Design of Cost-Effective Microcontroller Based Load Controller with Data Logging for Standalone Electric Plant

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Abstract

Maintaining the voltage and frequency fluctuation using a hydraulic governor in Standalone Micro-Hydro Projects (SMHEP) is costlier than the generator itself. So, an Electronics Load Controller (ELC) is used to regulate output power of generator used in the SMHEP. Developments in the ELCs will play an important role in increasing the efficiency and life span of the power plant thereby providing a lot of space for the further improvements. This paper analyzes the current trends and tries to identify their limitations and suggest a novel approach in designing a cost effective ELC system with the capabilities of data logging. In this study software simulation was carried out in Proteus, while the experimental model was designed using microcontroller and integrated sensor system. Both the software and hardware implementations showed positive results. The experiment was carried out under laboratory conditions in which the proposed model successfully diverted the excess power to connected dump loads and allowed the generator to generate the power at full load with efficient data logging and graphical user interface.

Keyword: Data Acquisition, Electronic Ballasts, Load Management, Sensor Systems and Applications, Standalone Power Supply

1   Introduction

Micro-hydro are emerging means of power supply which is an economic alternative to the national grid as they tend to reduce the high cost of extending grid [1]. Micro-hydro system utilizes the gravitational potential energy of water into electrical energy through necessary conversion [2]. The power available is proportional to the product of pressure head and volume flow-rate of the water through the turbine [3].

$$P = \eta\ \varrho\ g\ Q\ H \qquad\qquad (1)$$

Where, P= output power or potential from flowing water; η= efficiency of the turbine; ϱ= density of water (1000 kg/m^3); g= acceleration due to gravity; Q= flow rate in the pipe (m^3/s) and H= water head (m)

Micro-hydro is particularly suitable for mountainous regions of Nepal as it is very difficult for grid extension. They are currently a developing field with attempts mainly being carried out in countries such as Peru, Sri Lanka and Nepal [4]. Micro-hydro power plants do not require rigorous maintenance and are relatively easy to operate. Micro-hydro power stations are defined as hydro-electric system up to 100 kW power ranges [5].

The rate of rural electrification has increased significantly in the past few years [6]. Since ELCs play an important role in protection of the plant and ultimately the efficiency and life there is lot more space for the improvement in ELCs. The electronic load controllers (ELCs) used in micro-hydro will divert excess power to a dump load to regulate voltage and frequency of the system.

1.1 Background

Controlling the load fluctuation with a governor in a micro-hydro would be very costly and reduce the benefits. On the other hand, ELC would reduce the cost as well as the maintenance charge [4]. The overall concept of our Electronic Load Controller is that the generator always tries to maintain the same load on the demand side of the system or to run the generator always in the full load. To do this we needed to provide a means of drawing power that we could control, to ensure that the total power drawn will always equal to that supplied by the turbine. An Electronic Load Controller (ELC) is an electronic unit designed to regulate the frequency and voltage of the power system.

$$Generated\ Power\ (PG) = Consumer\ Power\ (PC) + Ballast\ or\ Dump\ Power\ (PD)$$

$$(2)$$

An ELC generally consists of mainly four steps [6]:

i. Input Sensor (reading frequency, voltage, and current)
ii. Generating necessary logic to control switching (analog circuit or digital microcontroller)
iii. A switch (basically a power electronic device like thyristor, TRIAC or an mechanical relay).
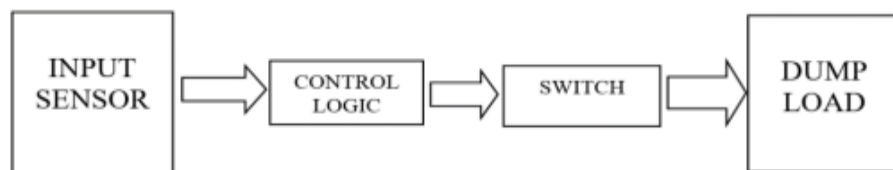iv. A dump load (typically a water resistance heater).

