REMOTE MONITORING OF EARTHING SYSTEMS

A THESIS

Submitted by

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THESIS CERTIFICATE

This is to certify that the thesis entitled **REMOTE MONITORING OF EARTHING SYSTEMS** submitted by **DHEERAJ KUMAR** to the Indian Institute of Technology, Madras for the award of the degree of **Master of Technology** is a bonafide record of research work carried out by him under my supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ABSTRACT

Modern electronic equipments have stringent requirements on power quality and demand an earth resistance value as low as 1 Ω in order to function reliably. Ensuring a low value of earth resistance is, thus, a very important task. For this, frequent monitoring of earth resistance is the most basic step. The value of earth resistance may change frequently probably due to reasons such as type of soil, weather/environmental conditions and type of earth pit. However, it is very difficult to monitor or know these changes without actually measuring them. If we measure the earth resistance more frequently, such as 2 to 3 times a day, timely corrective measures can be taken. However, in any large organization, where there are hundreds or even thousands of earth pits, this would mean purchase of a lot of earth testers and deploy them using manpower every now and then. This would mean a considerable portion of time will be spent in such measurements and also incur financial expenditure. It is therefore beneficial that such a system be made which can help in, firstly, automatic measurement of earth resistance and secondly, sending the data to a web server for regular monitoring while sitting anywhere. Commercially, such systems are available, but they are very costly. So, while the technology to undertake this task may already be existing in the market, development of a simplistic, go-no go type low cost system to carry out the same task will make it more and more affordable.

The objective of the project work is to automate a 61.8 percent commercial earth tester with the help of an ATmega328P based microcontroller (used in Arduino UNO) so as to carry out automatic testing with the capability to send the measurement data over internet. The setup is completely battery operated and the data is intended to be stored in a cloud service such as Amazon Web Services (AWS). In other words, provide IoT capability to an earth resistance tester. In addition, it is endeavoured to design and simulate earth testers working on 61.8 percent method as well as clamp on method using TI-TINA software as well.

A commercial earth tester working on 61.8 percent method is used for achieving the objective. The tester is integrated with ATmega328P based microcontroller and an Ethernet card for networking. The microcontroller is used to perform functions such as, control the measurement device, measure the voltage and current to calculate corresponding earth resistance and send data to internet based server through router or switch with the help of an Arduino Ethernet Shield. A web based server is setup to record the measurements in a database. The values stored in the database are viewed on a webpage from any device having internet access. The device has been designed to accurately measure upto 10 Ω, as any value above 5 Ω may be treated as unacceptable, hence measurement much above this value will not be required. The tester has been integrated in such a way that any unserviceable tester with just a serviceable current generator can be used for the task. In addition to this, an attempt has been made to design and simulate a 61.8 percent earth tester and clamp on earth tester to achieve better understanding of their functioning and replace the commercial tester in the setup of main objective.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter-1
Introduction

Proper earthing is not only required for human safety, but also for efficient functioning of the modern electronic equipment. Ensuring a good quality earthing is thus a very prime requirement. However, there may be such conditions in certain places, which may cause the value of earth resistance to go above desired limits. Such conditions may be caused due to type of soil, degradation of earth pits with time, temporarily installed earthpits, weather, humidity and level of maintenance. Whatever the case may be, measurement, or at least knowing whether the value of earth resistance has crossed a threshold is the first step in taking corrective measures. However, it may become very cumbersome and time consuming to go to each earth pit and measure their earth resistances. Especially in larger organizations, where the responsibility of maintaining hundreds of earth pits may be placed under a single authority, an automated sensor system can be of great use.

1.1 Background and Literature Survey

The methods for measurement of earth resistance for single earth pits have been covered in detail in standards such as Indian Standard IS 3043:2018 and IEEE Std 81™-2012 (Revision of IEEE Std 81-1983). The two main methods are Fall of Potential or 61.8 percent method [1] and clamp on or stakeless method [2]. Certain modifications to these methods have been suggested which discuss placement of clamps to increase sensitivity [3]. Also, the effect of earth current on grounding resistance measurement has been studied [4]. Keeping the limitations of earth resistance measurement such as manpower constraint, automation of the measurement procedure using clamp on method [5] has been suggested. The method provides capability of carrying out measurement using a standalone battery powered unit and has a good range of measurement. However, many a times the user may only be interested in go/no go decision making with regards to condition of earth pits. For this, a cheaper solution can be brought out. If the requirement is defined as a go/no go tester, the measurement range can be kept lower and accuracy may be kept reasonable. This type of tester can warn a user to further investigate the condition of earth resistance and make a decision on their maintenance. The variable frequency earth tester [5] uses a C8051F006 microcontroller which has 12 bit ADC. If we are able to make a 10 bit ADC microcontroller based earth tester, a lot of cost saving can be done with some compromise on resolution. The Arduino UNO's microcontroller intended to be used in this project is about 10 times cheaper than C8051F006. The endeavour is also to use old or to be discarded earth testers, which may have working current generators, as useful component of design along with the microcontroller. As an added feature, the tester is intended to have IoT capability, which is not there in any of the tester discussed above.

1.2. Objectives

1. To automate a 61.8 percent commercial earth tester with the help of a standalone ATmega328P microcontroller (used in Arduino UNO) so as to carry out automatic testing and an added capability to send the measurement data over internet.

2. To host a web server on a cloud service such as Amazon Web Services (AWS) which can store the earth resistance data in a database and host a webpage to display the records.

3. To design and simulate a 61.8 percent earth tester with measurement range upto 10 Ω which can replace the commercial earth resistance tester of objective 1 above.

4. To design and simulate a clamp earth tester with measurement range upto 10 Ω which can be integrated with setup of objective 1 above.

1.3. Thesis Organisation

The thesis is organized in three chapters. Chapter 2 discusses the work carried out in four sections, namely, 2.2, 2.3, 2.4 and 2.5. There are simulations and actual experiments in section 2.6. In Chapter 3, the work has been summarised and future scope has been covered briefly.

Chapter-2

Testing and Recording of Earth Resistance

The system for measuring earth resistance is intended to measure upto 10 Ω. This value has been chosen because the tester is intended to be deployed where the norms do not allow an earth resistance value of more than 1 to 5 Ω. Figure 2.1 illustrates the block diagram of proposed scheme. Assuming that a very critical equipment is installed and connected to an earth pit at Test Electrode, then, two electrodes namely Potential and Current can be permanently dug in earth to enable measurement of earth resistance using 61.8 % method. An earth resistance tester working on 61.8 percent method has been used in combination with an ATmega328P microcontroller for carrying out this task, which can be powered using three AA batteries. The microcontroller is used for performing functions such as, control the measurement device, measure the voltage and current to calculate corresponding earth resistance and send data to internet based server through router or switch with the help of an Arduino Ethernet Shield. A web based server has been setup to record the measurements in a database. The values stored in the database can be viewed on a webpage from any device having internet access. For setting up the server, use of Amazon Web Services (AWS) has been made. Furthermore, an attempt has been made to design the complete tester from scratch based on the basic principle of measurement of earth resistance because of two reasons. Firstly, to get a greater understanding of how such a tester works. Secondly, it can help in avoiding the use of commercial testers, which usually have more functions than are actually required for implementation of such a scheme. For the case of two or more earth pits connected with the same critical equipment, a tester based on clamp on method has been designed and simulated. The measuring device can be replaced by a clamp on tester to avoid digging of any additional electrodes wherever two or more earthpits are bonded together.

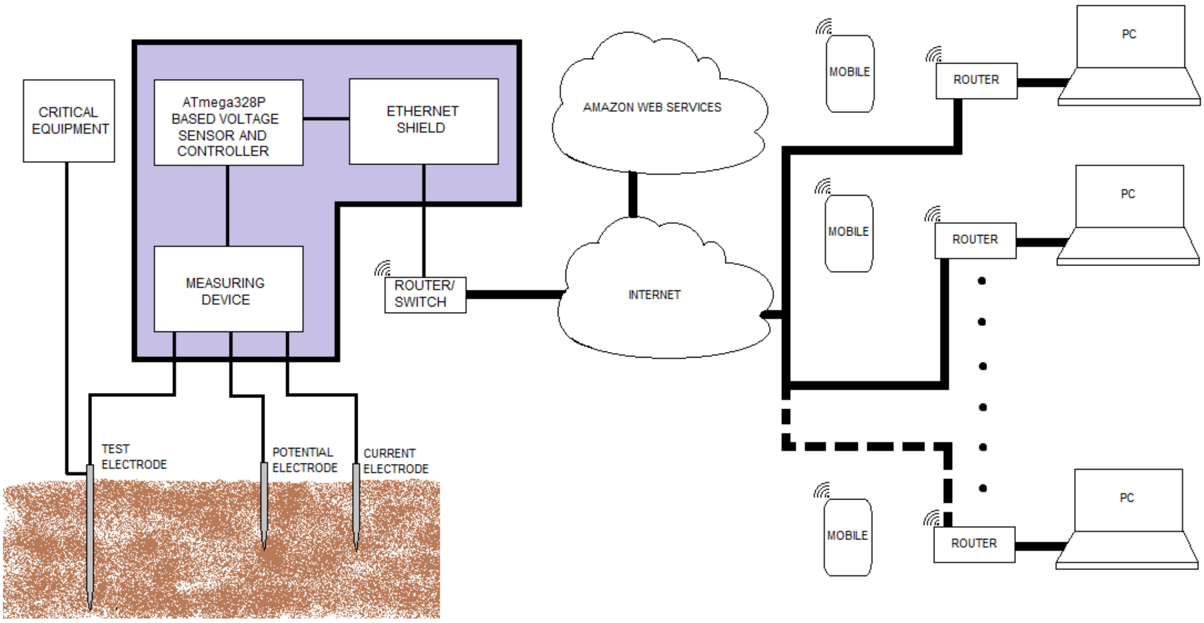

Fig 2.1. Block Diagram of Earthing Monitoring System.

2.1 Proposed Earthing Monitoring Scheme

Firstly, an actual earth resistance tester has been used to inject an alternating current through an earth resistance in conjunction with an ATmega328P microcontroller for measuring the injected current and resulting voltage across the earth resistance. This is followed by calculation of earth resistance value and sending the measurement data to a server on internet using an Arduino Ethernet Shield. Secondly, a webserver has been hosted using Amazon Web Services for recording the earth resistance data and also viewing the data as and when desired. Thirdly, a measuring device based on 61.8 percent has been designed and simulated which can replace the commercial tester used for the project. Lastly, a measuring device based on clamp on method has been designed and simulated for use wherever possible. All these works are discussed in subsequent sections.

2.2 Setup for Automated Earth Resistance Monitoring

A commercially available earth resistance tester was used as the measuring device. For simulation of earth resistances, known resistances were used as they are expected to give similar results to real earth resistances [4]. A standalone ATmega328P was programmed with the help of Arduino UNO board to be used for the purposes such as;

(a) Switching on and initiation of test by the measuring device using relays.

(b) Measurement of current running through the earth and voltage across test and potential electrodes.

(c) Calculation of resistance values based on measured voltage and current values.

(d) Sending the information such as tester location, station name and earth resistance value to a server over LAN or internet, using an Ethernet Shield. For the purpose of testing LAN based server, home WiFi network was used and for testing the internet based server, free tier service of Amazon Web Services was used.

2.2.1 Preparation of Measuring Device

The Measuring device was made using an earth resistance tester of M/s WACO make as shown in the picture in figure 2.2. As the tests need to be carried out only at specific intervals of time, a provision is to be made, firstly, for switching ON the tester and secondly, carrying out the test (manually, this is done by pressing the 'TEST' button). To achieve this, a bit of manipulation has been done in the tester. As can be seen in the picture, there is an LED indicator for charging of the tester. The LED was removed from its slot so that the customised wiring to control the tester can be brought out of the space thus created.

Fig 2.2. The commercial earth tester used for project.

In order to facilitate automatic switching ON of tester, the wire attached to the battery bank of tester (which is a set of qty-8 AA rechargeable batteries as shown in figure 2.3) was removed and soldered to another wire whose other end was connected to the common contact of relay K2 (white coloured wire). Another wire (grey coloured wire) was connected between the NO contact of the same relay with the other end soldered to the battery from where the tester's original wire was removed. At the same time, the '1000 Ω - OFF – 10 Ω' selection switch has been permanently kept in 10 Ω position. This arrangement takes care of switching ON of the tester using relay K2 which in turn is controlled using ATmega328P. In order to carry out the test, a pair of wires (yellow and green wires) was soldered across the terminals of test switch with the other free ends connected to the Common and NO contacts of relay K1. The intention behind all this arrangement is to first of all power ON the tester using relay K2 and then conduct test using relay K1. The tester will be ON only till the time relay K2 is energised. The test bench setup with Arduino UNO used for serial monitoring of measurements is as shown in figure 2.4.

