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An Arduino Uno Microcontroller Based Prototype Overvoltage and Overcurrent Protection System

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Abstract:-- **It is of significant academic interest to develop cheap, dependable and robust protection systems for simple electrical circuitries for both academic and commercial usage. This research paper is intended to propose and implement a prototype overvoltage and overcurrent protection scheme of single phase two terminal passive circuits utilizing the Arduino Uno microcontroller and the Arduino Software (IDE). The proposed scheme would acquire and process conditioned analog input values of voltage and current of a system in real time and the implemented Arduino programmes would monitor whether those values exceed a predefined threshold; exceeding that will trip a relay to protect the system. The scheme would have three major segments that are the current sensing segment, the voltage sensing segment and the relay module and these segments shall be properly interfaced with the Arduino Uno Microcontroller and the load. The scheme is tested on a resistive and a lamp load and an analysis of the obtained data through experimentation on these electrical loads suggest that the proposed scheme is essentially feasible with moderate sensitivity.**

Keywords:- **Arduino Uno Microcontroller, Relay, Overvoltage, Overcurrent, Protection.**

I. INTRODUCTION

Electrical circuitries with the addition of electronic components have become more complex in nature and anomalies might arise due to even very slight fluctuations in the circuit parameters. The successful and efficient operation of these circuitries is often attributed to the relays and switchgears that monitor the anomalies in various parameters of the system and isolate the faulty segments from the normal to ensure that the equipment is properly protected. In electrical & electronic engineering laboratories and industrial circumstances, it is extremely desirable to offer ample protection to the elementary circuitries & costly equipment that are used for various purposes. Any aberration in the parameters of these circuitries can result in instability in voltage and current levels and it may be detrimental to the equipment in use & supply lines. In this decade with the accelerating developments in engineering & technology, it has become imperative to analyze, monitor and synthesize numerical values of various intrinsic parameters of different complex systems in order to ensure the optimal and reliable functionality of those. Arduino Uno microcontroller board can be utilized to devise a form of digital relay with Arduino programming for real time protection of single & poly phase AC & DC systems.

II. LITERATURE REVIEW

Sridevi P., et al. [1] measured power and energy of electrical systems with Arduino. They utilized offset current and voltage conditioning cards to feed output values from current and potential transformers and the conditioned output values were fed to an Arduino which in turn measured power using sketches when interfaced with a personal computer. The tests were done on resistive, inductive, capacitive loads and also on lamp loads of 200 W rating. Naseem, Adil, and Naveed Alam [2] implemented a protection scheme of distribution transformers to offer protection from malfunctions arising out due to overloading currents, high voltage spikes and over-heating of transformer oil. They utilized Arduino Uno as the preferred microcontroller and it yielded favourable results with elevated sensitivity and accuracy. Bhat, Aakanksha, et al. [3] proposed an integrated architecture to offer automation in measurement of power using Arduino Uno and Raspberry Pi. The proposed system could detect abnormal power usage, analyze power consumption and monitor load and health of electrical appliances. Titu Bhowmick, Dharmasa, [6] proposed an electrical protection scheme for a solar power system using Arduino. The proposed setup used a 115V/15V transformer; a 50 W variable rheostat; an electro-mechanical relay and low burden electronic current sensors (ACS712). The author validated the proposed prototype model by creating a fault using the variable rheostat as load and investigated the efficiency to obtain accurate results on both internal and external faults. It was further concluded that the scheme was energy efficient. Thus, Arduino Uno microcontroller has been preferred for this proposed protection scheme.

