Design and Development of Smart Hydropower System

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July 2020

Undertaking

We certify that research work titled "*Design and Development of Smart Hydropower System*" is our own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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Dedication

Dedicated to our parents and teachers.

Abstract

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The world is moving towards smartness in almost every field. The main objective and idea of the project is to make a smart hydropower system which is capable of producing stable and uninterruptable power. Its output parameters including voltage, current, frequency, power etc. as well as the notifications of faults, if occur, will be available on the site at all the time so that it can be accessed by the supervisors of the power plants whether they are physically present in the generation area or not. This feature will greatly reduce the maintenance cost of the hydropower plant. The project also has a battery backup system if in case a major fault occurs and shuts the power system down, the power supply will still be continued, and the user will always be satisfied with the service. The project gives the solution of sudden voltage and frequency variation on heavy load changes by feedback mechanism i.e. by varying the voltage of excitation winding or changing the water flow to the turbine. Moreover, an IoT-based system that can easily monitor hydropower plant in case of any unwanted problems makes the whole system prone to any unwanted conditions. Arduino is employed as a primary control unit, NodeMCU 12-E for integrating Wi-Fi to Arduino and Curics.com as monitoring interface. This paper included all the simulations, turbine designs, codes of the controllers and techniques which can be used at power plants of any power generation capacity to produce the stable, uninterruptible and economical electrical power supply.

Acknowledgements

All praise to Allah almighty, the most gracious, the most merciful who made the human being super creative, blessed us with knowledge and without his help and blessings, we were unable to complete the project. We would like to thank our respected project supervisor Dr. Muhammad Faisal Nadeem, for his support, invaluable guidance and useful suggestions while we were working on this project. We express our gratitude to him for constant encouragement and providing continuous useful feedback on the project. His favorable reaction provided stimulus for the completion of this work.

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Chapter 1

Introduction

Hydropower system or hydropower plant is the term used for the system or a plant capable of producing electrical energy from water. In hydropower plants large turbines that are driven by water coming from the great height with pressure, are using to run generators which then produce electrical energy. This electricity is then supplied to the world so that people use it to make their lives easy. But why smart? IoT deals with electronic devices which could be linked for sensing and collection of data and then transfer it to community by employing cell phone applications, websites and sensor technologies. IoT based system needs a way to connect sensors and devices to the cloud. This is done through IoT gateways which act as bridges for data transfer. Each device is assigned a unique address and the data is sent to cloud through its gateway. A hydropower plant with online monitoring and control system is called "Smart Hydropower System" which has the capability to automatically deal with the problems like voltage and frequency fluctuations.

1.1 Problem Statement

The development in the renewable energy field and the increasing number of new uses of electricity generated a need to modernize the electrical system. These changes are forcing the control of power systems because of electricity consumption variations: electricity is more consumed in winter than in summer which makes it subject to daily peaks and hollows. It is a common problem in our power system that whenever variation in electricity consumption occurs, frequency of the system also tends to deviate from 50Hz. Also the voltage fluctuation is a very common problem in our system, which occurs when heavy load is suddenly disconnected or connected with the system, which in turn become the reason of many appliances failure.

In this modern world of technology and science, our systems should also be advanced enough to get managed and monitored without the necessity of physical appearance. Fault detection, working, usage, etc. These things of any system should be accessible through the internet in a safe way.

1.2 Motivation

The world is following a road to fully smart and intelligent systems. This can be seen in many appliances, auto-mobiles, AI computers etc. This advancement in technology has made life easier and facilitated with much luxurious lifestyle. Such smart and advanced tegnology in the system around us inspired us to built such a hydropower plant which will run on its own without the need of physical appearance, also will be troubleshoot itself when a fault occurs to facilitate the human being as much possible.

1.3 Project Scope

The scope of this project is to make such a hydropower plant which will be able to maintain and supply relatively stable voltages and keep the frequency of the system at 50Hz by using the feedback mechanism. It will also be able to supply uninterrupted power from power bank made up of batteries in case of any interruption. The system will be connected to the internet so the parameter of the system can be observed from anywhere and the system working can be seen through the data log.

1.4 Aims and Objective

The aim of this project is to make a smart hydropower plant by achieving following objectives

- Uninterrupted Power Supply
- Stabilized Frequency
- Stabilized Voltage
- 24/7 IoT based Monitoring
- Accessible from anywhere through an Internet Website
- Continuous Online Data Logging
- Fault alarming

Chapter 2

Literature Review

Humans have been harnessing water to perform work for thousands of years. The technology to take advantage of falling water and get useful mechanic energy is old. Several models of hydropower generation were investigated by scientists. The existing models depend upon the requirement involved in the study. Some of these models were simply analytical while others were constructed from robust system models showing the dynamic characteristics.

2.1 Waterwheels and Early Turbines

Hydropower was used in China at least 2000 years ago; the waterwheel was invented in ancient Greece and Rome, and in the year 13 B.C., the Roman engineer and writer **Marcus Vitruvius Pollio** described a grain mill driven by a waterwheel and a cogwheel gear. Archeologists later proved the early existence of such drives of mills and of waterwheels used for the irrigation of fields.

Around 1500, the waterwheel was the most important tool for power generation in Europe and elsewhere. Waterwheels were used to drive elevators for the conveyance of water, ore, and debris out of mines; to drive hammer mills, and of course, to drive the thousands of grain mills along the rivers. In the 16th century, Leonardo da Vinci made some sketches that are almost recognizable as water turbines as we know them today.

The first step toward a turbine was taken in France by **Jean Victoire**. In 1825, he built a waterwheel with curved blades. The curved blades effectively reduced internal hydraulic losses. A wicket gate proposed by **Euler** in 1754 forced the flow in a certain direction, thus reducing the hydraulic losses when entering the runner. As result, the first real turbines appeared. The name Turbine was first used in 1824 by the **Frenchman M. Burdin**. In 1860, the blades of such wicket gates were made adjustable, and gradually the many other types of turbines became speed controlled by centrifugal regulators.

2.2 Centrifugal Governors: The Flyball Principles

For at least 100 years, the flyball was the only component to control the running speed of hydraulic turbines. Although water turbines are neither the oldest nor the only prime movers controlled in such a way.

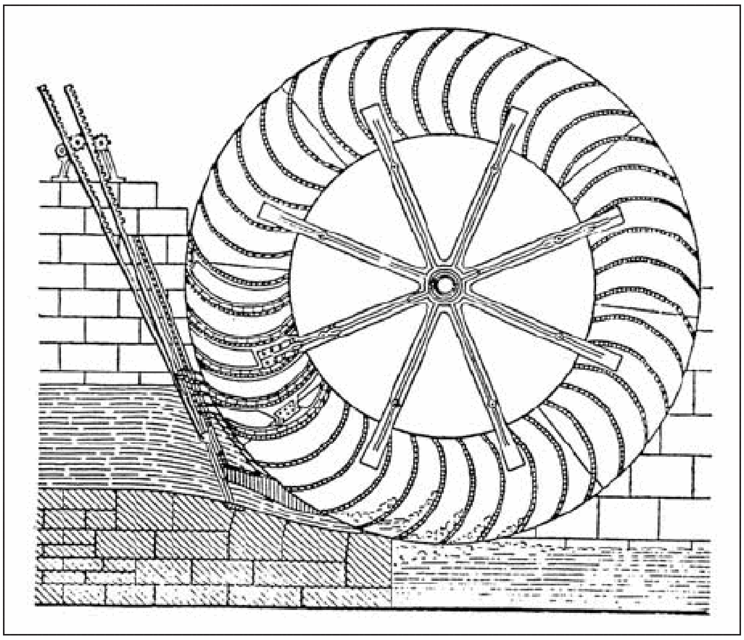

Fig. 2-0-1 Waterwheel with wicket gate

A centrifugal governor is a specific type of governor with a feedback system that controls the speed of an engine by regulating the flow of fuel or working fluid, to maintain a near-constant speed. It uses the principle of proportional control.

Centrifugal governors were invented by **Christiaan Huygens** and used to regulate the distance and pressure between millstones in windmills in the 17th century. In 1788, **James Watt** adapted one to control his steam engine where it regulates the admission of steam into the cylinder. Centrifugal governors were used on steam engines during the Steam Age in the 19th century.

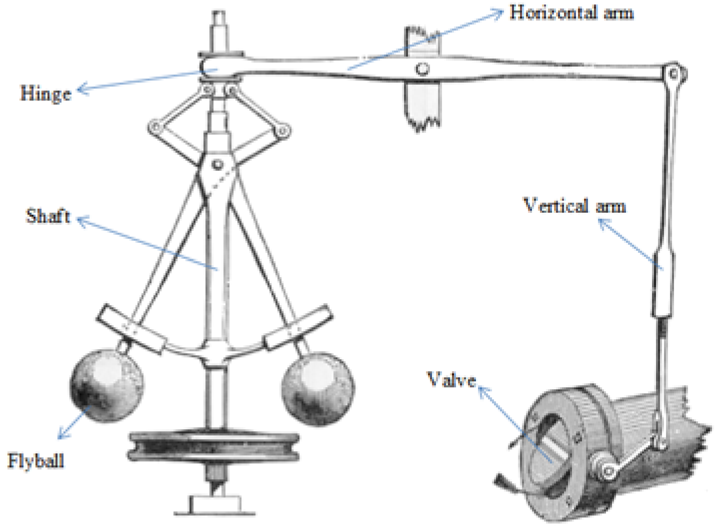

Fig. 2-0-2 Flyball Governor (5Watt)

2.3 The Feedback Pioneer

Any discussion of feedback pioneers must begin with the famed **Sir George Biddell Airy** and **James Clerk Maxwell**. **Airy** was the first person to investigate theoretically a closed control loop. **Maxwell** carried out the first systematic study of the stability problem about 1867. He evolved the stability conditions for one third-order control loop and derived a fifth-order differential equation to describe another system. In 1877, son-in-law of **Airy**, **Edward John Routh** viewed this task as a challenge, and he defined the characteristic equation and eventually published his well-known criterion.

2.4 Mechanical Governor

The early governors were nothing more than the flyball component that acted directly on the turbine's valve or wicket gate. The essential invention around 1880 was the use of power amplification to move the valve or the gates of the turbine. Thus, the **servomotor** appeared on the stage. The first servo systems were complicated mechanical gears that were called mechanical relays or sometimes differential regulators because they applied differential gears. The idea was to use the turbine's speed and power both to drive the flyball and to move the gates accordingly.

The mechanical governors built after 1930 were engineering masterpieces. These highly sensitive and precise devices may be called the "**first-generation**" turbine governors. Generally, they had fixed structures with either proportional-integral (PI) or proportional integral-derivative (PID) action.

2.5 Electronic Governors and Digital Systems

It took a long time for mechanical governors to be replaced by electric or electronic pilot units combined with conventional oil-hydraulic servo systems. These "**second-generation**" turbine governors were characterized by a short transitional phase, but their arrival ended the long and famous era of the flyball principle. The flyball, which was ultimately used as a speed sensor driven by a generator-motor system, was replaced by the electric measurement of rotating speed or frequency.

Electronics now reached the domain of signal processing. Operational amplifiers or transistors combined with condensers, inductors, and resistors in feedback determined the dynamic properties. The control parameters were to be adjusted by means of potentiometers, and the feedback of servomotor stroke was affected also by potentiometers or inductive sensors.

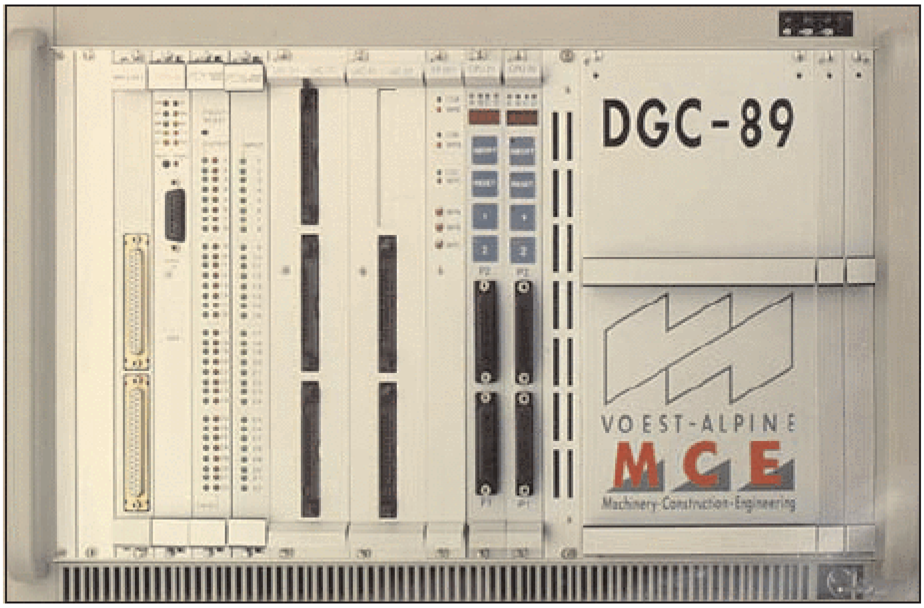

Fig. 2-0-3 Digital Governor

After that, "third generation" microprocessor controllers used for which both the hardware and software were developed by collaborators of the author. Designed for all kinds of closed-and open-loop control and monitoring, it was a modular multiprocessor system with 32-bit processors and a VME-bus structure. A firmware library and a block-oriented language made it possible to implement any

configuration and to adapt or change it, if necessary. Programming was done on a PC, as is common today.
The most recent development as part of a construction-kit system is shown in Fig 2.4. This sophisticated system provides several additional functions, such as the possibility of determining the optimal relation between wicket gate position and runner blade angle of Kaplan-type turbines, as well as process signal acquisition to observe temperatures, for instance.