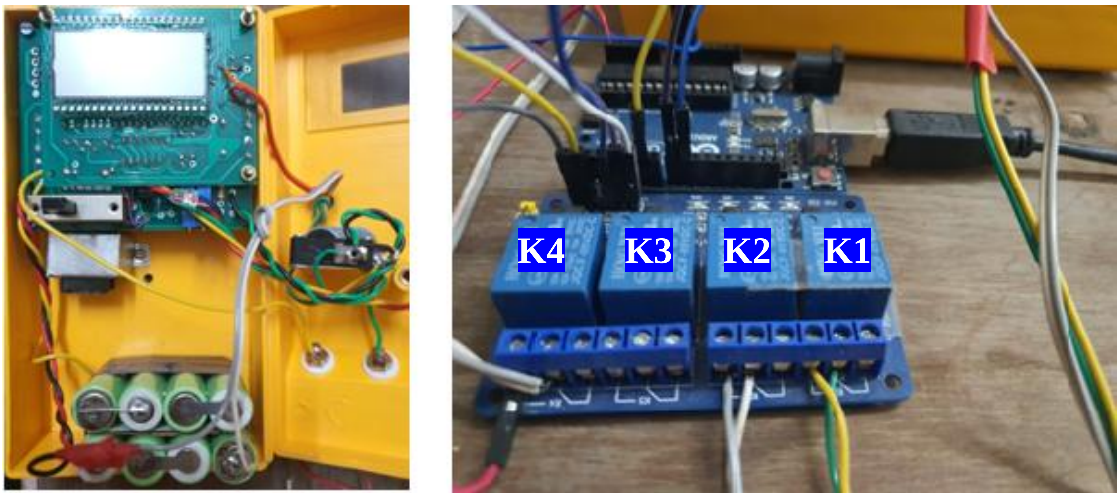

Fig 2.3. Inside the Earth Tester and Connection with Relays.

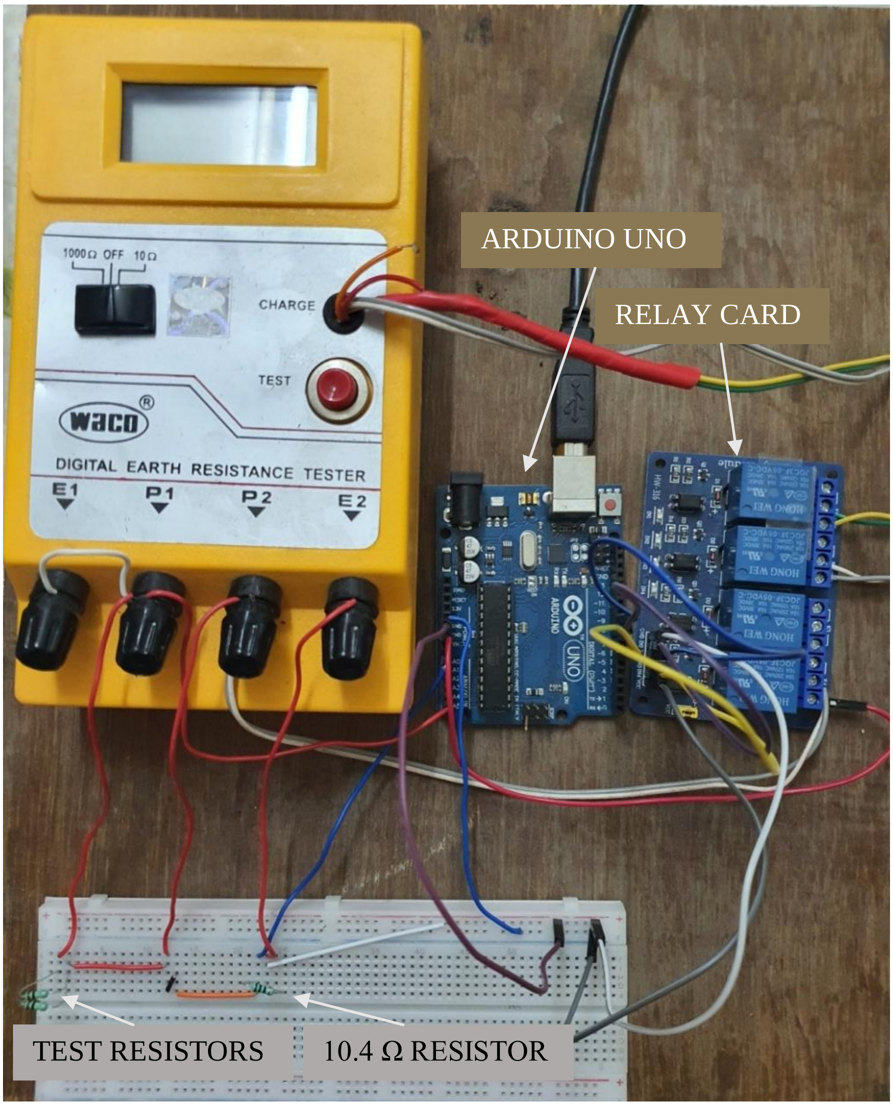

Fig 2.4. Test Setup.

2.2.2 Calibration of the Tester

The ATmega238P has got a 10 bit ADC hence 1024 voltage levels. Therefore, for a reference voltage of 1100 mV, the resolution is about 1.07 mV. The ATmega238P has been calibrated for measurement of DC voltage from ranging from 0 to 1000 mV using an Arduino UNO board. For this, a digital multimeter was used as standard having an accuracy of (±0.5% ±2 digits) for measurement of DC voltage. However, in actual practice, a higher accuracy standard must be used for calibration. To start the calibration, the following program was written and uploaded to the microcontroller using Arduino IDE;

```
void setup() {
    Serial.begin(9600);    // start serial communication at 9600 bits/s
    analogReference(INTERNAL); // ADC reference set as internal 1.1 V
 }
```

```
void loop() {
    float reading = 0.0;
    float cumulative = 0.0;
    float offset = 0.0;         //this value needs to be changed as per the offset observed
    float scaling = 1.0;        //this value needs to be changed as per the scaling required
    for (int i = 0; I < 1000; i++) {
            reading = analogRead(A0);
            cumulative = cumulative + reading;
     }
    reading = scaling*(cumulative/1000) + offset;
    Serial.println("Measured Voltage = ");
    Serial.println(reading);
    delay(1000);
}
```

Then, a setup as shown in figure 2.5 below was made. In this, a single AA battery was used with a variable resistor of 1 MΩ to provide voltage ranging from 0 to 1000 millivolt. The variable resistor was first adjusted to 0 Ω and the voltage was measured using the digital multimeter which has been found to be 0 mV. Then this value was measured using the designed sensor. It read 3 mV. The value of 'offset' variable in the above program was set as -3.0 (mV) and the program was again uploaded to the microcontroller. Then again 0 mV was measured and it indeed read 0 mV. Thereafter, the variable resistor was adjusted till it showed 1000 mV on the designed sensor. Then this voltage was measured on the multimeter and it read 884 mV. To compensate this, the 'scaling' variable was set as 0.884 in program above and it was uploaded to the microcontroller again. Thereafter, a number of readings at various values between 0 and 1000 mV were measured using the Arduino UNO. The measurements were verified using the multimeter and were found exactly the same. The measurements were repeated for the analog input pin A5 and same results were obtained.

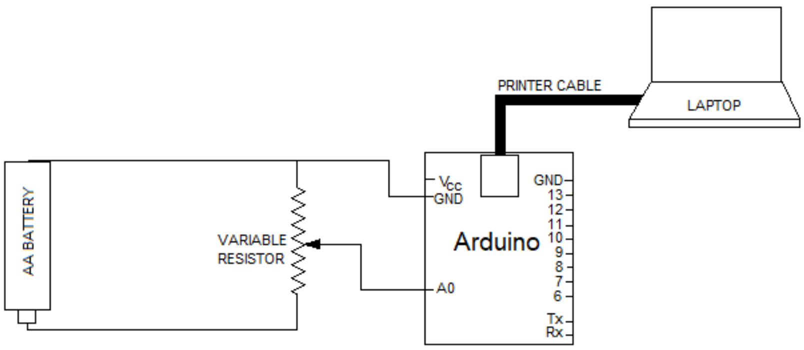

Fig 2.5. Setup for Calibration of Tester.

2.2.3 Working of the Scheme

The wiring diagram of the test setup is as shown in figure 2.6. Initially, the measuring device is in OFF state with standalone ATmega328P powered in power down mode using qty-3 AA batteries. The microcontroller can however be powered using 9 V PP3 batteries also by suing a 5 V voltage divider. The P1 terminal of the measuring device is connected to the Test Electrode, P2 with the Potential Electrode and E2 with the Current Electrode. The E1 and P1 terminals are shorted as per instructions in the manual of the tester. After a fixed interval (such as 8 hours), the ATmega328P wakes up to energise relay K2 by making pin 14 low, which in turn results in switching ON of the measuring device. After a delay of 1 second, the relay K1 is energised by lowering voltage at pin 15 of ATmega328P which initiates the testing. The delay of 1 second ensures stablisation of measuring device after switching ON. After 5 seconds of this, both relays K1 and K2 are de-energised by making pins 15 and 14 HIGH, resulting in switching OFF of the measuring device. During the 5 seconds of testing, an alternating current is forced through earth from the current and test electrodes. A known resistance R of 10.4 Ω has been inserted between the E2 terminal of measuring device and current electrode to facilitate measurement of current injected by the earth resistance tester. When the current from measuring device flows through this resistor, a voltage V_0 is produced across it. At the same time, voltage V_{diff} is produced between P1 and P2 terminals of the tester. While relays K1 and K2 are in energised state, 2000 samples of are taken for voltage V_0. After completion of sampling for V_0, a gap of 2 seconds is given so that the ADC of ATmega238P is stabilised and made ready for measuring V_{diff}. Thereafter, the relay K4 is energised by a LOW at pin 12 of ATmega328P to connect the P2 terminal with the GND pin of ATmega328P. At this point, sampling of V_{diff} starts and again 2000 samples are taken. Each sample of V_0 and V_{diff} is measured in terms of millivolts, squared and added to the previous sample value. Thereafter, the root mean square values (rms) of both V_0 and V_{diff} are found. The rms value of V_0 when divided by resistance R value, we get the value of current (I) flowing through earth. The value of current measured using this method was found to be varying between 42 mA to 34 mA depending on the battery state of the tester. When the battery is in fully charged state, the value of current measured was 42 mA consistently on repeated readings. As the measurements are made repeatedly, the battery of the tester kept on getting weaker progressively and the value of current slowly dropped. The lowest value of current measured was 34 mA, at which the tester started showing low battery indication. Once the corresponding values of V_{diff} and current I have been found, the value of earth resistance (R_e) can be found as $R_e = V_{diff}/I$. The earth resistance value thus obtained is then sent to a server setup over internet or LAN. For this, the ATmega328P first switches ON the Ethernet Shield by energising relay K3. The data is then sent to internet/LAN using a router or switch. The way earth tester has been used in this project enables use of any other earth resistance tester also in its place. Even an unserviceable earth resistance tester but with working current generator can be used. This setup makes possible the automation of earth tester without tinkering with its internal circuitry too much. Before migrating to standalone ATmega328P, the testing of setup was done using Arduino UNO board and corresponding pins of the board vis-a-vis ATmega328P are separated by slashes in the figure 2.6.

