric power in the grid to use when the system is idle is a very practical solution.

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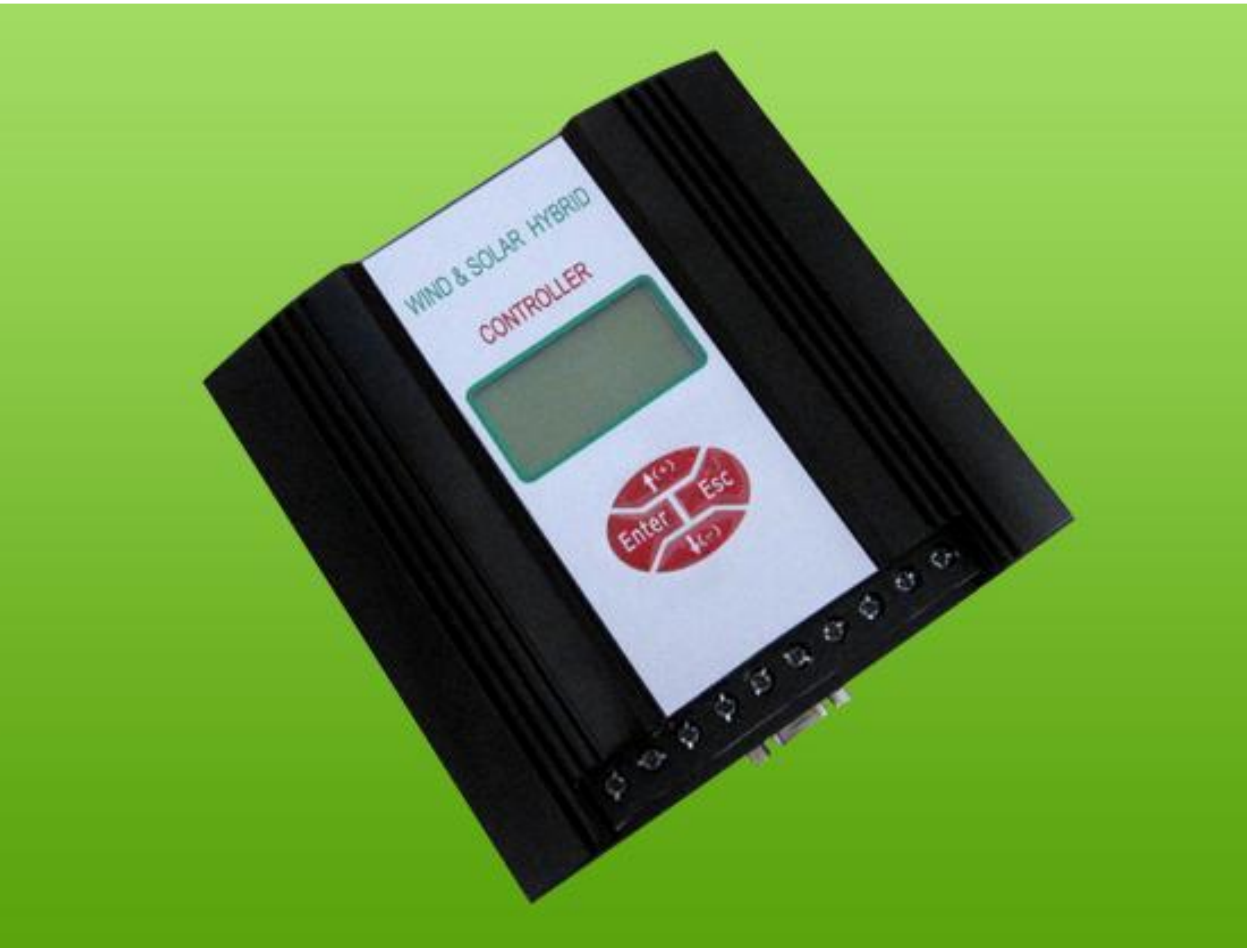
APPENDICES

APPENDIX A:
ADVANCED WIND/SOLAR HYBRID (STREET LIGHT) CONTROLLER TECHNICAL DETAILS

APPENDIX A:

ADVANCED WIND/SOLAR HYBRID (STREET LIGHT) CONTROLLER

TECHNICAL DETAILS



Advanced Wind/Solar Hybrid

（Street Light） Controller

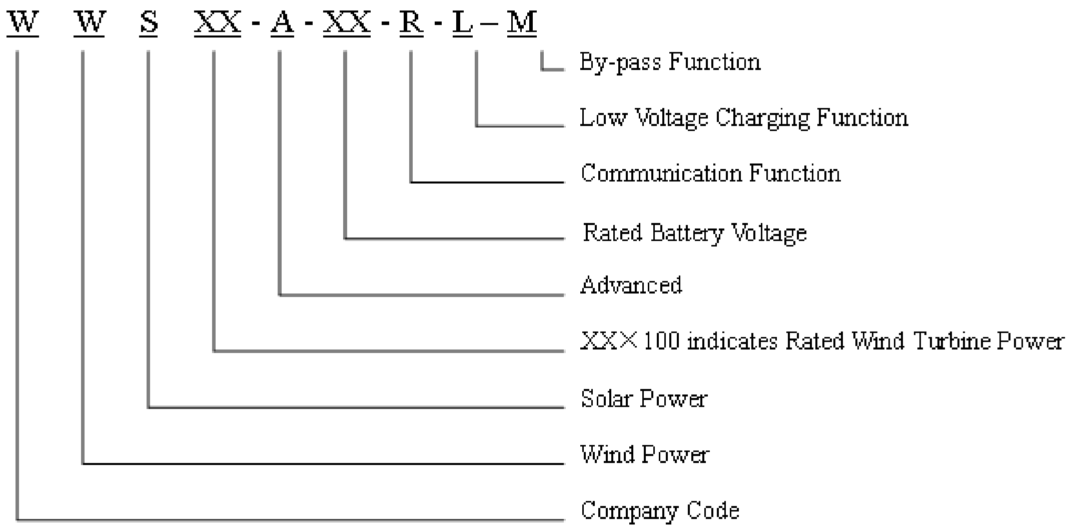
CE

1.General Description

The advanced wind/solar hybrid controller is specially designed for high-end small-scale wind/solar hybrid system and especially suitable for wind/solar hybrid street light system and wind/solar hybrid monitoring system. It can also control the wind generator and solar cells to charge the batteries safely and efficiently.

The advanced wind/solar hybrid controller is the core components of the off-grid power generation systems. The performance of the controller will impact the life and the stability of the whole system.,especially the life of the battery.

2、Model Explain



3、Performance Features

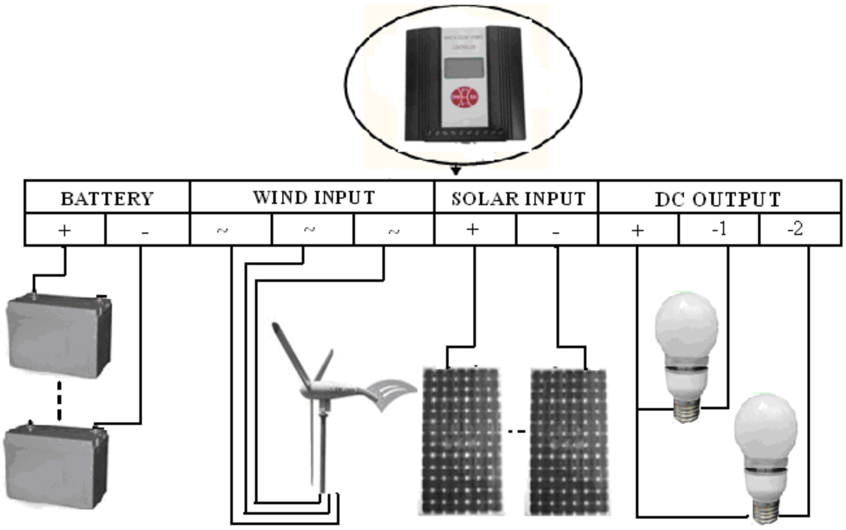
- **Reliability**：Intelligentized ,modularized, simple structure design with powerful function and stable performance.；The high-quality components and the strict production process make the controller suitable for the severe environment .It also have reliable performance and service life。
- ＰＷＭ **charging ways**, **voltage limiting and current limiting charging pattern**：Controller will charge battery with current limiting when battery power is low .Controller will charge battery with voltage limiting when battery power is high. In order to extend the service life of the battery. the over power will be unloaded by PWM
- **Two DC output** :There are various output control modes can be choose for each DC output. Including:

(1)constant on, (2)constant off , (3)constant half-power, (4)light-control on ,light-control off, (5)light-control on and time-control off, (6)light-control on, time-control & half-power , light-control off, (7) light-control on, time-control & half-power , time control off. Through the LCD buttons users can set three different output control modes including: (1)constant on. (2)light-control on ,light-control off, (3)light-control on and time-control off,

