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Design Topology of Sustainable Overload Protection of Transformer

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Abstract: Overload on transformer has been a principal cause of overheating in its windings, reduction of efficiency, lowering of lifespan and sometimes leads to burn. This can be attributed to a large quantity of current drawn by the loads in the circumstances. In this paper, a design topology capable of providing sustainable protection to transformer from overload is presented. The designed system detects current drawn when being loaded and able to protect the transformer by isolation while displaying the overload current immediately a load is placed resulting in drawing a higher amount of current than the rating of the transformer. This was verified using simulation and validated by experiment on a prototype design. The simulation and experimental results achieved show good correlation, and exhibited the cogency of the design topology.

Keywords: Current sensor, New Topology, Overload, Over-Current, Transformer Protection.

I. INTRODUCTION

Overload of transformers has been one of the major causes of fault in electric power system. This fault has to be considered in the quest for efficient operation and satisfy the needs of consumers with constant supply of electricity without interruption. Hence, power system protection is very imperative. It is not just to ensure that the electric power system is protected from faults but also that consumer and appliances are safe in their usage of electricity. When fault occurs in electric power systems, it could result in loss of power supply to the load and system stability, damages to component parts and appliances, danger to the human life, possibility of cascading events leading to system collapse [1]. Over the years, there has been an increase in the population of humans all over the world as well as economic growth likewise technological advancement. These have increased the demand for electricity as many more loads are presented into the system. When the electric power demand is beyond what the system can supply, it can lead to an overload on the Transformers.

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Therefore, there is a need for a device, component or system that can monitor power consumption to tally with capacity of transformer or save it from effects of overload. Such a mechanism must be devised to be able to interrupt supply if the power system is so loaded which can be dangerous to system components [2]. Distribution transformers are designed to adequately supply electric power to specified load and therefore, cases of overload can give rise to the damage of the transformers. To avoid such an occurrence, an elaborate system is used to monitor the excessive supply of electric power to the given load and controls current flow to the load to ensure that the transformers are not overburdened. Overvoltage and over-current relay has been used for quite a long time now and can be controlled electromechanically [3].

In this project therefore, a design topology with an Arduino UNO Microcontroller and current sensor is proposed to monitor cases of overload of transformer. This overload is then communicated to the relay to isolates the loading system from the distribution transformer. It has promises of high sensitivity, quick response and less maintenance. Distribution transformers are utilized for modification or alteration of voltage from one circuit to another without changing the frequency at distribution level. They are to lessen faults and attendant destruction as any impromptu fixing or mending principally substitution of defective piece or an entire transformer is capital demanding and taking considerable time [4]. Distribution transformers are essentially planned to work betwixt 40-60% of their full loads for consistency of operation and continued dependability [5]. Operating them over an elongated period under unusual conditions of faults and overloads will endanger their essence and health. Notwithstanding, the transformer requires to be kept with a competent protection plan to circumvent a forced outage or disastrous fiasco arising from its operation exceeding the tolerable bounds.

In the research papers of [6, 7], Arduino microcontroller (ATMEGA328P) was used to monitor and save the transformer from the menaces of overloads, voltage spike and overheating of transformer oil. However, the transformer in [6] was not fully protected from an over current fault that may lead to inadvertent operation while in [7], the overload situation is determined through voltage sensing. A digital differential current protection strategy of a transformer utilizing an Arduino UNO Microcontroller was designed in [8]. The system uses an imbalance in differential current values and transmits a trip alert to the relay functioning as a circuit breaker to unlock the circuit when there is a fault in the protected region.

This protection scheme was successful in transformer protection because it offers a better isolation, detects fault accurately and has a quick response time to clear faults but was not implemented to verify its results.

The research work reported by [9] designed and implemented an automatic means of protecting a transformer against overload, high input voltage and high temperature using ATMEGA328P microcontroller to take the place of the employment of fuse means. The current sensor (ACS756) was applied to sense the current which indicates the conduct and value of current. The output of the current sensor was supplied to the Microcontroller which takes the necessary action. The microcontroller detects under voltage fault of 200Vac and over voltage fault 250Vac. It conveys a trip signal to the relay during overheating of the transformer, meanwhile the over current relay suspends the load from the transformer and by that securing the transformer. However, this method cannot be used when loads of much lower voltages are involved. In all of references [6, 7, 8 and 9] above, the microcontroller monitors the parameters of the transformer and their values displayed using LCD.