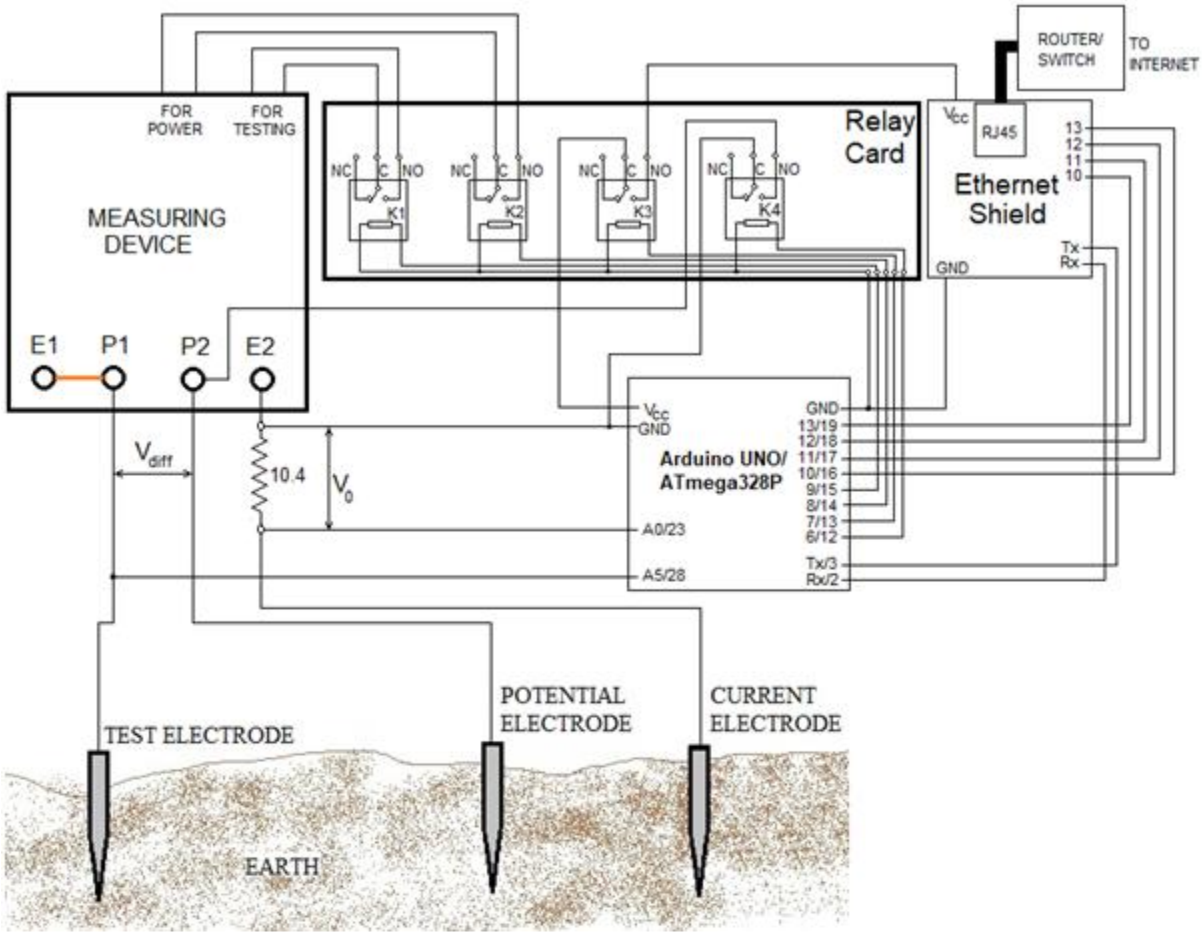

Fig 2.6. Wiring Diagram of Test Setup.

The ATmega328P has to be configured with the IP of the server to which the data has to be sent. The subnet and gateway may also be given in addition. After the data has been sent, the relay K3 is de-energised and the ATmega238P goes to Power Down mode for next 8 hours. A provision of buzzer can also be made as soon as the value of earth resistance crosses 1 **Ω** or 5 **Ω** (as applicable to a particular earth pit). In order to perform all the above functions, a program has been made and uploaded to the ATmega328P microcontroller using Arduino UNO and Arduino IDE. The ethernet part of the program is modification of code written by David A. Mellis and the power down mode program for timer switch has been picked up from the code by Nick Gammon. The full program is as follows;

```
#include <SPI.h>
#include <Ethernet.h>
#include <avr/sleep.h>
#include <avr/wdt.h>
float scaling = 0.884;    // The scaling factor is as per the value found during calibration
float offset = 3;         // The offset is as per the value found during calibration
float calfactor = 0.19;   // This is the correction factor for difference in earth resistance
                          // reading
```

```
 int samplesize = 2000; // This is the most appropriate sample size found
 int samplerep = 1;
 float runnum = 0.0;
 int hours = 8;               //This is the interval in hours between each measurement
 int pin8 = 8;
 int pin9 = 9;
 int pin6 = 6;
 int pin7 = 7;
 void setup() {
        pinMode(pin8, OUTPUT);
        pinMode(pin9, OUTPUT);
        pinMode(pin6, OUTPUT);
        pinMode(pin7, OUTPUT);
        digitalWrite(pin8, HIGH);
        digitalWrite(pin9, HIGH);
        digitalWrite(pin6, HIGH);
        digitalWrite(pin7, HIGH);
        analogReference(INTERNAL);
}
ISR (WDT_vect)
{
         wdt_disable();  // disable watchdog
}
ISR (ADC_vect)
{
        int adc_val;
        adc_val = ADCH;
        OCR0A = adc_val;
        ADCSRA |= 1<<ADSC; //conversion start
}
void loop() {
         int conv=(hours*3600)/8;     // convert hours to seconds for use later
         PRR &= ~(1<<PRADC);     // Disable power reduction
         ADCSRA = 0xcF;               // Enable ADC to start measurements
         analogReference(INTERNAL);
         delay(2000);
         float earthresistance = 0.0;
         float sensorReading = 0.0;
         float channel0 = 0.0;
         float channel12 = 0.0;
         float cumulative0 = 0.0;
         float cumulative1 = 0.0;
         float voltage = 0.0;
         float current = 0.0;
```

```
 float vdiff = 0.0;
 float intermediate = 0.0;
 digitalWrite(8, LOW);
 digitalWrite(9, LOW);
 delay(1500);
 //the following loops are used for taking voltage samples
 for (int y=0;y<=samplerep;y++) {
    for (int x=0;x<=samplesize;x++) {
         float sensorValue1 = scaling*(analogRead(A0)*1100.0)/1024+offset;
         channel0=channel0+pow(sensorValue1,2);
    }
    channel0=sqrt(channel0/samplesize);
    cumulative0=cumulative0+channel0;
 }
 digitalWrite(6, LOW);
 delay(1000);
 for (int y=0;y<=samplerep;y++) {
    for (int x=0;x<=samplesize;x++) {
         float sensorValue2 = (scaling*(analogRead(A5)*1100.0)/1024);
         channel12=channel12+pow(sensorValue2,2);
    }
    channel12=sqrt(channel12/samplesize);
    cumulative1=cumulative1+channel12;
 }
 digitalWrite(6, HIGH);
 digitalWrite(8, HIGH);
 digitalWrite(9, HIGH);
 cumulative0=cumulative0/samplerep;
 cumulative1=cumulative1/samplerep;
 vdiff=cumulative1;
 current=cumulative0/10.4;
 earthresistance=vdiff/current-calfactor;  //earth resistance measurement is complete
 delay(1000);
 digitalWrite(pin7, LOW);
 delay(5000);
 EthernetClient client;
 char server[] = "aaa.bbb.ccc.ddd";  //IP needs to be give according to server IP
byte mac[] = {
         0xDE, 0xAD, 0xBE, 0xEF, 0xFE, 0xED
};
IPAddress ip(192,168,1,8);
Ethernet.begin(mac, ip);   // start the Ethernet connection and the server
int reattempt=0;
while (reattempt<=10) {
```

```
        delay(6000);
        if (client.connect(server, 80)) {
                // Make a HTTP request:
                client.print("GET /EMS/EMS.php?TesterLocation=");     //YOUR URL
                client.print("Edusec1L2");
                client.print("&ResistanceValue=");
                client.print(earthresistance);
                client.print("&Station=");
                client.print("IIT%20Madras");
                client.print(" ");      //SPACE BEFORE HTTP/1.1
                client.print("HTTP/1.1");
                client.println();
                client.println("Host: aaa.bbb.ccc.ddd ");
                client.println("Connection: close");
                client.println();
                reattempt=11;
                delay(20000);
                } else {
                reattempt++;
                }
        }
        digitalWrite(pin7, HIGH);
        // The following code provides the functionality of TIMER SWITCH and it puts
        // the test setup to sleep mode and battery power consumption to about 38 µA
        for (int j = 0; j <= conv; j++){
                ADCSRA = 0;    // disable ADC
                MCUSR = 0;     // clear various "reset" flags
                WDTCSR = bit (WDCE) | bit (WDE);   // allow changes, disable reset
                // set interrupt mode and an interval, set WDIE, and 8 seconds delay:
                WDTCSR = bit (WDIE) | bit (WDP3) | bit (WDP0);
                wdt_reset();
                set_sleep_mode (SLEEP_MODE_PWR_DOWN);
                noInterrupts ();           // timed sequence follows
                sleep_enable();
                MCUCR = bit (BODS) | bit (BODSE);  // turn off brown-out enable in
                                                   // software
                MCUCR = bit (BODS);
                interrupts ();             // guarantees next instruction executed
                sleep_cpu ();
                sleep_disable();           // cancel sleep as a precaution
         }
}
```

2.2.4 Timer Switch

The purpose of timer switch as programmed above, is to switch on the measuring device after fixed interval of time such as 3 hour, 6 hour or 8 hour. This can be made using a standalone ATmega328P programmed using Arduino IDE. To keep the power consumption to bare minimum while the sensor is not measuring, the micro-controller needs to be kept in sleep mode. To further reduce the power consumption during the sleep mode, various features such as brown out detection, ADC, analog comparator etc need to be turned off during this period. This will ensure a very long battery life. At fixed intervals of time, such as 8 hours, the microcontroller can wake up, performs the measurement and sends the measurement data to the server on network. Thereafter, it again goes back to sleep to conserve the battery.

2.3 Hosting of Database and Webpage on Cloud Service.

There is a need to keep a log of values such as station at which measurement has been made, tester location inside the station, the value of earth resistance and the date/time information of the measurement made by the tester setup. It is intended that there will be hundreds of such sensors deployed across the country. In order to ensure that all the records are made available at a central place, each tester needs to send the required information to a server set up over internet. For setting up of internet based webserver, use of free tier services of Amazon Web Services (AWS) was made. In this, an instance of Windows Server 2016 Basic was installed and then accessed using Remote Desktop Protocol (RDP). Thereafter, an exception for the listening port 80 was added in the firewall. A server using open source platform XAMPP has then been installed as it provides Apache server and MySQL database service. Upon installation of XAMPP, a control panel as shown in figure 2.7 becomes available.

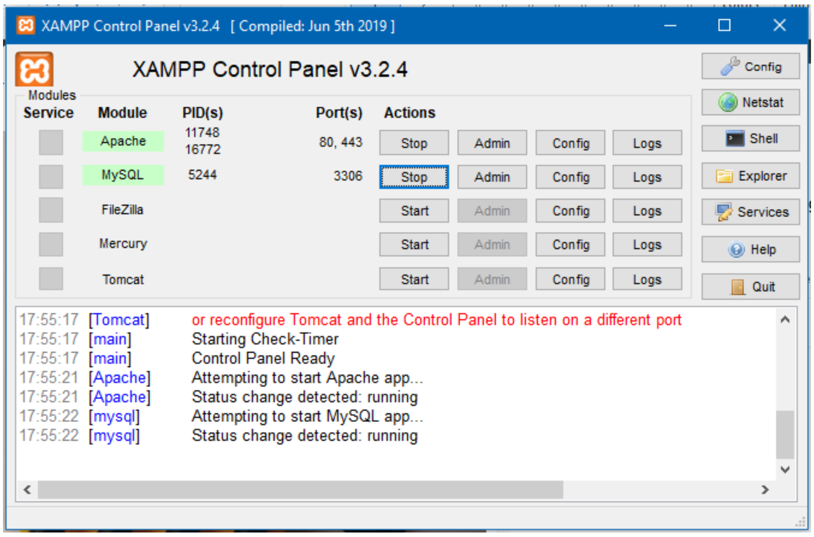

Fig 2.7. XAMPP Control Panel.

The services of Apache and MySQL is started using buttons provided on the control panel in order to use the instance as an application server for hosting a website and database. Thereafter, a database named ‘earthing monitoring system’ has been created using phpMyAdmin provided with XAMPP. A table named 'ems1' has been created inside this database with fields such as Tester Location, Resistance Value, Time info and Station as shown in figure 2.8. Thereafter, a folder named 'EMS_v1' (EMS for Earthing Monitoring System) has been created in the root directory (named htdocs) of the XAMPP. In this folder, two PHP Hypertext Preprocessor based files were created by name 'ems.php' and 'index.php' and programmed using PHP such that they respectively perform the function of storing the data sent by the test setup and displaying the records based on user's form based query in a web browser. The form based query results are displayed on a webpage having a table at the bottom as shown in figure 2.9.