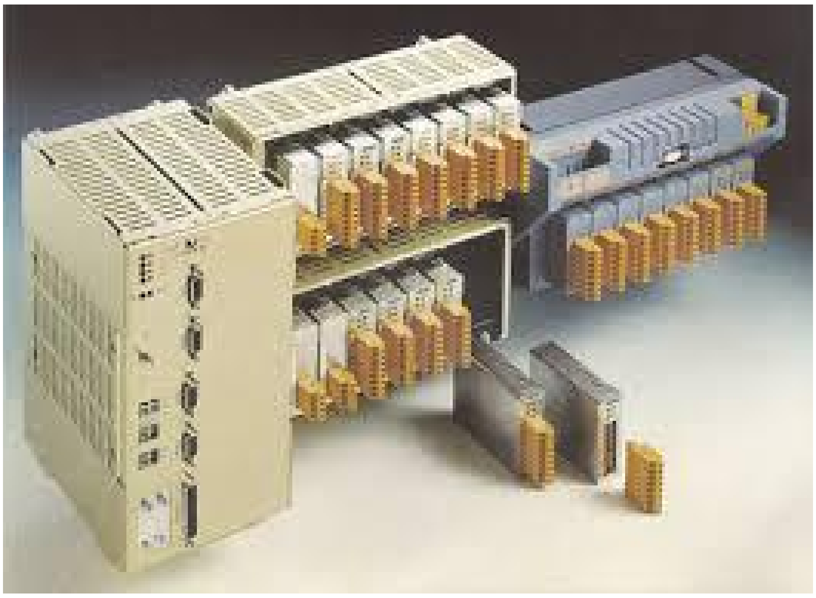

Fig. 2-0-4 1st Turbine Controlling System DTL 595

2.6 Hydroelectric Power Plant

The most important year in hydropower history was in 1831 when the first electric generator was invented by Michael Faraday. This laid the foundation for us to learn how to generate electricity with hydropower almost half a century later in 1878.

2.6.1 1st Hydroelectric Power Plant

The first hydroelectric power plant, located in Appleton, Wisconsin, began to generate electricity already in 1882. The power output was at about 12.5 kW. 7 years later, in 1889, the total number of hydroelectric power plant solely in the US had reached 200.

2.6.2 Largest Hydroelectric Power Plant

In the 19th century these power plants got an increased amount of commercial attention and were built rapidly in suitable areas all over the world. 1936 marks an important year – the **largest hydroelectric power plant**, the Hoover Dam, was opened and generated 1345 MW (installed capacity later increased 2080MW) from the flowing water in the Colorado River.

2.6.3 Water-Power Technologies

In 1880, a dynamo driven by a water turbine was used to provide arc lighting– a technique where an electric spark in the air between two conductors produces a light – to a theatre and storefront in Grand Rapids, Michigan, and in 1881, a dynamo connected to a turbine in a flour mill provided street lighting at Niagara Falls, New York; both of which used direct current technology. The breakthrough of alternating current, the method used today, allowed power to be transmitted longer distances and ushered in the first U.S. commercial installation of an alternating current hydropower plant at the Redlands Power Plant in California in 1893. The Redlands Power Plant utilized Pelton waterwheels driven by water taken from the nearby Mill Creek and a 3-phase generator which ensured consistent power delivery.

2.7 Internet of Things (IoT)

In this era of digitization and automation, the life of human beings is getting simpler as everything is automatic, replacing the old manual systems. Nowadays humans have made internet as an integral part of their lives and using internet they are able to get a hold over their devices. Thus, IoT offers a platform that lets devices to be connected, sensed and controlled remotely through cloud.

2.7.1 Smart Load Management using Zigbee

Dae-Man Han et al. designed smart home device definitions and interfaces that can interact with Zigbee devices for smart load energy management. The design includes multi-sensing for the smart energy management.

Fig. 2-5 Internet of Things

2.7.2 Smart Home Automation using IoT

Majid Al-Kowari et al. discussed about the automation of smart homes and proposed an IoT based solution to sense and monitor the home appliances. Design employed NodeMCU: a real time sensing microcontroller and EmonCMS a flexible and user-friendly platform to gather, track and control data from different home appliances.

2.7.3 Monitoring and Control through MQTT

R. Kishore et al. described that owing to the ubiquitous availability of Wi-Fi, all home appliances can be connected through a common gateway. In sensors and actuators have been connected to ESP8266 and a Mosquito based MQTT broker for remote monitoring and control.

2.7.4 HAS using Android Application

Vikram. N et al. illustrates the concept of internetworking of smart devices to provide a low-cost HAS system using Wi-Fi. In addition to this, user can access smart devices via android application based Graphical User Interface (GUI) on smart phones.

2.7.5 Home Automation using Zigbee with 3G/4G Technologies

Xiaobo Mao et al. adopted Zigbee wireless communication technique with 3G/4G network technology, cloud server, web gateway and smart phone app for home automation.

2.8 Arduino Microcontroller

Arduino is an open source hardware and software company. It designs and manufactures single board microcontrollers and microcontrollers kits. These microcontroller boards and kits are used for building digital and interactive devices that can control and sense other objects in the physical world.

Arduino board consists of various microprocessors and controllers. The board are equipped with sets of digital and analog input/output pins. One of the important features of board is serial communication interface, which includes Universal Serial Bus (USB). This interface is also used to burn programs from personal computer to the microcontroller of Arduino board. The microcontrollers are programmed using the programming of C and C++ languages. It provides an integrated development environment (IDE) based on the processing languages. Arduino project was started in 2003 as a helping tool for students. Its aim was to enable students and professionals to create devices that can interact with their environment. For example, making robots, motion detectors and thermostats etc. Arduino has simplified the process of working with microcontrollers, along with that it also offers some advantages to its users as:

- Reasonable
- Cross-Platform
- Simple and Clear Programming Environment
- Open Source and Extensible Software

Chapter 3

Smart Hydropower System

This chapter contains the design, simulations and hardware details of each and every part the project i.e. smart hydropower system. Design of the overall system starts with the design of the turbine and ended on controlling the whole system with Arduino microcontroller. Overall pictorial flow diagram of the project is as under:

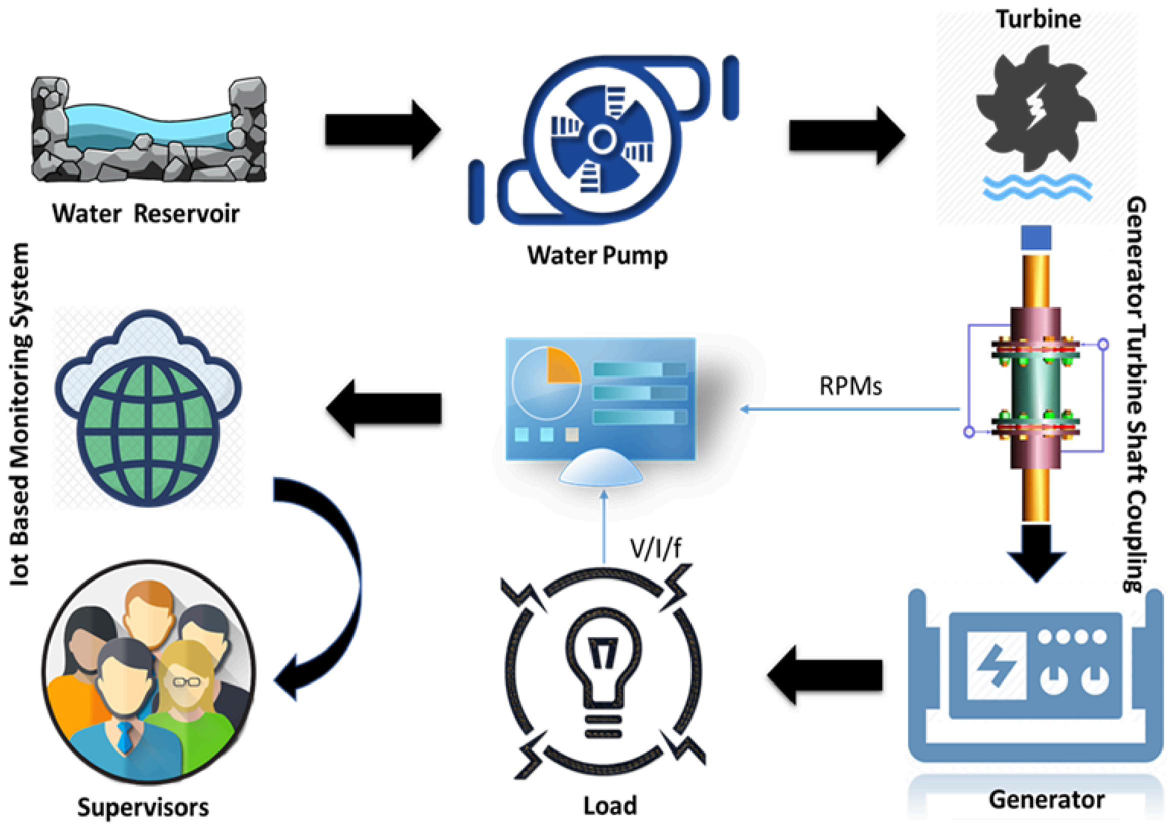

Fig. 3-1 Project Representation

Now let's start with the design of turbine.

3.1 Turbine

After reading about all the types of turbine we came up with the result that the Pelton Turbine would be the best match in our case because we have to made 200W with 10 meters of head and with the minimum flow rate. Pelton turbine is a type of turbine which can use on 10 meters of head and takes less flow rate as input. As we have to make turbine of our own specification so the best way was to produce a model on some software and then 3D prints all the parts and then assemble them. For this purpose, we use software named “CorelDRAW”.

3.1.1 Coral DRAW

Corel Corporation developed and released a software program called CorelDRAW, a vector graphics editor. The software is a robust graphics suite, providing many features for users to edit graphics. These features include contrast adjustment, color balancing, adding special effects like borders to images, and it is capable of working with multiple layers and multiple pages.

CorelDRAW was originally released in January 1989, running on the Windows 2.x operating system. Today, the software is still used by many people, with the latest version, X8, being released on March 15, 2016. CorelDRAW is primarily designed for the Windows operating system. There were several releases for macOS and macOS X, but poor sales resulted in the discontinuation of those versions. There was also a port to Linux in 2000, requiring a modified version of Wine to run the software.

CorelDRAW is available for download on the CorelDRAW website. Users can try the software with a free trial version, they can purchase an annual subscription, or they can purchase it for a one-time cost.

3.1.2 Turbine Design

We didn’t even know a single word related to that software so we started taking lectures on YouTube but that was not enough because we have to make a professional turbine with best efficiency. So we met with an instructor in Rawalpindi who was mechanical engineer and knew a lot about turbines. We started taking classes and help related to our cased from that instructor. We made different models of turbine on that software. We performed many calculations related to the turbine like size of bucket, runner width, blade angles and spacing between the blades of turbine. After few weeks with the help of calculations and researches of different people, we came up with the best design of Pelton Turbine. The final design of the turbine is as under with 60 blades to convert maximum hydropower to mechanical power to run generator.