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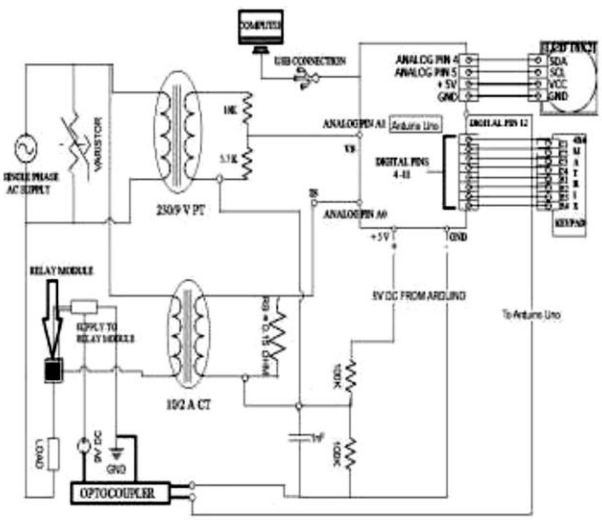
III. MATERIALS & METHODS

A. The Circuit

The complete circuit diagram of the proposed scheme is given in Fig. 1.



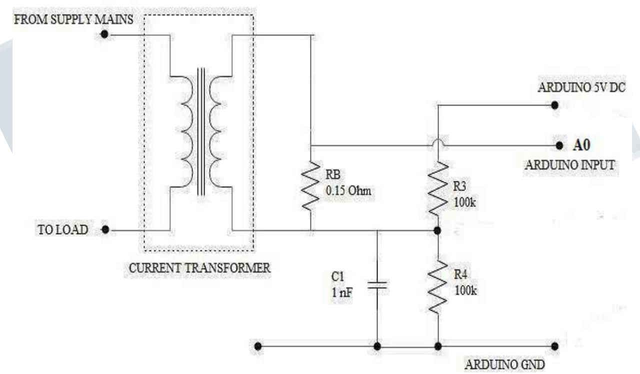
(Fig. 1 – Circuit Diagram of the Prototype)

The devised prototype has an Arduino Uno as the central microcontroller, one current sensing segment, one voltage sensing segment and one tripping segment. The two terminal load is connected to one terminal of the relay and one terminal of the power source. The Arduino Uno shall be interfaced with a personal computer where Arduino programmes (sketches) shall be run. This scheme would offer overvoltage and overcurrent protection to simple single phase two terminal loads especially passive loads. A keypad is used to input requisite data to the fundamental functional modules and can be used to display various values of voltage and current on the LCD module. One terminal from the current sensing segment is connected to the A0 pin of the Arduino Uno, one terminal from the voltage sensing segment is similarly connected to the A1 pin and the relay module is fed by the optocoupler, which is connected to digital pin 12 of the Arduino. The LCD module is interfaced by I2C serial communication protocol using eight digital pins, pins 4 – 11 of the Arduino Uno and this would essentially monitor the voltage across the load and the current through it with the help of these constituting segments. If any aberration and fault may occur, i.e. the values of current and voltage exceed a predefined threshold; the Arduino Uno shall generate a trip signal and trip the relay in order to protect the load from excessive voltage or current or both. The voltage and current sensing segments may operate simultaneously or work as standalone sensing components as per the circuit design and Arduino programming.

B. The Different Segments

(1) The Current Sensing Segment

It is an integral part of the proposed prototype protection scheme. The utilized current transformer (CT) of 10A/2A rating would electrically isolate the segment from the supply mains and through the designated circuitries, an electrical signal (IS) shall be fed to the Arduino Uno through an analog input pin (A0) and a biasing circuit of two resistors of 100 KΩ each and one capacitor of 1 nF shall be supplied from the power pins +5 V and GND of Arduino Uno

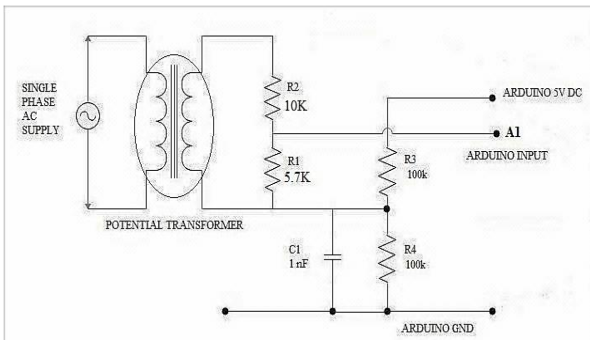


(Fig. 2 – The Current Sensing Segment

The CT is inadvertently the most important component of the current sensing segment. The whole segment would continuously monitor the current through the load and initiate proper actions as per programming. The incoming current signal (IS) to the Arduino Uno is conditioned by the biasing circuit, which provides an offset voltage of 2.5 volts in order to ensure the incoming AC signal oscillates about 2.5 volts and is limited within the permissible input range of 0 to 5 volts. The biasing circuit is formed by the 5 volts output and ground provided by the Arduino Uno board, two resistors of equal values and a capacitor to ensure a stable voltage output of 2.5 volts.