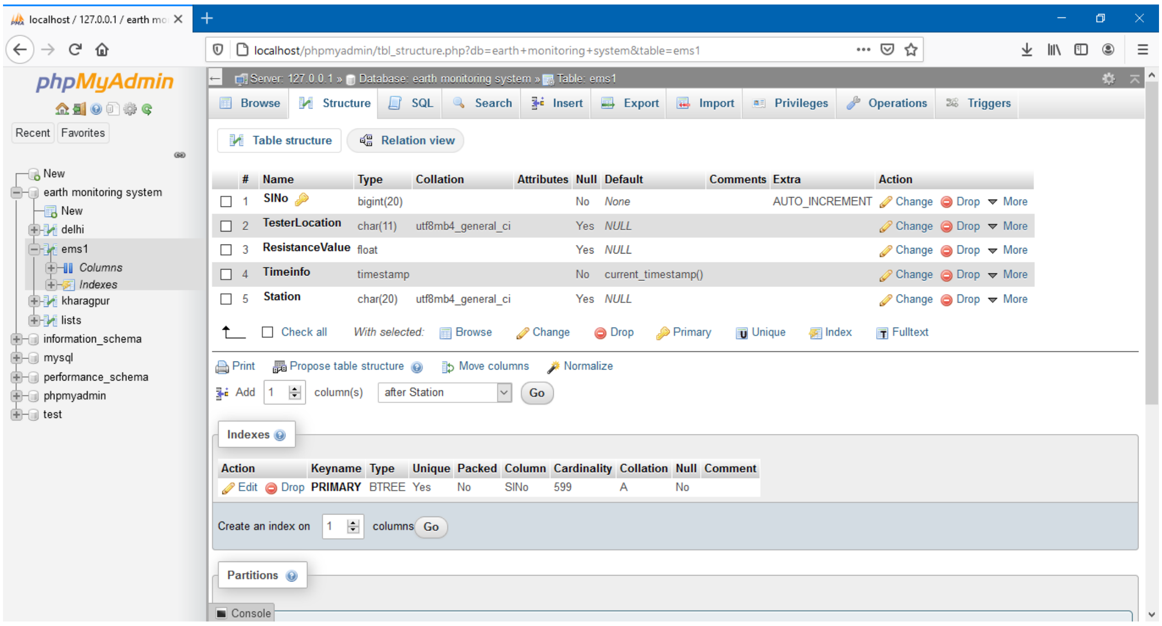

Fig 2.8. Database structure used for recording earth resistance data.

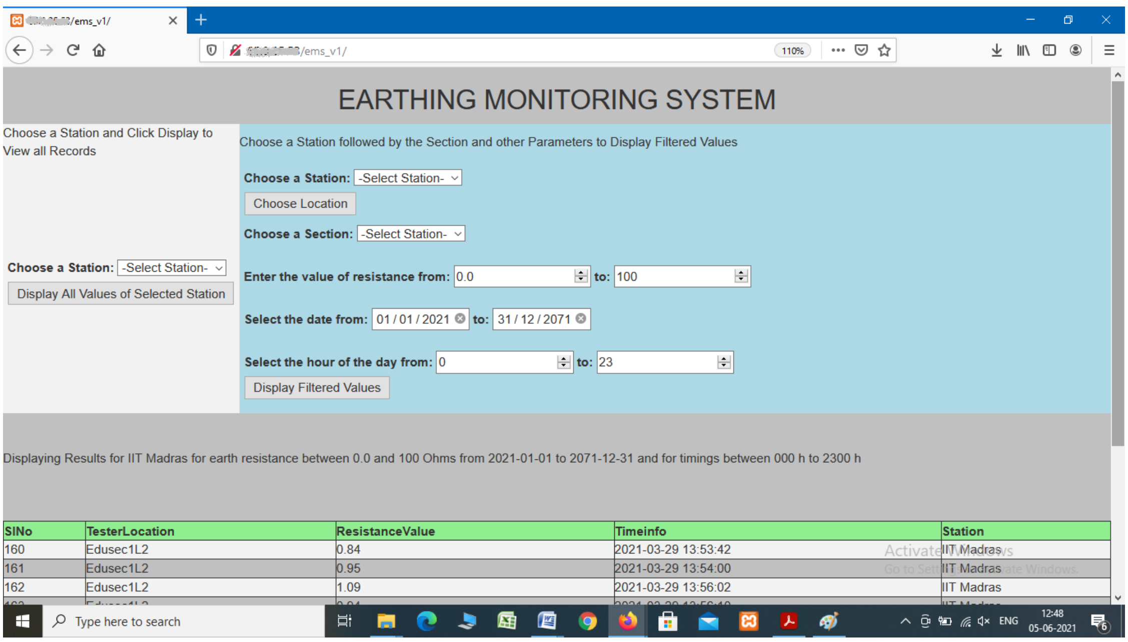

Fig 2.9. Displaying form based query results on Webpage.

2.4 Design of 61.8% Method Measuring Device

As stated earlier, a measuring device working on 61.8 percent method was designed and simulated to attain better understanding, also, integration with the Arduino and networking component of the project. The device has a current generator which forces an alternating current at a frequency of 128 Hz through the current and test electrodes. The current then flows through the earth which results in a voltage proportional to the earth resistance (V = IR). A potential electrode is dug at 61.8 % of the distance between test electrode and current electrode, the voltage measured between test electrode and potential electrode directly gives the value of earth resistance. This voltage sensor filters and converts the resulting alternating voltage to a DC value, which can be read using ATmega328P microcontroller. The microcontroller also controls the switching ON and OFF of the measuring device at fixed intervals of time using relays. The block diagram of the tester arrangement is given in figure 2.10.

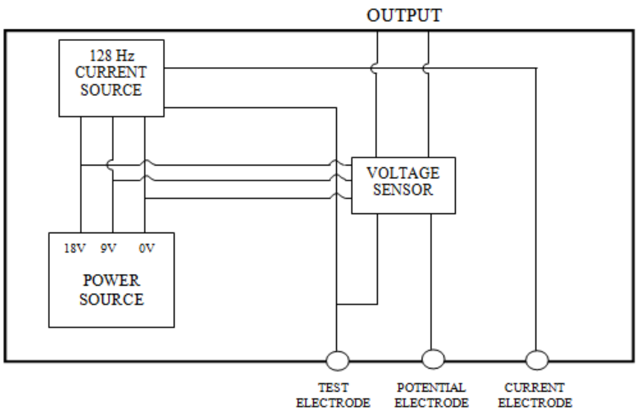

Fig 2.10. Block Diagram of Earth Tester for Single Earthpit.

2.4.1 Current Generator

The current generator is designed to give an output of 20 mA peak sinusoidal current at 128 Hz. The output current will be obtained by first generating a sinusoidal signal using Bubba phase shift oscillator and then deriving current with help of a Howland current source. The block diagram of the proposed current source is shown as figure 2.11.

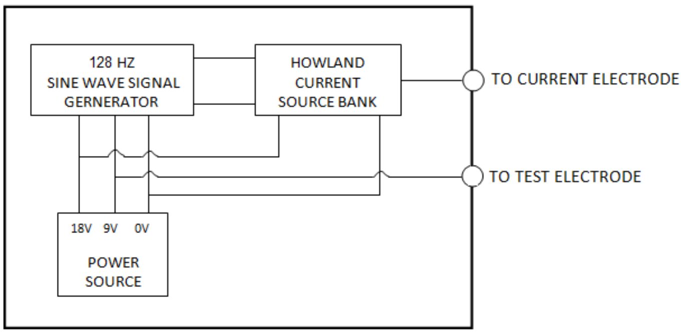

Fig 2.11. Block Diagram of Current Generator.

The circuit diagram of the 128 Hz Sine Wave Generator is as shown in figure 2.12. A Bubba oscillator has been used as the sine wave signal generator followed by a buffer amplifier. The values of all the resistances and capacitances of the Bubba oscillator have been set such that we get an output of 8.5 V peak to peak 128 Hz signal. The signal generated by the Bubba oscillator is then amplified or level translated so as to achieve the maximum possible value (within the operating voltage range of the operational amplifiers) using an inverting amplifier. This will enable us to draw maximum possible current from the current source. The output of Bubba oscillator has been taken between R_2 and C_2 and fed to a buffer amplifier stage. Thereafter, the signal from buffer amplifier has been fed to the level translator stage, which amplifies the oscillator voltage to 15 V peak to peak 128 Hz signal. This is the final output signal V_{sig} of the Sine Wave Generator. The device is intended to be battery powered, hence, a single supply operational amplifier such as TL084CN can be used for the realisation of the circuit.

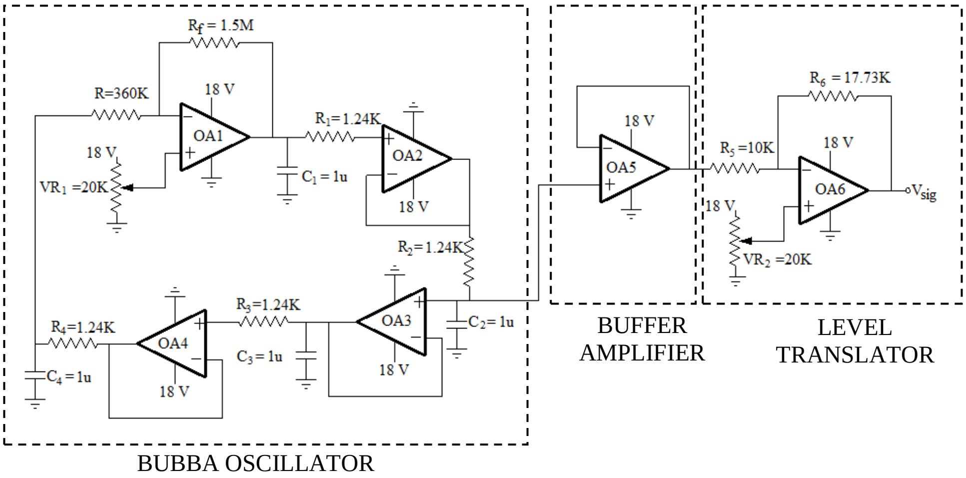

Fig 2.12. Circuit Diagram of 128 Hz Sine Wave Signal Generator.

The design of current source has to be carried out under the constraints of available voltage and maintaining linear range of the measuring device for changing values of earth resistance. After calculations and simulations, the circuit shown in figure 2.13 was found suitable for the requirement. During simulation study, it was found that the designed Howland current source stays linear for a load resistance of up to about 100 Ω. This is ten times the claimed design range of 10 Ω. However, if contact resistances, resistance of wires and earth electrodes of the practical circuit are also added, this much margin will be required.

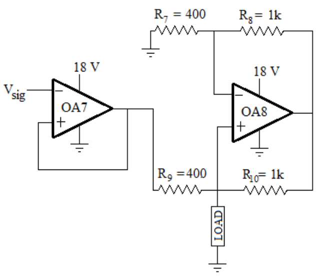

Fig 2.13. Circuit Diagram of Howland Current Source.

2.4.2 Voltage Sensor

The voltage across test and potential electrode is passed through four stages, viz., 128 Hz bandpass filter, amplification/peak detection and voltage measurement as shown in figure 2.14.

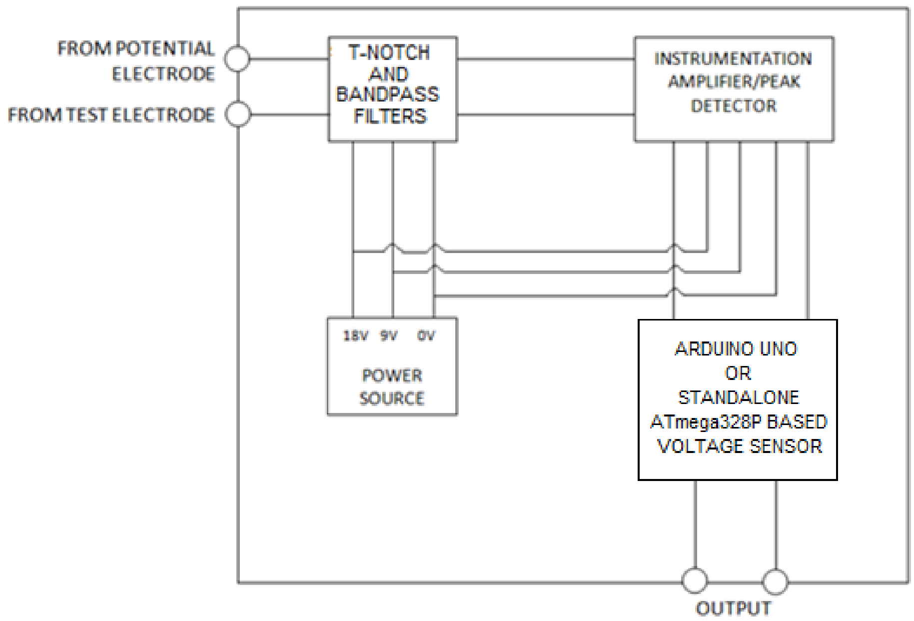

Fig 2.14. Block Diagram of Voltage Sensor.