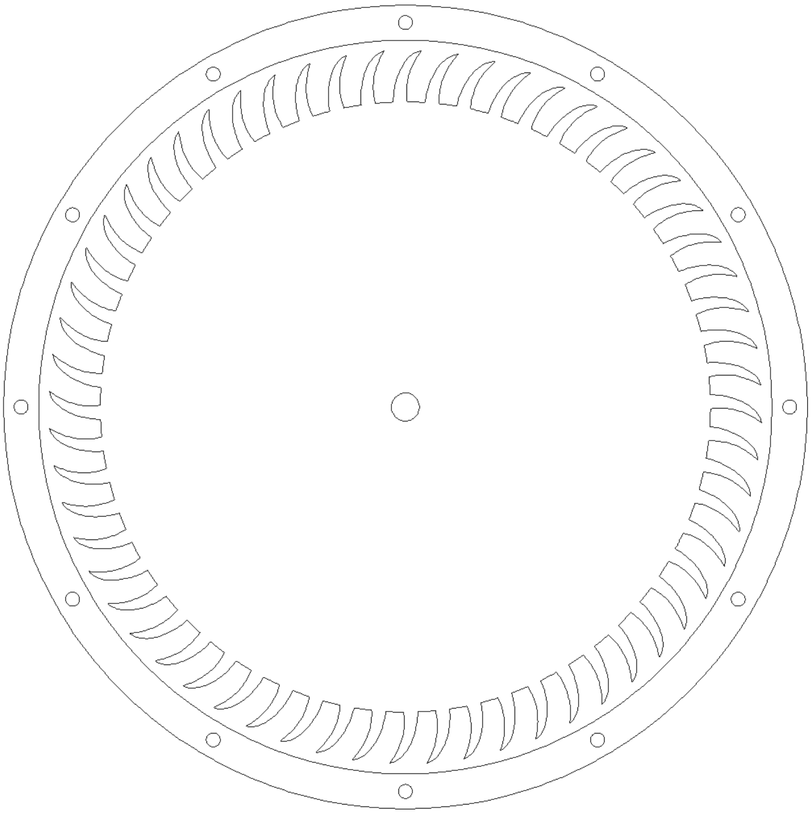

Fig. 3-2 Turbine Design on CorelDRAW

Number of blades is very important in designing of turbine. It is very important to select optimum numbers of blades to utilize the maximum water coming from the nozzle. If the number of blades are less it may not utilize the available water efficiently and if the number of number of blades are too much it may interruption and reduce the power.

$$n = k(\pi * D)$$

Where,

n = number of blades

k = 0.047

D = 20 cm

So

N= 0.047X3.14X200 = 30

For batter efficiency we can double the number of blades so we choose 60.

After the design of the turbine, next step was to design its casing with one inlet nozzle. Here is the casing design of this propeller type Pelton turbine assembly with 60 blades.

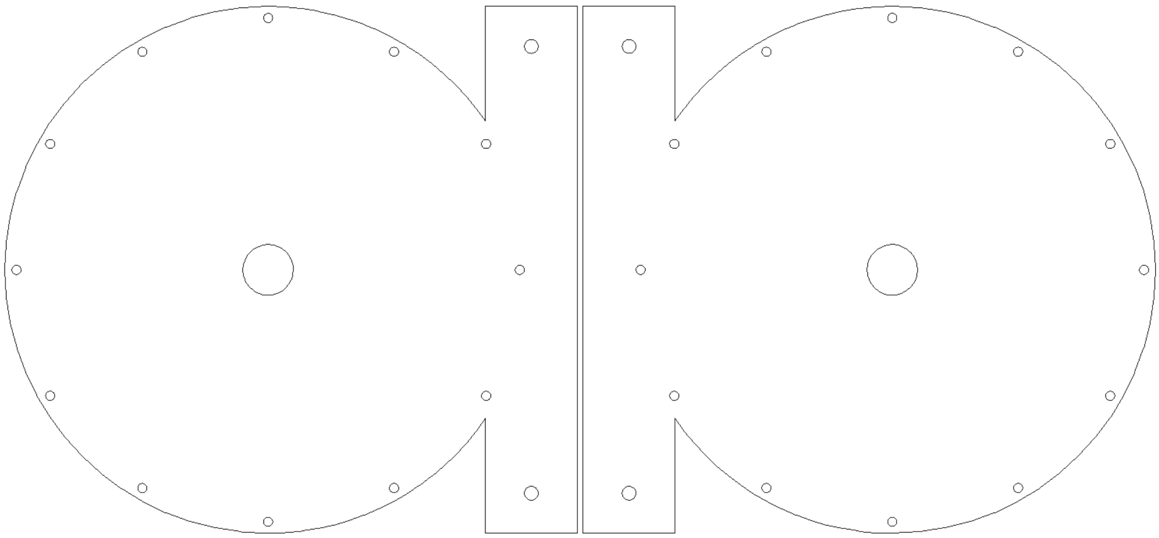

Fig. 3-3 Turbine Casting

High “velocity jets or water stream from a nozzle is used to drive the Turbine blade buckets. This results in an impulse which moves the turbine in circular motion. The water coming from the water reservoir strikes the turbine after passing through the inlet.

The final actual look of the turbine after 3D printing is as follows:

Fig. 3-4 3D Printed Pelton Turbine

3.2 Generator

A conversion of mechanical or chemical energy into electrical energy is done by using a device called generator. Generator uses turbines, motor or other electrical appliances to produced electrical energy from mechanical energy. It forces electrons from an external source to an electrical circuit but doesn't produce electricity itself. It can be used in variety of purposes and is available in different forms.

3.2.1 Working of Turbine

It works on the principle of faraday's law of electromagnetic induction. When conductor is placed in a magnetic field, emf is produced which is equal to rate of change of flux. Generators consist of electrical conductors, coils of copper wire tightly wound on the metal core mounted on the large conductors. The electrical current induces inside the conductor when electrical conductor moves in a magnetic field which interfaces with the electrons in the conductor.

The main parameters of the generators are as follows

- Movement of coil within magnetic field
- Magnetic field

The weak magnetic field in the iron pole appears when generator armature starts to move. As armature moves, it raises the voltage. This voltage is responsible for the production of electrical winding current which raises the magnetic field strength. So the field windings produce more voltage in the armature.

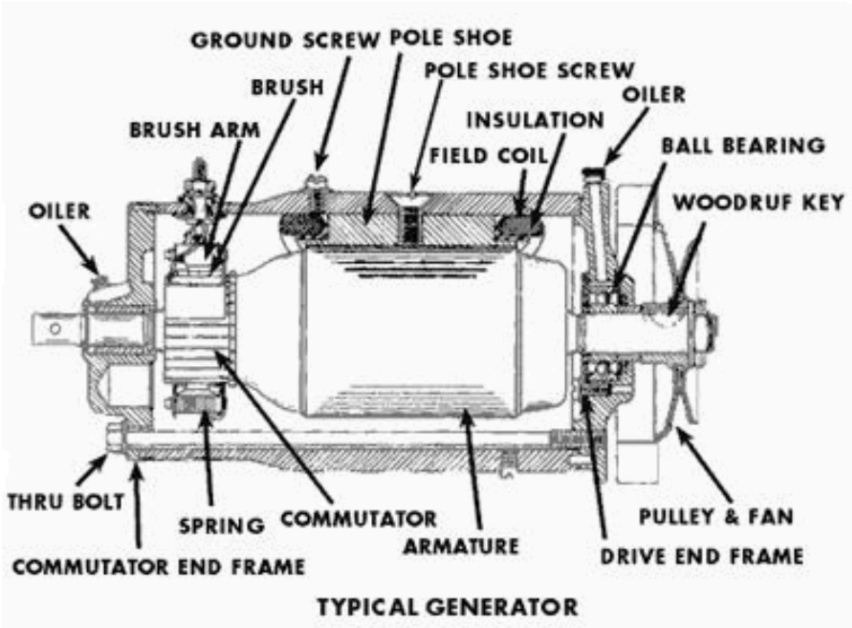

Fig. 3-5 Typical Generator

As in our case production of AC output is the main concern so there are two main types of AC generators

- Induction Generator
- Synchronous Generator

Our whole project assembly and simulations deals with synchronous generator which is also called alternator so now let's get into the detail of alternator.

3.2.2 Alternator

An alternator is a generator of electric power in a car and is a major component of the vehicle's charging system. All cars with an internal combustion engine except for some hybrids have an alternator. When an engine is running, the alternator charges the battery and supplies additional electric power for the vehicle electrical systems. Alternators produce AC power through electromagnetism formed through the stator and rotor relationship.

3.2.2.1 Construction of Alternator

Opening the alternator reveals a large cylinder with triangular finger poles around the circumference. This is the rotor. A basic alternator is made up of a series of alternating finger pole pieces placed around coil wires called field windings that wrap around an iron core on the rotor shaft. The rotor assembly fits inside the stator with enough room or tolerance between the two, so the rotor can spin at high speeds without striking the stator wall. On each end of the shaft sits a brush and a slip ring.

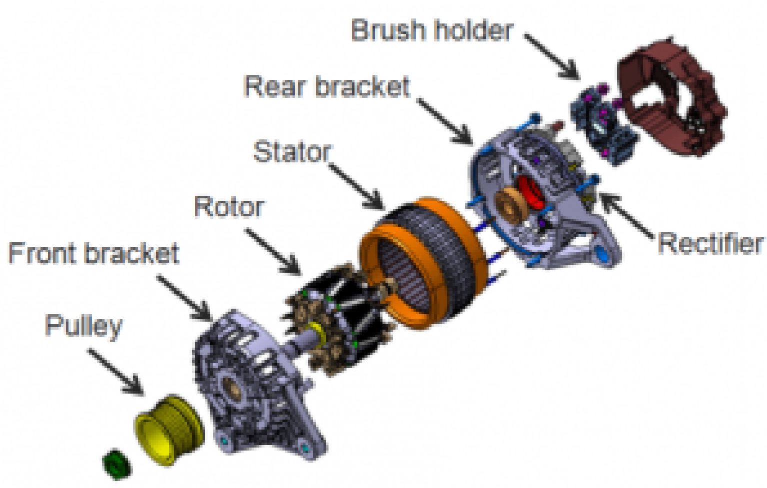

Fig. 3-6 Alternator Construction

3.2.2.2 Working of Alternator

As we touched on briefly, alternators generate power through magnetism. The triangular finger poles fixed around the circumference of the rotor are staggered, so the north and south poles alternate as they surround the wire rotor field windings. This alternating pattern creates the magnetic field that in turn induces voltage into the stator.

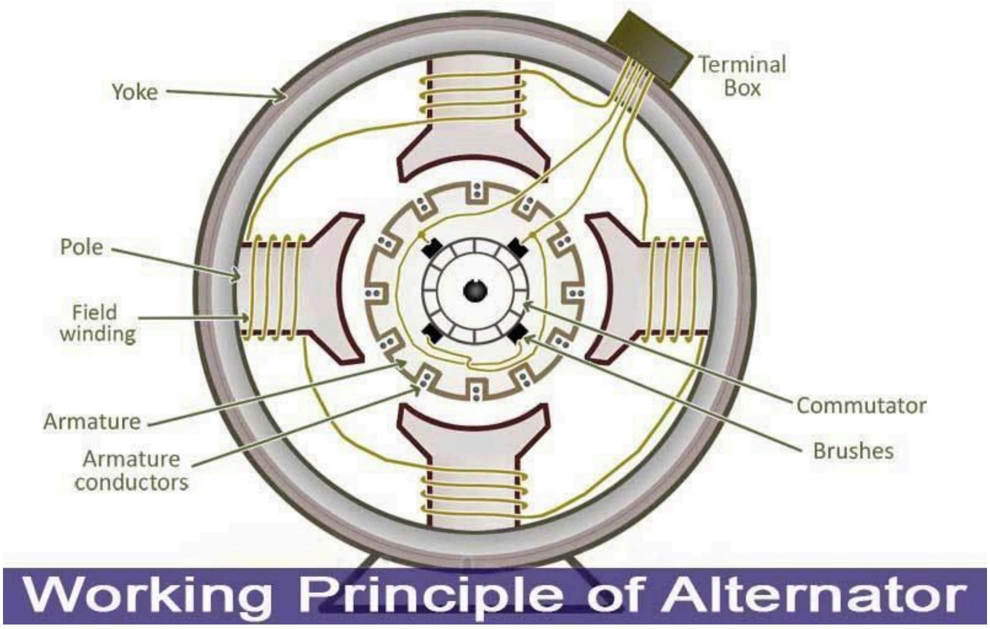

Fig. 3-7 Alternator Working

Output voltage is generated and controlled by the excitation winding o the alternator which is also called exciter. The main purpose of exciter in a generator is to provide stationary rotating magnetic field. Which is used to induce the emf in the armature coil. So, DC power is given to exciter and the exciter is nothing but a coil, and the exciter creates a magnetic field.

If a mechanical supply is given to the exciter, then there will be a rotating magnetic field which cuts the stationary armature coils and induces elf in the stationary armature coil.

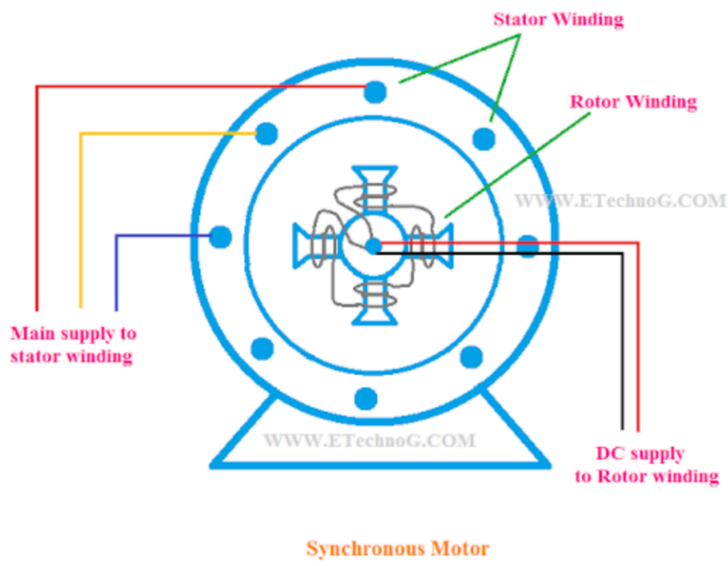

Fig. 3-8 Alternator internal windings

To produce voltage of desired magnitude the alternator needs a very big turbine which we were unable to design due to the corona situation and lockdown so we used the stepper motor instead which too provides the AC output if it is used as a generator so now let's get into it in detail.

