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A

MID-TERM PROGRESS REPORT

ON

" DESIGN OF MINIGRID BASED ON DISTRIBUTED MICRO HYDRO PLANTS"

(As a partial fulfillment of Bachelor's Degree in Electrical Engineering)

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LIST OF ACRONYMS AND ABBREVIATIONS

ELC Electronic Load Controller

MHP Micro Hydro Powerplant

SPV Solar Photo Voltaic

SMHP Standalone Micro Hydro Powerplant

HG Hydraulic Governor

CHAPTER 1 INTRODUCTION

1.1 Background

Nepal is a nation rich in water, with various rivers, rivulets flowing from the Himalayas at an elevation of 3500 m or higher. According to estimates from rural energy (2007), Nepal has the potential to generate 40,000 MW from large-scale hydro power and 50 MW from micro-hydro plants, but to date, facilities producing only about 533 MW (527 MW from large-scale and 6 MW from small-scale hydro projects have been developed[1].

Nepal is a Himalayan country with its 83% of its geography being composed of hills and mountains. Around 22% of the Nepalese population is not receiving electricity through the national power utility and is forced to identify alternative approaches to electrification. The Micro/Mini-Grid (MG) system is one of the promising approaches in terms of cost, reliability and performance for rural electrification, where electrification through national power utility is not techno-economically feasible. However, various issues must be identified and considered during the implementation of MGs in a rural community[2].

Although Nepal has enormous potential to generate electricity from different renewable energy resources, around 4.5% of the population is still out of reach to electricity. One of the main reasons behind it is the mountainous geography of the country; more than 60% of the population are living in the hilly area, resulting in complications in supplying the electricity through the national utility grid. In such cases, the isolated energy system is found to be a suitable solution to provide electricity. Those small-scale hydro projects are referred as mini grid[1][3].

Mini grids are a new concept that is currently being developed in response to the problem of integrating renewable energy into the existing electrical grid. Mini grids can be defined as a set of electricity generators and, possibly, energy storage systems interconnected to a distribution network that supplies the entire electricity demand of a localized group of customers. A key feature of mini grids is that they can operate autonomously with no connection to a centralized grid. However, a mini grid may be designed to interconnect with the central grid and operate under normal conditions as part of the central grid with disconnection occurring only if required to maintain power quality[4][5].

Table 1 Classification of MHP

Type	Size
Very Small MHP	upto 8 kW
Small MHP	8-20 kW
Medium MHP	20-50 kW
Large MHP	50-100 kW

(e.g., if there is a central grid failure). Alternatively, a mini grid may be designed to operate autonomously in a remote location with the option to connect to the central grid when grid extension occurs.

1.2 Problem Statement

One of the most pressing environmental concerns of Nepal is its need for stable, community-managed power in the rural areas. Because extending the Nepalese national power grid would be expensive and problematic, micro hydro projects have proven to be an economical and efficient alternative in the effort to power remote villages deep in the mountains. However, the efficiency of many of these projects is debatable. The problem in micro-hydropower system is fluctuation in frequency and voltage generated by the generator which causes adverse effect in various electrical appliances, since there has been no provision of synchronization in current ELC system. Along with the ELC, synchronization of governor in the parallel grid operation is a challenging perspective in present context. There is the lack of provision for power balancing between interconnected ELC's & governor in mini-Grid System.

Having said that, to introduce an ELC & a governor that utilizes minimal amount of water and produces lesser harmonics resulting to minimum water loss is a testing concern.

1.3 Objective of Project

1.3.1 Major Objective

- To design a mini grid with connection of two different distributed micro-hydro each controlled by ELC and governor.

1.3.2 Specific Objective

- Design of ELC model
- Design of governor model
- Implement Governor and ELC model on distributed micro hydro powerplant and form a mini grid

1.4 Scope of Project

- Mini grid based distributed micro-hydro plants can be utilized for rural electrification with more reliability.

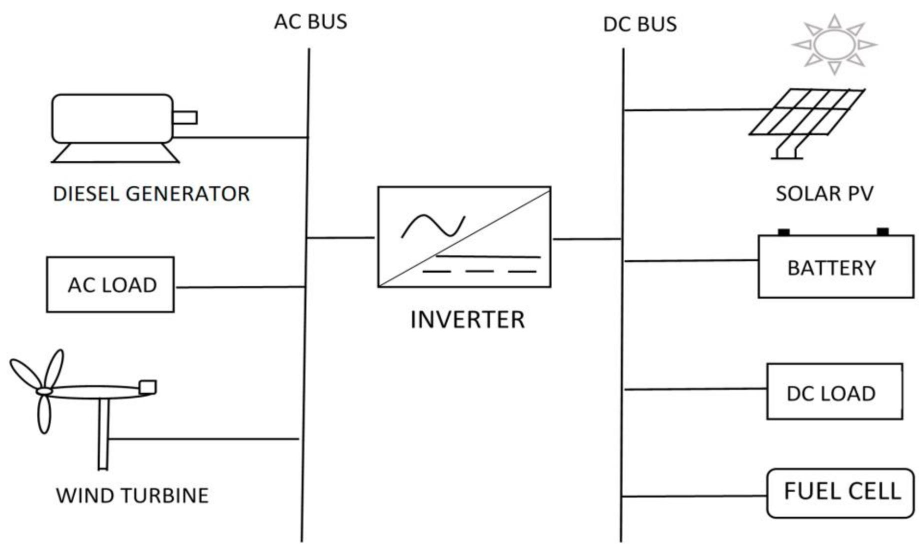
CHAPTER 2: LITERATURE REVIEW

2.1 MINIGRID

2.1.1 BACKGROUND

The exponential demand for energy has led to the depletion of fossil fuels such as petroleum, oil, and carbon. This, in turn, increases the greenhouse effect gases. Energy systems have incorporated small-scale and large-scale renewable sources such as solar, wind, biomass, and tidal energy to mitigate the afore mentioned problems on a global scale[6]. The reliability of the renewable sources is a major challenge due mainly to mismatch between energy demand and supply. Renewable energy resources, distributed generation (DG), energy storage systems, and minigrids (MG) are the common concepts discussed in several papers The hybrid energy systems are typically used for electricity supply for several applications such as houses or farms in rural areas without grid extension, telecommunication antennas, and equipment, and many other stand-alone systems[7]. Minigrid combines distributed power, load, energy storage devices and control devices, forming a single and controllable power supply system[8].

Based on the type of source they manage, microgrids can be classified as direct current line (DC), alternating current line (AC), or hybrid shown in Figure 1.



Source:[7]

Figure 1 An isolated mini-grid scheme

From many research papers, it has been proven that the mini-grid concept contributes to the enhancement of social impact. This is achieved by improving the local governance structure via direct participation of the local community, since it is the best option to electrify the isolated rural communities. It includes proper infrastructure to guarantee the system for sustainable operation and maintenance[9][10].

RES has placed a firm foundation to supply the electricity in the communities and village around the rural areas of Nepal. Focusing toward Nepal, till date more than 55 MW of electricity has been produced from MHP and Solar energy providing access to 3.6 million households which accounts to 18% electricity access by the population. During the electricity crisis that begins in 2006, when Nepal suffered rolling blackout up to 16 hours in a single day at the dry season, people have shifted their trust to Solar PV and MHP to fulfil their electricity demands. Till 2018, AEPC led more than 1,700 community-owned off-grid micro/mini-hydropower plants of around 30 MW and more than 600,000 solar house systems in rural Nepal to guarantee the basic lighting requirements via various projects[11].

Table 2 List of MG installed in Nepal until 2019

Type of Generation Sources	**Number of Installed systems**	**Capacity (kW)**	**No. of Household**
Micro/ mini hydro	3	1,144	7,796+
Solar–wind	10	333.2	409+
Solar only	20	554.6	1,400+
Solar-wind-hydro	1	28	170+

Source:[11]

2.1.2 IMPORTANT RENEWABLE ENERGY RESOURCES IN NEPAL

Energy resources in Nepal consist fuel wood, agricultural residues, animal waste, hydro-electric power, solar and potentially wind energy. Some of important and commonly used renewable energy resources for electricity production are listed below:

2.1.2.1 Fuel wood

Forest biomass is a crucial resource for rural livelihoods in Nepal and 75% of energy is in the form of fuel wood, which is commonly harvested from forest[11].

2.1.2.2 Solar energy

This technology, however, requires higher initial investment as it costs about $14,286 per kW of electricity generation depending upon the capacity, which the rural population may not be able to afford. Also, NEA has carried out centralized solar photovoltaic-based rural electrification in different locations.

The cost of a centralized solar PV-based power system is higher compared to electricity generation by smaller micro-hydropower units. Furthermore, solar PV is weather dependent and fails to provide consistent energy supply to households. This technology is most likely not appropriate in most of the mountainous areas that do not receive ample sunshine[11].

2.1.2.3 Biomass technology

Livestock is an integral component of Nepalese farming system. The total households with cattle and buffalo in Nepal were estimated to be 1.2 million in 2001. Based upon the study, technical biogas potential of the country is estimated to be 1.0 million household level plants, out of which 57.0% in the Terai (plains), 37.0% in hills and rest 6.0% in remote hills or in mountain region[11].

2.1.2.4 Micro hydro technology

Though 50 MW of electricity is estimated to be generated by micro-hydro, it costs around $2860 per kW of electricity which is higher than the capital cost of per kW electricity generation from larger hydropower plants. Also, small hydro turbines need specific topographical conditions that are only found near a small percentage of users' dwellings. Similarly, most of the rivers are seasonal and during winter, the discharge is very low, causing higher fluctuation in electricity generation[11].

2.1.2.5 Wind energy

To date, little has been achieved in this sector. The Kagbeni wind power project was one of the biggest projects with installed capacity of 20 kW built in 1987 under the support of the Danish Government. Unfortunately, the wind power project could not sustain itself due to the lack of maintenance. The establishment of wind-solar hybrid systems of 400W with 150W solar power projects in six rural communities has been completed. More than 48 households and two secondary schools have directly benefitted from these micro-projects[11].

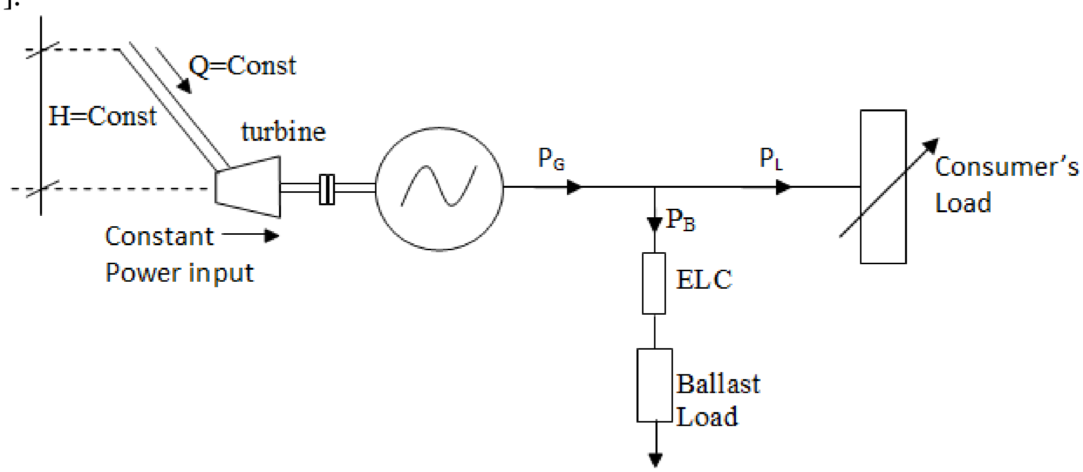
2.1.3 STATUS OF MINIGRID IN NEPAL

A pilot project installed in Baglung, Nepal, where six MHPs previously running in isolation mode with sizes ranging from 9 kW to 26 kW were connected to a local grid, forming an MG power system of 11kV with total grid power of 107kW. Similarly, another project interconnection two micro-MHPs was completed in Gulmi at 11kV transmission line extending 1.5km. One of the biggest ongoing projects of Nepal is in Taplajung that connect 6 micro and mini hydropower plants of commutative capacity of 823kW. On the other side, development in solar-based MG has also increased in high number in the recent era. Private companies such as Gham Power establish its first solar-based MG of 70kW capacity located at Khotang in 2014. There is a total of 26 known solar plus hybrid MGs installed by AEPC. Malladehi Solar MG (30kW), Sugarkhal solar MG (75kW) and Saptami solar wind hybrid (70kW) are the latest projects of AEPC under the SASEC. A hybrid micro-grid installed at Nawalparashi includes two wind turbines of 5kW and Solar PV array of 2.1kW supplying electricity to 46 HHs. Total ten such hybrid connections have been noted by AEPC with capacity ranging from 80kW in Narakot to 7.2 kW Harrekanda solar-wind-MG, Surkhet, supplying electricity to more than 400 households along with few industries. Thingan Miteri Hybrid MG was installed which is powered by 20kW MHP, 5kWp PV system and a 3kWp wind turbine, supported by battery back-up. This grid line extended seven km from the point of generation and supplying the electricity through three substations[11].