(2) The Voltage Sensing Segment

The voltage sensing segment is also an integral part of the proposed prototype. The potential transformer (PT), of transformation ratio 230/9, used in it would electrically isolate the segment from the supply mains and step down the supply voltage to lower and safer levels. An electrical signal (VS) shall be fed to the Arduino Uno through an analog input pin (A1) and the biasing circuit would be used for conditioning the input signal. The whole segment would continuously monitor the load terminal voltage and would necessitate proper protective measures once aberrations are duly detected.



(Fig. 3 – The Voltage Sensing Segment)

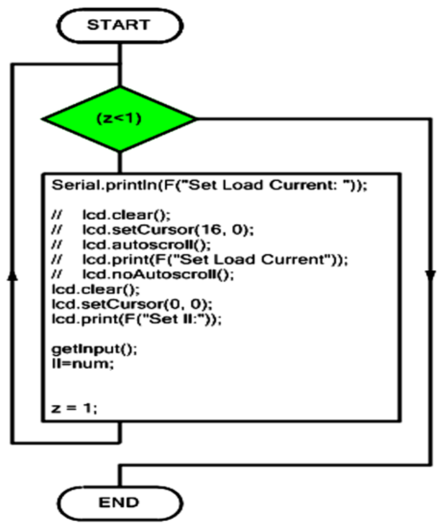
Herein, a voltage divider circuit formed by two resistors, specifically by a 10k and a 5.7k ohm resistor further steps down the secondary voltage, which is then supplied, to the analog pin A1 of the Arduino Uno for further processing. A Zener diode may, in addition, be connected in parallel to the input analog pin A1 and the ground in order to provide additional protection to the Arduino Uno microcontroller board. The incoming voltage signal (VS) to the Arduino Uno is conditioned by the biasing circuit which provides an offset voltage of 2.5 volts in order to ensure the incoming AC signal oscillates about 2.5 volts and is limited within the permissible input range of 0 to 5 volts.

(3) The Tripping Segment

The utilized volt cube relay is connected between the single phase supply mains through one terminal of the utilized CT and one terminal of the load. It is a 12V DC operated AC 250V 10A relay. The relay module can tolerate an electric current up to 10 A and it may be programmed to trip the circuit at any value of current below the maximum. The N/C terminal is, by default, connected to the Common/Pole and the N/O is normally kept open. Its fixed terminals are connected to variable 9 V DC conductor line and GND emanating from the optocoupler, which in turn is connected to the digital pin 12, and GND of Arduino Uno. The relay itself gets tripped by the signals from the digital pin 12 of the Arduino Uno via the optocoupler.

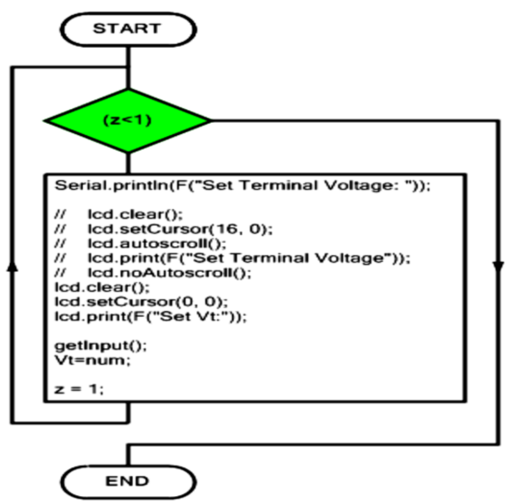
C. The Fundamental Programme Algorithms

(1) Load Current



(Fig. 4 – The Load Current Algorithm)