The 50 Hz T- Notch Filter is used to safeguard against interference from 50 Hz commercial power supply signal. This is followed by two cascaded 128 Hz bandpass filters to safeguard against interference from other signal sources. The circuit diagram of the filters is shown in figure 2.15. The input of bandpass filters will be provided from the potential electrode (as shown in figure 2.14). The voltage at potential electrode will be fed to the filter through a buffer amplifier. The output of the filters will be fed to the instrumentation amplifier.

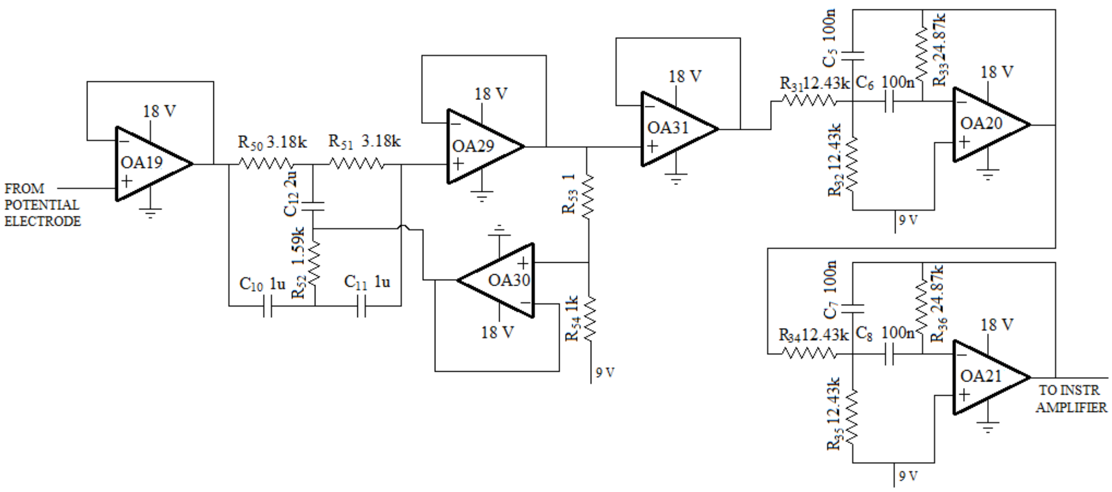

Fig 2.15. Circuit Diagram of T-Notch and Bandpass Filters.

The voltage signal after filtration by the filters is amplified to a suitable level for measurement, rectified using a precision rectifier and then passed through a peak detector. The output has been calibrated such that the measuring device gives 5 V DC as output, for an earth resistance of 50 Ω. This peak detected voltage is intended to be measured using ATmega328P based voltage sensor. The circuit diagram of the instrumentation amplifier, precision rectifier and peak detector is as shown in figure 2.16.

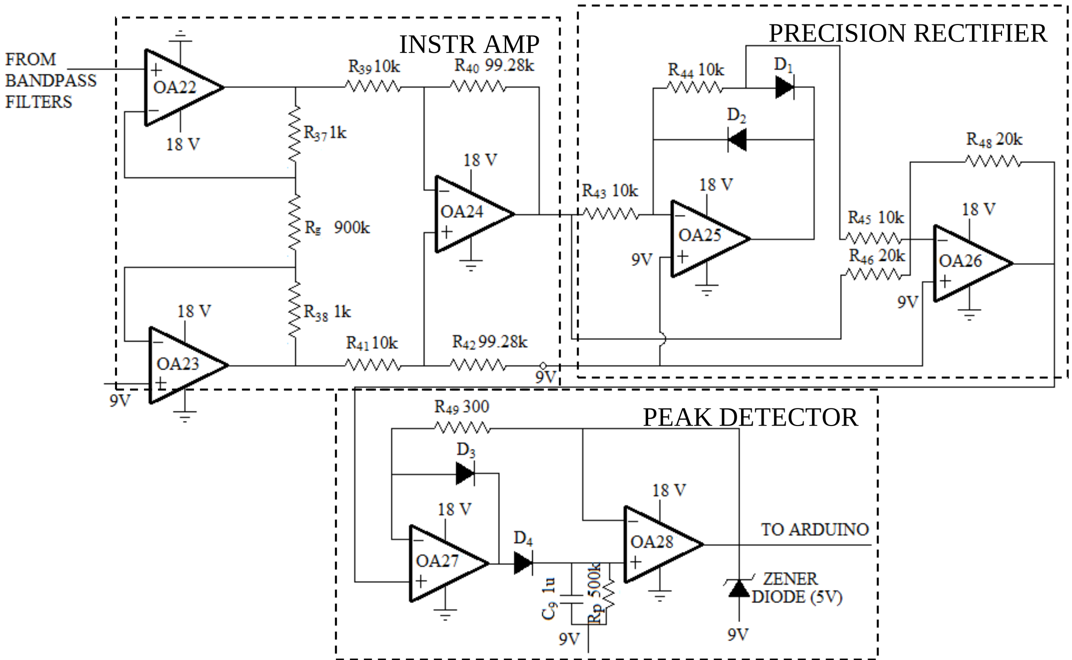

Fig 2.16. Circuit Diagram of Instrumentation Amp, Precision Rectifier and Peak Detector.

2.4.3 Power Source

The power source required is 18 V dc with a centre tap. Practically, this can be achieved using quantity-02 9 V PP3 batteries in series.

2.4.4 Proposed Circuit

The overall circuit based on proposed setup of block diagram in figure 2.17 is given in figure 2.9. The earth resistance has been simulated using a potentiometer. The circuit should perform such that the resistance value to the right side of wiper should not affect the reading of the actual earth resistance which is on the left hand side of the wiper. The current to the earth resistance is fed through isolation transformer T1 to ensure electrical isolation of the circuitry. The voltage measured across Potential and Test electrodes can be fed to one of the analog pins of the Atmega328P microcontroller. The center tap of the battery, which is 9 V, is required to be fed to the GND pin of the Atmega328P. The Vcc pin of ATmega328P needs to be fed with 5V. For this, a voltage divider can be used if the setup is being powered using PP3 batteries.

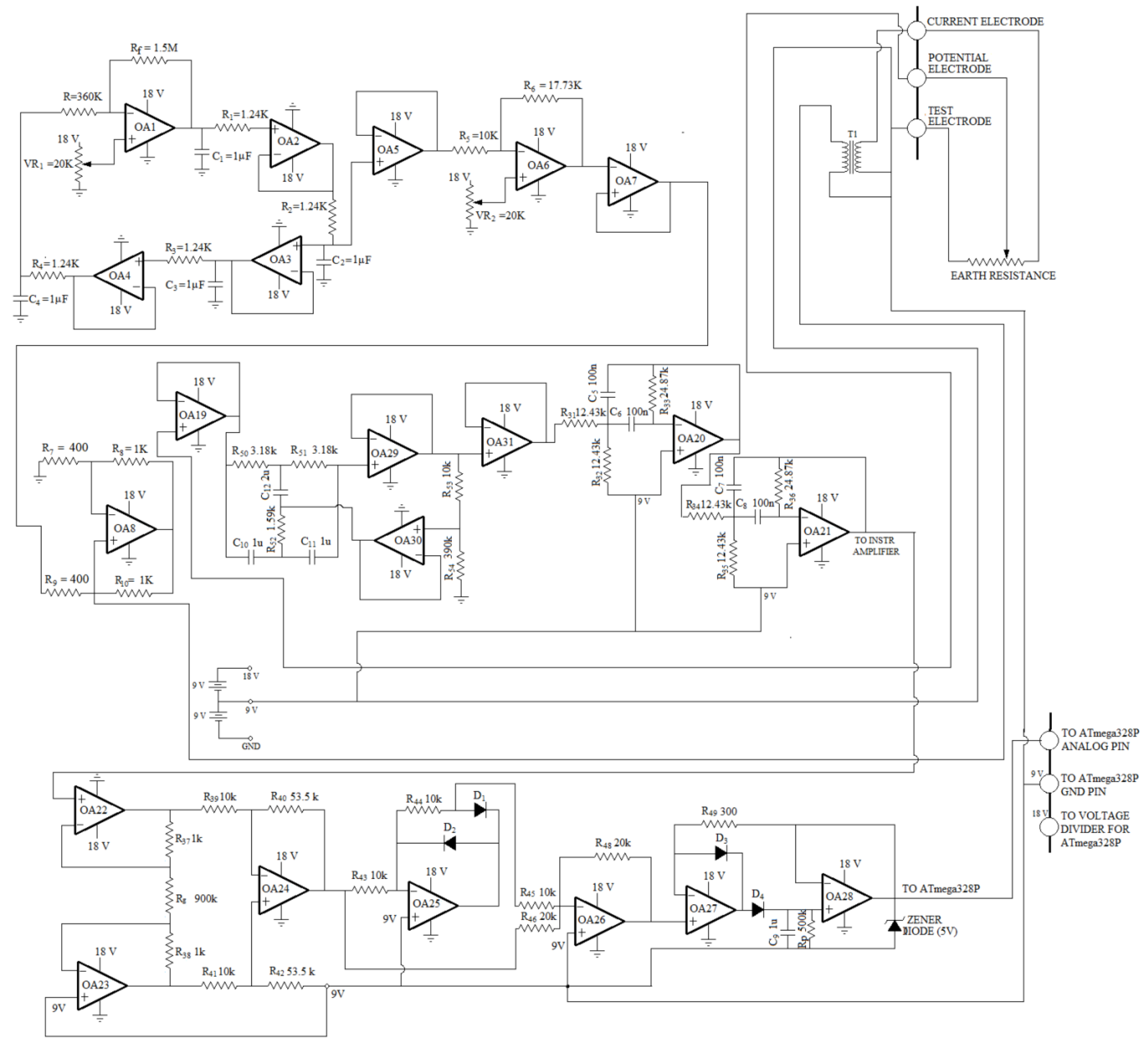

Fig 2.17. Circuit Diagram of Simulated Measuring Device.

2.5 Design of Clamp On Method Measuring Device

In order to measure earth resistance of two or more earthpits bonded together, another test equipment has been designed and simulated. Although, such testers are commercially available, they have way more functionalities than are required for our application and hence, are costly. Therefore, if a dedicated tester is designed with limited range and functionality, that is just sufficient to meet our requirement, a lot of cost saving can be done. The scheme is shown in figure 2.18. A voltage source will induce a voltage at 128 Hz into a loop formed by the two earthpits. This voltage will cause a corresponding current to flow in the loop, the value of which will depend on the total resistance in the loop. This current is sensed through another transformer and further taken up for measurement. During simulation experiments, it was found that with few modifications in the circuit of sub section 2.4.4 above, a clamp on measuring device can be set up.

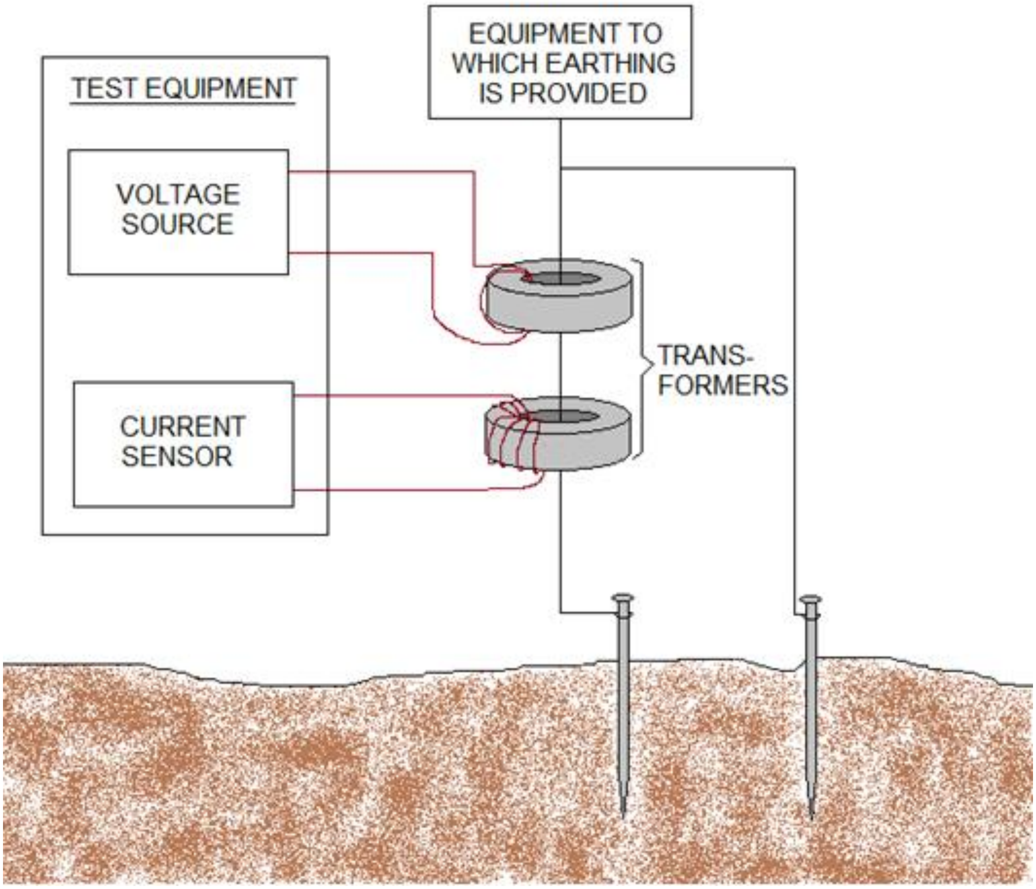

Fig 2.18. Block Diagram of Earth Tester for Multiple Earthpits bonded together.