2.2 MICROHYDRO POWER PLANT

Micro hydro power plants are the small-scale hydro power plants of the sizes in between 5 kW and 100 kW. Conventionally micro hydro is being promoted by government sectors through community participation as a part of rural electrification where national grid is not likely to reach in near future. So, all the MHP plants are operated in isolated mode[12][13]. Micro hydro have positive socio-economic impact in the rural communities like lower consumption of firewood, extended study time for children, reduced drudgery for women, increased economic activity due to productive end use, and social participation[12]. In micro hydro, frequency changes with change in consumer load. So, an electronic load controller (ELC) or a governor is used to maintain constant frequency i.e., 50 Hz (in Nepal) for consumer load[14]. Micro hydropower plants operating in isolation mode are serving many remote settlements of Nepal. They have been electrifying the rural communities for more than two decades which was only limited to lighting purpose. Micro hydropower plants operating in isolation mode are serving many remote settlements of Nepal. They have been electrifying the rural communities for more than two decades which was only limited to lighting purpose[15].

Electrification of remote areas is highly important for a developing country like Nepal. Although Nepal has an enormous potential to generate electricity from different renewable energy resources, around 4.5% of the population is still out of reach to electricity [11]. One of the main problems behind such is due to huge installation cost of transmission system and geographical situation, more than 61% of the population are living in the hilly areas, resulting in complications in supplying the electricity through the national grid [2]. Rural electrification can be carried out either through grid extension or isolated RES such as mini and Micro Hydro power Plant (MHP), Solar Photo voltaic (SPV), wind energy, biomass [16]. Thus, for a rural areas Micro hydro power plays significant role electrification. Micro Hydro power Plants (MHP) are popular source of electrical energy in the rural areas of developing countries where the population is small and sparsely distributed, and the extension of national grid is not financially feasible because of high power loss in transmission line and high-cost investment required for transmission line. The figure 1 shows the basic components of Micro hydro in an isolated mode with its ELC [17].

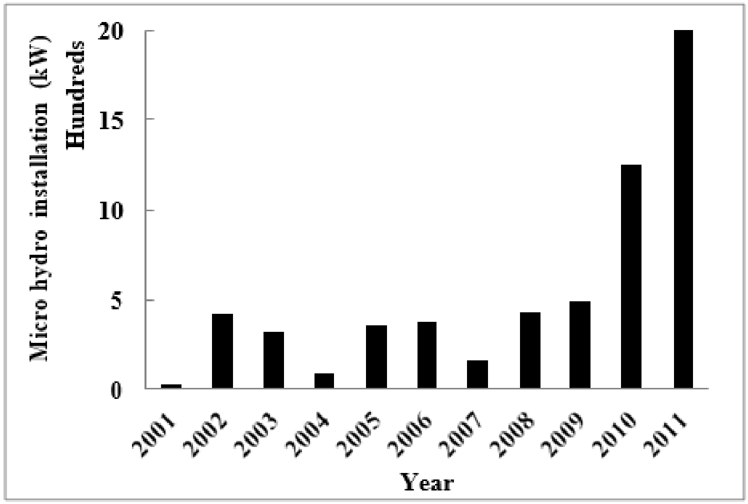


Source:[18]

Figure 2: Stand Alone Micro Hydro With its ELC

2.2.1 MICROHYDRO IN NEPAL

Nepalese micro hydro powers are sustainable in three dimensions of sustainability framework: ecology, economy and social. Micro hydropower should be given precedence to solar PV for lighting since solar lighting is costlier than micro hydropower projects in terms of unit costs. Figure 3 below shows the micro hydro installation by AEPC/ESAP on annual basis from 2001 to 2011. This chart shows increasing trend of micro hydro installation per year from year 2007 to 2011[12].

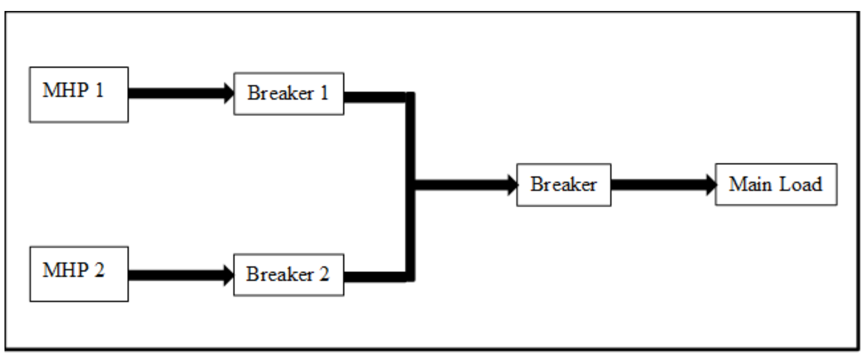


Source:[12]

Figure 3 Micro hydro installations by AEPC/ESAP (Source: AEPC, 2012)

2.2.2 MINIGRID USING MICROHYDRO POWER PLANTS

Two different MHP (MHP1 and MHP2) plants are taken for developing Mini-Gird Model. Two MHPs related to each other via transmission line, which was connected to the Main Load via breaker. To check complete performance of ELC, Main Load was always equal to total generation.



Source:[13]

Figure 4 Block Diagram of Mini-Grid Using MHP Only

The reason for using micro hydro instead of other energy sources can be listed as:

1. Nepal has large source of naturally occurring high potential water resources which makes micro hydro a good option compared to other sources.
2. Micro-hydro can provide a constant supply of electricity which other sources like wind and solar can't.

3. Overall cost of operation of micro-hydro is less compared to solar or wind and there is no need for energy storage system which makes it even more superior.
4. Environmental impacts of operating micro-hydro are very minimal. Micro-hydro doesn't produce any greenhouse gases, air pollutants or any other waste[19][20].

2.3 MAJOR COMPONETS OF A MICROHYDRO POWERPLANT

Generally, a micro hydro powerplant consists of three major components. They are listed below:

1. Electronic Load Controller
2. Generator Unit
3. Governor Unit

2.3.1 ELECTRONIC LOAD CONTROLLER (ELC)

2.3.1.1 Background of ELCs

Many research and designs has been done with ELC in the past. The new designs are created from time and again by various authors with increasing reliability, robustness and cost effectiveness. In July 1984, Kormilo and Robinson described the role of electronic load controllers in reducing the cost of small hydro schemes with reference to the situation in Papua New Guinea. A prototype controller based on an AIM 65 microcomputer is described[21].

In December 2006, Singh and Kasal described the analysis and design of voltage and frequency controllers for asynchronous generators to be used in isolated constant power applications such as Pico and micro hydro sites. These controllers are basically load controllers which maintain the load power at generator terminals which in turns maintain the system frequency constant. A set of load controllers are designed, modeled and simulated in MATLAB using Simulink and PSB (Power System Block-set) toolboxes to demonstrate their performance[21].

In November 2003, Gurung and Freere investigated the influence of excitation capacitors on the power output and efficiency of a 4 pole, 3 phase self-excited squirrel cage induction generator running at 1500 rpm and feeding a single-phase resistive load at 220v output. The comparative study of different capacitor configuration and sizes on the generator performance was the main area of interest. They achieved a maximum efficiency of 67% as a single-phase output from three phase induction generator[21].

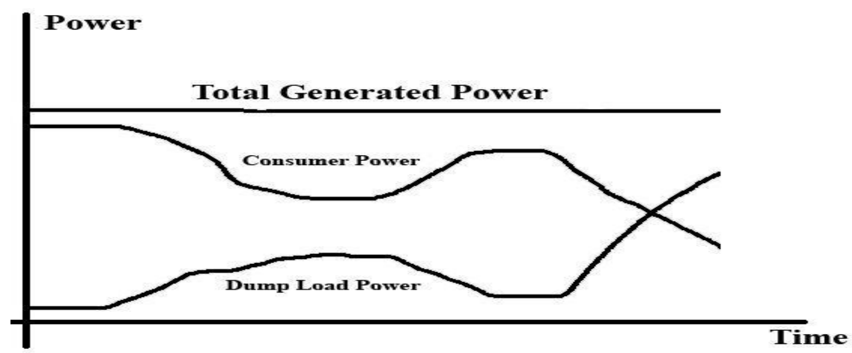
In 2013, Roodsari, Nowiki and Freere described a new concept of distributed electronic load controller for voltage regulation in micro hydro systems with transfer of excess power to households. Instead of dumping excess power at the generating station itself on heaters the authors proposed a new concept of decentralizing the excess power to each household. Each household would be allocated certain power and the excess power from each household would be used on the same house as water heater[21].

Electronic load Controller is an electronic governor that functions as a frequency and voltage regulator on a generator. Load control is suitable for a micro hydro power plant applied on rivers (without a dam). An ELC is a solid-state electronic device designed to regulate output power of a micro hydropower system and maintaining a near-constant load on the turbine generates stable frequency[14][22].

The SG used in standalone MHP (SMHP) is subjected to voltage and frequency variations due to continually varying load, resulting in excess heat and mechanical vibrations in SG. The SG generator thus needs a control system to regulate the perturbations on the generator side, referred to as electrical control, turbine side referred to as mechanical control, or on both sides called electromechanical control. In turbine side control or mechanical control, the speed of water is regulated using an inlet valve to control the speed of water to maintain the constant frequency and voltage of the SMHHP. Due to the high cost of the hydraulic governor (HG), HG is not a preferable option to maintain the frequency and voltage of a standalone MHPP (SMHHP). An electronic load controller (ELC) is considered as an alternative to the high-cost HGs[23].

When there is change in system load, the frequency tends to change. In order to keep the frequency constant, the conventional speed governing system regulates the input water supply to the hydraulic turbine. In ELC, the balance in power is maintained by using ballast load or dummy load. For this, ELC maintains a constant electrical load on the generator in spite of changing user loads[24]. During the lightly loaded condition, speed of the turbine increased, the ELC sense it and it diverts the surplus power to ballast load. Thus, in spite of change in consumer loads the total load on the generator remains constant. And at the time of full load, the ballast load is cut off and total power is supplied to the consumer load or main load. Ballast load is usually a heavy-duty resistive load such as a water heater, which acts as a sponge to soak up any extra power, preventing it from overloading[25].

The concept is well described by the figure 2.



Source:[21]

Figure 5 Consumer Power and Dump Load Power relation in ELC System

Thus, synchronous generator feeds two loads in parallel such that thetotal power is constant, that is,

$$P_G = P_C + P_D$$

P_G = Generated power of the generator (which should be kept constant)

P_C = Consumer load power, and

P_D = Dump load power the power dissipated in the dump load can be used for battery charging, water heating, cooking, etc.[21]

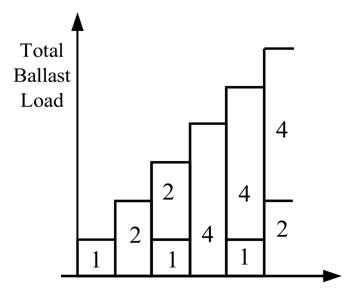
2.3.1.2 Types of ELCs

The main type of ELC designs that are prevalent are:

- Binary load regulation.
- Phase angle regulation.
- Pulse width regulation.
- Controlled bridge rectifier.
- Uncontrolled rectifier with a chopper.
- Fuzzy Control for frequency control

a) Binary load regulation

In binary load regulation the ballast load is made up from a switched combination of binary arrangement of separate resistive loads. In response to a change in the consumer load, a switching selection is made to connect the appropriate combination of load steps. This switching operation occurs during the transient period only, thereafter full system voltage is applied to the new fraction of the ballast load and hence harmonics are not produced by this method in the steady state. In addition, it is usually the practice to adopt solid-state switching relays which include a zero-voltage switching circuit that reduces the harmonic distortion associated with the transient switching period.



Source:[26]

Figure 6 Binary Weighted Ballast Load

Costs of Solid-State relay are far higher than the TRIACS because each of them contains steering electronics. The number of dumps loads, and the associated wiring is high and to achieve smooth regulation, these dump loads should all have exactly the right capacity. With a low number of dump loads, steps between dump load combinations remain too large and the system cannot regulate smoothly[27].

b) Phase angle regulation

In phase angle regulation, the ballast load comprises of a permanently connected single resistive load circuit of magnitude equal to (or slightly greater than) the full load rated output of the generator. As a result of the detection of a change in the consumer load, the firing angle of present power electronic switching device, such as a triac, is adjusted, thus altering the average voltage applied to and hence the power dissipated by, the ballast load. As with all power electronic switching of this nature, this technique introduces harmonics onto the electrical system. In phase angle regulation method, some of the shortcomings presents are the presence of harmonics and that effectiveness limited by timing accuracy of trigger pulse. Phase angle modulation also seriously distorts the generator, and this leads to the increasing of size of the generator to almost 25%.