Figure 1: Basic Block Diagram of Current Electronic Load Controller

The power dissipated in the dump load can be used for battery charging, water heating, cooking, etc. Proper number of dump loads with right capacity help to achieve smooth regulation [7].

This study carries out all of these necessary steps for a normal ELC as well as insures the storage of the real time data in a storage device for future analysis and also provides an efficient GUI for easier operation of the ELC.

There are generally two ways of dumping the excess power [6]:

i. Dumping the excess power in the power house itself.
ii. Distributed ELC or Dumping the excess power in each and every household.

There are several advantages of electronic load controller [5].

i. Simpler but cheaper turbine with less moving part can be used as the load variation is controlled by ELC.
ii. Load variation will not cause any hammering effect and this will insure lighter as well as less robust penstocks pipes.
iii. Reliability and maintenance cost are improved.
iv. ELC can be installed at any point in electrical system.
v. Dump or ballast load can be used for water and/or space heaters which would ensure 100% load factor of the power plant.
vi. ELC is cheaper than equivalent governor that control the flow rather than the output power.

In the future, MHPs could have a huge impact on the development of the local community. So, an efficient load controller would play a vital role for its development. Figure 2 demonstrates the generated power sharing between dump load and consumer load along the time.
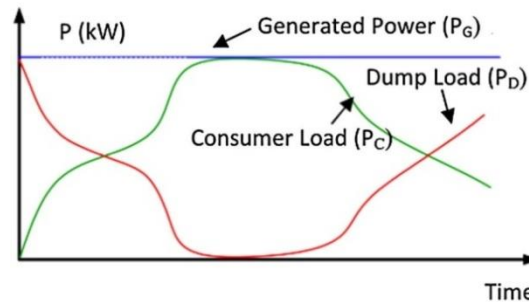

Figure 2: ELC Graph Showing it's Principle Operation[5]

1.2 Literature Review

Controlling the power output by the generator is very costly using hydraulic governor or by regulating the flow of water. This led to the development of Electronic Load Controller that allows generator to run on full load capacity no matter the consumer load fluctuation [8]. STATCOM which is a fast acting, static synchronous compensator has also found rapid application for controlling the voltage, frequency, load flow, harmonic elimination and neutral current compensation in the stand alone micro hydro power plants [8].

Automatic Voltage Regulators (AVR) is also used to regulate the voltage generated by the generators by controlling the amount of excitation current. Various studies have also proven that the use of AVR can result in stable output voltage from the generator [9]. The main types of ELC design that are currently available are [7]

i. **Binary load regulation**

It utilizes fixed dump load sizes to regulate the power and reduce the harmonics from the system. A large number of dump loads are required for effective operation.

ii. **Phase angle regulation**

In this type of design, power electronics switching devices are triggered at different firing angles depending on the consumer load variation. The firing of such devices the operation of single resistive load connected in the system.

iii. **Pulse width regulation**

PWM regulation works on the principle of controlling the duty cycle of the rectifier circuit. In this type, a rectified voltage is used to control the operation of dump loads. As these involve heating and current problems so, it is merely used at higher frequencies but, it has fast response as compared to other systems at lower frequencies.

iv. **Controlled bridge rectifier**

Here, a variable DC voltage is generated form a controlled bridge rectifier like Silicon Controlled Rectifier (SCR)/ Thyristor. SCR is used both as converter and controller of electrical power in this system. This system also introduces harmonics that limits the effectiveness of the system.

v. **Uncontrolled bridge rectifier with a chopper**

Here, AC voltage is first rectified and then the chopper converts it into variable DC by controlling the duty cycle. It can use any number of dump load and its combinations.

Similar kind of load controller can also used in other types of standalone plants like biogas plants, wind energy pants etc. Nepal has good potential of producing energy from biomass as cattle farming is one of the key animal husbandry. Electricity can be produced using this energy source [10].

1.3   Objective of the Study

This study focuses on designing a load controller which could distribute adequate power to consumer form a micro-hydro and divert the excess to the dump loads. In addition, the research intends to maintain the system frequency and voltage at 50 Hz and 220 V with 5% tolerance respectively. Furthermore, all the data from various sensors are displayed into a LCD with proper data logging for future analysis.