2.5.1 Proposed Circuit

In the circuit for the measuring device, the Howland current source stage of figure 2.17 has been removed. All other circuit elements such as 128 Hz signal generator, T-Notch filters, bandpass filters, instrumentation amplifier, precision rectifier and peak detector are present in this circuit also. The elements have already been covered briefly in sections 2.4.1 and 2.4.2. The output of signal generator is directly fed to the earthing loop through transformer T1. A stepped down voltage is then present across the secondary of the transformer T1. As a result, a current starts flowing though the loop containing earth resistance. When this current flows through the primary of transformer T2, a small current results in its secondary winding. This current flows through a 10 kΩ resistance, hence results in a voltage across the resistance. The value of this voltage varies inversely with the increasing earth resistance. After amplification, rectification and peak detection, a dc voltage between the range of 5V and 0V is presented at the output of operational amplifier OA28. In order to read, process and interface the corresponding earth resistance value with internet, the output can be fed to the analog pin of ATmega328P microcontroller after level shifting the output. The turn ratios of transformer T1 was set as 100:1 and that of T2 was set as 1:1000.

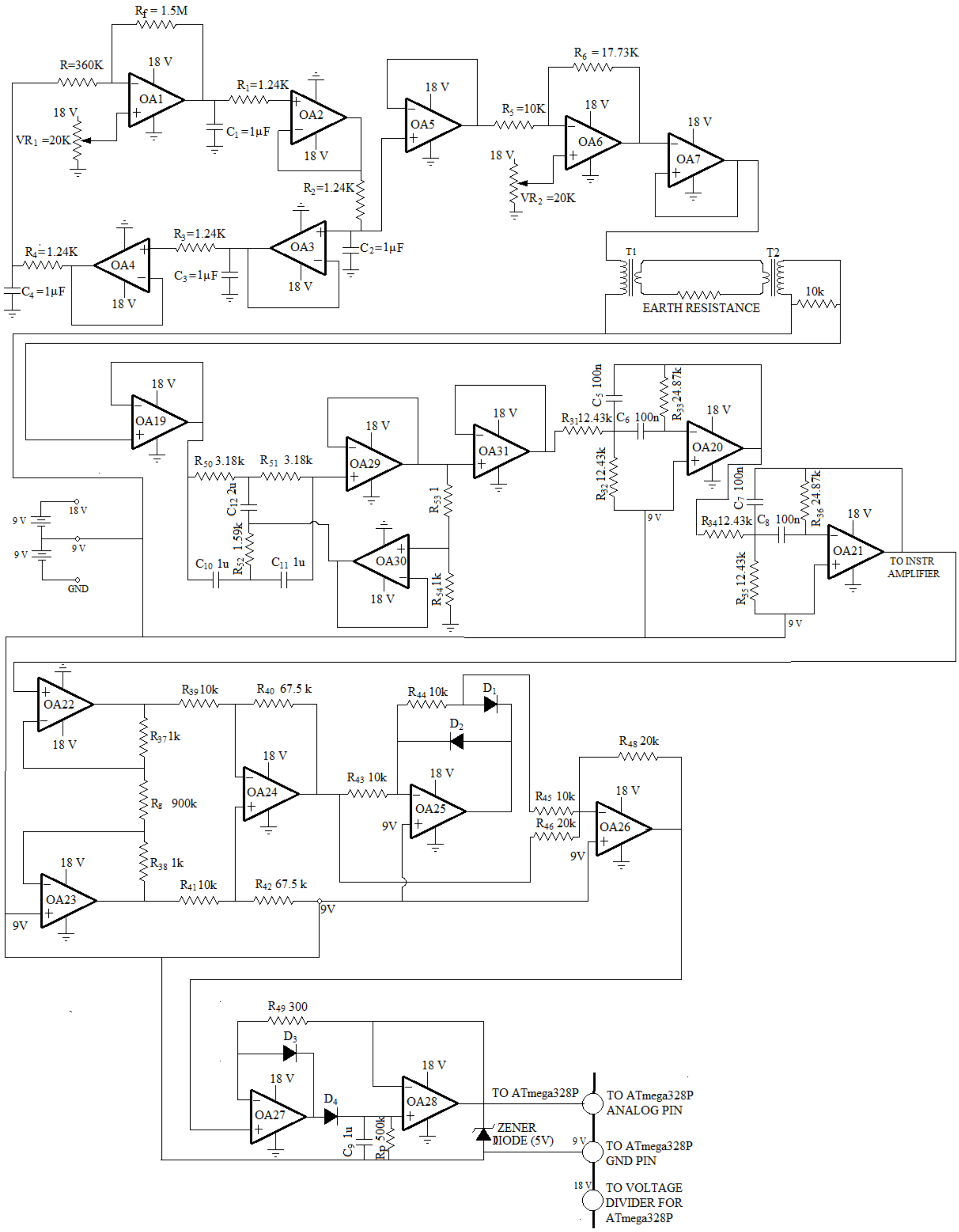

Fig 2.19. Circuit Diagram of Earth Tester for Multiple Earthpits bonded together.

2.6 Results

There were three studies carried out during the course of work. First one was experimentation with the setup covered in section 2.2, second one was simulation study of the tester covered in section 2.4 and third one was simulation of the tester covered in section 2.5.

2.6.1 Finding accuracy and repeatability of the test setup of section 2.2

The accuracy of the sensor was checked by measuring known resistances of values such as 1 Ω, 10 Ω, 22 Ω, 33 Ω and 100 Ω, each having ±5% tolerance, in various combinations between terminals P1 and P2 of the earth tester. At first, 1 Ω resistance was measured using the tester. It can have a value between 0.95 Ω to 1.05 Ω for 5% tolerance. The value measured using the designed tester was 1.02 Ω, which was within the possible range of the known 1 Ω resistance. Thereafter, two 1 Ω resistances were connected in series combination to make it 2 Ω. The worst case error in resistance value in this case was 10%, therefore, the measured value should have been between 1.90 Ω to 2.10 Ω. When measured using the designed tester, the value obtained was 2.08 Ω, which was again within the tolerance range. In order to test the values below 1 Ω, the known resistances such as 10 Ω, 22 Ω, 33 Ω and 100 Ω were put in parallel combination with 1 Ω resistance one by one. The reference device available for measurement was a (±0.8%±2 digits) accuracy digital multimeter and has a display resolution of 0.1 Ω. With 5% tolerance resistors and a multimeter of this accuracy, the most suitable reference was worked out. It was found that for some combinations, calculations give a better reference and for other combinations, multimeter serves better reference. To check which reference was suitable for what combination of resistances, the following relation was derived;

$$\frac{1}{R_e \pm \Delta R_e} = \frac{1}{R_1 \pm \Delta R_1} + \frac{1}{R_2 \pm \Delta R_2} \tag{2.1}$$

$$\Rightarrow \frac{1}{R_e \pm \Delta R_e} = \frac{R_1 \pm \Delta R_1 + R_2 \pm \Delta R_2}{(R_1 \pm \Delta R_1)(R_2 \pm \Delta R_2)} \tag{2.2}$$

$$\Rightarrow R_e \pm \Delta R_e = \frac{(R_1 \pm \Delta R_1)(R_2 \pm \Delta R_2)}{R_1 + R_2 \pm (\Delta R_1 + \Delta R_2)} \tag{2.3}$$

$$\Rightarrow R_e \pm \Delta R_e = \frac{R_1 R_2}{R_1 + R_2} \cdot \frac{\left(1 \pm \frac{\Delta R_1}{R_1}\right)\left(1 \pm \frac{\Delta R_2}{R_2}\right)}{1 \pm \frac{\Delta R_1 + \Delta R_2}{R_1 + R_2}} \tag{2.4}$$

$$\Rightarrow R_e \pm \Delta R_e = \frac{R_1 R_2}{R_1 + R_2}\left(1 \pm \frac{\Delta R_1}{R_1}\right)\left(1 \pm \frac{\Delta R_2}{R_2}\right)\left(1 \pm \frac{\Delta R_1 + \Delta R_2}{R_1 + R_2}\right)^{-1} \tag{2.5}$$

Expanding the last term by binomial theorem, we get:-

$$R_e \pm \Delta R_e = \frac{R_1 R_2}{R_1 + R_2}\left(1 \pm \frac{\Delta R_1}{R_1}\right)\left(1 \pm \frac{\Delta R_2}{R_2}\right)\left(1 \mp \frac{\Delta R_1 + \Delta R_2}{R_1 + R_2} + higher\ power\ terms\right) \tag{2.6}$$

Neglecting the higher power terms in binomial expansion, we get:-

$$R_e \pm \Delta R_e = \frac{R_1 R_2}{R_1 + R_2}\left(1 \pm \frac{\Delta R_1}{R_1}\right)\left(1 \pm \frac{\Delta R_2}{R_2}\right)\left(1 \mp \frac{\Delta R_1 + \Delta R_2}{R_1 + R_2}\right) \quad (2.7)$$

$$\Rightarrow R_e \pm \Delta R_e = \frac{R_1 R_2}{R_1 + R_2}\left(1 \pm \frac{\Delta R_1}{R_1} \pm \frac{\Delta R_2}{R_2} \pm \frac{\Delta R_1 \Delta R_2}{R_1 R_2} \pm \frac{\Delta R_1 + \Delta R_2}{R_1 + R_2} \pm \frac{\Delta R_1}{R_1}\cdot\frac{\Delta R_1 + \Delta R_2}{R_1 + R_2} \pm \frac{\Delta R_2}{R_2}\cdot\frac{\Delta R_1 + \Delta R_2}{R_1 + R_2} \pm \frac{\Delta R_1 \Delta R_2}{R_1 R_2}\cdot\frac{\Delta R_1 + \Delta R_2}{R_1 + R_2}\right) \quad (2.8)$$

Using the equation above, the effective resistance R_e and error in resistance ΔR_e can be found as:-

$$R_e = \frac{R_1 R_2}{R_1 + R_2} \quad (2.9)$$

And,

$$\Delta R_e = \frac{R_1 R_2}{R_1 + R_2}\left(\frac{\Delta R_1}{R_1} + \frac{\Delta R_2}{R_2} + \frac{\Delta R_1 \Delta R_2}{R_1 R_2} + \frac{\Delta R_1 + \Delta R_2}{R_1 + R_2} + \frac{\Delta R_1}{R_1}\cdot\frac{\Delta R_1 + \Delta R_2}{R_1 + R_2} + \frac{\Delta R_2}{R_2}\cdot\frac{\Delta R_1 + \Delta R_2}{R_1 + R_2} + \frac{\Delta R_1 \Delta R_2}{R_1 R_2}\cdot\frac{\Delta R_1 + \Delta R_2}{R_1 + R_2}\right) \quad (2.10)$$

Where, R_e is the earth resistance, ΔR_e is the error in earth resistance, R_1 and R_2 are the resistors used for parallel combination, ΔR_1 and ΔR_2 are their respective tolerances.

Using the equation above, the values of effective resistances were found as shown in the table 2.1 below. Since the resolution of the digital multimeter is 0.1 Ω with an accuracy of (±0.8% ±2 digits), only calculation based values of $R_e \pm \Delta R_e$ having ΔR_e less than 0.2 Ω (as shown in table 2.1) were used as reference. However, the values of ΔR_e for all combinations given in table 2.2 based on calculations were found to be more than 0.2 Ω. Therefore, the range of $R_e \pm \Delta R_e$ for these combinations was based on the measurement using the digital multimeter. As can be observed, all the values when measured using our designed tester were found to be within the tolerance limits of the parallel combination of known resistances. Each measurement was repeated 10 times to find the repeatability of the design and monitored on serial monitor of Arduino IDE. For example, repeated measurements for two 1 Ω resistances in parallel is shown in figure 2.20. After measuring all the values on tester, it was found that repeatability was within ± 0.02 Ω.