(2) Terminal Voltage



(Fig. 5 – The Terminal Voltage Algorithm)

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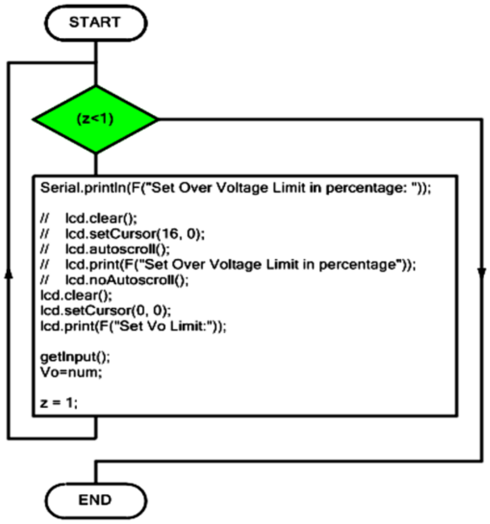
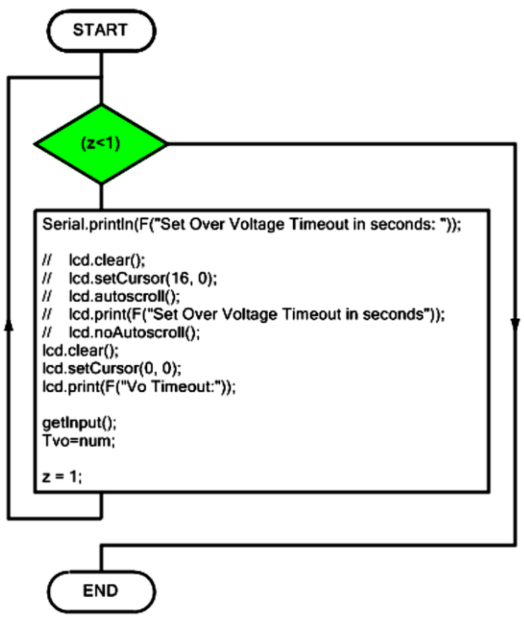
(3) Overvoltage Limit



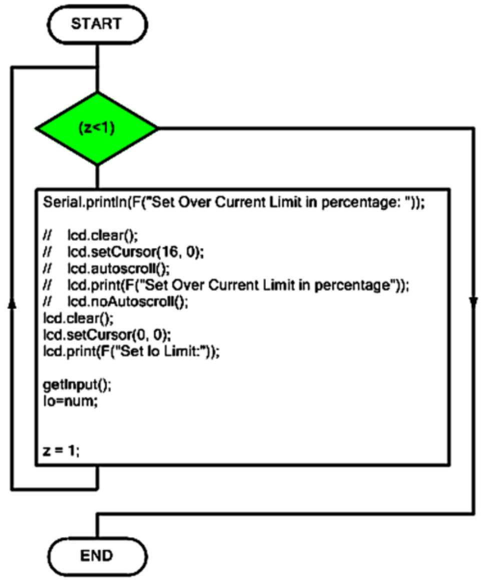
(Fig. 6 – The Overvoltage Limit Algorithm)

(4) Overvoltage Timeout



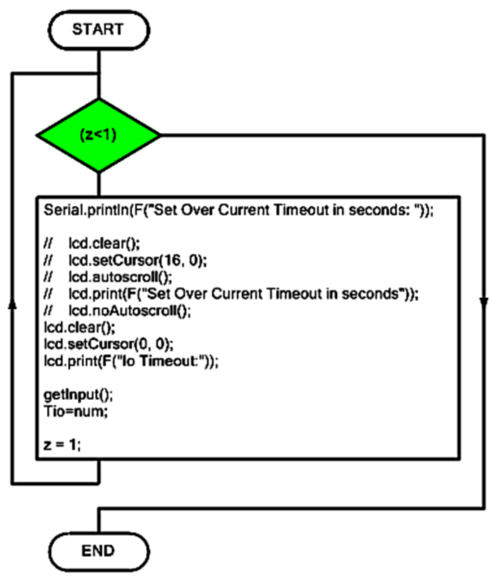
(Fig. 7 – Overvoltage Timeout Algorithm)