2   Research Methodology

The study focuses on development of a new approach for the implementation of a complete ELC capable of regulating the power from the generator as well as storage with excellent user interface. In order to undertake these aspects experimental and simulation based research methods were selected. Figure 3 represents the flow chart for the dump load operation and the logic involved under varied conditions.
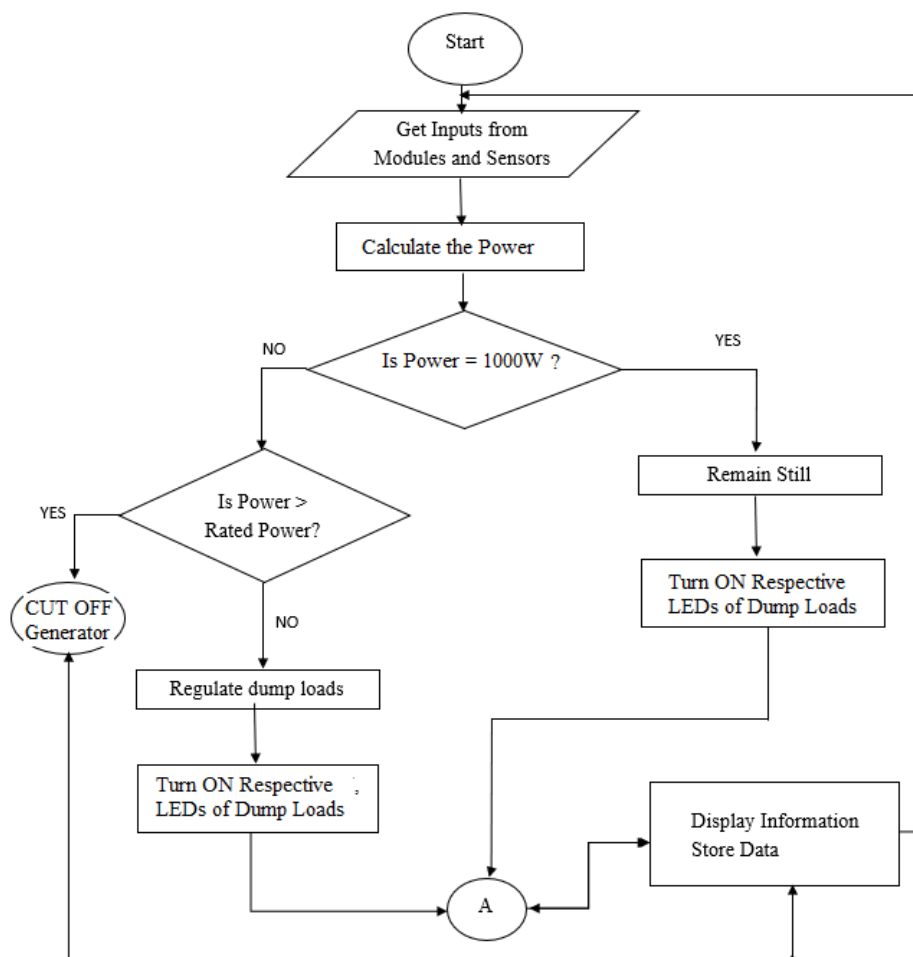

Figure 3: Flow Chart for the Operation of Dump Loads Under Various Conditions

Firstly, the sensors connected to the respective ports of microcontroller gather the data and these data are manipulated to obtain the active power consumption in the demand side of consumer. Here the generator is always operated in the full load capacity. If the consumed power in the demand side is less than 1kW

then respective dump load is turned on so that the overall power consumed will be equal to the total power generated (that is 1000W). The respective indication LEDs for dump load is also turned on and all the information is displayed in LCD and stored in a Micro SD Card. This system runs continuously to maintain the system voltage and frequency at desired level.