Table 2.1. Measurement of resistance values with ΔR_e less than 0.2 Ω

Sl No	R_1	ΔR_1	R_2	ΔR_2	R_e	ΔR_e	Range of Values ($R_e \pm \Delta R_e$)	Measured Value
1.	1	0.05	1	0.05	0.50	0.08	0.42 to 0.58	0.54
2.	1	0.05	10	0.5	0.91	0.14	0.77 to 1.05	0.96
3.	1	0.05	22	1.1	0.96	0.15	0.81 to 1.11	0.98
4.	1	0.05	33	1.65	0.97	0.15	0.82 to 1.12	0.98
5.	1	0.05	100	5	0.99	0.16	0.83 to 1.15	0.99

Table 2.2. Measurement of resistance values with ΔR_e equal to or greater than 0.2 Ω

Sl No	R_1	R_2	R_e	ΔR_e ($\pm 0.008R_e \pm$ 2 digits)	Range of Values ($R_e \pm \Delta R_e$)	Measured Value
1.	2	10	1.7	0.2	1.5 to 1.7	1.70
2.	2	22	1.9	0.2	1.7 to 2.1	1.79
3.	2	33	2.0	0.2	1.8 to 2.2	1.91
4.	2	100	2.1	0.2	1.9 to 2.3	1.99
5.	10	10	5.1	0.2	4.9 to 5.3	4.92
6.	10	22	7.0	0.3	6.7 to 7.3	6.83
7.	10	33	7.8	0.3	7.5 to 8.1	7.69
8.	10	100	9.2	0.3	8.9 to 9.5	9.19
9.	22	33	13.4	0.3	13.1 to 13.7	13.10

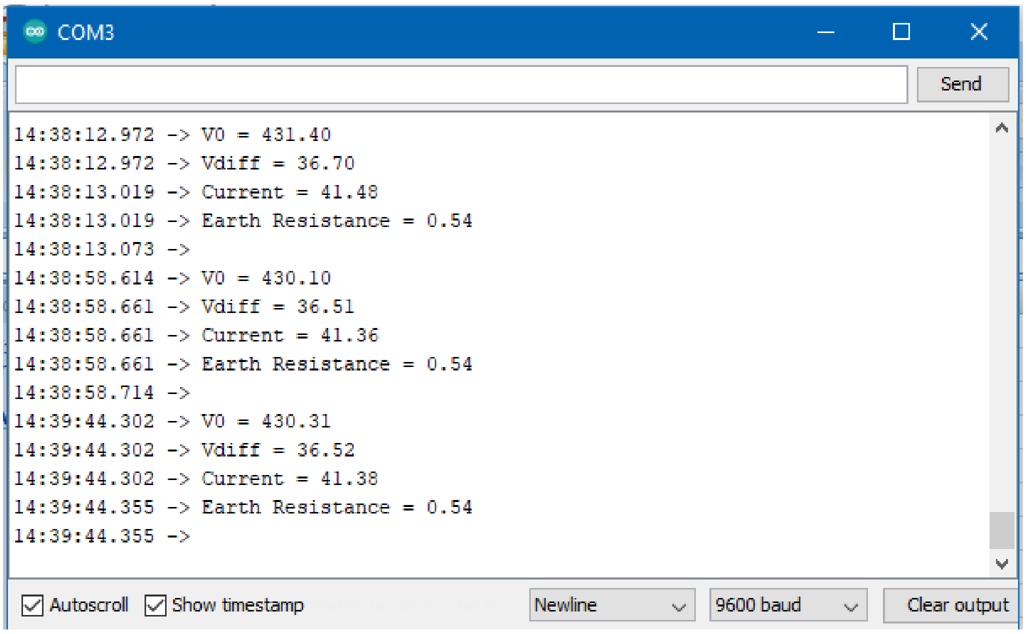

Fig 2.20. Arduino IDE serial monitor output for two 1 Ω resistances in parallel.

Inferences: The test setup was able to read the resistance values and gave output within the tolerance band of the resistors. When these resistors were used in parallel combination, the values were either read within the propagated tolerance or within the accuracy range of multimeter having accuracy (±0.8%±2 digits). The setup may even have higher accuracy but needs a higher standard to verify that. Also, after repeated readings for each resistance combination, it was found that the readings did not vary from each other by more than ± 0.02 Ω. Also, the tester is set up in such a way that the reading of resistance between P1 and P2 of earth tester is not affected by insertion of varied values of resistances between P2 and E2. An advantage of this setup is that even if the commercial earth tester is not itself calibrated, it can be made use of to carry out quite accurate measurements by calibration in program of ATmega328P. Also, the same setup should work for any other tester which has a working current generator but is overall unserviceable.

Limitiation: The test setup was run using both Arduino UNO and standalone ATmega328P. It was observed that both the setups performed equally, however, with standalone ATmega328P, the records, say 1 out of 20, were not reliably being stored in server database. But this problem was no there with Arduino UNO. Most probably, PCB implementation instead of breadboard implementation will resolve this issue.

2.6.2 Simulation Study of 61.8% Tester

The complete circuit of measuring device (except ATmega328P and timer switch) is given in figure 2.9. This circuit was simulated using the TI-TINA software and the output waveforms were observed for various values of simulated earth resistance. The earth resistance was simulated using a potentiometer set at 61.8%. Therefore, in order to simulate an earth resistance of 1Ω, the total resistance value of the potentiometer was set as 1.618 Ω. Similarly, to simulate 50 Ω earth resistance, the value of potentiometer was set as 80.9 Ω. The output of the peak detector was obtained with reference to the central voltage of power supply, i.e., 9 V. The circuit output has been calibrated such that it gives an output of 5 V DC above the central value of 9 V. However, in a practical circuit the values of contact resistances, wires and mild steel stakes need to be measured and accounted in order to calibrate the device. In order to initiate oscillations in the Bubba oscillator, a current source of 1 mA pulse for 1 ns was used during simulation. However, this should not be required in a practical circuit due to presence of noise. The screenshots of output waveforms of precision rectifier and peak detector overlapped for simulated earth resistance of 1 Ω, 10 Ω and 50 Ω are shown in figure 2.21, figure 2.22 and figure 2.23 respectively.

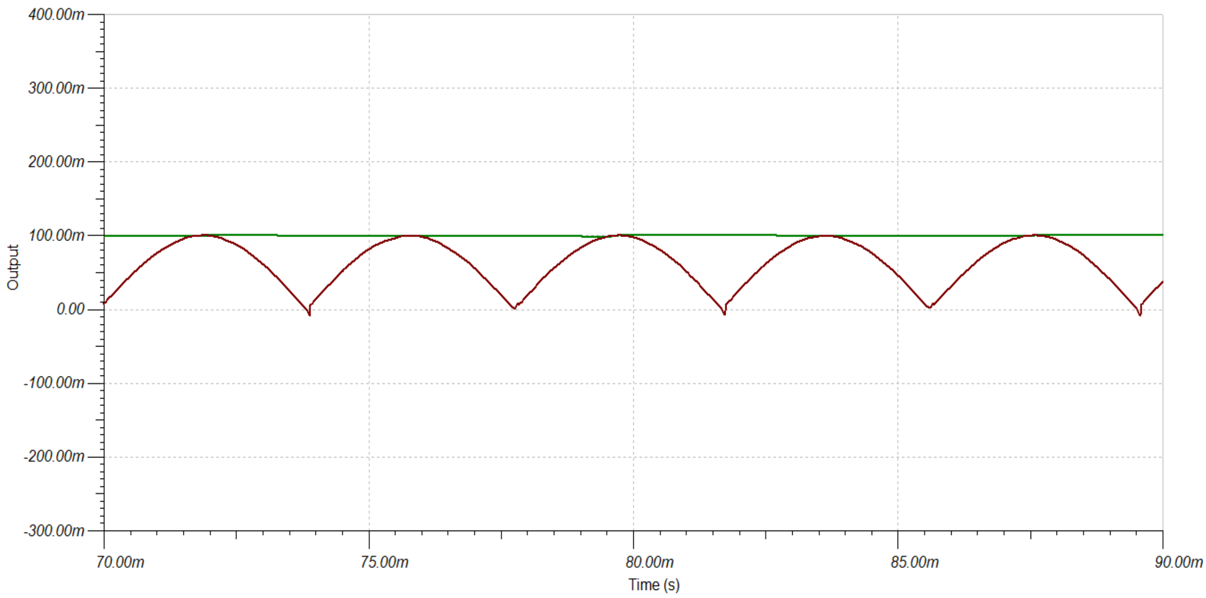

Fig 2.21. Output of simulated 61.8 percent tester for 1 Ω earth resistance.

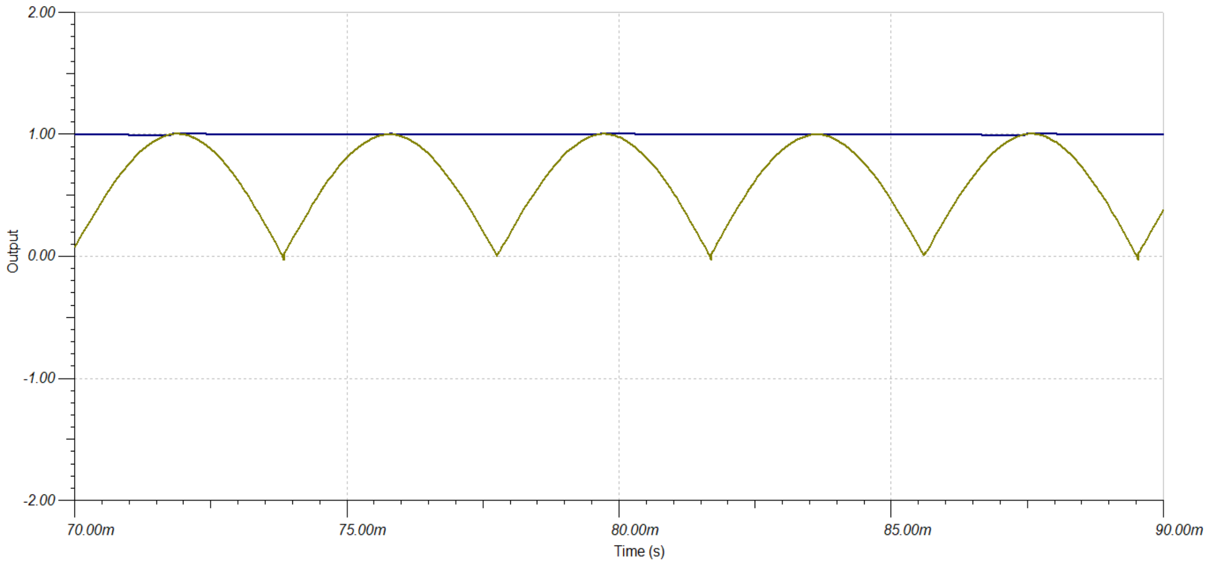

Fig 2.22. Output of simulated 61.8 percent tester for 10 Ω earth resistance.

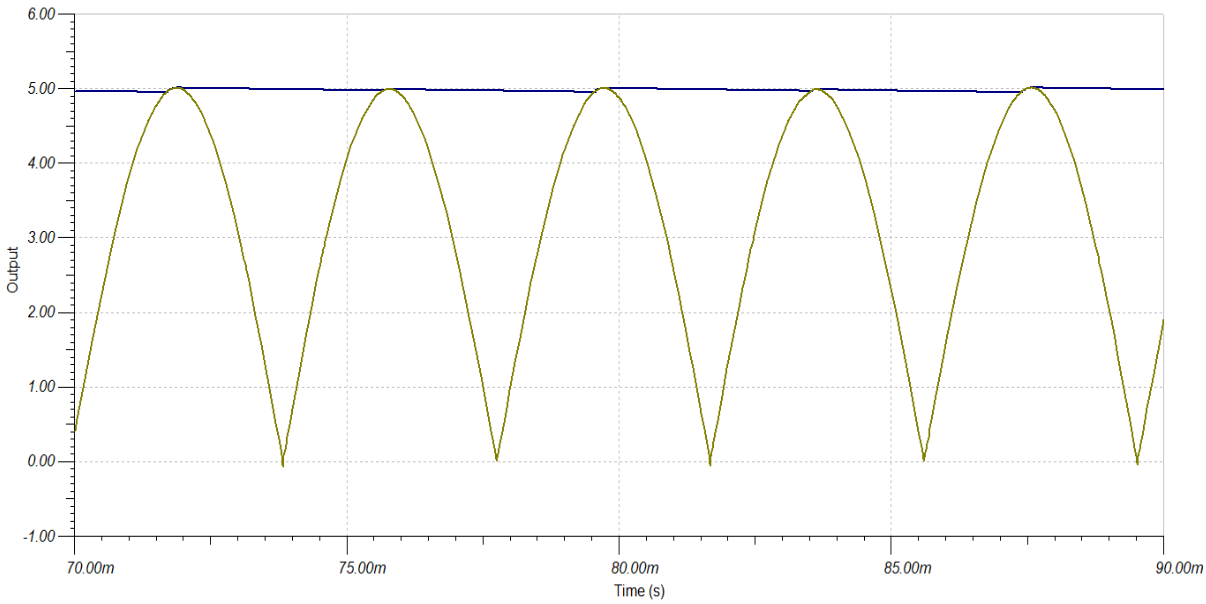

Fig 2.23. Output of simulated 61.8 percent tester for 50 Ω earth resistance.