3.3 Stepper Motor

A stepper motor is an electromechanical device it converts electrical power into mechanical power. It is a brushless DC electric motor that divides a full rotation into a number of equal steps.

3.3.1 Working of Stepper Motor

A stepper motors have a stationary part known as the stator and a moving part the rotor. On the stator, there are teeth on which coils are wired, while the rotor is either a permanent magnet or a variable reluctance iron core.

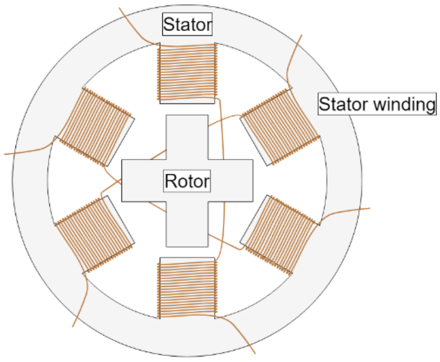

Fig. 3-9 Stepper Motor

By energizing one or more of the stator phases, a magnetic field is generated by the current flowing in the coil and the rotor aligns with this field. By supplying different phases in sequence, the rotor can be rotated by a specific amount to reach the desired final position. The following diagram shows the driving sequence of a stepper motor.

3.3.2 Types of Stepper Motor

There are three basic styles of stepper motor which are as:

- Permanent magnet rotor: The rotor is a permanent magnet that aligns with the magnetic field generated by the stator circuit.
- Variable reluctance rotor: The rotor is made of an iron core, and has a specific shape that allows it to align with the magnetic field.
- **Hybrid rotor:** This kind of rotor has a specific construction, and is a hybrid between permanent magnet and variable reluctance versions.

3.3.3 Pros and Cons

Pros:

- Due to their internal structure, stepper motors do not require a sensor to detect the motor position.
- The motor does need a driver, but does not need complex calculations or tuning to work properly. In general, the control effort is lower compared to other motors.
- Stepper motors offer good torque at low speeds, are great for holding position.

Cons:

- They can miss a step if the load torque is too high.
- These motors always drain maximum current even when still, which makes efficiency worse and can cause overheating.
- Stepper motors have low torque and become pretty noisy at high speeds.

Stepper motors have low power density and a low torque-to-inertia ratio.

3.3.4 Stepper Motor as Generator

Stepper motors generate power at low RPMs, which makes generating power an option. At a few hundred RPMs, usable power can be produced. Like wind turbines and other low RPM power sources this means the stepper motor can be driven directly from the source without having to use gearing. Any electric motor will also output a voltage when it's freely spinning. Stepper motors are much better at this because they have many times more poles to pass next to each other thus generating electrical pulses. These pulses are actually AC voltage that can be used to directly drive LEDs. Stepper motors can generate power from a tenth of a watt up to several watts. ... Like wind turbines and other low RPM power sources this means the stepper motor can be driven directly from the source without having to use gearing. Reaching an efficiency level above 35% is possible. Here the CRO waveform of the output of step motor.

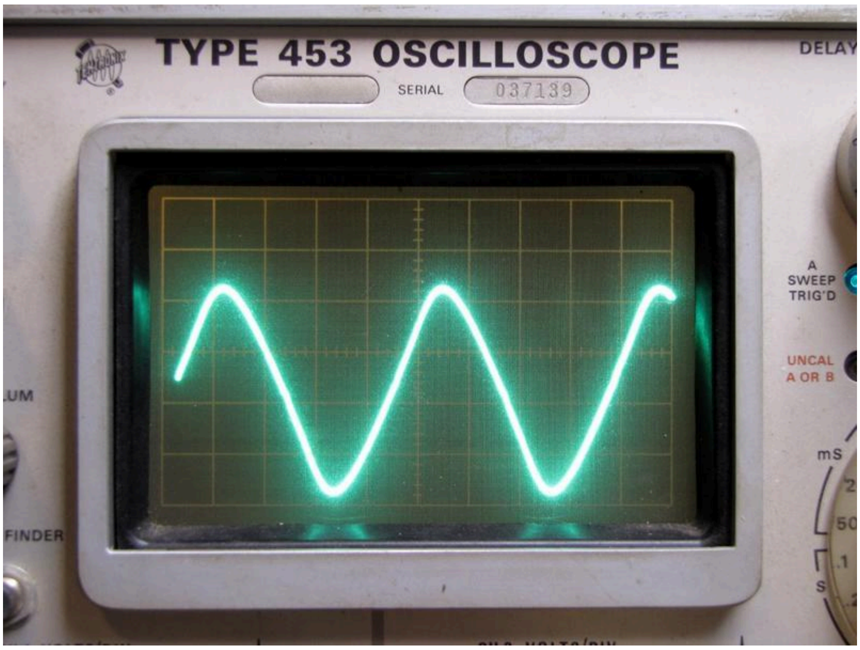

Fig. 3-10 AC Output of Stepper Motor as a Generator

Now this can either be used directly to run low wattage AC loads or to Run DC loads after rectification or to charge DC batteries.

3.4 Voltage Rectifier

A rectifier is an electrical device that converts AC, which periodically reverses direction, to DC, which flows in only one direction. The process is known as rectification.

3.4.1 Types of Rectification

There are two types of rectification as:

- Half-wave Rectification
- Full-wave Rectification

In the half-wave rectification, half of the sinusoidal wave either negative or positive too is cut and thus output is given as shown:

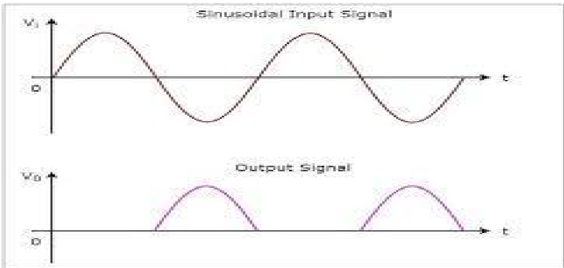

Fig. 3-11 Half wave Rectified waveform

In the full-wave rectification both positive and negative sides of sinusoidal came to the sine output as:

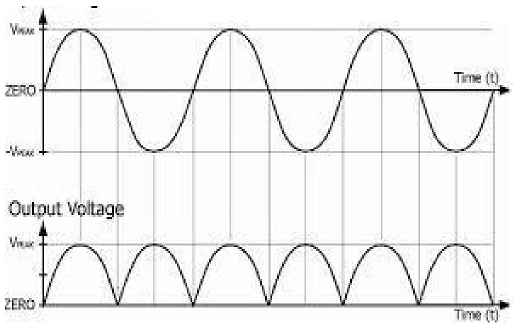

Fig. 3-12 Full Wave Rectified Waveform

3.4.2 Full Bridge Rectifier

A Full wave rectifier is a circuit arrangement which makes use of both half cycles of input AC and converts them to DC. This arrangement is known as a Bridge Rectifier.

3.4.2.1 Configuration of Bridge Rectifier

Power Diodes can be connected together to form a full wave rectifier that convert AC voltage into pulsating DC voltage for use in power supplies. A full wave rectifier circuit produces an output voltage or current which is purely DC or has some specified DC component. Full wave rectifiers have some fundamental advantages over their half wave rectifier counterparts. The average DC output voltage is higher than for half wave, the output of the full wave rectifier has much less ripple than that of the half wave rectifier producing a smoother output waveform.

The main advantage of the bridge circuit is that it does not require a special center tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below:

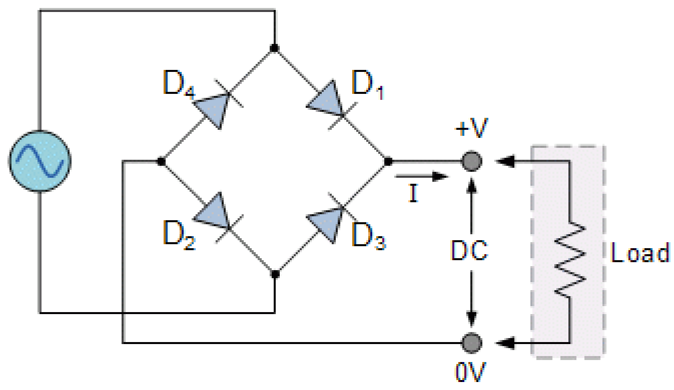

Fig. 3-13 Full Wave Rectifier Circuit

In this diagram D1 and D2 are at same direction allowing on cycle of input sinusoidal tall wave and D3 and D4 at same direction allowing other cycle of input sinusoidal wave. tall This is the basic arrangement of bridge rectifier.

Here is the CRO image of rectified generated output of step generator.

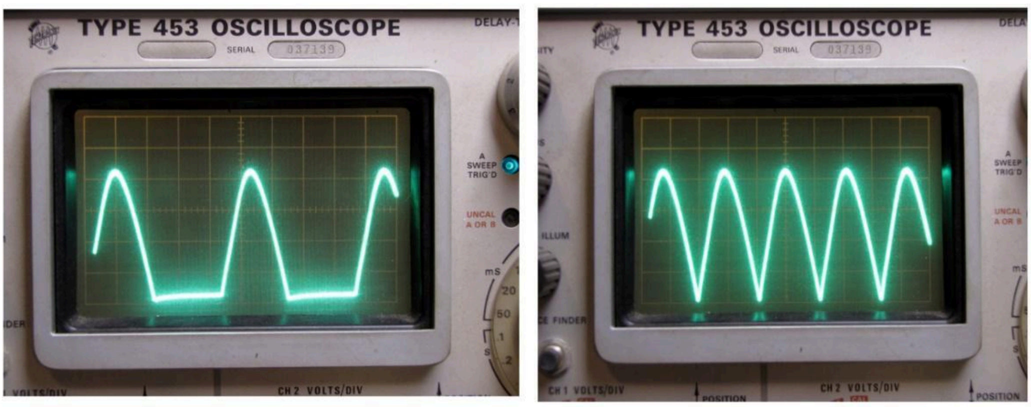

Fig. 3-14 Rectified Stepper Output

3.5 Transformer

A transformer is defined as a passive electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction. A transformer is an electrical device that trades voltage for current in a circuit, while not affecting the total electrical power. Transformers can be used either to increase the voltage also known as stepping up the voltage, or they can decrease the voltage also known as stepping down the voltage.

3.5.1 Working of Transformer

Mutual induction between two or more windings allows for electrical energy to be transferred between circuits. According to Faraday's law of electromagnetic induction, there will be an EMF induced in the second winding due to change in flux in the first winding. If the circuit of this second winding is closed, then a current will flow through it. This is the basic working principle of a transformer. The first winding and the second winding are known as primary and secondary winding respectively. Whether the transformer increases or decreases the voltage level depends on the relative number of turns between the primary and secondary side of the transformer. If there are more turns on the primary coil than the secondary coil than the voltage will decrease known as step down transformer while if there are less turns on the primary coil than the secondary coil than the voltage will increase known as step up transformer.