2.1 Architecture

The proposed ELC consists of mainly three circuits such as Control Circuit, Power Circuit and Display and Storage Unit. These circuits and units further consists of:

Control Circuit

- i.   Microcontroller
- ii.   Voltage, current and Zero Crossing Sensors.
- iii.   Power Supply circuit

Power Circuit

- i.   Consumer Load Power Circuit
- ii.   Dump or Ballast Load Power Circuit

Storage and Display Unit

- i.   LCD 20×4
- ii.   Micro SD Card with Module.

Figure 4 represents the overall system architecture of the proposed model of ELC. A synchronous generator of 1kW capacity was used for experimental testing of the system. A miniature circuit breaker (MCB) of 6A breaking capacity was used for the protection of the generator and the entire system was assembled accordingly.
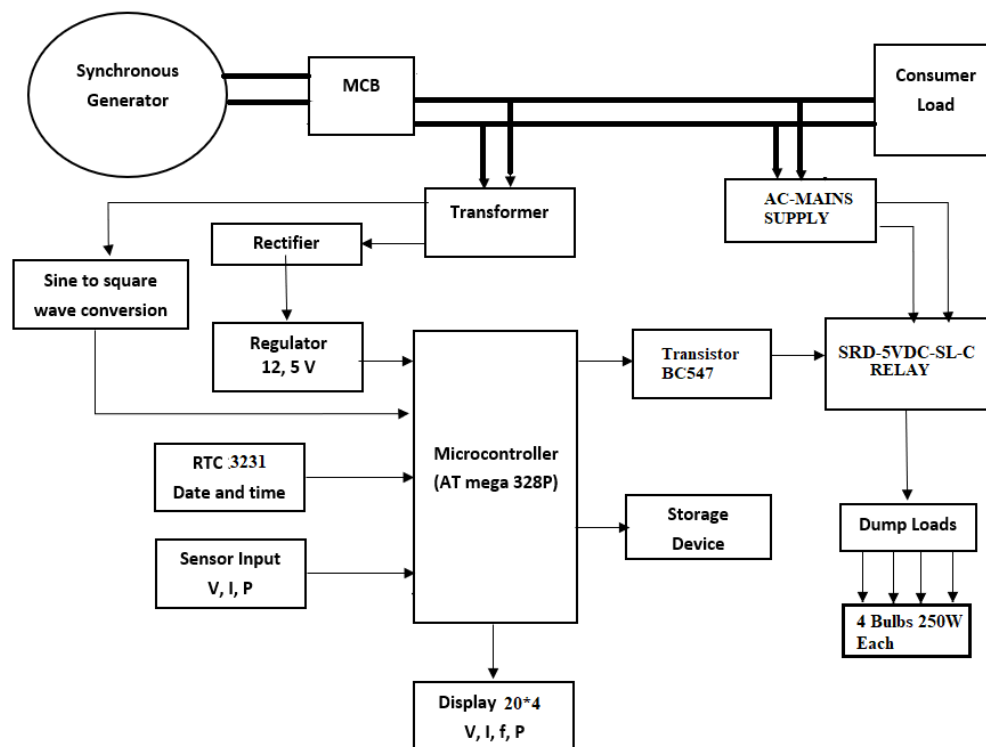

Figure 4: System Architecture of the Entire Model of Proposed ELC.

The consumer and dump load were connected in parallel with each other keeping a constant voltage across them. The consumer load was varied in steps using a resistive load bank meanwhile, the voltage,

current and frequency of the entire system was observed by various sensors and fed as an input to the ports of microcontroller. These input parameters were then analyzed and processed by the microcontroller which ultimately regulated the operation of dump loads as per the program through transistor (BC 547, NPN) and relay set. The variation and operation of dump load under different consumer load condition can be viewed in table 1. This system displays all the measured input parameters in a LCD 20×4 display and also the power drawn by both the loads. Furthermore, this system also logs all the required data in a storage device. A sample of the stored data is shown in table 2. The power required for the microcontroller was drawn from generator mains using a dc regulated power supply system designed specifically to feed necessary power demand of the microcontroller.