(5) Overcurrent Limit



(Fig. 8 – Overcurrent Limit Algorithm)

(6) Overcurrent Timeout



(Fig. 9 – Overcurrent Timeout Algorithm)

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D. Keypad & LCD Interfacing

To interface the 4X4 Matrix Keypad Module with the Arduino, the following 4x4 Matrix Keypad pins are connected with the respective Arduino pins as tabulated below:

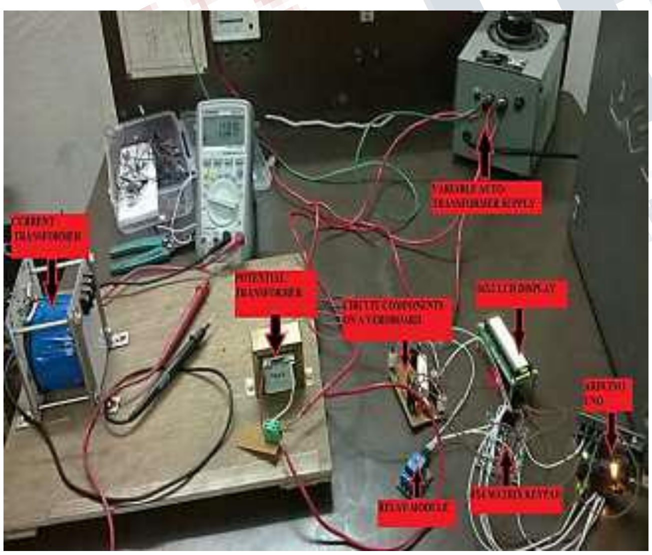
Keypad Pin	*Arduino Uno Pin*
R1 to R4	D8 to D11
C1 to C4	D4 to D7

(Table – 1 Pin to Pin Connections)

An I2C interfacing is done between the Arduino Uno and the 16X2 LCD Display. A 4 pin cable is required to initiate the I2C communication between an LCD and the Arduino Uno. On an Arduino Uno, VCC pin provides the +5 V, GND provides the ground, analog pin 4 provides the SDA and the analog pin 5 provides the SCL. LiquidCrystal_I2C library functions are required to set the interfacing and programming of the LCD.

III. RESULTS

Experiments were conducted on a resistive element and a lamp load. A photograph of the circuit before the connection of the loads is shown herein:



(Fig. 10 – The Circuit to be Connected to the Load)

●*Experimental Results on a Resistive Element:*

One rheostat was used in performing the experiment on the devised prototype. The supply from the variable autotransformer was set to 200 V and the slider was slid until the connected tertiary measuring equipment, an ammeter, showed a current of 2 A. Thus the resistance was set to be 100 ohm. The programme was set to trip the relay module at 260 V to provide overvoltage protection and at 2.8 A for overcurrent protection.

(1) Readings of the 230/9 V potential transformer with no overcurrent tripping implementation:

Sl. No.	Primary Voltage (V)	Secondary Voltage (V)	Tripping Condition
01	200	7.94	Does Not Trip
02	220	8.70	-Do-
03	240	9.44	-Do-
04	260	10.25	-Do-
05	276	10.96	Circuit Trips

(Table – 2 Overvoltage Protection of a Resistive Load Using PT)

(2) Readings of the 10/2 A current transformer with no overvoltage tripping implementation:

Sl. No.	Primary Current (A)	Secondary Voltage Across Burden (V)	Tripping Condition
01	2.03	0.39	Does Not Trip
02	2.21	0.42	-Do-
03	2.44	0.47	-Do-
04	2.63	0.51	-Do-
05	2.81	0.54	-Do-
06	2.98	0.58	Circuit Trips

(Table – 3 Overcurrent Protection of a Resistive Load Using CT)

● *Experimental Results on a Lamp Load:*

A 200 Watt lamp load was utilized in performing the experiment on the devised prototype. The programme was set to trip the relay module at 230 V to provide overvoltage protection and at 3.20 Ampere to provide overcurrent protection.