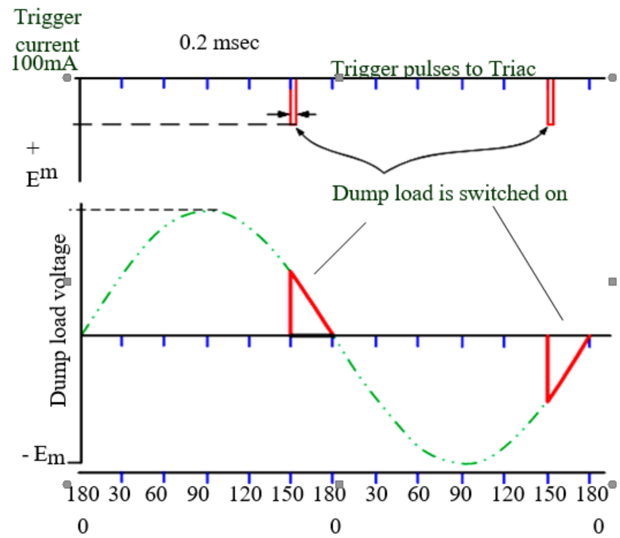


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Figure 7 Firing angle of phase angle regulation

c) Pulse width regulation

In pulse width regulation, AC voltage is first rectified and dump load is switched on and off with a variable duty cycle. Duty cycle is the ratio of switch on time of a cycle to the time for a cycle. Control is done by varying the on-time of a cycle when the time of a cycle is constant for fixed frequency. PWM control can have fast response and compared to other schemes they usually have very smooth speed control, but total heat that is produced in this type of ELC is high and this is due to current problems with both rectifier and the transistor switching losses is really noticeable and significant in high frequency

d) Controlled bridge rectifier

In controlled bridge rectifier, AC voltage is not only rectified to DC voltage but also controlled to variable DC output voltage whose magnitude is varied by phase control. So, a controlled bridge rectifier involves both conversion and control of electrical power. To achieve both conversion and control of electrical power, silicon-controlled rectifiers (SCR) which are also called thyristors are used in power circuit as the power electronic devices. To turn SCR on, gate pulse must be provided to the gate of SCR. To achieve the dump load control, the rectifier output voltage is controlled by varying the delay time of gate pulse called delay angle (α). As phase angle regulation, this technique introduces harmonics onto the electrical system. Moreover, the timing accuracy of trigger pulses is very complex and limits the effectiveness of the system.

e) Uncontrolled bridge rectifier with a chopper

In uncontrolled bridge rectifier with a chopper, AC voltage is first rectified to DC voltage and then a chopper controls it to variable DC voltage by varying the chopper duty cycle (D) for dump load control. Dump load power is controlled by adjusting the duty cycle (D). It is very similar to pulse width regulation method except the chopper design. But it has two control methods such as pulse width modulation and pulse frequency modulation. In pulse frequency modulation, the time of a cycle must be varied for frequency modulation when the switch on time is constant.[26]

f) Fuzzy Control for frequency control

Several new controllers such as intelligent controllers and adoptive controllers have been applied for load frequency control of micro hydro powerplant. However, fuzzy logic is an important technology and a successful branch of automation and control theory, which provides good results in control of power system[28].

However, ELC waste precious energy that can be used gainfully. Also, they do not carry out flow control, implying that the mineral rich water is made to spill away, which could have been diverted at high heat for irrigation purposes. Fuzzy controller is used to maintain the MHPP frequency constant using an ELC governor and to adjust the water flow to limit the dissipated power on the ballast load[29].

2.3.1.3 Advantages of ELC

There are several advantages of electronic load controller:

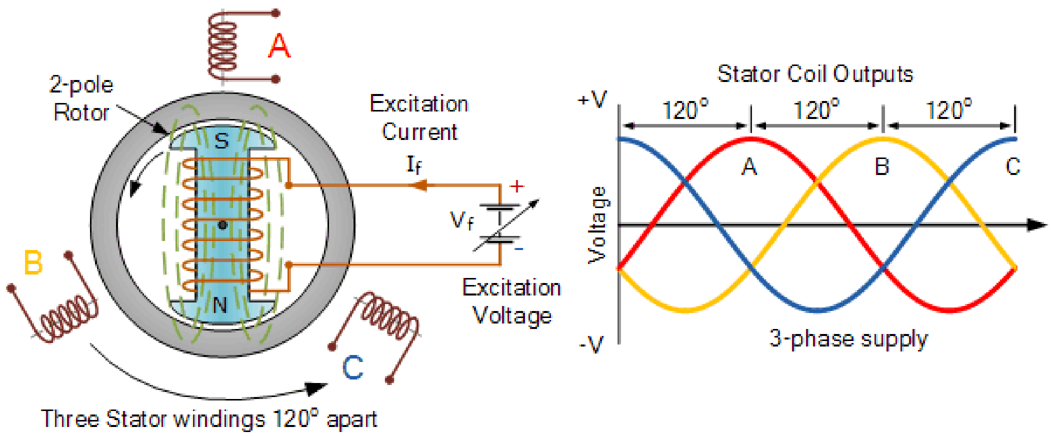
- ELC enables the use of simpler, cheaper turbine with less moving part.
- ELC allows lighter, less robust penstock and imposes less wears and tears on machinery.
- High reliability, low maintenance and simple to operate.
- ELC can be fitted at any point in electrical system.
- Ballast load can usefully deployed example water and/or space heaters implying 100 load factors of the power plant.
- ELC is less inexpensive than equivalent flow control governor[26]

2.3.2 SYNCHRONOUS GENERATOR

Alternating current (ac) generators are commonly referred to as synchronous generators or alternators. A synchronous machine, whether it is a generator or a motor, operates at synchronous speed, that is, at the speed at which the magnetic field created by the field coils rotates. As shown in equation, an expression for the synchronous speed N, in revolutions per minute (rpm) as:

$$N = \frac{120f}{p}$$

Where f is the frequency in hertz (Hz) and P is the number of poles in the machine. Thus, for a 4-pole synchronous generator to generate power at 50 Hz, its speed of rotation must be 1500 rpm[30].



Source:[31]

Figure 8 Construction of Synchronous Generator

2.3.3 GOVERNOR UNIT

2.3.3.1 Introduction

Governing system or governor is the main controller of the hydraulic turbine. The governor varies the water flow through the turbine to control its speed or power output. Generating units speed and system frequency may be adjusted by the governor.

Governing system as per IEEE std. -75 includes following.

a) Speed sensing elements

b) Governor control actuators

c) Hydraulic pressure supply system

d) Turbine control servomotors-these are normally supplied as part of turbine

The primary functions of the hydraulic turbine governor are as follows:

i. To start, maintain and adjust unit speed for synchronizing with the running units/grid.
ii. To maintain system frequency after synchronization by adjusting turbine output to load changes.
iii. To share load changes with the other units in a planned manner in response to system frequency error.
iv. To adjust output of the unit in response to operator or other supervisory commands.
v. To perform normal shut down or emergency over speed shut down for protection.

The speed governor is an essential component of MHPP which regulates the flow of water through the penstock-turbine, by controlling the gate position, based upon the feedback error signal generated by analyzing the speed and load variations. This ensures not only the gird frequency stability but also balance of the active power considering variations in the load. Principally, it is a combination of devices and mechanisms that detects the deviation in speed from the set point reference; the speed deviation is transformed into a signal and then amplified to trigger an actuator that controls and regulates the inlet water flow into the turbine[32].

2.3.3.2 Governing System used for Small Hydro

Basically, there is no difference in governors used for large generating units and small units except for sizes, operating pressure and control features as per requirement of individual project. Also, for smaller units, hydro-mechanical part of governor is built on the sump of oil pressure plant for compactness. Higher operating pressure is used to reduce sizes of control elements and pipelines. Nitrogen cylinders are used in place of pressure air to avoid use of high-pressure air compressors. Oil pipelines of sizes up to 50 mm are used in stainless steel with dismantlable couplings to reduce welding and maintain cleanliness[33].

Following types of governing system are used:

Micro Hydro (up to 100 kW) - Digital speed control system will load actuator is used.

Small Hydros (Up to 3 MW) - Flow control governing system with hydraulic actuator and digital PID speed and power control system. Mechanical motor type actuator has also been, used up to 1000 kW unit size with microprocessor-based level control PI Controller.

Small Hydro (Above 3 MW) **-** Flow control PID governor with hydraulic actuator

Large hydro - PLC based flow control PID governor with hydraulic actuator[32]

Ballast capacity of ELC = 1.2* Installed Capacity

The speed governing control system ensures the constant speed operation during variation of load. The transient behavior of generator voltage, current and the rotor speed are also captured. Restoration of steady state condition within few seconds while changing the load ensures the stability of the entire system.

Micro hydro power plant is the conventional source of energy. It has basically its two main sections, firstly the mechanical part of the plant which includes hydraulic turbine, penstock, controller, hydraulic servo motor, control valve etc. Second part of the plant is electrical section which mainly consists of generator and load. The combined form of hydraulic turbine, controller and hydro-electric servo system is known hydro turbine governor. In order to explain the mathematical modelling of hydro turbine governor, this chapter is introduced

Figure 1.0 shows a complete block diagram of hydro power plant. The stored water at certain head contains potential energy. This energy is converted to kinetic energy. When it is allowed to pass through the penstock, this kinetic energy is converted to mechanical energy (rotational energy) which allows water to fall on the runner blades of the turbine. As the shaft of the generator is coupled to the turbine, the generator produces electrical energy by converting the mechanical energy into electrical energy. The speed governing system of turbine adjusts the generator speed based on the feedback signals of the deviations of both system frequency and power with respect to their reference settings. This ensures power generation at synchronous frequency

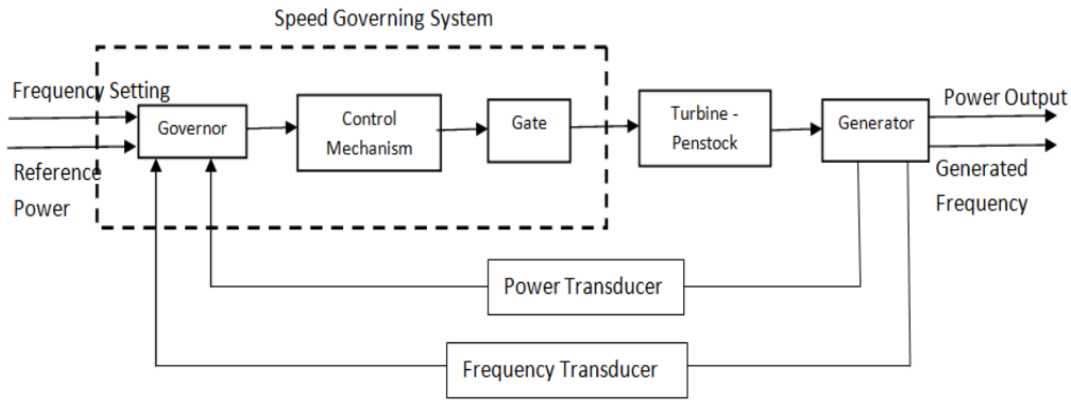


Figure 9 Functional Block Diagram of a Hydraulic Power Plant

2.3.3.3 Sizing of ELC:

The size of ballast load in ELC for Micro hydro are calculated in such a way that, if all the consumers load are off at a time, then all the generated power should be dumped across the dummy load. In simple way, we can say that the size of ballast should be not less than installed capacity of generator. But the thumb rule is taken as, the ballast rating of ELC is increased by 20% of installed capacity if the plant.

CHAPTER 3 METHODOLOGY

In our proposed project, we are designing an AC mini grid consisting of two micro-hydro power plant each connected through Electronic Load Controller (ELC) and a governor separately. We will simulate and obtain the result in MATLAB.

To complete our project, we first design ELC and a governor, connect them to the respective micro-hydro power plant and at last we connect micro-hydro in parallel to form a mini grid.

3.1 Basic Model Design:

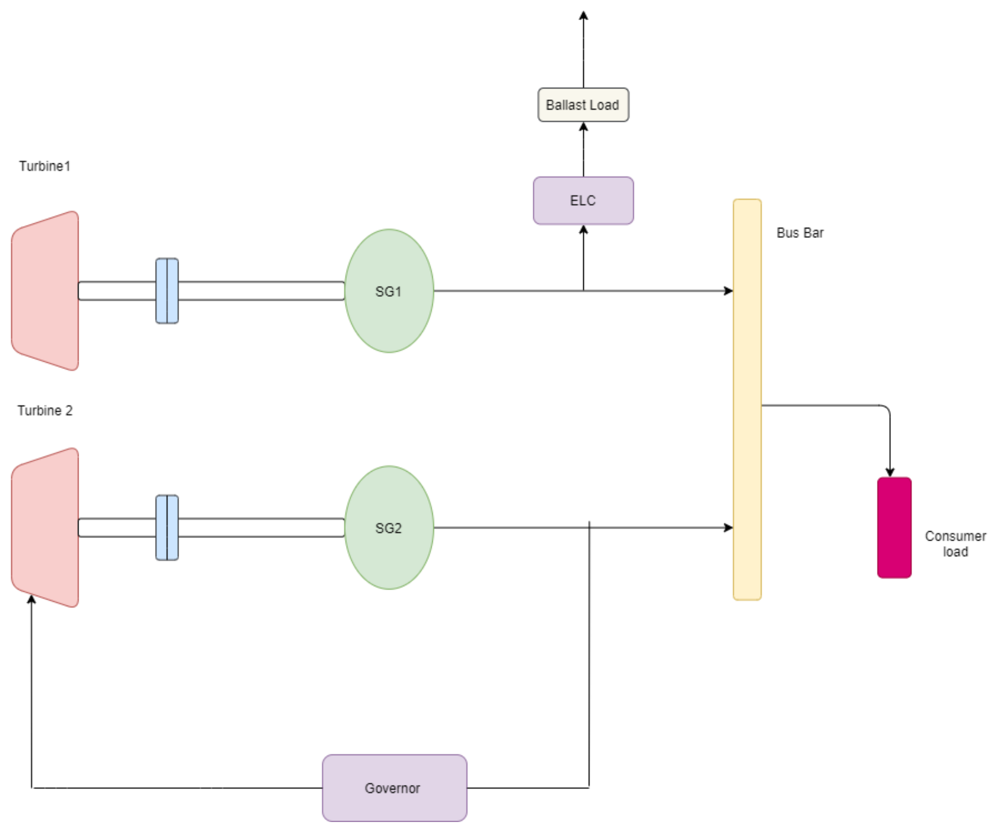


Figure 10 Proposed model

The above figure gives basic view of two micro-hydro generator operating in parallel which forming a mini grid which feds the consumer load collectively. Here the generator-1 is connected to the governor and generator-2 is connected to the ELC and both of these component helps in stabilizing the generating frequency.