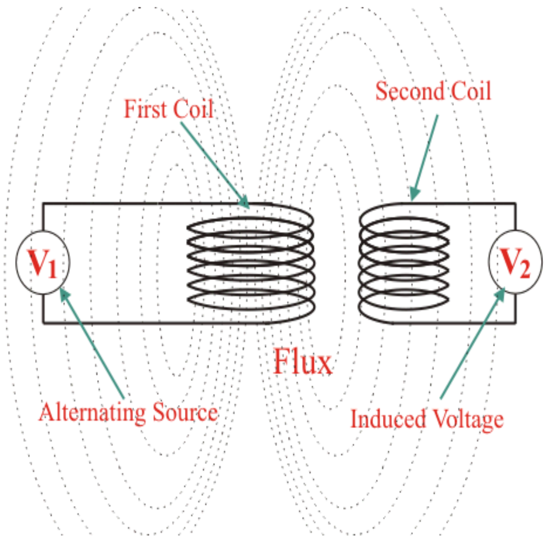

Fig. 3-15 Mutual Induction

3.5.2 Construction of Transformer

There three main parts of a transformer:

- Primary Winding of Transformer
- Magnetic Core of Transformer
- Secondary Winding of Transformer

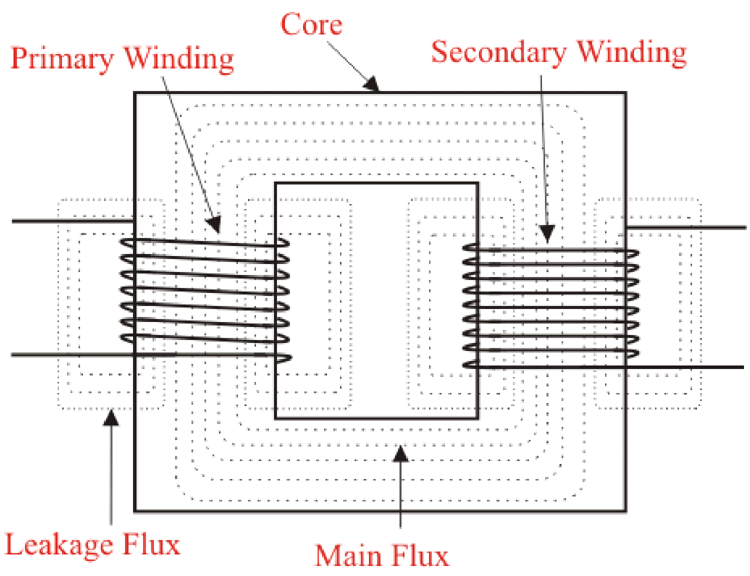

Fig. 3-16 Transformer

3.6 Power Inverter

Electronic inverters can be used to produce a smoothly varying AC output from a DC input. They use electromagnetic switches that flick on and off at high speed to reverse the current direction. Inverters like this often produce what's known as a square-wave output: the current is either flowing one way or the opposite way or it's instantly swapping over between the two states. They also use electronic components called inductors and capacitors to make the output current rise and fall more gradually than the abrupt, on/off-switching square wave output.

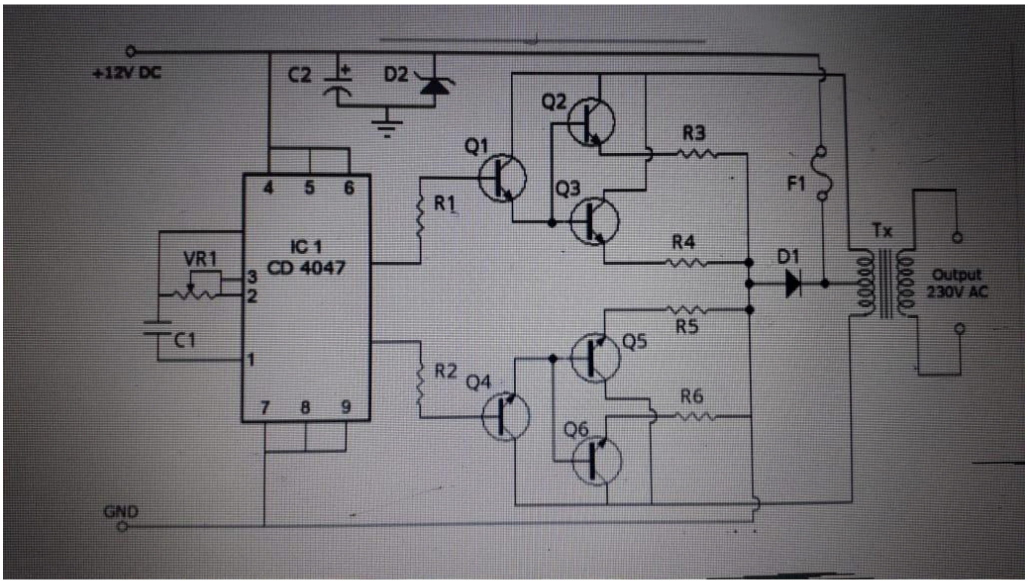

Fig. 3-17 Inverter Circuit

3.7 Arduino

Arduino is an open-source hardware and software company, project and user community that designs and manufactures single-board microcontrollers and microcontroller kits for building digital devices. The Arduino platform has become quite popular with people just starting out with electronics, and for good reason. Unlike most previous programmable circuit boards, the Arduino does not need a separate piece of hardware like a programmer in order to load new code onto the board. The Arduino IDE uses a simplified version of C++, making it easier to learn to program.

3.7.1 Components on Arduino UNO

There different families in Arduino but these components are common in each which are as:

- USB connector
- Power port
- Microcontroller
- Analog input pins
- Digital pins
- Reset switch
- Crystal oscillator
- USB interface chip

- TX RX LEDs

Fig. 3-18 Arduino

3.8 Handheld Tachometer

The handheld tachometer is a means of measuring revolutions within the industrial sector, either optically or mechanically. The handheld tachometer can be used for maintenance and calibration of machines that have moving parts. The principle is similar to a bicycle speedometer, where time will be measured until a wheel has completely turned. The handheld tachometer has two different measurement methods. The handheld tachometer may have a contact connection to the moving parts. Alternatively, the handheld tachometer works with reflecting marks. This will be secured on the moving part. As the laser strikes the reflecting mark during rotation, it will be reflected and detected in the handheld tachometer via a sensor. Rotation speed and speed can be seen on the handheld tachometer. The handheld tachometer may combine both possibilities (contact and non-contact connection).

Fig. 3-19 Handheld Tachometer

3.9 ACS712 Current Sensor

Measurement of voltage is passive task and it can be done without affecting the system. Whereas measurement of current cannot be detected directly as voltage. For measuring current in a circuit, a sensor is required.

ACS712 Current Sensor is the sensor that can be used to measure and calculate the amount of current applied to the conductor without affecting the performance of the system. ACS712 Current Sensor is a fully integrated, Hall-effect based linear sensor IC. This IC has a 2.1kV RMS voltage isolation along with a low resistance current conductor.

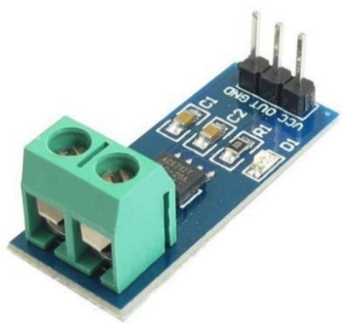

Fig. 3-20 ACS712 Current Sensor

3.9.1 Working Principle

ACS712 Current Sensor uses Indirect Sensing method to calculate the current. In Indirect Sensing, the current is measured by calculating this magnetic field by applying either Faraday's law or Ampere law. To sense current a liner, low-offset

Hall sensor circuit is used in this IC. This sensor is located at the surface of the IC on a copper conduction path. When current flows through this copper conduction path it generates a magnetic-field which is sensed by the Hall effect sensor. A voltage proportional to the sensed magnetic field is generated by the Hall sensor, which is used to measure current.

3.9.2 Applications

This IC can detect both AC and DC current so, it has a wide range of applications. This IC can measure current for high voltage loads operating at 230V AC mains. ACS712 is used in many industrial, commercial and communication applications. This IC is applicable for Automobile applications. Some of the typical applications of this IC can be found in motor control circuits, for load detection and management, SMPS, overcurrent fault protection circuit.

3.10 Smoke Sensor

A smoke detector is a device that senses smoke, typically as an indicator of fire.

3.10.1 Types of Smoke Detectors

The two most commonly recognized smoke detection technologies are ionization smoke detection and photoelectric smoke detection. Ionization smoke alarms are generally more responsive to flaming fires.

3.10.1.1 Ionization Smoke Detection

Ionization-type smoke alarms have a small amount of radioactive material between two electrically charged plates, which ionizes the air and causes current to flow between the plates. When smoke enters the chamber, it disrupts the flow of ions, thus reducing the flow of current and activating the alarm.

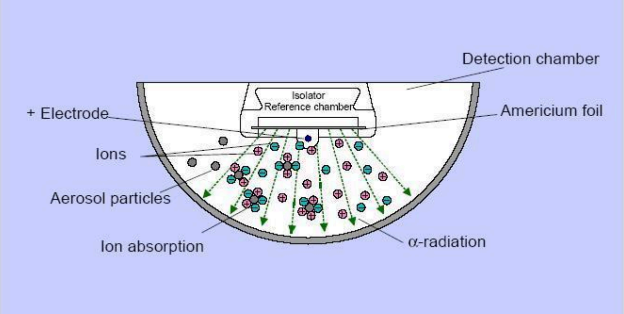

Fig. 3-21 Ionization Smoke Detection

3.10.1.2 Photoelectric Smoke Detection

Photoelectric-type alarms aim a light source into a sensing chamber at an angle away from the sensor. Smoke enters the chamber, reflecting light onto the light sensor; triggering the alarm.

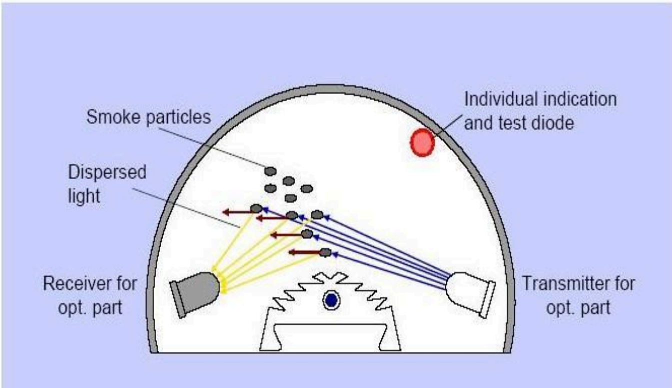

Fig. 3-22 Photoelectric Smoke Detection

3.11 LCD 20 x 4

A 20x4 LCD display is very basic module and is very commonly used in various devices and circuits. These modules are preferred over seven segments and other multi segment LEDs. A 20x4 LCD means it can display 20 characters per line and there are 4 such lines. In this LCD each character is displayed in 5x7 pixel matrix.

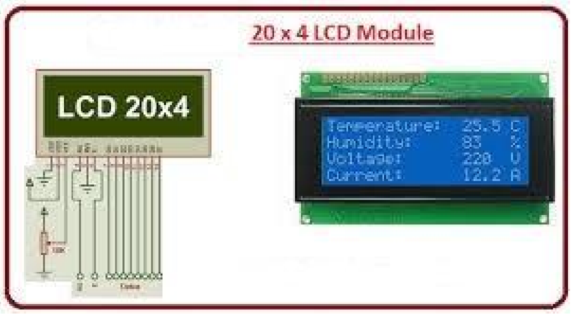

Fig. 3-23 20x4 LCD

3.12 ESP8266 NodeMCU 12E

ESP8266 NodeMCU 12E is developed by Shenzhen Doctors of Intelligence & Technology (SZDOIT) based on the low power UART-WiFi ESP8266, which is for mobile devices and application of IoT (Internet of Things). ESP-12E is widely applied to internet, intelligent home and industry etc.

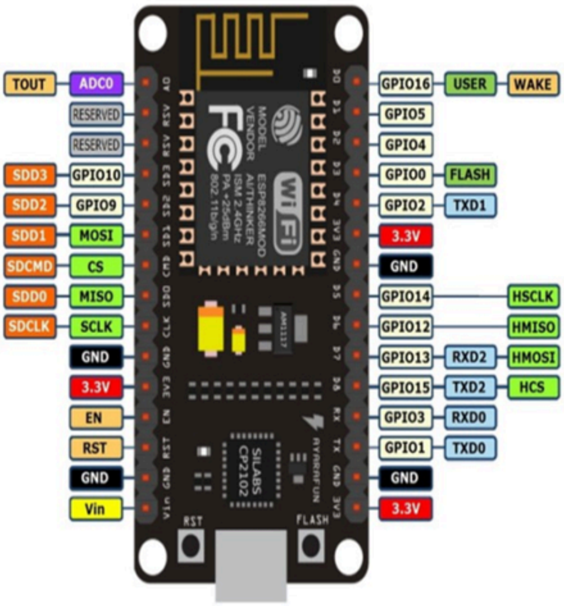

Fig. 3-24 ESP8266 Node MCU

The ESP8266 is SOC with integrated TCP/IP protocol stack that can give any microcontroller access to Wi-Fi network. It is capable of either hosting an application or offloading Wi-Fi networking functions from another application processor. Each module comes pre-programmed with an AT command set firmware so you can use it directly with Arduino device and get Wi-Fi -ability as a Wi-Fi Shield offers. The ESP8266 module is cost-effective board.

3.13 Servo Motor

A servo motor is a rotary actuator or a motor that allows for a precise control in terms of the angular position, acceleration, and velocity. Basically it has certain capabilities that a regular motor does not have. Consequently, it makes use of a regular motor and pairs it with a sensor for position feedback.

Fig. 3-25 Servo Motor

3.14 Simulation

Simulation of the project was done in proteus software 8.9 version. The overall simulation is as under.