The research work of [10] proposed an algorithm to boost the relaying responsiveness of fault detection applying a fuzzy logic way capable of detecting faults in the transformer. This research conveys a fresh plan to differentiate between magnetizing inrush current and interior fault current of a power transformer. For appraisal of offered algorithm, transmitting signals of diverse operating situations of power transformer, comprising internal faults, external faults, over-excitation and inrush conditions were accessed via transformer modeling and then implemented in MATLAB. Research carried out by Sarsamba M., et-al, [11] proposed a load monitoring and power lines approach based on Global System for Mobile communication (GSM) technology. Same technology was used by the researchers in [12] for distribution transformer. The approach was designed and implemented for tracing and noting current and voltage changes in electrical power lines and transformer. It manages these parameters when line breaks during high loads and load parameters themselves accurately. When fault occurs on account of voltage and current variation, overheating and change in oil level, parameters' values will be displayed on the LCD and a quick Short Message Service (SMS) will be sent to stipulated phone numbers and the control room via GSM modem. However, the greatest disadvantage is that multiple users share the same bandwidth, interferences encountered and lack of alarm system that will have informed any other person within the vicinity.

The research work carried out by Dey and others in [13] implemented a power transformer differential protection in accordance with Clarke's transform and fuzzy system. The system used AT89S52, PIC16F877A microcontroller and have a prototype relay produced. Electrical power system was modeled using MATLAB software to acquire the operational settings and fault circumstances required to examine the algorithm evolved which produced data for definite environment for the analysis and the validation of their suggested model. It was also revealed that in the fuzzy logic relay studies, the running pattern for the device was able to eradicate unusual work situations which produce failures. However, the power transformer was not fully protected from an over current fault that may lead to inadvertent operation.

The research carried out the authors in [14] was on microcomputer predicated multitouch time operated power switching system with overload protection. The switching time can be modified using electronic devices such as the keyboard and a mouse but due to the low power processors of the microcomputer, their performance is typically poor. Ibrahim and colleagues in [15] worked on protection transformer and transmission line in power system where differential and over-current relay performance characteristics were evaluated and promoted using MATLAB/Simulink. However, the work showed the output signal of only differential relay and not that of over-current relay, and no alarm when fault occurred. Overload protection of distribution transformer by automatic load sharing was researched on by Nebey [16]. It was about how to logically supply power in the management of load condition using intelligent controller to make decision by discerning the quantity of load on the transformer. The system instantly interfaces and disengages switch to allot the loads of transformer. However, the system cannot sense surge voltage and fault current.

Here in this work therefore, a topology of protection system is designed for a distribution transformer to yield a high level of safety circumspection by way of an automatic over current relay embedded in an Arduino UNO Microcontroller to intelligently read the power transformer currents, detect overload situations; over current fault due overload that may lead to adverse operation. The insertions of current sensors was to track the current at the predetermined limit, once the currents goes beyond an explicit brink, visual and audio warnings inform the system operator that transformer is over loaded. The novelty in this work compared to existing ones in the literature includes incorporation of alarm system and display unit meant to work simultaneously to quickly notify the operator in vicinity of transformer fault occurrence.

II. MATERIAL AND METHODS

The design of the circuit of over load protection of a transformer was done by carefully selecting the hardware and software components. The availability, effectiveness and affordability of materials are the factors put into consideration. The circuit was modeled with the ***Proteus Professional Design Suite Software, Version 8.9***. The block diagram of the protective system is depicted in Fig. 1. It composes of the Power Supply Unit, Current Sensing Unit, Isolation Unit, Microcontroller Module, Loading Unit, Display and Alarm Units.