In this project we design and simulate both the Governor and ELC in MATLAB.

3.2 **Basic Flowchart of ELC**

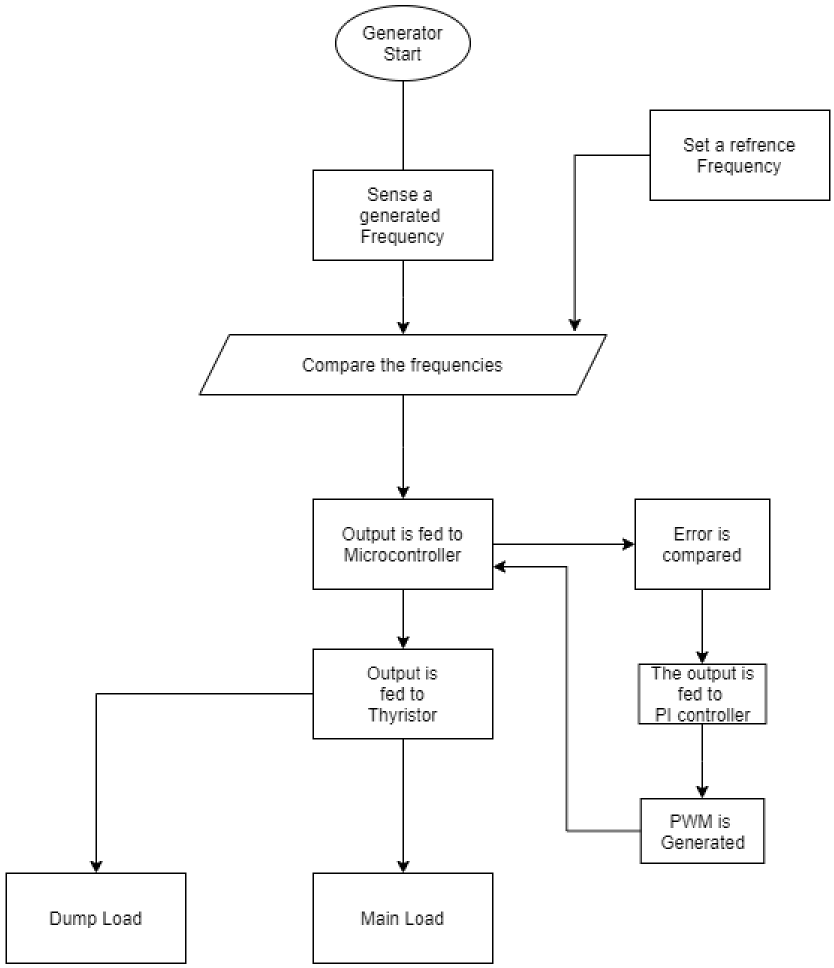
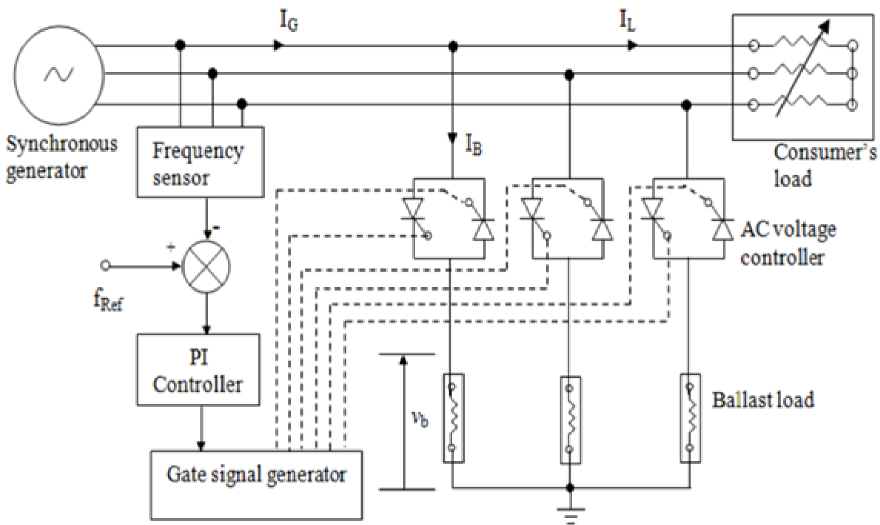


Figure 11 : ELC Flowchart

The main function of the ELC is to make output power of generator constant at a varying consumer load. ELC dumps the surplus power to their ballast load and generator provides the required power as demand by the consumer.

When the load decreases by a certain amount, there is a certain deviation in rotor speed (rotor speed gives actual frequency of generator). The deviated frequency is sensed by the closed loop feedback control which is present inside the ELC block. On comparison between the increased frequency and reference frequency gives the error signal which when multiplied by required gain it generates gate signal (PWM) to open the switch of (thyristor, MOSFET, ideal switch) of the ballast load to dump the power to make total always constant.

3.3 **Micro-hydro Controlled with ELC**



Source:[18]

Figure 12 Schematic Diagram of MHP with ACVC-ELC

Above fig shows the schematic diagram of an isolated MHP with ACVC- ELC. The generator is driven by un-regulated turbine with constant power output.

$P_{Gen} = P_{load} + P_{Dump}$

is kept constant all the time.

$Where,$

P_{Gen} = generated power

P_{load} = power consumed by load

P_{dump} = power consumed by dump load of ELC

When the active power of the load decreases, the frequency increase. The frequency sensor senses the frequency and it is compared with the reference frequency. The error signal thus obtained drives the PI controller to change the firing 'α' of the ac voltage controller to increase the active power flow through the dumped resistive load by an amount equal to decrease in active power of the load so that the total load on the generator remains constant resulting in a constant. This type of ELC has disadvantages of harmonics due to the chopping of waveform of current through the dump load

3.4 Basic Governor Flowchart:

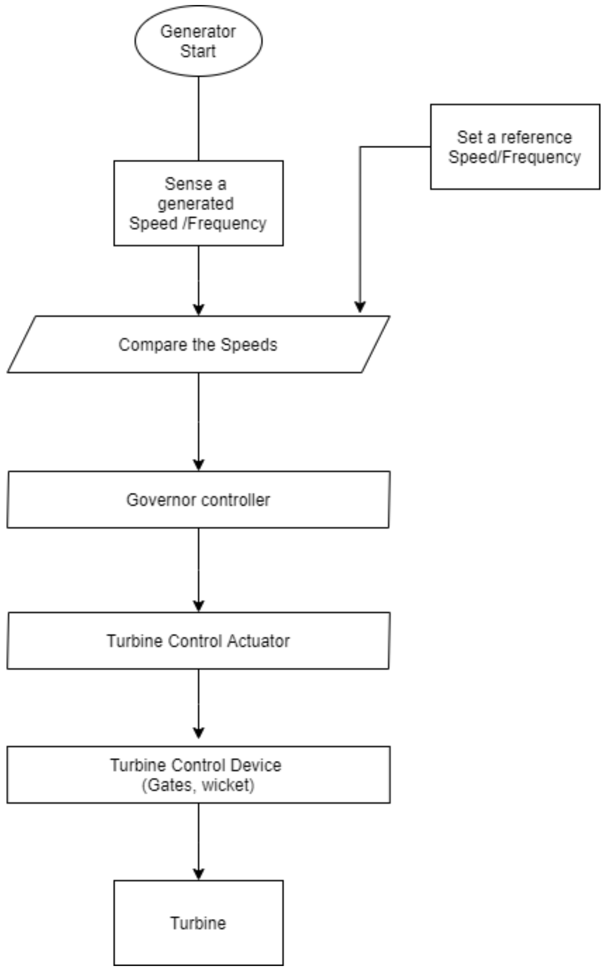


Figure 13 Flowchart for working of Governor

In figure 13, governor control system for Hydro Turbines is basically a feedback control system which senses the speed and power of the generating unit or the water level of the forebay of the hydroelectric installation etc. and takes control action for operating the discharge/load controlling devices in accordance with the deviation of actual set point from the reference point.

Actuator system compares the desired turbine actuator position command with the actual actuator position. In most of the hydroelectric unit's reaction turbines are used. In these turbines it requires positioning of wicket gates, including turbine blades in Kaplan units. In Pelton units it requires positioning of spear and deflector. Pressure oil system with oil servomotor is most commonly used actuator.

3.5 Block diagram of Governor with Generator:

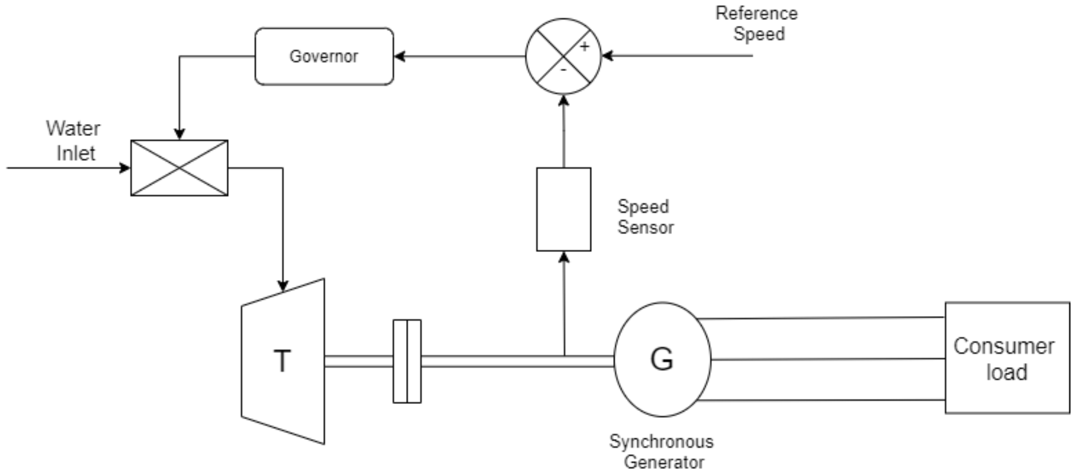


Figure 14 Governor Block Diagram

The above figure shows the block diagram of a governor with a generator and connected to the consumer load. When the consumer load changes, the speed senses the change in generated speed. Now, the speed is compared with the reference speed and the error is fed to the controller which then controls the water inlet valve to maintain the required speed.

CHAPTER 4 SIMULATION

4.1 SIMULATION RESULTS

4.1.1 SYNCHRONOUS GENERATOR(SG) OF 16kVA, 400V, 50Hz, 3-ϕ

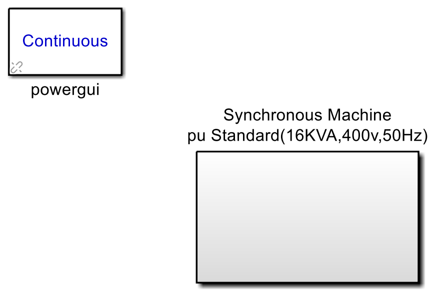


Figure 15 Block View of 16 kVA, 3 phase, 400V, 50Hz Synchronous Generator

The main objective of this simulation is to observe the frequency response of output of generator with respect to the load change. We analyzed the simulation in three different cases. They are: a) Optimum loading or zero ballast load b) Overloading and c) underloading.

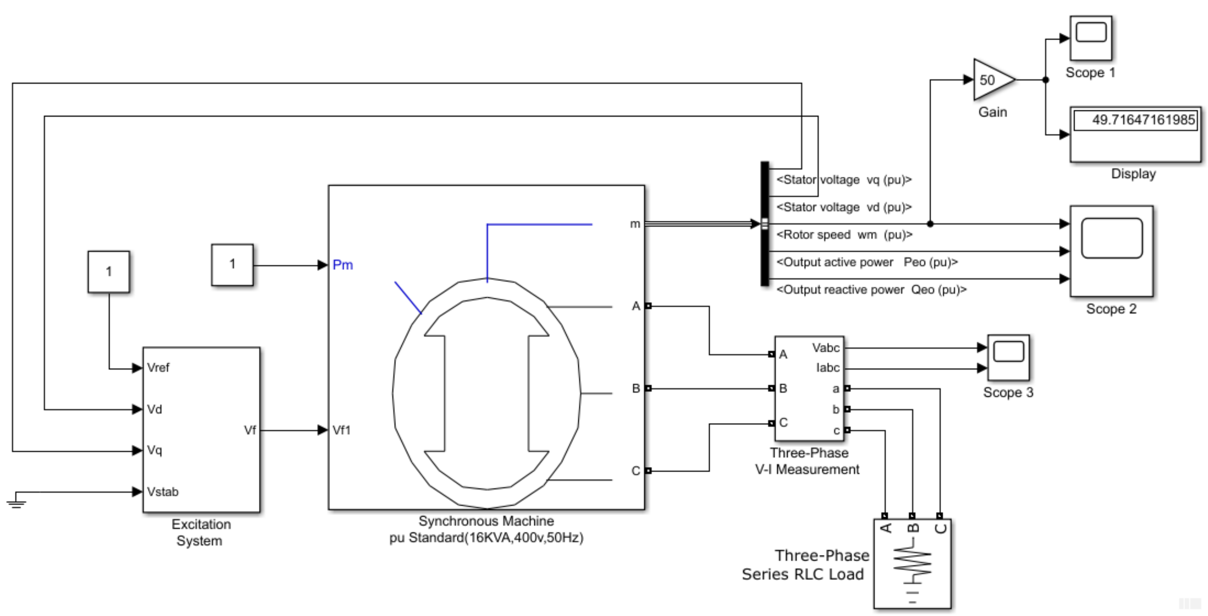


Figure 16 MATLAB Simulink model for 16 kVA, 3 phase Synchronous Generator

In this simulation we have chosen 16 KVA, 400 V isolated micro hydro without considering its ELC. The main function of the ELC is to dumped the surplus power generated by micro hydro. The main components of this Simulink are synchronous generator, resistive load as consumer load and the frequency measurement unit.