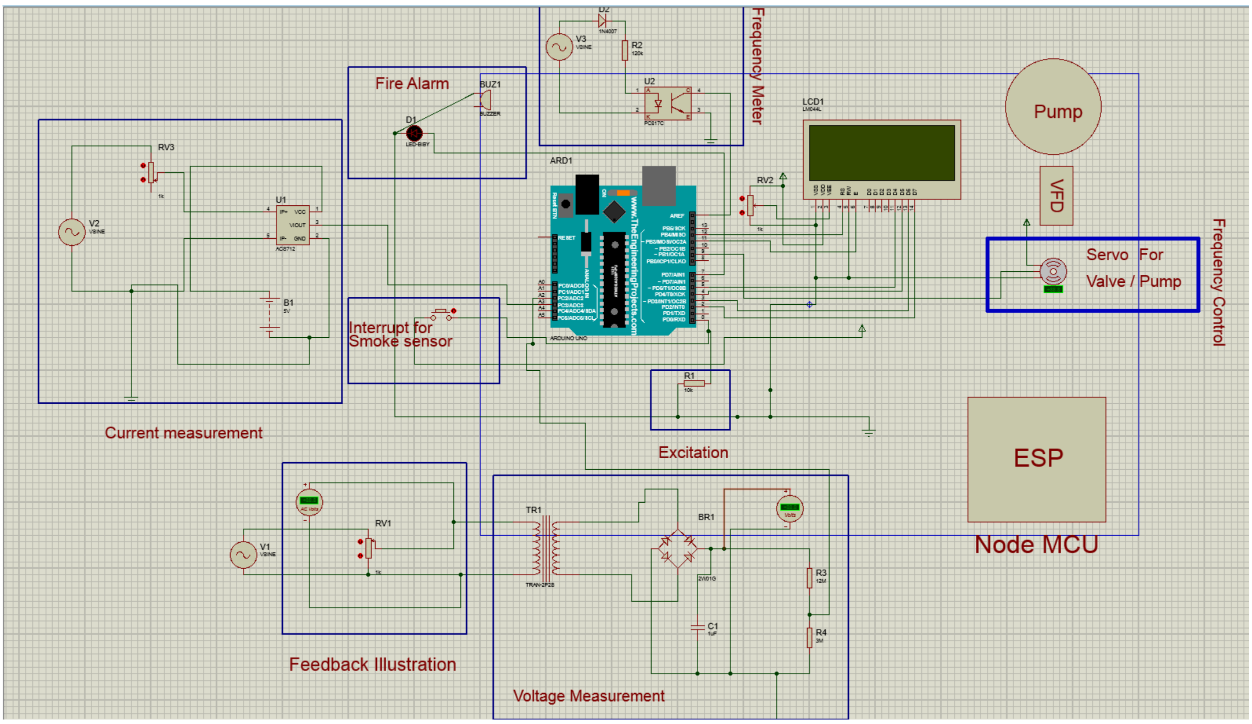

Fig. 3-26 Smart Hydropower System Simulation

3.14.1 Frequency Measurement

Frequency of AC is found with the help of photo coupler PC 817C and a diode 1N4007 as follows:

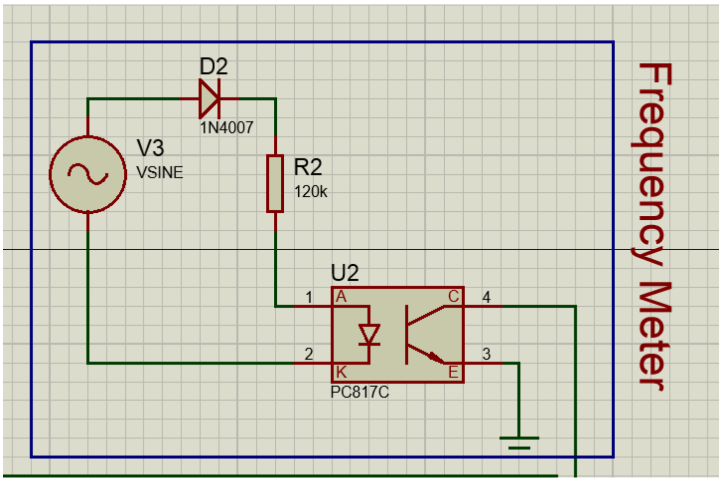

Fig. 3-27 Frequency Measurement Circuit

3.14.2 Current Measurement

Current is sensed and measured by 712 current sensor whose details are already given in this chapter previously.

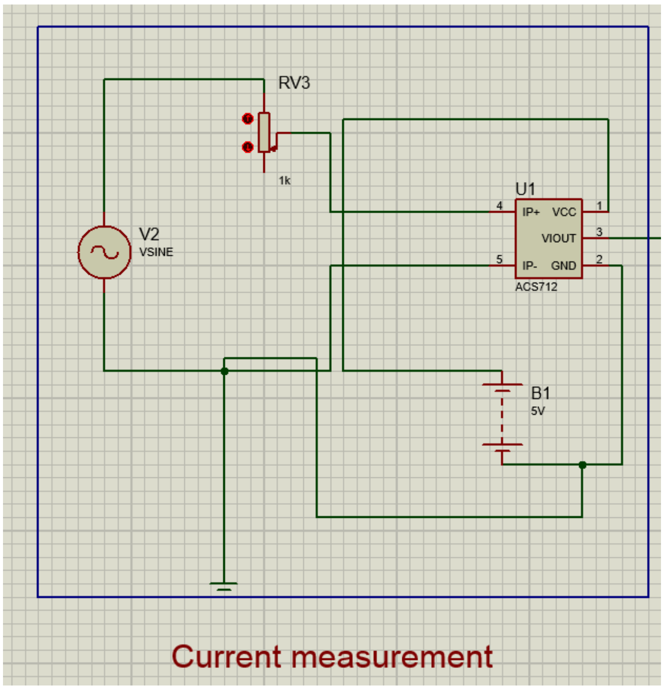

Fig. 3-28 Current Measurement Circuit

3.14.3 Voltage Measurement

Voltage is measured by stepping it down and rectifying it and after rectification dividing it through circuit divider so that it can be fed to the controller.

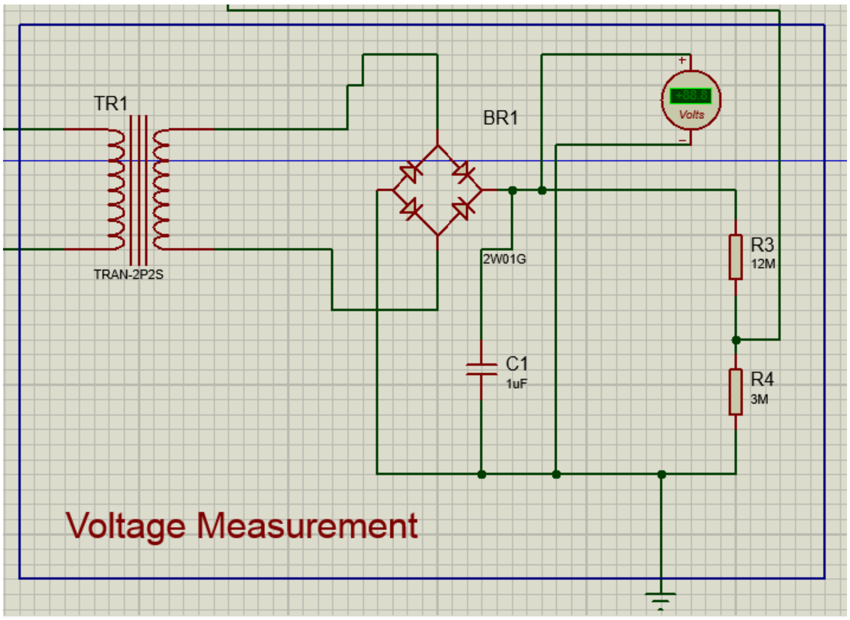

Fig. 3-29 AC Voltage Measurement Circuit

3.14.4 Feedback Circuit

This circuit is only an illustration circuit to see how our system will react if the voltage suddenly increases or decreases

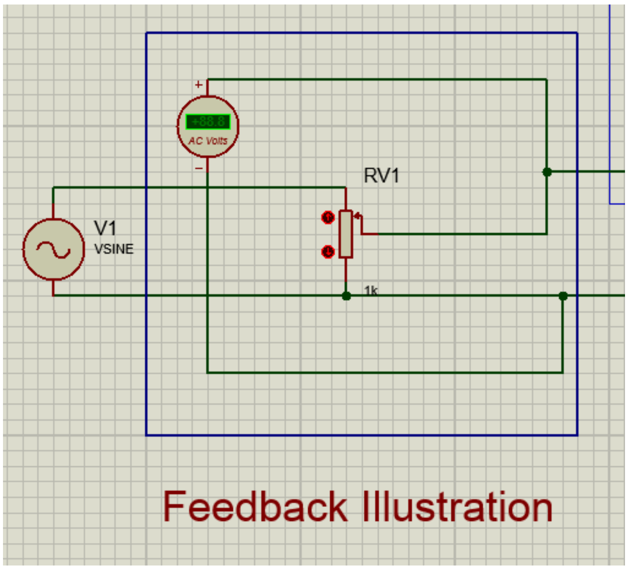

Fig. 1-30 Feedback Illustration Circuit

3.14.5 Output Frequency Control

Pump voltage increase or decrease the voltage and frequency of the AC generator that we are using. This thing is done by a regulator that is coupled with a servo motor which rotates according to the requirement and maintained the constant frequency of the system.

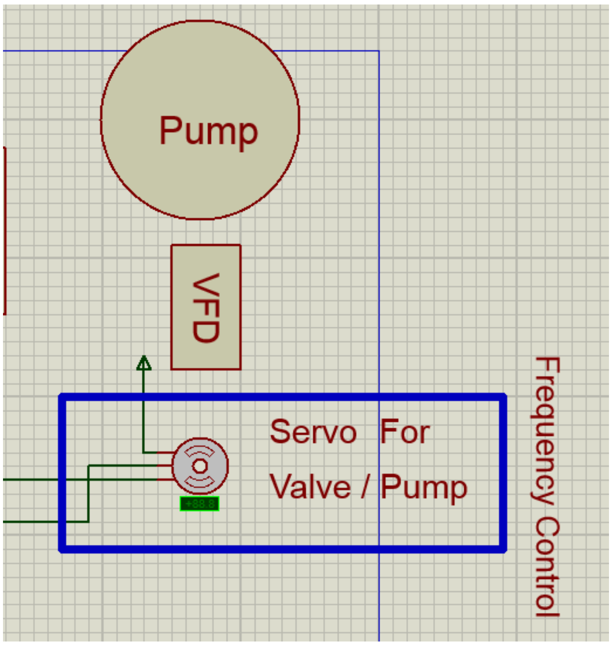

Fig. 3-31 Frequency Control using Servo

3.14.5 Output Voltage Control (Exciter)

As we can't simulate an alternator or synchronous motor in a proteus so we have only shown he excitation winding of alternator by a resistor (it should be an inductor in reality but as it is only an illustration).

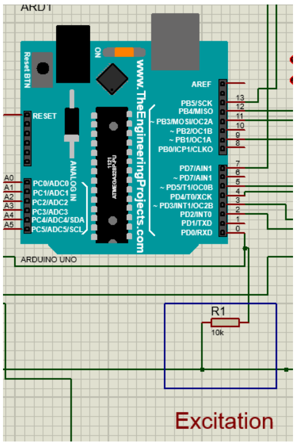

Fig. 3-32 Output voltage control circuit

3.14.6 Fire/Smoke Alarm

Fire Alarm and smoke sensor is there to detect any internal of external thermal hating faults that lead to fire and smoke.

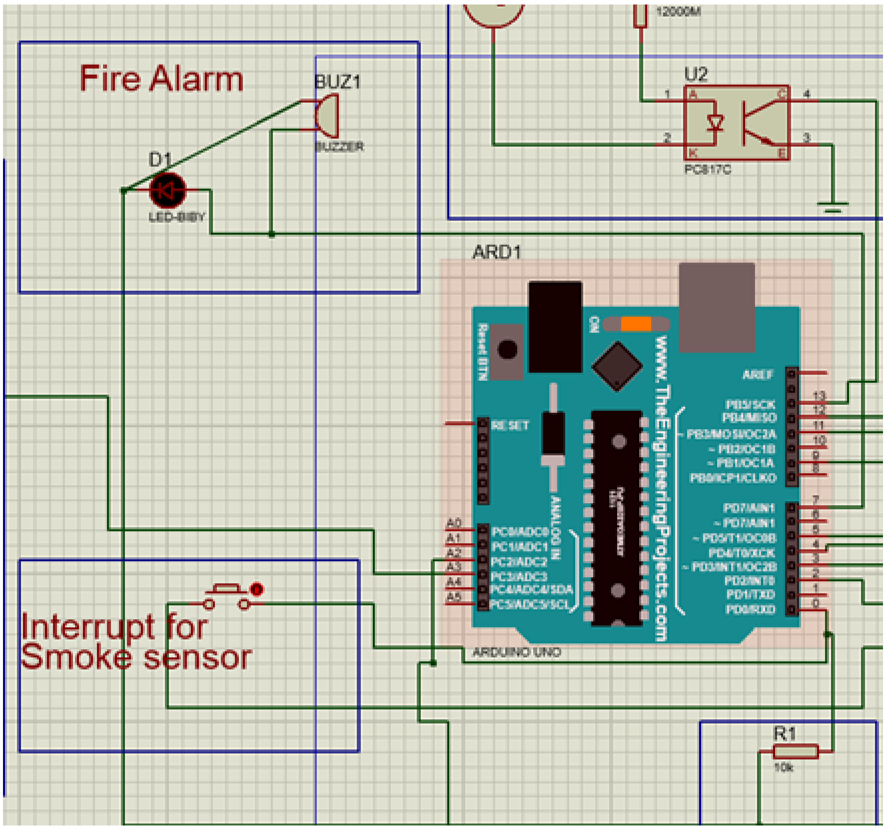

Fig. 3-33 Fire Alarm and smoke sensor

Chapter 4

Results

4.1 DC Current Measurement

Formula used to find Direct Current in Amperes:
As 712 current sensor was used to measure the current of the load so following points should be in or concern before using it to sense current

- 0.185 is the step size
- 1A current = 0.185 mV
- 2.5 V is the reference voltage

So,
5A of current means = 0.185*5
= 1 approx.