2.2   Parameter Measurement Methods

Dump Load Operation Mechanism

We used binary load regulation method for the operation of dump load as per the variation in the consumer load so as to run the generator at full load capacity. In this method dump load or ballast load is a set of switched combination of separated resistive load where the switching selection is made by appropriate combination of load step. This method reduces the harmonic distortion associated with transient switching to achieve smooth regulation. But, fewer number of dump loads leads to large combinational difference in steps to which system cannot regulated smoothly [7].

Current Measurement Mechanism

The measurement of current was done using Allegro ACS712 which is a fully integrated, Hall Effect based liner current sensor. It is economical and provides precise measurement of current for load detection and management. The current applied in the sensor passes through a copper conduction path that generated magnetic field which is then converted into equivalent voltage by the Hall IC. Figure 5 shows the functional block diagram of the sensor. In the sensor 1 and 2 represents IP+ , 3 and 4 represents IP- are the terminals for current being sensed which are fused internally. It is a very stable and has nearly zero magnetic hysteresis [11].
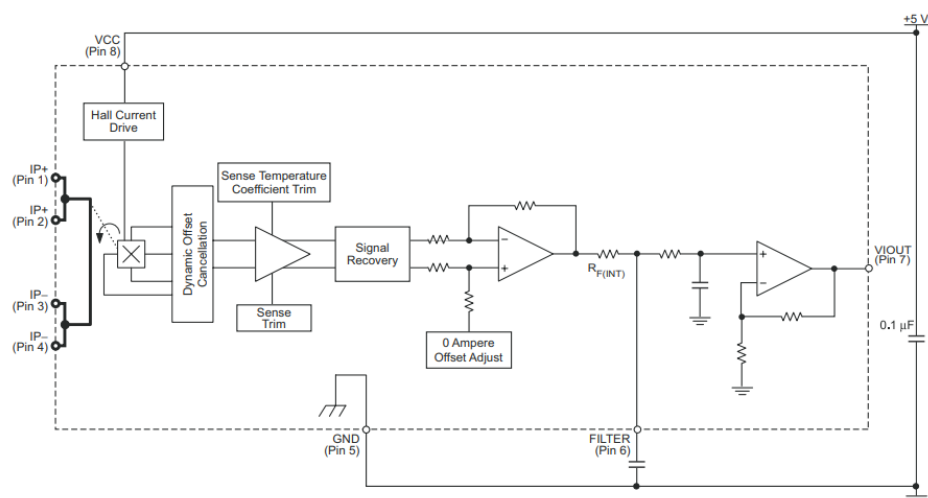

Figure 5: Functional Diagram of Allegro ACS 712 Current Sensor [10].

Voltage Measurement Mechanism

A 220/12V step down transformer was used to step down 220V AC to 12V AC. The AC signal was then fed to the bridge rectifier giving 12V DC. Later the 12V DC signal was fed to the voltage divider circuit

to step it down to about 5V. A 5V Zener diode was used to limit the voltage to 5V. The signal was then fed to the microcontroller to measure instantaneous voltage.

$$Vout = Vin \times \frac{R2}{R1+R2} \qquad (3)$$

If Vin = 12V, R1 = 10k and R2 = 5k Then: Vout = 4V

But in the practical scenario the output of the transformer is not exactly 12V but at 220V peak it is near to about 15V so in order to protect the microcontroller a Zener Diode of 5V reverse breakdown voltage is used
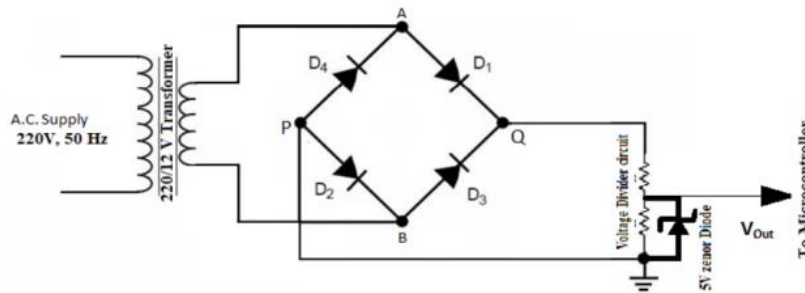

Figure 6: Circuit Diagram for the Measurement of Voltage.