4.1.2 Frequency Response of SG

4.1.2.1 When load is 14843.8 Watt (Optimum Loading)

Few iterations of simulation around 16 kW were performed to find the optimum loading capacity of synchronous generator which was found to be 14843.8 watts. We run the simulation up to so second. And we found that the frequency remains constant at 50.003 Hz. With the help of this simulation, we concluded that, for this micro hydropower plant we have to maintain the constant loading of 14843.8-watt load with the help of ELC to give the 50 Hz frequency constantly.

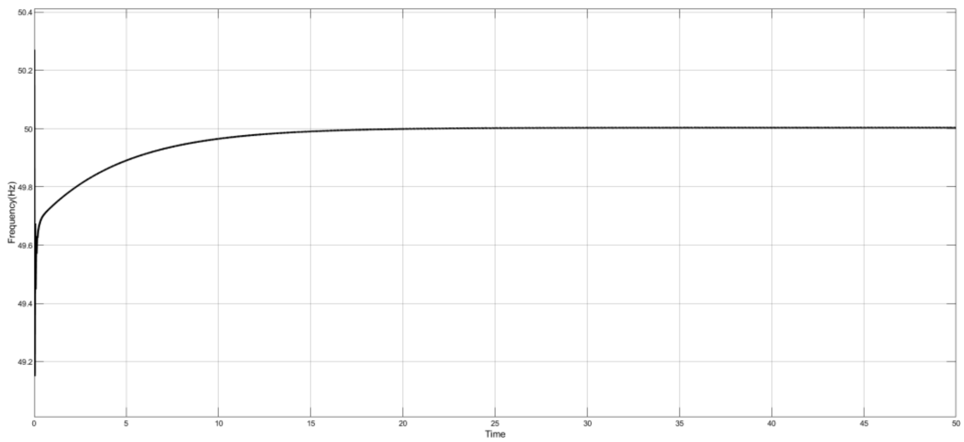


Figure 17 Frequency vs time for 14838-Watt load

4.1.2.2 When load is 16328.18 Watt (10 % Over-loading)

In second case, we increased the load by 10 % i.e., we run the micro hydro power plant in over loading condition. Even in small load change, we observed that there is drastically change in frequency from 50 Hz to 4.47 Hz. In this case we have to increase the load with the help of ELC.

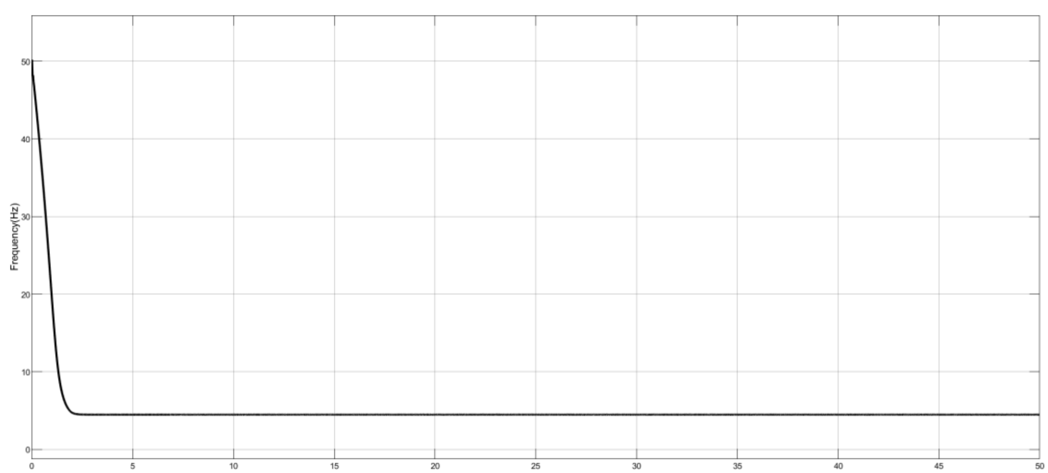


Figure 18 Frequency vs time for 16321-Watt load

4.1.2.3 When load is 13359.42 Watt (10% Under-loading)

In third case, we decreased the load by 10 % i.e., we run the micro hydro power plant in under loading condition. Even in small load change, we observed that there is drastically change in frequency from 50 Hz to 122.88 Hz. In this case we have to decrease the load with the help of ELC.

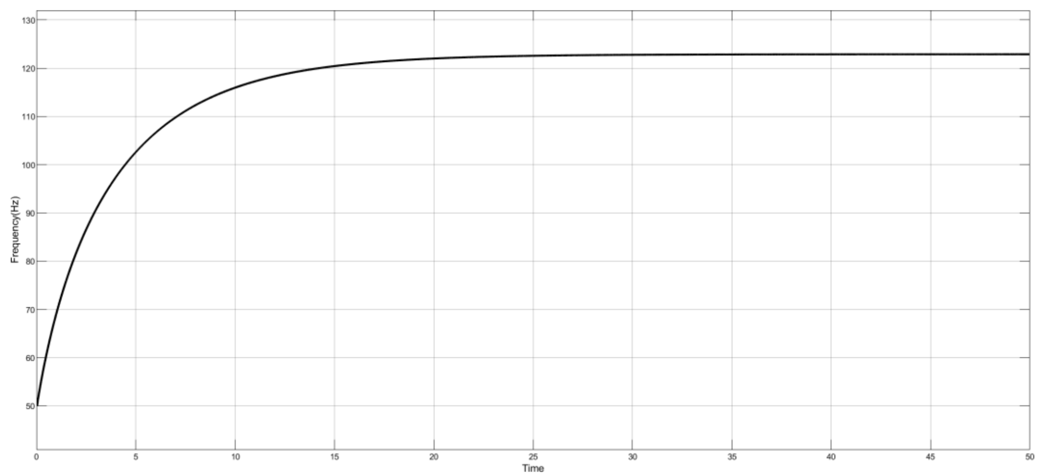


Figure 19 Frequency vs time for 13354-Watt load

4.1.3 Frequency Response of MHP and ELC Operation

Here, the rating of generator is 16KVA. That is installed capacity of micro hydro power is 16KVA. So, the ballast load of 16kW can't be placed in ELC because during the operation of MHP huge amount voltage or power will be dumped in ballast if the consumer load very low (no load case). Due to heating effect the load may damage early and cannot withstand the power properly. Hence, we should be remained at safe side so, that oversizing of ballast is required. From the literature review we came to know that if the size of MHP is less than 50kW, we can generally increase by 20% of installed capacity.

$$\text{Ballast Capacity} - 16\text{KV A} - \text{SG (kW)} = 1.2 * 16 = 19.2\text{kW} \cong 20\text{kW}$$

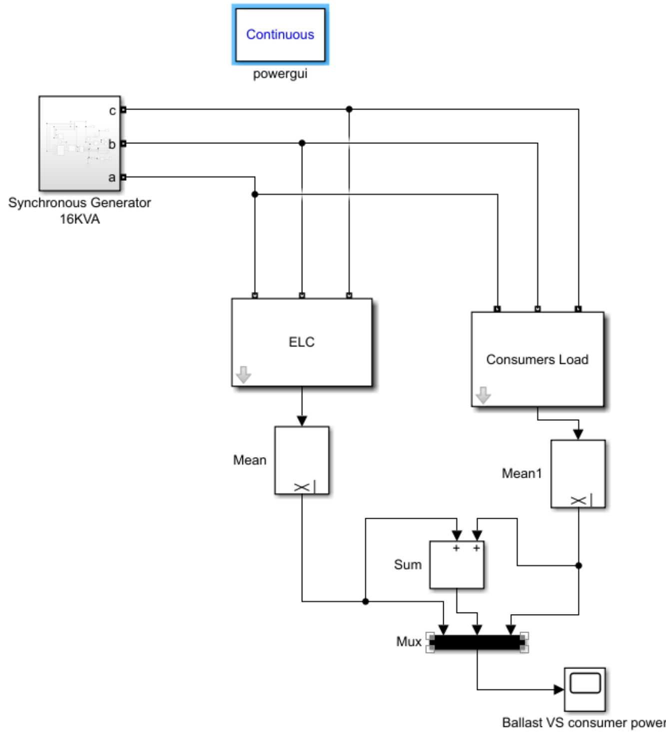


Figure 20 Overall block diagram of MHP1 with ELC and Consumer Load

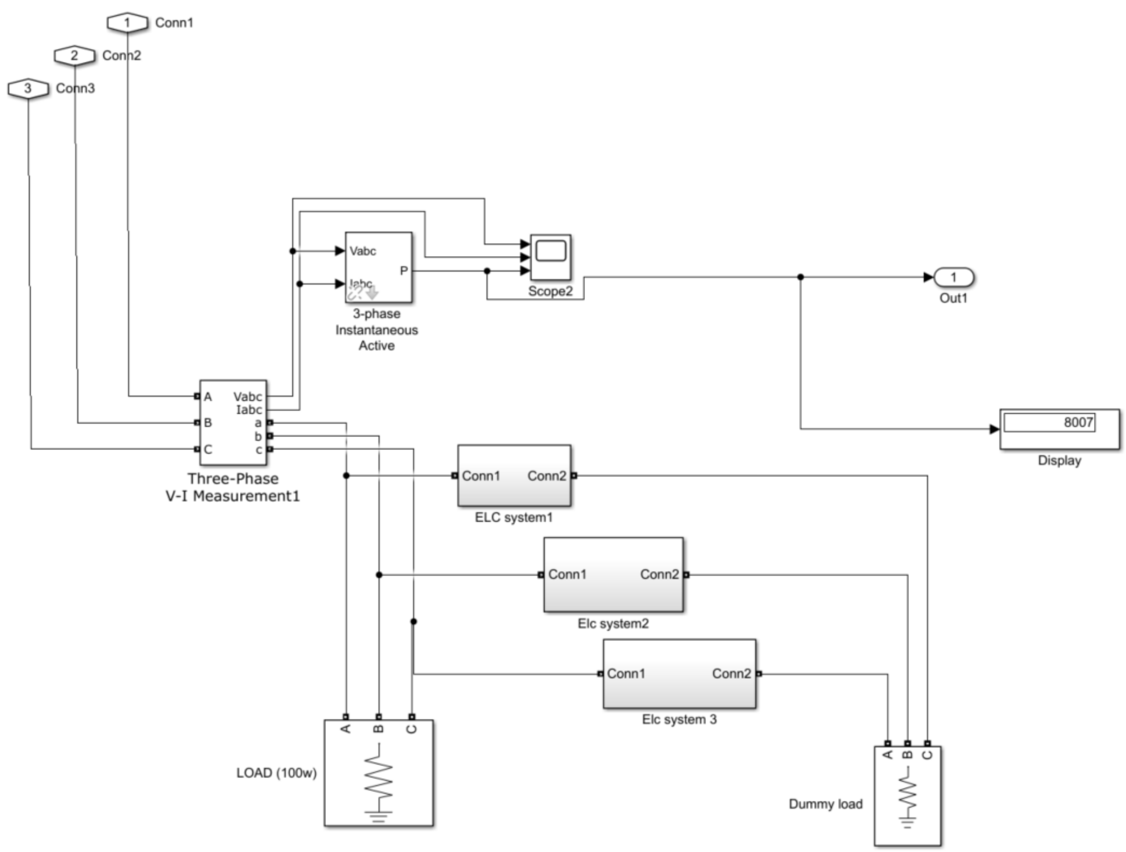


Figure 21 ELC and Ballast Load

MHP model consist of Synchronous Generator, Automatic Voltage Regulator, Electronic load controller and consumer load. We used to predefine models of SG and AVR rated 16 KVA, 400V, 50Hz. Ballast load for they system was calculated to be about 20KW and consumer load was sized to 5kW. The complete model of MHP is seen in figure 21.

The inputs of the generator are input mechanical power and excitation voltage. Input mechanical power is the amount of torque feed from shaft of turbine. For MHP this value is fixed as MHP runs at fixed head and fixed flow. So, the input value is fixed by constant. AVR senses the voltage of the synchronous generator and is maintained. IN the model the input voltage of the system is given from the measurement port of SG as V_d and V_q. The SG output power is defined by input power from mechanical input. So, full torque from input side relates full generation from SG.

In figure 22, we made a system that creates a control signal inside the ELC through which we can kill the surplus power in the dummy load. Here we used voltage peak control method having gain 100. In a single phase, whenever there is excess power in consumer load it creates a gate signal such that ideal switch creates a path between generator and dummy load. Hence excess power will be consumed by dummy load giving constant frequency and power.