- **LCD display**： Running data and system status are displayed in the LCD screen. Including: battery voltage, wind turbine voltage, PV voltage, wind power, PV power, wind current,PV current, load current,output control mode ,the output off time of load , voltage point of light-control on, voltage point of light-control off, indicating lamp stands for day or night, battery power status, load status, as well as over-voltage, under-voltage, over-load, short circuit, etc.
- **Protection functions:** Including: solar panel reverse-charging, solar panel reverse-connection, battery over-charge, battery over-discharge, battery reverse-connection, load short-circuit, over-load, lightning, wind turbine current limiting, wind turbine automatic brake and manual brake.
- **Optional remote communication function**： The software can demonstrate monitoring control system status in real-time, such as battery voltage, wind turbine voltage, solar panel voltage, battery charging current, wind turbine charging current, battery charging current, battery charging power, solar panel charging power, wind turbine charging power, Wind Turbine RPM etc. User can adjust parameters from software. Meanwhile the software can control running status of wind turbine and load.
- **Optional Low voltage charging module**：This function enables wind turbine to charge battery under low power. The input impedance and the wind turbine starting charge voltage point can be modified through serial port communication depending on the different characteristics of wind turbine .
- **Optional By-pass function**：When the battery is over discharged, the device can automatically switch to city grid and use city grid power to charge the load to ensure stability of power system. If the battery is over discharged the second time in the same day ,the controller will not recovery automatically.Only when the battery voltage restores to the voltage recovery point and the lights are off once (the lights are on for the next day),it will automatically switch to the battery for the load power .
- **Optional temperature compensation function**

4.Operation Process

The wiring diagram of wind&solar hybrid system and Terminal connection of wind/solar hybrid controller as following.



After installing wind wind/solar hybrid system, please connect the controller accurately as the sequential operation

- Open the package and check whether the equipment is damaged due to transportation or not.
- Choose the appropriate line diameter. The current through per square millimeter of wires is not more than 5A .
- Connect DC load to “DC OUTPUT” terminal : The first load should be connected to "+" and "-1" of the “DC OUTPUT” terminals , The second load should be connected to "+" and "-2" of the “DC OUTPUT” terminals. The modes of load output can be set according to the requirements of system .(The half-power output is only applicable to LED load).
- Connect battery positive pole to the positive (+) “BATTERY” terminal, Connect battery negative pole to the negative(-) “BATTERY” terminal with copper core cable.

Although the controller has anti-reverse protection, but reversing battery is still forbidden!

- Ensure wind turbine in brake status and then connect the wind turbine output lines to the “WIND INPUT” terminals in back panel .
- Cover solar panel with a shelter and then connect solar panels to the “SOLAR INPUT” terminals in back panel.
- Remove the shelter of solar panel and release the brake switch of wind turbine.
- Install matched software into computer (XP system). then connect controller with computer through

RS232 or 485 serial port communication and data cable.The software will display the system parameters.

- Users can set parameters and load output modes through the software and the LCD key-press

5. LCD operation and Display Instructions

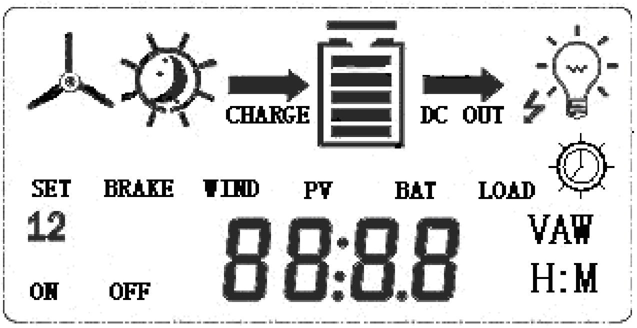
5.1 Description of Key-Press:

LCD backlight is on after pressing any key. The backlight will auto-off 10 seconds later while stop pressing any key

- "↑(+)" key symbolizes increase or next one. In browsing window, press this key to check next parameter. In setting window, press this key to check next adjustable parameter or increase the value of the current parameter.
- "↓(−)" key symbolizes decrease or previous one. In browsing window, press this key to check the previous parameter. In setting window, press this key to check the previous adjustable parameter or decrease the value of the current parameter.
- "Enter" key symbolizes set or confirm . In browsing window, press this key to access setting window. In setting window, press this key to save parameter and return to browsing window.
- "Esc" key symbolizes cancel or manual switch. In setting window, press this key to return to browsing window and do not save the modified parameters. In browsing window, the key is as a manual reset key for load short-circuit or overload

5.2 Displayed Content Description

LCD screen displays the following picture.