2.5 V = No current
3.5 V = 5 A

So the current was fined through

Current =(float)(((ii*0.00488281)-2.5)/0.185)

4.2 AC Voltage Measurement

Using the proportional method to find the unknown voltage:

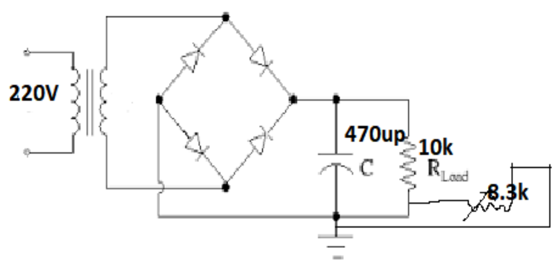

Fig. 4-1 AC Voltage Measurement

6 : 5 = 10k : x

x=10k * (5/6)x

x=8.3k

adc = adc *0.00488

$$=[(adc * 0.00488)/5]*11$$

$$=(adc*0.0048/5)*11*0.727*(220/8)$$

$$=0.2146* adc$$

DC voltmeter**:**

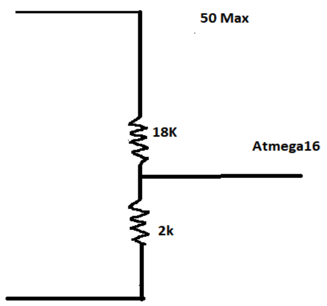

Fig. 4-2 DC Voltage Measurement

DC voltage =[(adc*0.0048)/5]*50

4.3 AC Current Measurement

AC voltage measurement is done through the following steps successfully.

- First we need to interface our module with the Arduino board and check the signal shape when the dimmer is ON – Full Cycle – Half Cycle.
- Then we are going to check a simple code that doesn't require any library, but it works only with Sinewaves signal (it will be tested).

After that we are going to see the code that will measure the AC, and use the LCD.

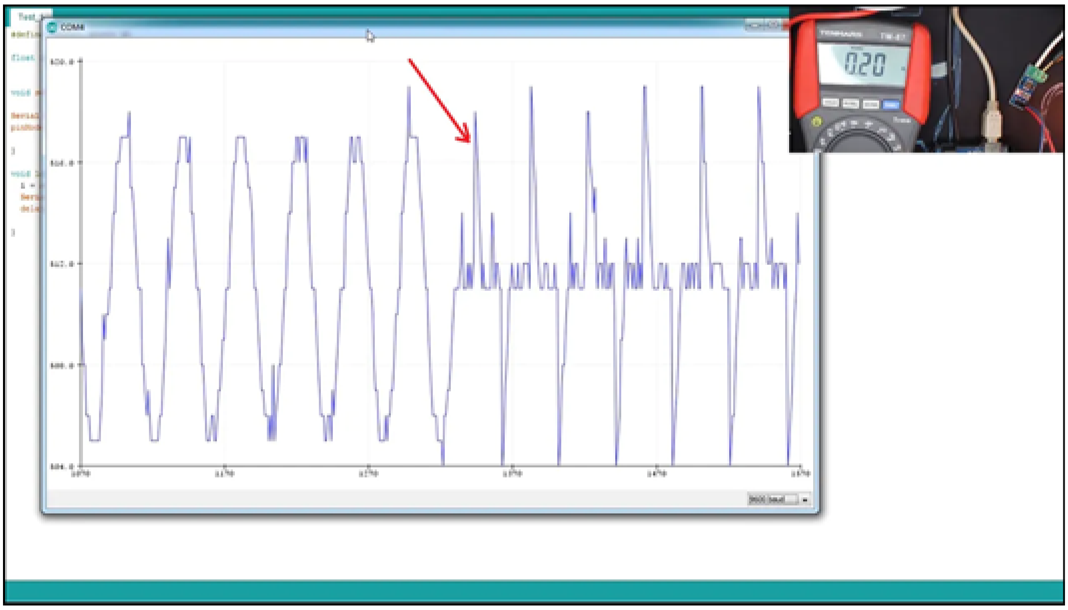

Fig. 4-3 AC Measurement on Serial Monitor

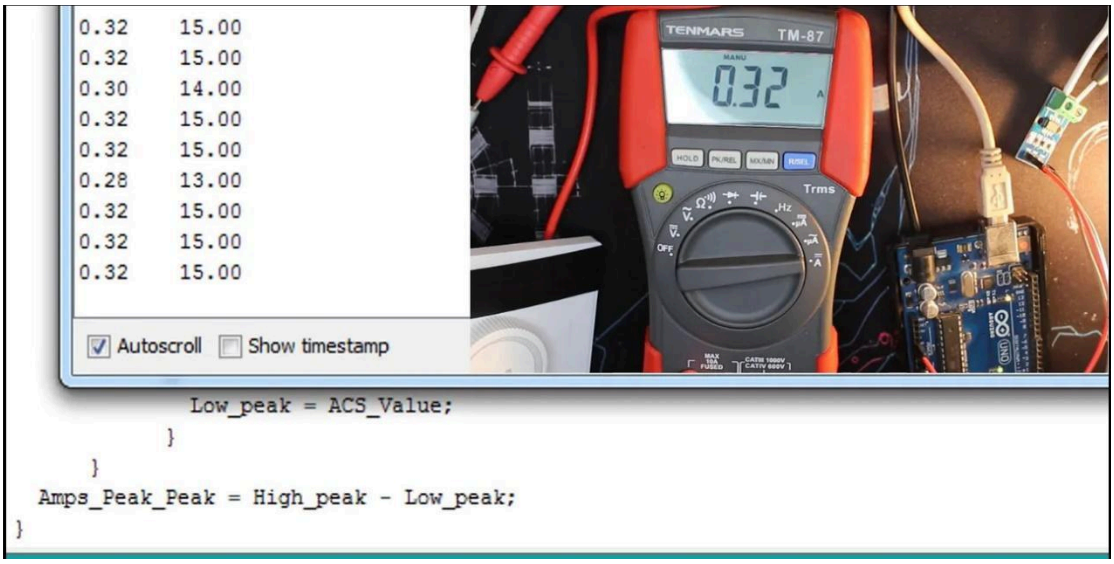

Fig. 4-4 Serial Monitor Displaying Results

4.4 Frequency Measurement

The AC input is connected to the circuit as shown where diode 1N4007 is used to eliminate negative half cycles because the PC817 optocoupler maximum reverse voltage is 6V. The optocoupler is connected to AC main through 120k ohm resistor (and also the 1N4007 diode) which limits the current that passes through the optocoupler LED (IF). With the 120k ohm resistor and with source of 220V, the peak forward current is equal to (neglecting diode voltages): 220x√2/120k = 2.59 mA and the RMS current (half wave) = 2.59/2 = 1.3 mA. The output of the PC817 optocoupler is connected to the Arduino as follows:

The emitter is connected to Arduino GND; the collector is connected to Arduino digital pin 2. This pin is also for external interrupt 0. The collector is connected to Arduino +5V pin through pull up resistor of 10k ohm.

When the optocoupler LED is forward biased, its output is (transistor collector) is attached to GND (logic 0). During signal negative cycles the PC817 output is logic 1. With the optocoupler high voltage side is isolated from low voltage side.

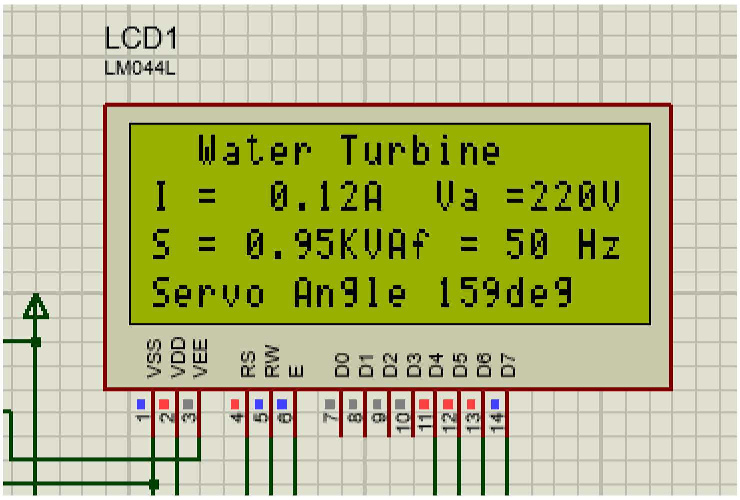

Fig. 4-5 50 Hz Frequency

4.5 Online Monitoring

SHPP online website to showcase system stats and errors if any, microcomputer will make call to online API built in PHP and will store values in MySQL database. System will then showcase values on front end website **shpp.curics.com.** Here is showcase of all technologies we have used for developing the system.

4.5.1 Technology Stack Used

- PHP
- HTML5
- CSS3
- Bootstrap 4
- MYSQL Database

4.5.2 Domain & Hosting

- Interserver Shared Hosting
- Godaddy Domain Name

4.5.3 Features of Online Platform

- Showcase Alerts/Errors
- Showcase current stats
- Showcase previous values changes
- Showcase product details/values

4.5.4 Technical Feasibility

All the technologies used in developing this system was open source, we did not need to buy any license or source code. PHP is open source back-end language we used for development, for front-end bootstrap is free to use CSS3 framework.

4.5.5 Operational Feasibility

Our platform is very easy to operate in future, we are tried keeping our non-technicality regarding web development in mind, keeping it as simple to operate in future, making changes is quite easy and fast.

4.5.6 Economical Feasibility

Our platform is quite economical we have bought domain name from GoDaddy which costs us Rs. 1000/Year and bought shared hosting package from interserver which costs us low as well.

4.5.7 Design Flow/Monitoring Results

4.5.7.1 Screen 1

The first screen showcasing the current stats of our system, all the images showing are free to use and available with free license for commercial use, you can find copies of images from flaticon.com

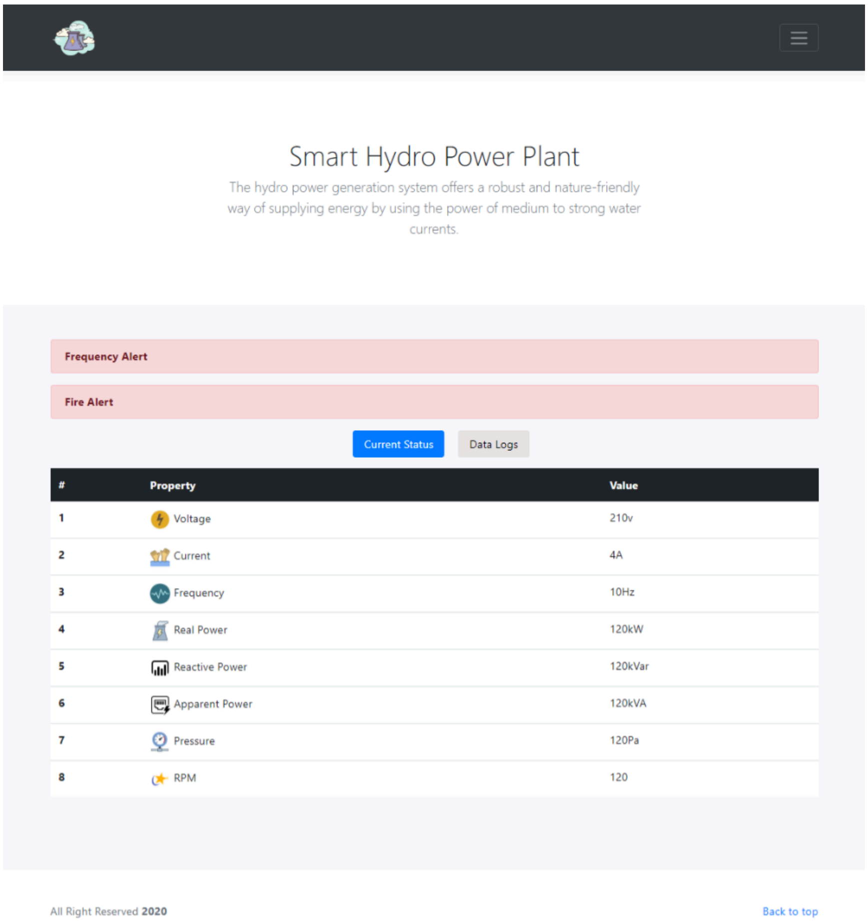

Fig. 4-6 Screen 1 of shpp.curics.com

4.5.7.2 Screen 2

This screen showcasing all past data changes and logs of our platform, we have track record of one month, we can extend it later if needed.