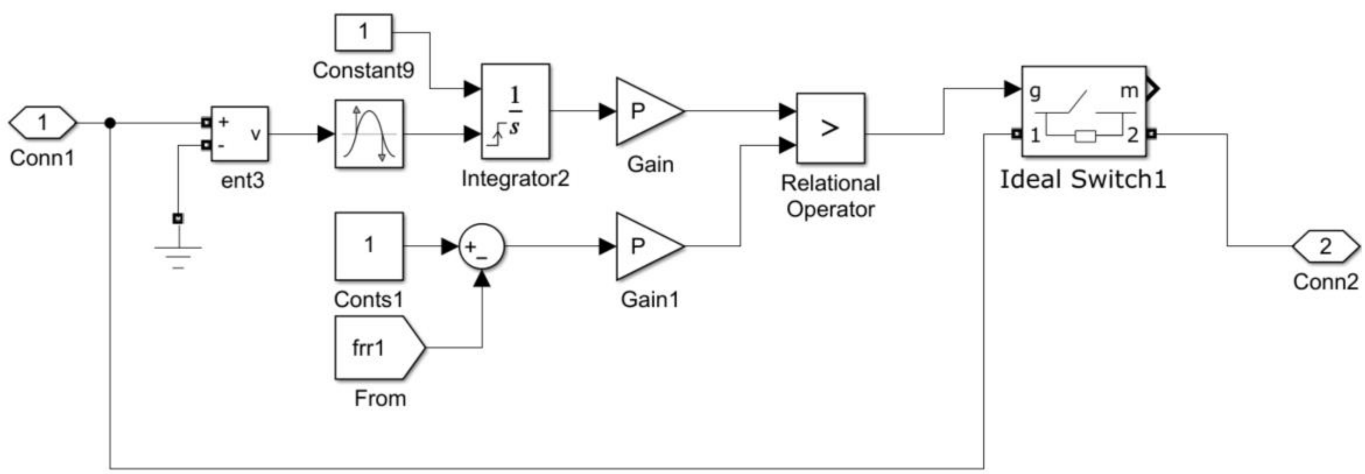


Figure 22 ELC model for a Single Phase

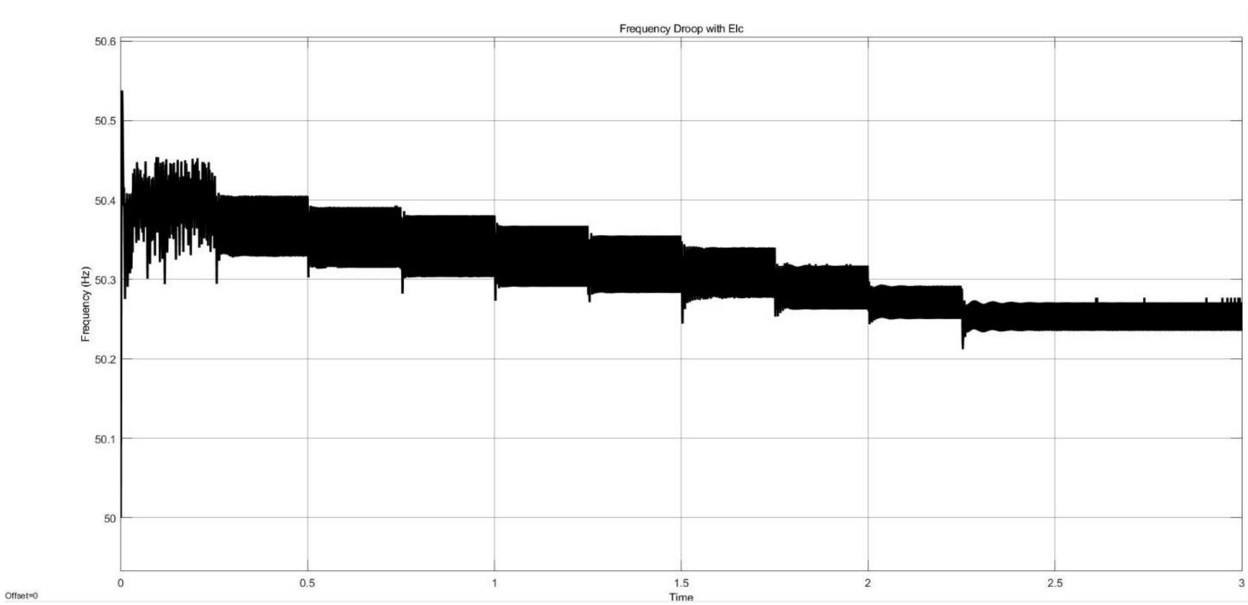


Figure 23 ELC Maintaining the constant frequency

From the figure 23, we saw that after the start of synchronous generator having ELC and varying consumer load, it immediately maintains its constant frequency in the range of 50 Hz.

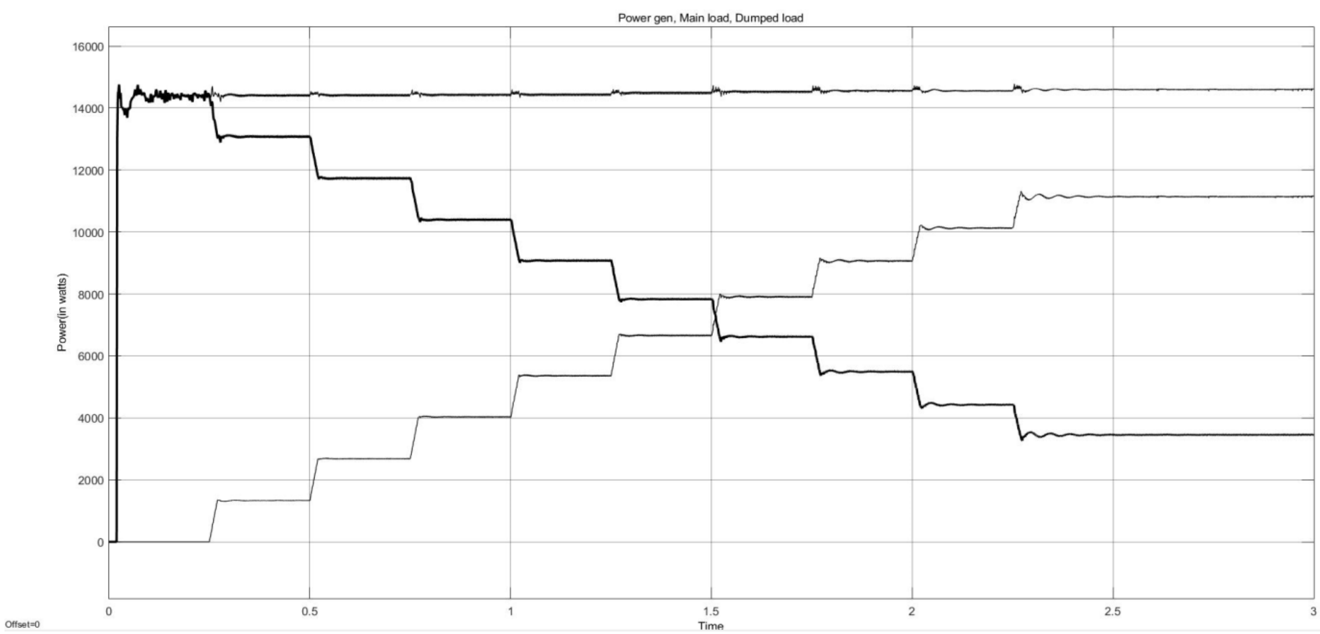


Figure 24 Graph showing Power Generated, Dummy Power & Consumed Power

In our simulation, we used a dynamic consumer load which changes its value in every 0.25 second. Consumer load of 10 KW is shown in figure 19. Also, from the graph shown in figure 23, we saw that consumer load changes its value constantly so that ELC can kill the surplus power in dummy load. Hence, total power generated by the synchronous generator remains constant.

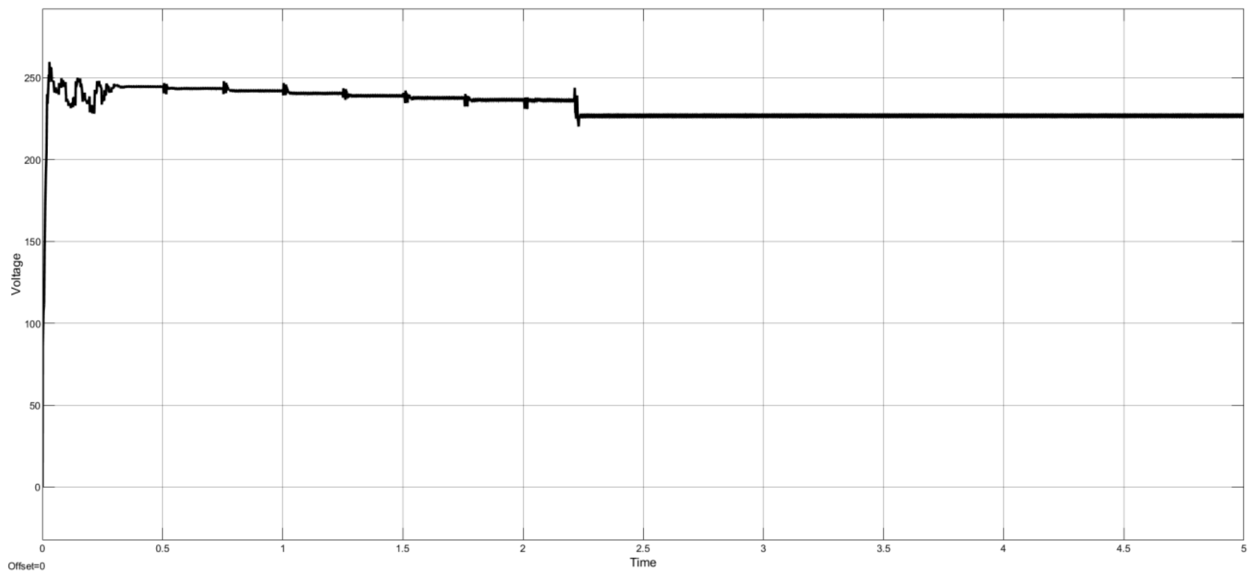


Figure 25 Voltage of a Single Phase

In above graph, we saw that the value of single-phase voltage remains constant at around 230 V.

4.1.4 Simulation of MHP with Governor Control

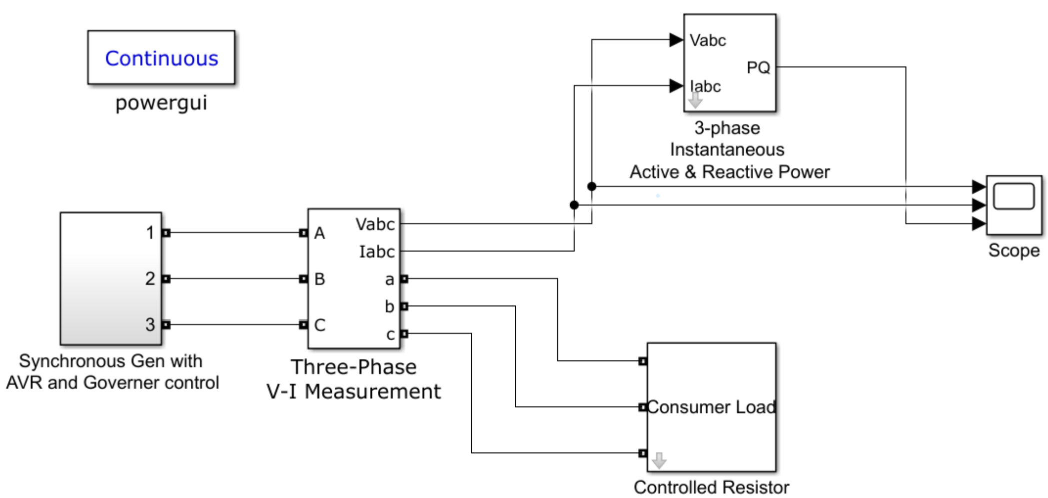


Figure 26 Micro-hydro model with Governor

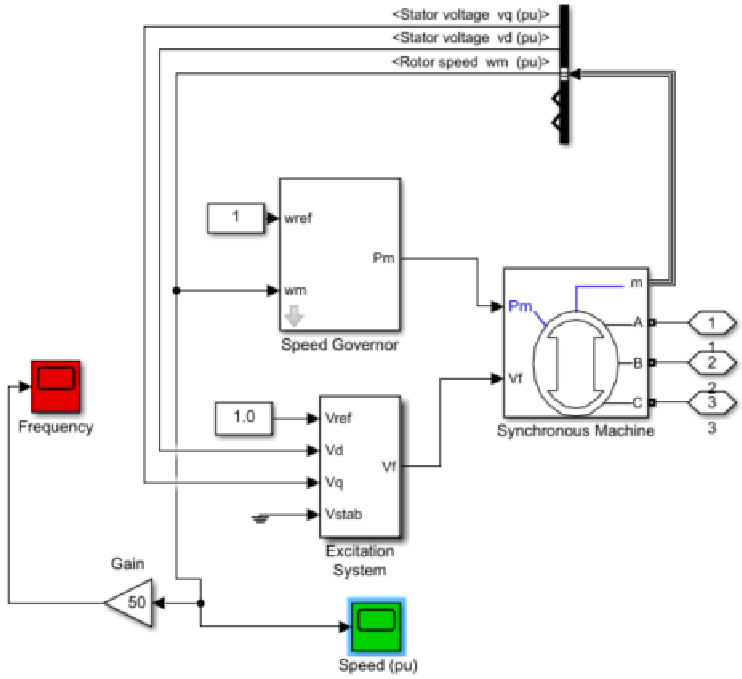


Figure 27 Synchronous Generator with Governor Block

Above Figure 25 and Figure 26 shows the MHP Block with synchronous generator of rating 16KVA,400V,50HZ. The consumer load is set at 14KW which increases at every 5sec.