Frequency Measurement Mechanism

Frequency was measured using the zero-crossing detection technique. The circuit designed uses zero voltage switching where the moment of switching corresponds to voltage zero. This minimizes harmonic distortion and radio frequency interference (RFI). The switching between different loads implies that the control is not stepless. The interval between successive negative-going zero-crossings or positive-going zero-crossings of the phase voltage waveform is measured by microcontroller. Below is the microcontroller code for measuring the positive and negative pulse time after necessary sine to square wave conversion .

Code for Frequency Measurement

```
positivetime = pulseIn(frequencySensor, HIGH);
negative_time = pulseIn(frequencySensor, LOW);
Total_time = positive_time + negative_time;
frequency = 1000000/Total_time;
```
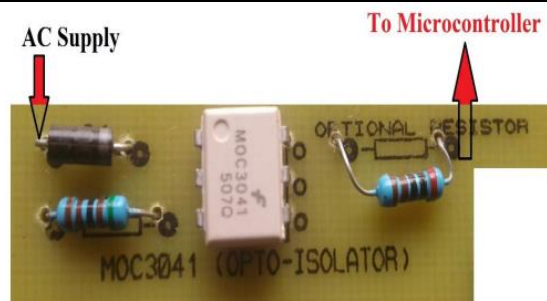

Figure 7: Circuit for the Measurement of Frequency using MOC3041 (Opto Isolator)
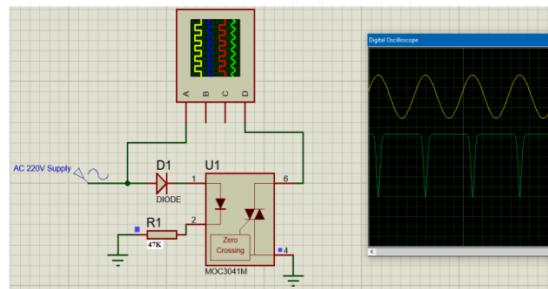
Figure 8: Simulation of the Experimental Circuit in Proteus.

Display and Storage of Data

General ELC systems only regulated the dump loads as per the variation in the consumer load following one or the other method but, the ELC we developed does all of these works and also displays all the measured parameter in a single LCD as well as efficiently stores it. The storage is done as per the date and time of event with the help of DS3231 real time clock. The DS3231 is a low-cost, highly accurate Real Time Clock which can maintain hours, minutes and seconds, as well as, day, month and year information. Also, it has automatic compensation for leap-years and for months with fewer than 31 days[12]. The storage is done in a 2 GB Micro SD card.

3 Results and Discussion

A model for the proposed ELC was developed and experiments were carried out under laboratory conditions. For experimental purpose, the system used a generator with peak load capacity of 1 kW. Hence, all the sensor, switchgear and protection equipments were designed as per that power rating. We used binary load regulation method in which four different sets of 250 W resistive dump loads were turned on and off respectively as per the load variation in the consumer side. A controlled consumer load variation was carried out which was taken as input parameter to the AT Mega 328 microcontroller which controlled the dump loads automatically. The table 1 below shows the patterns of dump load operations as per the consumer load variation. The table 1 also indicates the amount of current flowing in the dump loads under different conditions.

Table 1: Current Drawn by the Dump Loads during Consumer Load Variation

Pattern of Dump Load Operation	Current Measured by the Current Sensor	Setting of Consumer Load (in Watts)
Dump Loads OFF	0.16 A	1000
Dump Load 1 ON	1.60 A	750
Dump Load 1 and 2 ON	2.56 A	500
Dump Load 1,2 and 3 ON	3.95 A	250
Dump Load 1, 2,3 and 4 ON	5.45 A	0

As shown in the table 1, the increase in the steps of consumer load the respective dump loads gets turned off and the respective results were shown in 20 × 4 LCD. The dump load current measured by Allegro ACS712 sensor is also shown in the table which reflects a gradual increase as per the turning ON of multiple dump loads. When there were no dump loads ON, the current shown was 0.16A but as the number of dump load increases it reached a maximum of 5.45A when all the dump loads were ON. The consumer load was varied in five steps that is, 0W, 250 W, 500W, 750W and 1000W using a single phase 1kW resistive load bank arrangement in the laboratory.