(1) Readings of the 230/9 V potential transformer with no overcurrent tripping implementation:

Sl. No.	Primary Voltage (V)	Secondary Voltage (V)	Tripping Condition
01	152.16	6.05	Does Not Trip
02	184.09	7.32	-Do-
03	209.50	8.31	-Do-
04	223.50	8.91	-Do-
05	238.00	9.42	-Do-
06	251.43	9.95	Circuit Trips

(Table – 4 Overvoltage Protection of a Lamp Load Using PT)

(2) Readings of the 10/2 A current transformer with no overvoltage tripping implementation:

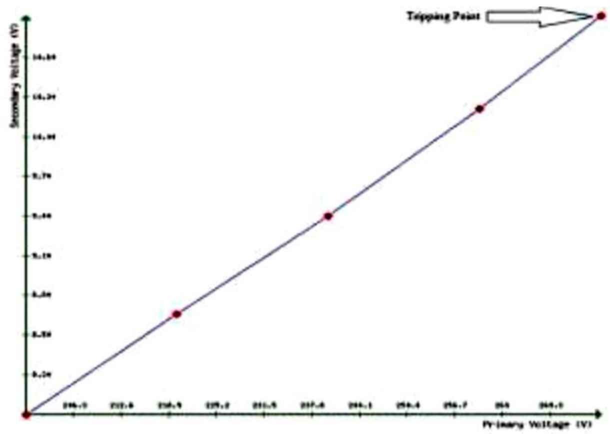
Sl. No.	Primary Current (A)	Secondary Voltage Across Burden (V)	Tripping Condition
01	1.03	0.18	Does Not Trip
02	1.50	0.26	-Do-
03	2.25	0.41	-Do-
04	2.90	0.56	-Do-
05	3.20	0.60	-Do-
06	3.60	0.71	Circuit Trips

(Table – 5 Overcurrent Protection of a Lamp Load Using CT)

IV. DISCUSSION

The testing of the devised prototype was carried out on a resistive (a rheostat) and on a lamp load. The principal programme was set to trip the relay for general overvoltage and overcurrent conditions. The devised prototype was successful in tripping the circuit for both overvoltage and overcurrent conditions within a margin of error which is acceptable for laboratory equipment. The programme was set to trip the circuit for overvoltage protection of the resistive load at 260 V and it eventually tripped at 276 V. Similarly, it was set to trip at 2.8 A for overcurrent protection and it eventually tripped at 2.98 A. An ammeter was utilized to set the slider of the rheostat so as to make it draw a current of at 2 A at the initiation to a supply voltage of 200 V by an auto - transformer which implied that the resistance of the rheostat was set at 100 ohm. In similarity with the resistive load test, the lamp load test was carried out to offer overvoltage protection beyond 230 V and overcurrent protection beyond 3.20 A.

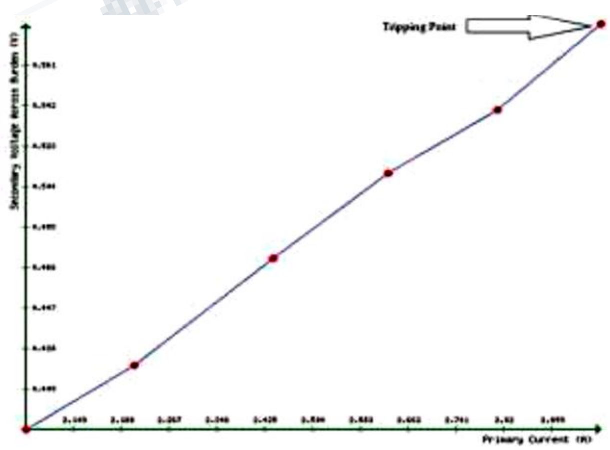
A. Graphs & Error Calculation:
(1) For the resistive load:



(Fig. 11 – Primary vs Secondary Voltage of the Utilized PT Graph)

For overvoltage protection, the circuit tripped at 276 V following a fairly linear characteristic curve whereas it was programmed to trip at 260 V.
Therefore the obtained error is given by:

$$\text{Error} = \frac{276-260}{260} X100 = 6.15\%$$



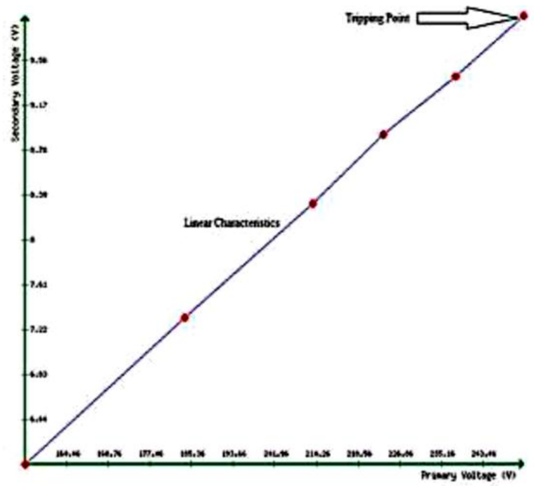
(Fig. 12 – Primary Current vs Secondary Voltage across the Burden of the CT Graph)

For overcurrent protection, the circuit tripped at a primary current of 2.98 A through the CT whereas it was programmed to trip at 2.8 A.

Therefore the obtained error is given by:

$$\text{Error} = \frac{2.98-2.80}{2.80} X100 = 6.43\%$$

(2) For the lamp load:

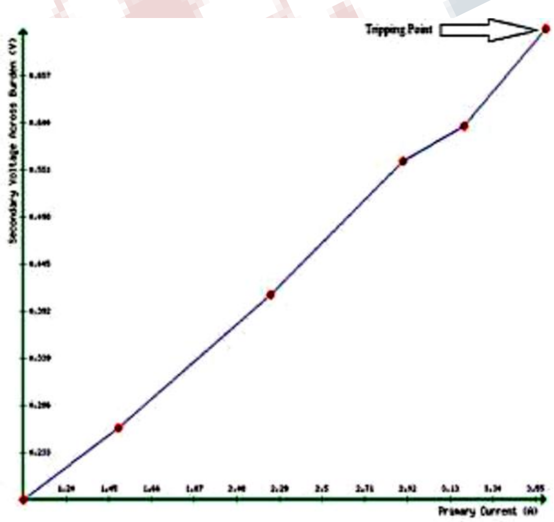


(Fig. 13 – Primary vs Secondary Voltage of the Utilized PT Graph)

For overvoltage protection, the circuit tripped at 251.43 V following a fairly linear characteristic curve whereas it was programmed to trip at 230 V.

Therefore the obtained error is given by:

$$\text{Error} = \frac{251.43-230}{230} X100 = 9.31\%$$



(Fig. 14– Primary Current vs Secondary Voltage across the Burden of CT Graph)

For overcurrent protection, the circuit tripped at 3.60 A whereas it was programmed to trip at 3.20 A.

Therefore the obtained error is given by:

$$\text{Error} = \frac{3.60-3.20}{3.20} X100 = 12.5\%$$

V. CONCLUSION

Thus the proposed prototype protection system has been devised and implemented to trip the load elements successfully at different overvoltage and overcurrent conditions within a margin of error that might further be ameliorated upon future iterations of this scheme.

This scheme is simple, moderately sensitive and reliable and may further be improved based upon this prototype to implement overvoltage and overcurrent protection simultaneously and improve the simplicity and efficacy of it. It can also be extended and reprogrammed to offer further protection schemes such as undervoltage, undercurrent and earth fault protection and could offer protection to single phase AC motors and other electrical machineries. It can also be devised and programmed to offer comprehensive protection to three phase systems and it may be regarded as a future scope of work of this prototype.

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