1)  symbolizes the wind turbine.

2） symbolizes the day, symbolizes the night.

3） symbolizes the battery, internal strip graph represents the status of battery power., The symbol is flashing when the battery is over-discharge, this flashing will not stop until over-discharging recover ;The symbol is flashing when the battery is over-voltage,The flashing will not stop until over-voltage recover.

4) symbolizes the status of load and error

- stands for normal load without output , stands for normal load with output .
- The symbol flashing stands for over-load, users must remove the extra load, click “Esc” key to recover the over-load
- The symbol of short-circuit flashing stands for short-circuit protection status, users should check load wiring, confirm the line wiring is normal and press “ Esc “ key to recover the short-circuit

5) symbolizes light-control and time-control. symbolizes light-controll on and light-control off. symbolizes light control on and time control off.

6) The character "SET" symbolizes the setting status.

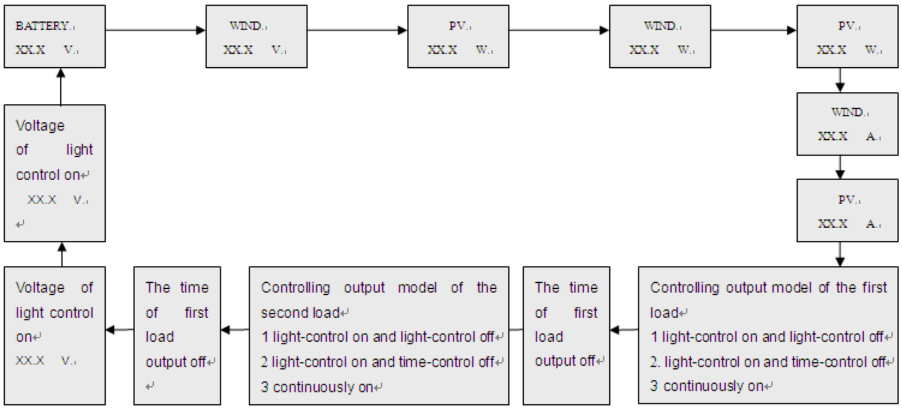
7) The character "12" symbolizes the first output and the second output.

8) 88:88 is parameters showing. The LCD displays all system status value and system parameters with intuitive digital and graph.

5.3 Browsing Parameters and Output Modes Description

1) Turn on the power, the LCD is under browisng window and displays battery voltage: XX.X V;

2) In browsing window, LCD will circularly display the following parameters by pressing "↑(+)" key, battery voltage, wind turbine voltage, solar panel voltage, wind power, solar panel power, wind turbine current, solar panel current, controlling output modes of the first load, the time of first load output off, controlling output modes of the second load, the time of second load output off, voltage point of light-control on, voltage point of light-control off. LCD will display parameters in reverse order by pressing “ ↓(−) “ key.



LCD can display three controlling modes of load output, including light-contrl on and light-control off, light -control on and time-control off, constant on.

Three controlling modes of the first output which are shown on the LCD as follows :

1) The belown picture shows interface of light-control on and light-control off. (Note: In order to show particularly the necessary content, we delete the other contents of the LCD) .

Lower-left corner of LCD displays "1" which symbolizes the first load output. The right side displays "load" and a sun symbol which suggest that the load is under light- control (light-control on and light -control off. In this mode), the controller will detect the light intensity from solar panel voltage, Initiate the corresponding load output automatically when it is dark and stop output automatically at dawn. The voltage point of light- control on and light-control off can be set by LCD key and serial port communication.

Interface of light-control on and light-control off

2）The belown picture shows interface of light-control on and time-control off.

Lower-left corner of LCD displays "1" which symbolizes the first load output. The right side displays "load" and a sun symbol which has a clock symbol inside. All suggest that the load is under light-control on and time-control off. In this mode, the controller will detect the light intensity from solar panel voltage, Initiate the corresponding load output automatically when it is dark and stop load output automatically when the load is up to the time of time-control off . Or stop load output eventhoug the load isn’t up to the time-control off but it is at dawn .

Interface of light control on and time control off

3) The belown picture shows interface of constant on .

Lower-left corner of LCD displays "1" which symbolizes the first load output and displays character “ on ” symbolize the load is constant on which means that the corresponding load has output within 24 hours except for low voltage protection status or fault condition. The right side displays character "load" This mode is applicable to outdoor monitoring system.