Table 2: Sample of the Data in the Data Logging System

Date	Time	Frequency (Hz)	Voltage (V)	Load Current (A)	Consumed Power (Watt)	Dumped Load(Watt)
5 NOV 2021 (FRI)	11:53:08	50.09	209.21	0.18	30.5	969.44
5 NOV 2021 (FRI)	11:59:51	48.21	210.50	1.67	282.14	717.69
5 NOV 2021 (FRI)	12:00:20	49.30	215.0	4.41	759.01	240.98

The table 2 emphasizes on the patterns of data logged in a storage device. These data could be used for future analysis as it records most of the parameters like date, time, frequency, voltage, load current, consumed power and dump power at specified interval of time. A micro SD card of 2 GB capacity was used to store the data for experimental purpose. The stored data can be used to identify the patterns of load consumption, cause of faults, load duration and variation curves and demand curves. It can also be used for the identification of peak and no load demand time that could be essential during the regular as well as annual maintenance of the plant. The data shown in the LCD and stored in the micro SD card were very precise and showed very positive results. It also shows that the designed system was capable in maintaining the frequency and voltage at a specified range as per the objective of the research.

Code in Microcontroller for Program Initialization

```
/*Initialization Codes for AT Mega 328*/
#include <LiquidCrystal.h>
#include <SPI.h>
#include <SD.h>
#include <Wire.h>
#include "RTClib.h"
    LiquidCrystal lcd(4,5,6,7,8,9);
    const int chipSelect = 10;
    RTC_DS3231 rtc;
    char daysOfTheWeek[7][4]= {"SUN", "MON", "TUE", "WED", "THU", "FRI",
    "SAT"};
    char monthOfTheYear[12][4] = {"JAN", "FEB", "MAR", "APR", "MAY", "JUN",
    "JUL", "AUG", "SEP", "OCT", "NOV", "DEC"};
     int frequencySensor = A0;
    int voltageSensor = A1;
     int currentSensor = A2;
    int mVperAmp = 185;
    double Voltage = 0;
```

```
    double VRMS = 0;
    double AmpsRMS = 0;
    int dump1 = 0;
    int dump2 = 1;
     int dump3 = 2;
    int dump4 = 3;
    int buzz = 13;
    float frequency;
    float dump_power;
void setup()
    {
       rtc.begin();
       lcd.begin(20,4);
       Initilize_SD();
       Initilize_RTC();
    }
```

The above codes initialize all the respective input/output ports for AT Mega 328. It also alerts the compiler of the microcontroller about all different kind of sensors and actuators used in the system. The above code provides the general idea of various class and structure created in the code and the way forward. It can be clearly seen that various modules and sensors are initialized in the program such as Real Time Clock (RTC DS 3231), Liquid Crystal Display 20×4 (LCD), Micro SD Card, Voltage Sensor System, Current Sensor (ACS 712), Frequency Sensor System and respective i/o ports for these sensors and modules. The code also initializes the respective ports for dump loads control. The entire code is not displayed due to its length.

4   Conclusion

The paper mainly focuses on designing electronic load controller which can be adaptable in any type of standalone micro-hydro plants. The capabilities of existing ELC could be enhanced if they could incorporate efficient user interface and data logging system. The developed ELC not only monitors the system parameters like voltage, current, frequency and power but also displays it in a single LCD with proper storage for future analysis. The system voltage and frequency were experimentally found to be within the tolerance limit of ±5%. The dump loads was reliably and accurately controlled by the developed ELC. Moreover, using a single integrated system like this, to observe, control, store and display most of the parameters of the micro hydro plant not only reduces the cost but also makes the system more compact. Hence, this system could be instrumental to reduce the cost of ELC as well as make it more versatile. The developed ELC was for single phase system, slight improvement and modification can be done to use it for three phase system which could be the area for further research.

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