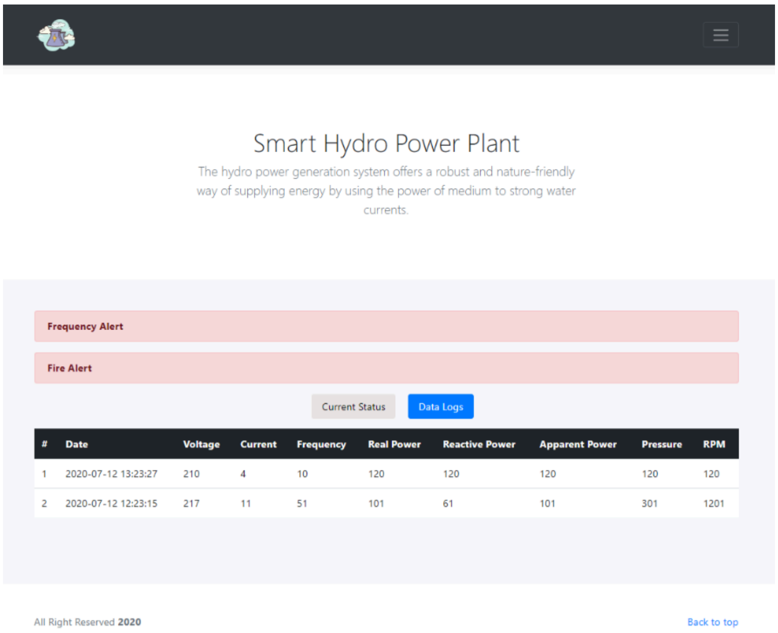

Fig. 4-7 Screen 2 of shpp.curics.com

Chapter 5

Conclusion

Smart hydropower plant went exactly according to our expectations and we succeeded in achieving the output of desired frequency and voltage i.e. 220 V 50 Hz. High efficiency voltage regulator circuit was used to adjust the voltage of the pump to maintain frequency to around 50 Hz. The output data of power plant was continuously logged to the created site. Let's conclude it step by step.

It started with the design of Pelton turbine that can give us at least 200W power but soon we realized that it is too much power to be achieved at this small level because I needed an alternator of about 500 KVA which required a large turbine. So we reduced our output power goal to around 30 to 40 Watts and began designing the turbine of that much power. We took the help of an engineer from Rawalpindi who helped us design the required turbine. Now for generation need we had 2 options either we can use an alternator or a step motor as a generator. But as due to lockdown using alternator was not possible as it needed great hardware support so we went with stepper motor and used it as a generator to generate an output of around 15 to 20 volts AC. Then to check voltage and frequency drop on load increase 3 loaded were connected to circuit. As we know that output frequency of the synchronous generator depends on the voltage in the excitation winding i.e. DC excitation. So to maintain the constant output logic was to increase the DC excitation on the increase of load. Similarly, we know that on sudden load changes frequency of the generator become unstable i.e. it tries to jump up if suddenly a heavy load is disconnected and it drops on overload. To resolve this issue, we changed the voltages of the pump which was supplying the turbine with water. When load increased frequency began getting lower and lower which was sensed by the microcontroller (Feedback). On the bases of it, microcontroller mapped the voltages of the pump through a servo-regulator assembly. So by controlling the servo angle we controlled the voltages of the pump through the regulator.

Now our next aim was to step up the voltage to utility range. So we stepped the voltage to around 220V and connected a load with it too.

Then after resolving the stability issue we increased the safety of the system by applying the smoke and fire alarm in the system.

Now next step after stability and safety was flexibly of the system Flexibility of the system was achieved by adding the battery backup system. The generated output of the step generator is performing two functions. First it is running the load and second, it is charging the batteries of the battery backup system.

Final characteristic of this project is the online monitoring of the system. It was done by the NodeMCU module which is a Wi-Fi module. Using php and HTML5 mainly a site was created from where we can check the output parameters of the system anytime and from anywhere.

Chapter 6

Suggestions for Future Work

The idea and results of this research can be used for the hydropower generators at higher levels. In Pakistan, the hydropower plants are not monitored and controlled through internet. As everything in the world is moving towards smartness so there is a great need to convert the manual operated systems in the hydropower plants to IoT based systems. The same idea of the project can be utilized there. It will greatly reduce the maintenances cost of the power plants. Moreover, the stability of the system is greatly increased and overall system become way more efficient.

6.1 Supervisory Control and Data Acquisition

Automation is the use of control systems, intelligent electronic devices, instruments and new communication technologies to enhance the quality of work, better monitoring and controlling of the system to reduce the human interface with system. Automation plays an increasingly important role in the world economy. Automation has had a notable impact on power sector beyond manufacturing industries also. Now a day's Power plant control systems have evolved from SCADA-centered platforms to communicate with industry standard hardware and software, and then to integrate power plant automation systems with almost unlimited connectivity. The system will embrace the latest information and communication technologies (ICT), and multiple communication channels (some traditional and some personal, such as instant messaging).

6.2 IoT and Future of Hydropower

Hydropower has evolved through multiple industrial revolutions. Today, the Internet of Things (IoT) offer solutions to take the industry to a whole new level. Rules-based analysis, advanced pattern recognition, machine learning, and augmented reality can all help optimize performance and assist operators in achieving greater reliability.

6.3 App Development

As technology is improving with every single day. According to a survey conducted in 2019 it was estimated that around 3.2 billion people in this world are using smarts phones. So national level app development can be proved effective. User can easily view the system status and output parameter from anywhere in Pakistan. As common layman is not interested in such type of information but its access can be given to the electrical engineers which will help them in understanding the power system effectively.

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Abbreviations

Abbreviations should be placed at the end. Sample is given below:

MW: Mega Watt

SCADA: Supervisory control and data accusation.

KVA: Kilo Volt Ampere

ADC: Analog to Digital

IC: Integrated Circuit

IEEE: Institute of Electrical and Electronics Engineers

GCU: Graphic Control Unit

MCU: Multipoint Control Unit

MW: Mega Watt

Hz: Hertz

Arduino Code

Without Battery Backup with Alternator

```
// include the library code:
#include <LiquidCrystal.h>
#include <Servo.h>
float V,Va;                                   // Voltage variable
float I;
float S;
int f=7, O=0;
Servo myservo;

// initialize the library by associating any needed LCD interface pin
// with the arduino pin number it is connected to
const int rs = 12, en = 11, d4 = 5, d5 = 4, d6 = 3, d7 = 2;
LiquidCrystal lcd(rs, en, d4, d5, d6, d7);
int i=0,val;
void setup() {
  // set up the LCD's number of columns and rows:
    Serial.begin(9600);
  lcd.begin(20, 4);
  // Print a message to the LCD.

   myservo.attach(9);
   pinMode(A0, INPUT);
   pinMode(O, INPUT);
```

```
  pinMode(A2, INPUT);

  pinMode(A3, INPUT);

  pinMode(f, OUTPUT);


}


void loop() {

 lcd.clear();

   lcd.setCursor(0, 0);

 lcd.print("  Water Turbine  ");

 V = analogRead(A2);                                   // Read the voltage on the A0 pin

// Set R equal to the raw ADC value

 delay(10);

 Va = (V/1023);

 Va= Va*366;                                  // Convert the digital ADC value to volts

 I= analogRead(A3);

 I= I/1023;

 S=(I*V);

 S= S/1000 ;


if(digitalRead(0)==HIGH)

  {

   digitalWrite(f,HIGH);

   lcd.clear();

   lcd.print(" Fire Alert !!");
```

```
}
else
{digitalWrite (f,LOW);}
sensorValue = Va ;
val = map(sensorValue, 120 , 350, 0, 180);
myservo.write(val);
lcd.setCursor(0, 1);
lcd.print("I = ");
lcd.setCursor(5, 1);
lcd.print(I);
lcd.setCursor(9, 1);
lcd.print("A");

 lcd.setCursor(12, 1);
lcd.print("V = ");
lcd.setCursor(16, 1);
lcd.print(Va);
lcd.setCursor(19, 1);
lcd.print("V");

delay(100);

 lcd.setCursor(12, 1);
lcd.print("Va = ");
lcd.setCursor(16, 1);
```

```
lcd.print(220);
lcd.setCursor(19, 1);
lcd.print("V");
lcd.setCursor(0, 2);
lcd.print("S = ");
lcd.setCursor(4, 2);
lcd.print(S);
lcd.setCursor(8, 2);
lcd.print("KVA");


lcd.setCursor(11, 2);
lcd.print("f = ");
lcd.setCursor(15, 2);
lcd.print(50);
lcd.setCursor(18, 2);
lcd.print("Hz");


lcd.setCursor(0, 3);
lcd.print("Servo Angle ");
lcd.setCursor(12, 3);
lcd.print(val);
lcd.setCursor(15, 3);
lcd.print("deg");
```

```
  delay(500);
    lcd.clear();
}
```

With Battery Backup and Stepper Motor as Generator

```
#include <Wire.h>
#include <LiquidCrystal_I2C.h>
#include <Servo.h>


Servo myservo;
LiquidCrystal_I2C lcd(0x20, 20, 4);
int val;
int pos = 75;
float i = 0, watt,fire=0;
float voltage;


const int currentPin = A1;
int sensitivity = 66;
int adcValue = 0;
int offsetVoltage = 2472;
double adcVoltage = 0;
int currentValue = 0;
void setup() {
  // set up the LCD's number of columns and rows:
  Serial.begin(9600);
  lcd.backlight();
```

```
  lcd.init();

  myservo.attach(9);
  pinMode(A0, INPUT); // Generator Feedback
  pinMode(A1, INPUT); // CT

  pinMode(8, INPUT);   // smoke sensor
  pinMode(11, OUTPUT); // fire alarm buzzer
  pinMode(13, OUTPUT); // MOTOR relay
}

void loop() {
  if (digitalRead(8) == HIGH)   // if FIRE detected
  {
    fire++;
    digitalWrite(13, HIGH);
    digitalWrite(11, LOW);
    lcd.clear();
    lcd.setCursor(0, 1);
    lcd.print("    Alert....!!!!   ");
    digitalWrite(11, HIGH);
    delay(300);
  }

  if (fire == 0)
```

```
{
 if (i == 0)                    // INITIALIZE
 { myservo.write(75);
  digitalWrite(13, HIGH);
  lcd.setCursor(0, 1);
  lcd.print("      Smart      ");
  lcd.setCursor(0, 2);
  lcd.print("  Hydropower Plant  ");
  delay(2000);
  lcd.clear();
  lcd.setCursor(0, 1);
  lcd.print(" UET Taxila ");
  lcd.setCursor(0, 2);
  lcd.print("         ");
  delay(2000);
  lcd.clear();
  lcd.setCursor(0, 1);
  lcd.print(" Starting Turbine...");
  myservo.write(75);
  digitalWrite(13, LOW);
  delay(3000);
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("  Hydropower Plant  ");
  lcd.setCursor(0, 1);
```

```
    lcd.print("Frequency    =");
    lcd.setCursor(0, 2);
    lcd.print("Current      =");
    lcd.setCursor(0, 3);
    lcd.print("Power        =");
    i++;
  }
  int sensorValue = analogRead(A0);                          // Reading voltage from
generator
  voltage = sensorValue * (5.0 / 1023.0) * 10;

  adcValue = analogRead(currentPin);                         // reading current sensor
  adcVoltage = (adcValue / 1024.0) * 5000;
  currentValue = ((adcVoltage - offsetVoltage) / sensitivity);
  watt = currentValue * 12;

  int  f = map(pos, 75, 160, 49.5, 50.5 );                   // frequency mapping with
servo angle
  lcd.setCursor (16, 1);
  lcd.print    (f);
  lcd.setCursor (16, 2);
  lcd.print  (currentValue, 1);
  lcd.setCursor (16, 3);
  lcd.print  (watt, 1);
  Serial.println(voltage);
```

```
    Serial.println(pos);
    Serial.println("-----------");
    Serial.print("Current = ");
    Serial.println(currentValue);
    Serial.println("-----------");
    if (pos < 160 && voltage < 12.5)
    { myservo.write(pos);
      delay(100);
      pos++;
    }

    if (pos > 70 && voltage > 12.5)
    { myservo.write(pos);
      delay(100);
      pos--;
    }

    delay(500)
  }
}
```

ANNEXURE

Annexure (if any) should be placed at the end of thesis report.

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