Interface of constant on

5.4 Setting Parameters and Output Modes Description

User can set following parameters from LCD press-key : output modes of first load .output modes of second load, the time of first load off, the time of second load off, the voltage point of light-control on and the voltage point of light-control off. And three output modes for each load :Light-control on,light-control off,light-control on,time-control off, constant on .

When users need to modify any given parameter, enter into setting window by pressing “↑(+)“ or “ ↓(−)" key and “ Enter “ Key, and then user can view and modify parameters by pressing “↑(+)“ or “ ↓(−)" key .Save the modified parameters and return to browsing window by pressing "Enter" key after setting parameters, not save the modified parameter and return to browsing window by pressing “Esc” key.

5.5 Manual Brake Setting:

Press the "Enter" key and "Esc" key at the same time, LCD displays the symbol BRAKE that suggests wind turbine is in brake status. Press the "Enter" key and "Esc" key at the same time in brake status, the symbol BRAKE will disappear and the brake status is released. In normal situation, the wind turbine can not be set in brake status.

6. Monitoring Software

Network monitor system is a high expansibility monitoring software. The software produced for the advanced wind/solar hybrid controller allows for setting the parameters and for control and for monitoring the electrical parameters.

Users can check or set the parameters and the running state of the system’s running process. Users can also control the running stats of the wind turbine. Meanwhile, the software have some advantages ,including,simple to use, high capacity, multifunctional, multiple languages ect.

7. Performance Parameters

Rated Battery Voltage	24V
Rated Wind Turbine Power	600W
Wind Turbine Maximum Input Power	1000W
PV Power	300W
Unload Voltage	28V
Unload Current	25A
Battery Over-discharge Voltage Shutoff	22V
Battery Over-discharge Voltage Recovery	24V
Output Protection Voltage	32V
PV Voltage Of Light-Control On	2V
PV Voltage Of Light-Control Off	3V
Line 1 Rated Output Current	10A
Line 2 Rated Output Current	10A
Line 1 Output Mode(Factory Default)	3 Modes selection（Light-control on and Light-control off）
Line 2 Output Mode(Factory Default)	3 Modes selection（Light-control on and time-control 5 hours）
Control Mode	PWM
Display Mode	LCD
Quiescent Current	≤20 mA
Working Temperature & Humidity	Ordinary：-20~+55℃/35~85%RH（Without Condensation） Industrial：-30~+55℃/35~85%RH（Without Condensation）
Communication Function（Optional）	RS232、RS485、RJ45、GPRS
Temperature Compensation Function	-4mV/℃/2V ,–35℃--+80℃,Precision：±1℃
By-Pass Function (Optional)	Automatic Switch
Product Size（Width×Deep×High）	142×150×80mm
Product Weight(kG)	1.9kg
Low-voltage charge fucntion :	

Wind Turbine Starting Charge Voltage	4V
Input Admittance	1-10/30S
Line 1 Output Mode(Factory Default)	7 Modes selection（Light-control on and Light-control off）
Line 2 Output Mode(Factory Default)	7 Modes selection（Light-control on and time-control 5 hours）
Product Size（Width×Deep×High）	220×150×80mm
Product Weight(kG)	2.8kg
In order to serve our customers better.Our company can adjust parameters configuration according to customer's requirement.	

8.Abnormal phenomenon and treatment

Phenomenon	Description
The symbol flashing, without charge or discharge	Battery is over-voltage, check battery voltage, and the cable is well connected or not, re-connect all components;
The symbol flashing and no output	Battery is over-discharging and battery is empty. Please continue to use the battery after battery is fully charged. Remove the battery and recover it with battery-charging device if the battery is over discharging for a long time.
The symbol flashing and no output	Over loading occurs. Please check the load and ensure that the load power consumption is not exceed the rated current of product, remove the extral or abnormal load, press "Esc" key to recover
The symbol flashing and no output	Short-circuit protection occurs. Please check load and wiring, remove the short-circuit risks or damaged load, press "Esc" key to recover .

If the phenomenon do not meet the description or cannot be returned to normal please contact our service department or salesman to repair or replace.

9. Warranty and after Sales Service

We provide 1 year warranty for our product from the date of delivery

If the product is exceed warranty or damaged by transportation, improper operation , human element, force majeure, it is not under warranty.

Declare: The product has applied for patent protection, counterfeiting will be subject to legal sanctions. Our Company reserves the right to change products and without notice when products update.