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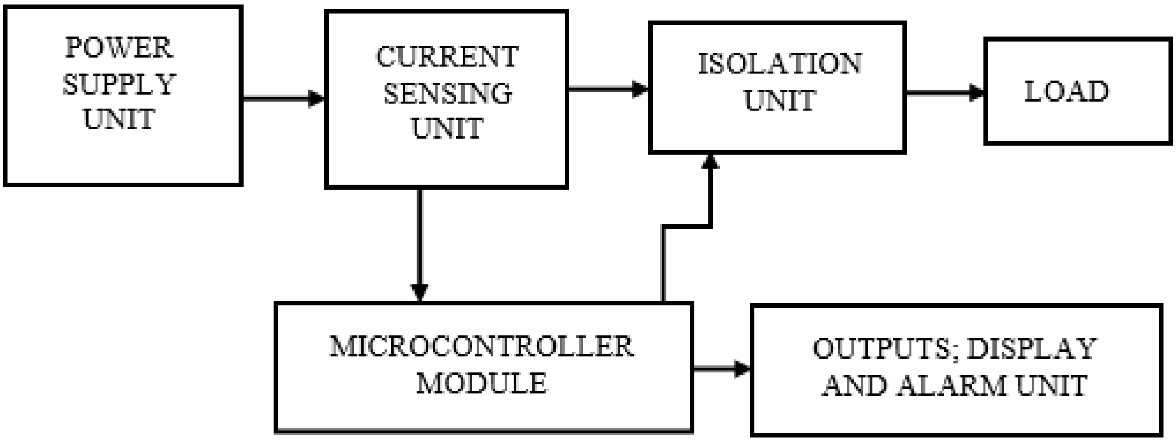

Fig. 1. Block Diagram of Over Current Protection of a Transformer

A. Power Supply Unit

The unit consists of step down transformer (TR1) (220/15V), bridge rectifier (BR), AC voltmeters, conductors, capacitors, DC voltmeters, transistor (TIP 42C), resistor and voltage regulator (IC 7812). The circuit is shown in Fig. 2.

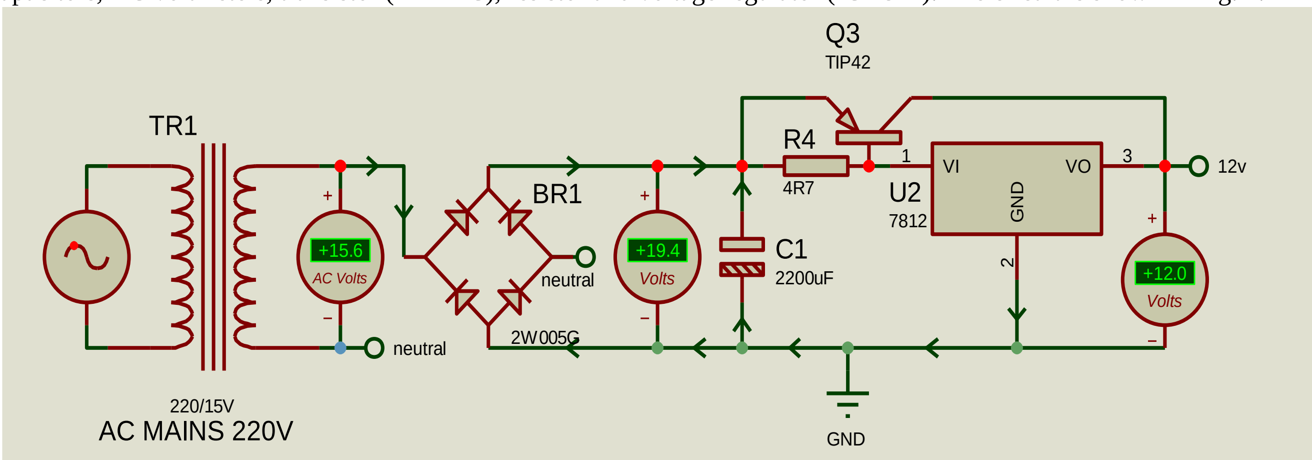

Fig. 2. Power Supply Circuit

The transformer input voltage from the mains is 220V at frequency of 50Hz which is then stepped down to 15V (r.m.s. value). The bridge rectifier transforms the AC of 15V to DC voltage of 12.59V and capacitor filters the ripples. Then the resistor biases the transistor to turn ON. The 12V regulator regulates the DC voltage of 12.59V to 12V which can supply the maximum current of 2Amp.
Peak voltage,