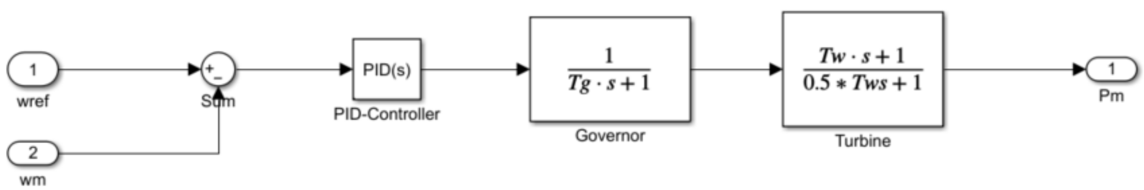


Figure 28 Hydro Turbine Governor

Above figure shows our modeled governor system with a Hydraulic Turbine system. Here rotor speed (Wm) is fed back from synchronous generator and compared with 1 pu value. The error is fed to the PID controller.

Here value of T_g and Tw are 0.2 and 1 respectively.

Now we tuned the PID controller to get the desired frequency response. And, tuned values of P, I and D are 25, 30 and 5 respectively.

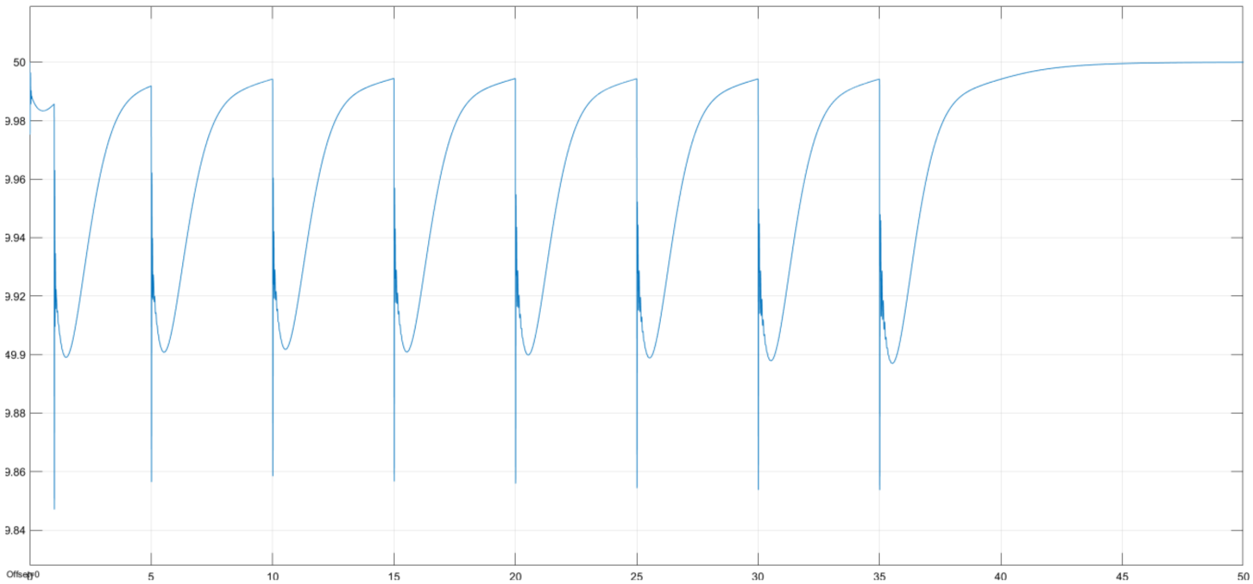


Figure 29 Frequency Response of MHP with Governor

The graph shows the frequency response of MHP system with Governor. Here we run the simulation for 50sec. The consumer load increases every 5 sec. And in the graph, we see, frequency becomes unstable every time load increases in the system governor tries to make it stable at 50Hz. And after full consumer load is applied, the governor system fully controls the frequency to 50Hz as shown in above graph.

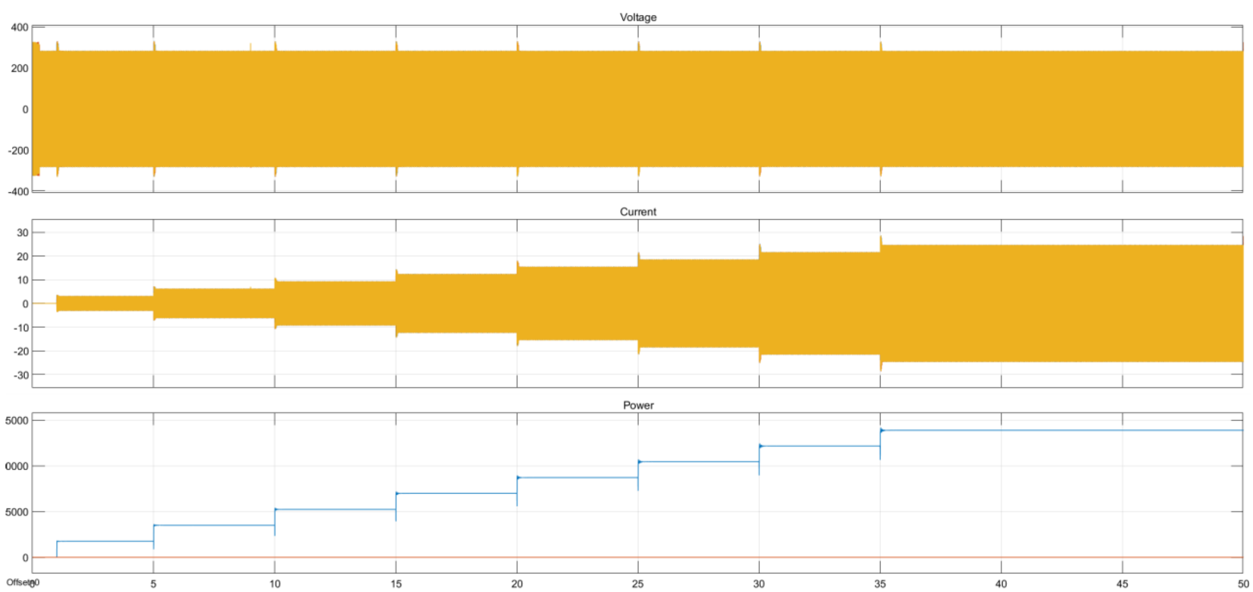


Figure 30 Generated Power Response

Above graph shows the Generated active power of the system. As consumer load increase, the generated power also increases to full fill the demand as shown above.

4.1.5 **Simulation of two MHP operated in parallel with ELC**

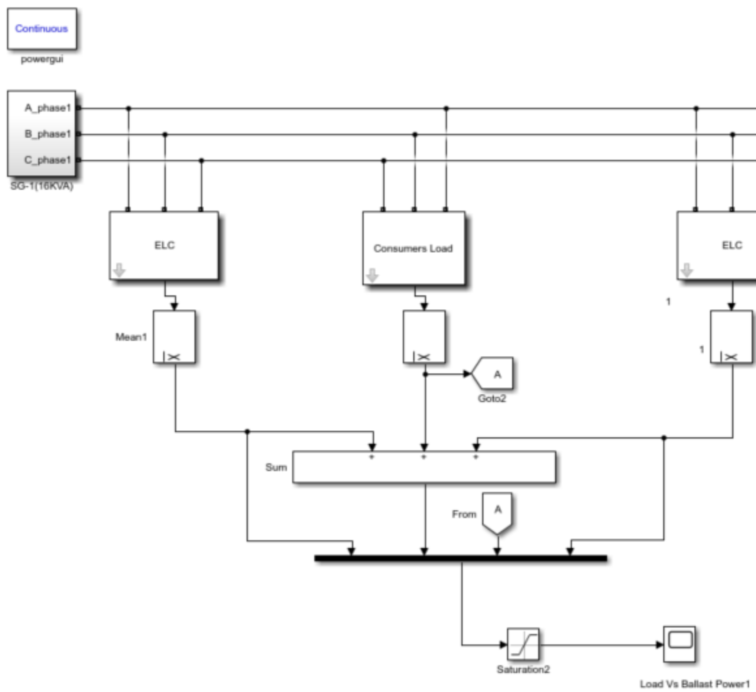


Figure 31 Two MHP with ELC operated in Parallel

The above figure shows the model of two MHP of rating 16 KVA, 400V, 50HZ each connected to ELC delivering power to a common load. So, it can say that, these two MHP form a mini-grid model. The consumer load increases at the delay of 0.25sec. Ballast load was set to 20KW for both ELC and main consumer load was kept 23KW.

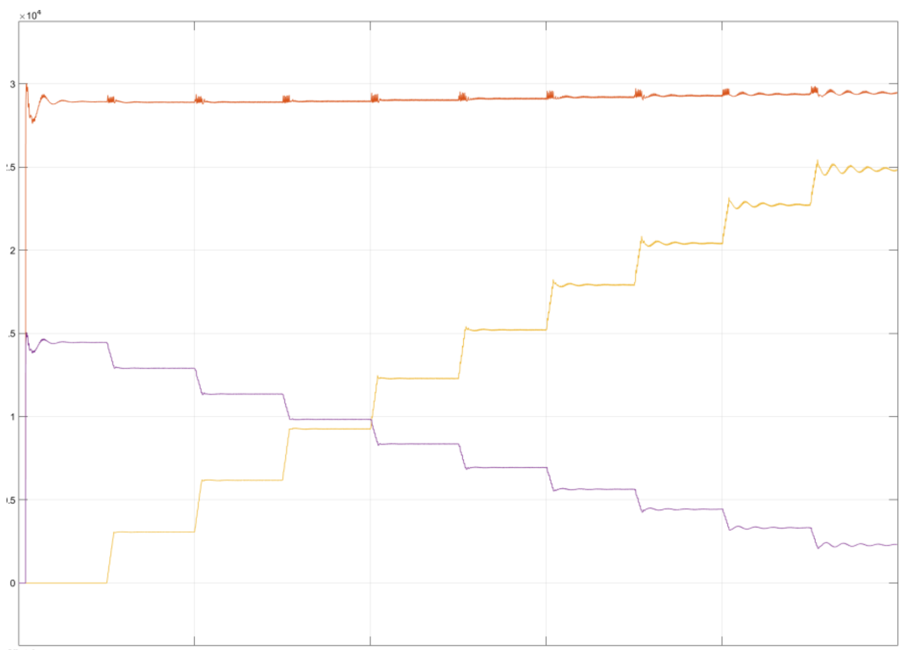


Figure 32 Power generation, ballast Power and Consumer power

Since the ballast of two MHP are of same size so power consumption of each ballast is exactly equal. So, the curve for MHP-1 and MHP-2 overlap each other in above figure 32.

As the consumer load increases, the same amount of power is decreased from two ballast and the total generated power remains constant.

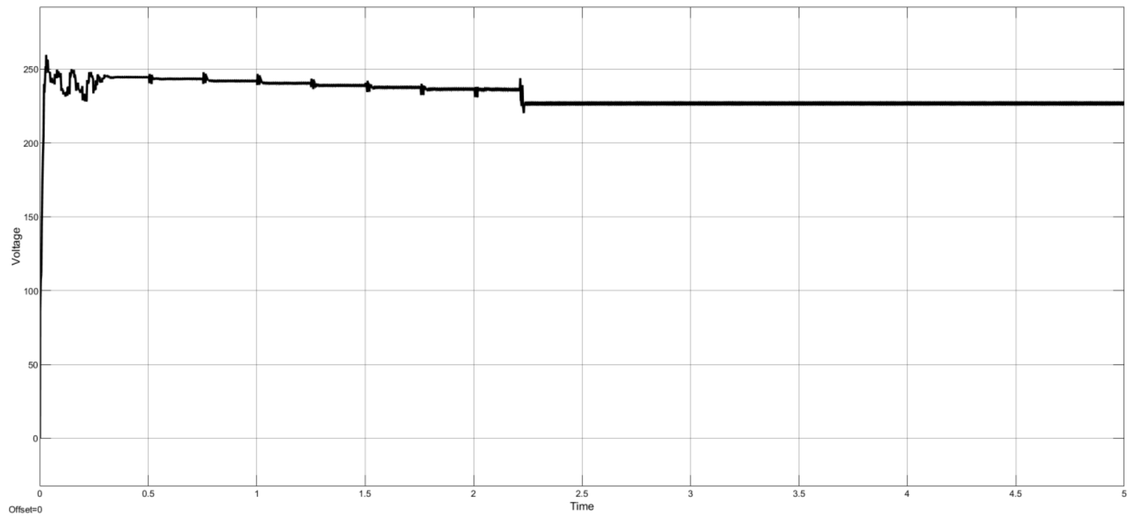


Figure 33 Voltage Vs Time response

Above figure represents the rms voltage phase of MHP after connecting two MHP in parallel. In beginning the rms voltage phase exceed 250V during transient period which is in the range of milli-second. But when the ballast load was connected voltage tends to drop. Excitation system called AVR helps to develop and maintain the voltage level of the system as shown in a figure 33.