The circuit was simulated for the simulated earth resistance values from 1 Ω to 60 Ω in steps of 5 ohms. The circuit was simulated first without the isolation transformer T1 and then with it. It was found that there is slight fall in the value of current of the current source as the resistance value increased when simulation was carried out without the isolation transformer. However, when the simulation was repeated with the isolation transformer, the value of current remained constant irrespective of the earth resistance value. The results for simulation carried out with the isolation transformer are given in table 2.3 below. It can be observed that the circuit gives the desired result during simulation (with slight inaccuracies of below 1%).

Table 2.3. Output of simulated 61.8 % tester for various values of earth resistances.

Simulated Earth Resistance (Ohms)	Sine Wave Generator Voltage (V p-p)	Current Source Output (mA p-p)	Voltage Across Test and Potential Electrode	Peak Detector Output	Expected Value	%Error
1	15.05	20.03	20.03 mV	100 mV	100 mV	0.0
5	15.05	20.03	100.16 mV	501 mV	500 mV	0.2
10	15.05	20.03	200.29 mV	1 V	1 V	0.0
15	15.05	20.03	300.37 mV	1.5 V	1.5 V	0.0
20	15.05	20.03	400.57 mV	2 V	2 V	0.0
25	15.05	20.03	500.74 mV	2.51 V	2.5 V	0.4
30	15.05	20.03	600.85 mV	3.02 V	3 V	0.7
35	15.05	20.03	700.99 mV	3.5 V	3.5 V	0.0
40	15.05	20.03	801.24 mV	4.01 V	4 V	0.2
45	15.05	20.03	901.45 mV	4.51 V	4.5 V	0.2
50	15.05	20.03	1 V	5.01 V	5 V	0.2
55	15.05	20.03	1.1 V	5.51 V	5.5 V	0.2
60	15.05	20.03	1.2 V	6.01 V	6 V	0.2

Inferences: The circuit designed for the measurement of earth resistances for single earth pits is behaving linearly for values of earth resistances upto 60 Ω with an error of less than 1%. This is well above our requirement of measuring upto 10 Ω earth resistance. It gives a maximum output of 1 V for a 10 Ω earth resistance and hence is suitable for practical implementation in combination with test setup of section 2.2. Also, it has been found that with the use of an isolation transformer to feed current to the current electrode, the value of current can be kept more constant as compared to without its use. Hence, the need for measurement of current in addition to the output voltage of the tester can be eliminated if we use an isolation transformer.

Limitations: There is a need to deploy two auxiliary earth electrodes permanently for using this tester. Hence, it is important to identify most critical earth pits so that its use is made as limited as possible.

2.6.3 Simulation Study of Clamp on Tester

The complete circuit of proposed clamp on tester (except ATmega328P and timer switch) is given in figure 2.19. This circuit was simulated using the TI-TINA software and the output waveforms were observed for various values of simulated earth resistance. The output of the peak detector was obtained with reference to the central voltage of power supply, i.e., 9 V. The circuit output has been calibrated such that for 1 Ω loop resistance, it gives an output of 5 V DC above the central value of 9 V. However, in a practical circuit the values of contact resistances, wires and non linearity of transformers used need to be known and accounted in order to calibrate the device. Again as in previous simulation, to initiate oscillations in the Bubba oscillator, a current source of 1 mA pulse for 1 ns was used during simulation. However, this should not be required in a practical circuit due to presence of noise. The screenshot of output waveforms of precision rectifier and peak detector overlapped for simulated earth resistance of 1 Ω is shown in figure 2.24.

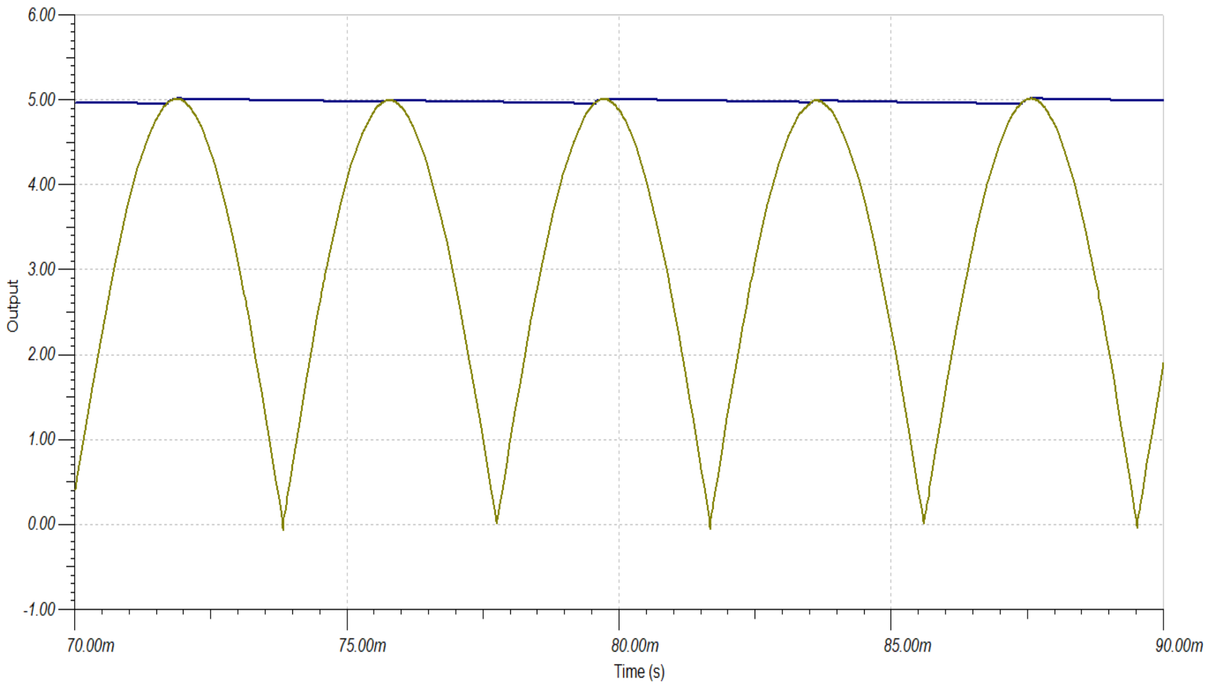

Fig 2.24. Output of simulated clamp on tester for 1 Ω earth resistance.

The circuit was simulated for the simulated earth resistance values from 1 Ω to 25 Ω in steps of 5 ohms. The results are given in table 2.4 below. It can be observed that the circuit gives the desired result during simulation with an error of upto 2% for earth resistance upto 10 Ω.

Table 2.4. Output of simulated clamp on tester for various values of earth resistances.

Total Earth Resistance (Ohms)	Sine Wave Generator Voltage (V p-p)	Peak Detector Output	Expected Value	%Error
1	15.05	5.03 V	5 V	0.6
5	15.05	1.02 V	1 V	2.0
10	15.05	510 mV	500 V	2.0
15	15.05	345 mV	333 V	3.6
20	15.05	258 mV	250 V	3.2
25	15.05	206 mV	200 V	3.0

Inferences: The circuit designed for the measurement of earth resistances for multiple earth pits is behaving linearly for values of earth resistances upto 25 Ω. This is well above our requirement of measuring upto 10 Ω earth resistance and hence can be considered suitable for practical implementation in combination with test setup of section 2.2. Also, it is most favourable tester for two or more earth pits as there is no need of digging auxiliary test electrodes as required for tester in sections 2.2 and 2.4. It can also be observed that as the value of earth resistance decreases, we get a higher output voltage. Therefore, if this voltage is measured with the help of an ADC, it will be nearer to the full range value and hence accuracy at lower resistance values will be more.

Limitations: The measurements carried out with this method will give the value of two or more earth resistances in series and hence will be that of total combination. Measuring the value of a single earth resistance will require individual earth pit measurement after isolation.

2.7 Conclusions

In this project, a commercial earth resistance tester has been integrated with an Arduino UNO and its microcontroller ATmega328P in turns. The tester injects a current in simulated earth resistance which results in appearance of a voltage. The voltage is read, processed and interfaced with internet using Arduino UNO as well as standalone ATmega328P microcontroller in combination with and Arduino Ethernet Shield. It is found to be accurate atleast upto the standard used for the work and repeatability figure of ± 0.02 Ω. The setup has also been used for transmission of recorded data to a web server based on Amazon Web Service and the measurements were recorded in a database on the server. A web page has been designed for reading the data stored in the database which is accessible from anywhere on the internet.

In addition to this, two types testers, first one working on the 61.8 percent principle and second one on clamp on principle, have been designed and simulated.

Chapter-3

Summary and Future Scope

3.1 Summary

Provision of good quality earthing is one of the most prime requirements to ensure human safety and reliable operation of electrical/electronic equipments. The most obvious indicator of the quality of earthing is the earth resistance value. Measuring and monitoring earth resistance is thus an inescapable task which every service provider should consider seriously. Therefore, monitoring the earth resistance automatically and recording the values can prove to be a very handy. At the outset, the investment in making such systems may look a bit high but the damage it can help in preventing to the costly electronic equipments is immeasurable. Even though, such systems are available commercially, designing own solution can result in major cost cutting for organisations especially if the testers can be created in a laboratory environment.

The remote monitoring of earthing system project has been designed keeping in mind that on date, internet is the best way through which the sensor readings can be accessed remotely. For this, a battery powered system has been attempted to be made. A test setup has been fabricated using an actual earth resistance tester and performance checked. It is found to be accurate atleast upto the standard used for the work and repeatability figure of ± 0.02 Ω. The output of earth tester is read, processed and interfaced with internet using an Arduino UNO or ATmega328P microcontroller in combination with and Arduino Ethernet Shield. The setup has also been used for transmission of recorded data to a web server using Amazon Web Services and the system with Arduino UNO has been found to reliably record the data in a database on the server. A web page has been designed for reading the data stored in the database which is accessible from anywhere on the internet. A large number of such testers can be integrated over internet. In short, this brings IoT and earth resistance measurement together.

Additionally, simulation studies have been carried out to design two type of testers. The first tester is based on the 61.8 percent method of testing earth resistance. In this, a method has been found using which there should be no need to measure current separately in order to find the earth resistance. The voltage presented across the Test and Potential electrodes alone can directly give the value of earth resistance. The tester has an error of less than 1 percent as compared to the actual value of earth resistance. The second type of tester is based on the principle of induction of voltage in a loop formed by two or more earth pits. The resulting current is picked up using a transformer and processed to finally give a corresponding output voltage. This type of tester may help in eliminating the use of auxiliary test electrodes wherever two or more earthpits are bonded together.

3.2 Future Scope

The system made using actual earth tester has been tested and found to be reliably measuring the resistance values of simulated earth resistances. The T Notch filters, bandpass filters, precision rectifier and peak detector as designed in simulation may be used with the current generator of commercial tester for more accurate results. Furthermore, testing may be carried out in actual conditions and multiple such testers can be integrated to test for reliably recording of data in the server.

The test setup sends the data reliably to AWS server when using Arduino UNO. However, behaviour in this aspect is little less reliable with standalone ATmega328P based test setup. The reason may be investigated so that the advantage of significantly lesser power consumption by standalone microcontroller may be made use of. Probably, PCB implementation instead of breadboard implementation will resolve this issue.

The webpage has a limited functionality and can be improved with security features such as user authentication and installation of SSL certificate on server. Additional features such as sending sms to mobile phones based on increased earth resistance values and automatic raising of alarm for unacceptable values can also be added.

The earth testers designed and simulated may be actually fabricated and checked for performance. Also, a method can be devised which can measure the earth resistance without the use of any current or voltage source. Thereafter, this module can replace the measuring device part of the experimental test setup and integrated with the Arduino UNO/ATmega328P for interfacing and networking part.

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