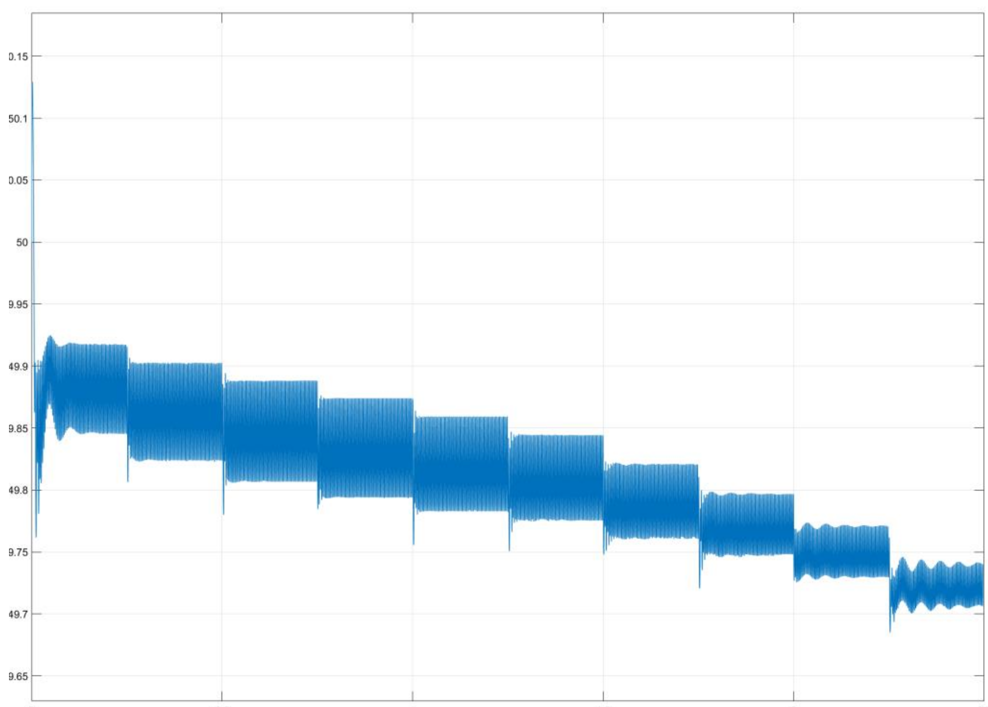


Figure 34 Frequency response of MHP1 and MHP-2 with ELC

The connected network will have the same frequency. The above figure 34 describes the frequency response of the system. Since the consumer load increases after each 0.25 sec so, the frequency versus time graph tends to decrease after increase of 0.25 sec. we can see that the frequency is well controlled within acceptable range. The frequency variation is from 50.15 Hz to 49.70 Hz

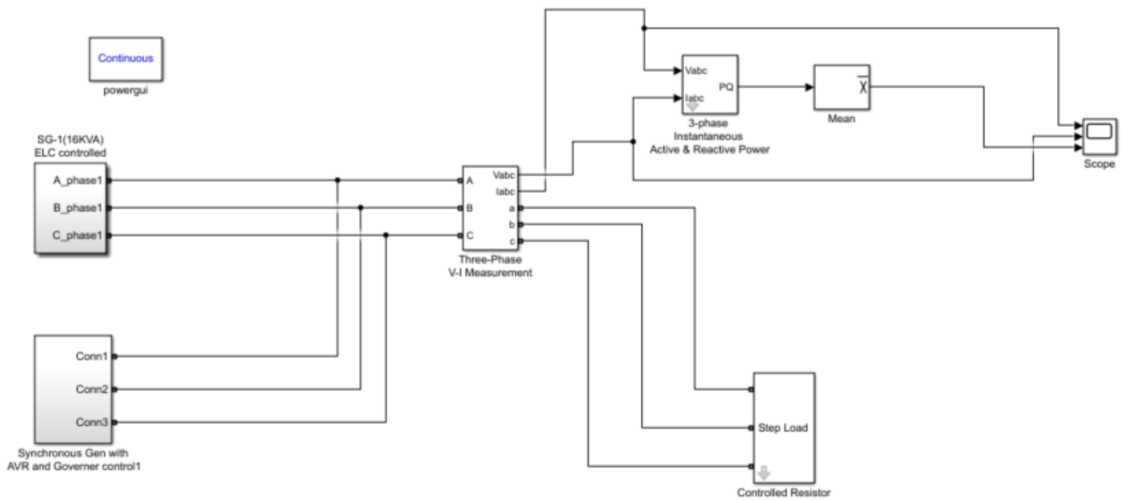


Figure 35 Two Micro Hydro Supplying the power to a common Load

REFERENCES

[1] Pushpa Chitrakar, “Micro-Hydropower Design Aids Manual,” no. October, pp. 89–97, 2005, [Online]. Available: https://energypedia.info/wiki/Micro_Hydro_Power_(MHP)_Manuals_/_Micro-Hydro_Design_Aids_Manual.

[2] B. Mainali and S. Silveira, “Financing off-grid rural electrification: Country case Nepal,” *Energy*, vol. 36, no. 4, pp. 2194–2201, 2011, doi: 10.1016/j.energy.2010.07.004.

[3] K. K. Panthi and B. Nilsen, “Predicted versus actual rock mass conditions: A review of four tunnel projects in Nepal Himalaya,” *Tunn. Undergr. Sp. Technol.*, vol. 22, no. 2, pp. 173–184, 2007, doi: 10.1016/j.tust.2006.04.005.

[4] W. Ali, H. Farooq, A. Ur Rehman, M. Jamil, Q. Awais, and M. Ali, “Grid Interconnection of Micro Hydro Power Plants: Major Requirements, Key Issues and Challenges,” *RAEE 2018 - Int. Symp. Recent Adv. Electr. Eng.*, pp. 1–6, 2018, doi: 10.1109/RAEE.2018.8706893.

[5] Ahmed Sharique Anees, “Grid Integration of Variable Renewable Energy Sources: Research Challenges and Opportunities,” *Networks*, 2011.

[6] C. Marinescu and I. Şerban, “Analysis of frequency stability in a residential autonomous microgrid based on a wind turbine and a microhydro power plant,” *2009 IEEE Power Electron. Mach. Wind Appl. PEMWA 2009*, 2009, doi: 10.1109/PEMWA.2009.5208400.

[7] Y. E. G. Vera, R. Dufo-López, and J. L. Bernal-Agustín, “Energy management in microgrids with renewable energy sources: A literature review,” *Appl. Sci.*, vol. 9, no. 18, 2019, doi: 10.3390/app9183854.

[8] X. Zhou, T. Guo, and Y. Ma, “An overview on microgrid technology,” *2015 IEEE Int. Conf. Mechatronics Autom. ICMA 2015*, pp. 76–81, 2015, doi: 10.1109/ICMA.2015.7237460.

[9] P. Shrestha, A. Shrestha, N. T. Shrestha, A. Papadakis, and R. K. Maskey, “Assessment on Scaling-Up of Mini-Grid Initiative: Case Study of Mini-Grid in Rural Nepal,” *Int. J. Precis. Eng. Manuf. - Green Technol.*, vol. 8, no. 1, pp. 217–231, 2021, doi: 10.1007/s40684-020-00190-x.

[10] I. Journals, “AIJRSTEM13-239.”

[11] A. Shrestha *et al.*, “Status of Micro/Mini-Grid Systems in a Himalayan Nation: A Comprehensive Review,” *IEEE Access*, vol. 8, pp. 120983–120998, 2020, doi: 10.1109/ACCESS.2020.3006912.

[12] A. Khemraj and B. Triratna, “Current status of Microhydro in Nepal,” *IOE Grad. Conf.*, no. March, 2013.

[13] R. Dahal, S. K. Jha, and B. Adhikary, "Performance of droop based load controller in interconnected micro hydro power plants," *ICDRET 2016 - 4th Int. Conf. Dev. Renew. Energy Technol.*, 2016, doi: 10.1109/ICDRET.2016.7421502.

[14] L. Phunchok, S. Kumar, A. P. Om, and P. Rahi, "Frequency Control Of Micro Hydro Power Plant Using Electronic Load Controller," *J. Eng. Res. Appl.*, vol. 2, no. 4, pp. 733–737, 2012.

[15] N. P. Chaudhary and R. Dhital, "'Micro & mini hydro based mini-grid for rural energy access in Taplejung, Nepal," *Proc. IOE Grad. Conf*, pp. 71–83, 2016, [Online]. Available: http://conference.ioe.edu.np/ioegc2016/papers/IOEGC-2016-10.pdf.

[16] B. Shakya, "ANNEX - A 2 Mini Grid Development in Nepal : An Experience from RERL," no. July 2012, 2015.

[17] N. P. Gyawali, "Universal electronic load controller for microhydro power plant," *IEEE Int. Conf. Control Autom. ICCA*, vol. 2016-July, pp. 288–292, 2016, doi: 10.1109/ICCA.2016.7505291.

[18] S. Timilsina, "Parallel Operation of MHP Plants with ACVC- ELC and Discrete-ELC," no. November 2017, pp. 1–6, 2018.

[19] B. Shakya, "' A Community Managed Micro Hydro Connected Mini Grid in Nepal-Challenges and Opportunities ' Bhupendra Shakya Renewable Energy Expert Renewable Energy for Rural Livelihood Programme / AEPC Kathmandu , Nepal," no. February 2013, 2015, doi: 10.13140/RG.2.1.2837.8964.

[20] B. Adhikary, B. Ghimire, and P. Karki, "Interconnection of two micro hydro units forming a mini-grid system using soft connection," *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, pp. 1–5, 2009, doi: 10.1109/TENCON.2009.5396207.

[21] A. R. Giri, B. Shrestha, and R. Sinha, "Performance analysis of microcontroller based electronic load controller," *Kathmandu Univ. J. Sci. Eng. Technol.*, vol. 13, no. 1, pp. 20–35, 2018, doi: 10.3126/kuset.v13i1.21250.

[22] S. K. Rai, O. P. Rahi, and S. Kumar, "Implementation of electronic load controller for control of micro hydro power plant," *Int. Conf. Energy Econ. Environ. - 1st IEEE Uttar Pradesh Sect. Conf. UPCON-ICEEE 2015*, 2015, doi: 10.1109/EnergyEconomics.2015.7235098.

[23] I. Sami, N. Ullah, S. M. Muyeen, K. Techato, S. Chowdhury, and J. S. Ro, "Control Methods for Standalone and Grid Connected Micro-Hydro Power Plants with Synthetic Inertia Frequency Support: A Comprehensive Review," *IEEE Access*, vol. 8, pp. 176313–176329, 2020, doi: 10.1109/ACCESS.2020.3026492.

[24] U. Ur Rehman and M. Riaz, "Design and implementation of electronic load controller for small hydro power plants," *2018 Int. Conf. Comput. Math. Eng. Technol. Inven. Innov. Integr. Socioecon. Dev. iCoMET 2018 - Proc.*, vol. 2018-Janua, pp. 1–7, 2018, doi: 10.1109/ICOMET.2018.8346450.

[25] D. Shrestha, A. B. Rajbanshi, K. Shrestha, and I. Tamrakar, "Advance Electronic Load Controller for Micro Hydro Power Plant," vol. 8, pp. 1802–1810, 2014.

[26] N. W. Aung and A. Z. Ya, "Design Calculation and Control System Simulation of a

Microcontroller Based Design Calculation and Control System Simulation of a Microcontroller Based Electronic Load Controller for Stand-alone," no. December 2014, 2016, doi: 10.13140/RG.2.1.3775.9123.

[27] D. Henderson, "An advanced electronic load governor for control of micro hydroelectric generation," *IEEE Trans. Energy Convers.*, vol. 13, no. 3, pp. 300–304, 1998, doi: 10.1109/60.707611.

[28] N. E. l. Salhi, S. Doubabi, "Fuzzy control of micro hydro power plants."

[29] S. V. Kamble and S. M. Akolkar, "Load frequency control of micro hydro power plant using fuzzy logic controller," *IEEE Int. Conf. Power, Control. Signals Instrum. Eng. ICPCSI 2017*, pp. 1783–1787, 2018, doi: 10.1109/ICPCSI.2017.8392021.

[30] A. J. Ellison, "Electric Machinery and Control," *Electron. Power*, vol. 11, no. 4, p. 144, 1965, doi: 10.1049/ep.1965.0114.

[31] S. Krishna, "Synchronous Generator." pp. 1–43, 2014, doi: 10.1007/978-81-322-1847-0_1.

[32] O. R. Hydraulic, S. E. T. P. Adjustmnets, F. B. Transmitter, S. F. Pt, and G. Or, "CHAPTER-6 HYDRO-TURBINE GOVERNING SYSTEM (Reviewed by Dr . R . Thapar)," vol. II, pp. 147–173.

[33] M. Hanmandlu and H. Goyal, "Proposing a new advanced control technique for micro hydro power plants," *Int. J. Electr. Power Energy Syst.*, vol. 30, no. 4, pp. 272–282, 2008, doi: 10.1016/j.ijepes.2007.07.010.