$$V_p = V_{rms} \times \sqrt{2} = 15 \times \sqrt{2} = 21.2\text{V} \quad (1)$$

Maximum output dc voltage,

$$V_{o(max)} = V_p - 2 \times V_d = 21.2 - 2 \times 0.7 = 19.8\text{V} \quad (2)$$

where V_d is the voltage drop across the silicon diode.
The value of the of the capacitor C can be calculated as given in [17] by

$$C = I_T / (4\sqrt{3} f \gamma V_{o(max)}) \quad (3)$$

where I_T is the load current of the transformer = 2A and γ, the tolerable ripples of voltage = 0.02. By "(3)", the filtering capacitance is 14579µF. However, the closest of 14579µF in practice and available in market is 1000µF.

B. Current Sensing Unit

The current sensor senses the current that the load is consuming and gives a corresponding output voltage. It is powered by 5V from the Arduino UNO Microcontroller and it gives an output of 2.5V from the pin (V/OUT) as shown in Fig. 3 which the Microcontroller also measures. So when there is an increment in current, there is also a rise in the output voltage from 2.5V to 2.55V and above depending on the amount of current consumed by the load. Therefore, the current that is being consumed by the load causes an increase in the output voltage from the current sensor.

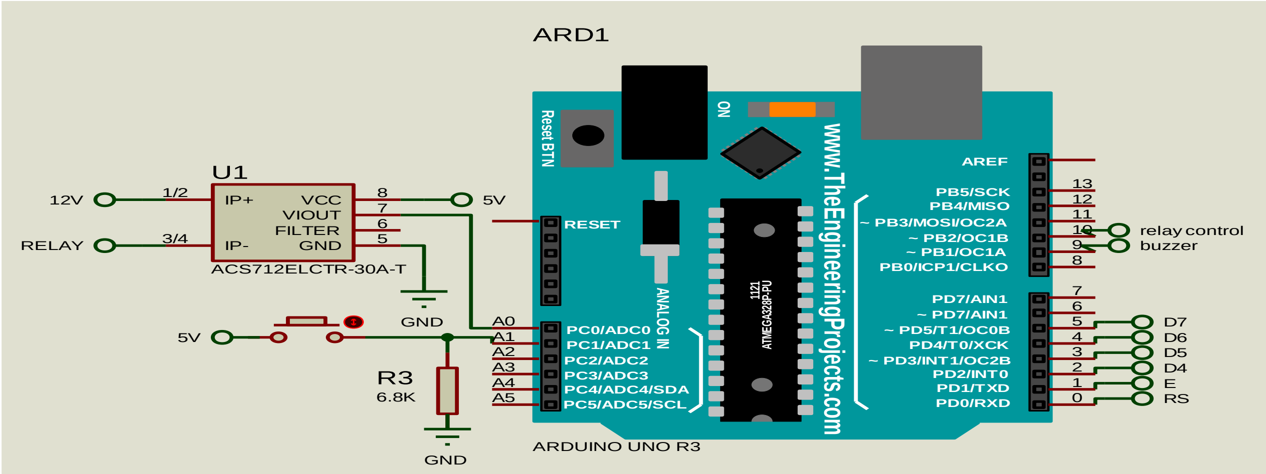

Fig. 3. Arduino UNO Microcontroller – Current Sensor

C. Isolation Unit

An electromagnetic relay has been engaged as a switch to disconnect the system from the transformer in the event an over current fault arises. The rating of the relay utilized in the prototype system is 12V, 12mA and powered from output of rectifier circuit. A resistor (1KΩ) is connected from the Arduino UNO Microcontroller to the transistor (NPN type – BD 139) and then connected to the relay as shown in Fig. 4. The Microcontroller activates the relay coil through a transistor which acts as a current amplifier.

The relay is used close-by a contactor since; the transformer employs high currents that the 12V relay cannot withstand. The relay transmits signals to the contactor which in turn disengages the circuit and detaches the system from the transformer.

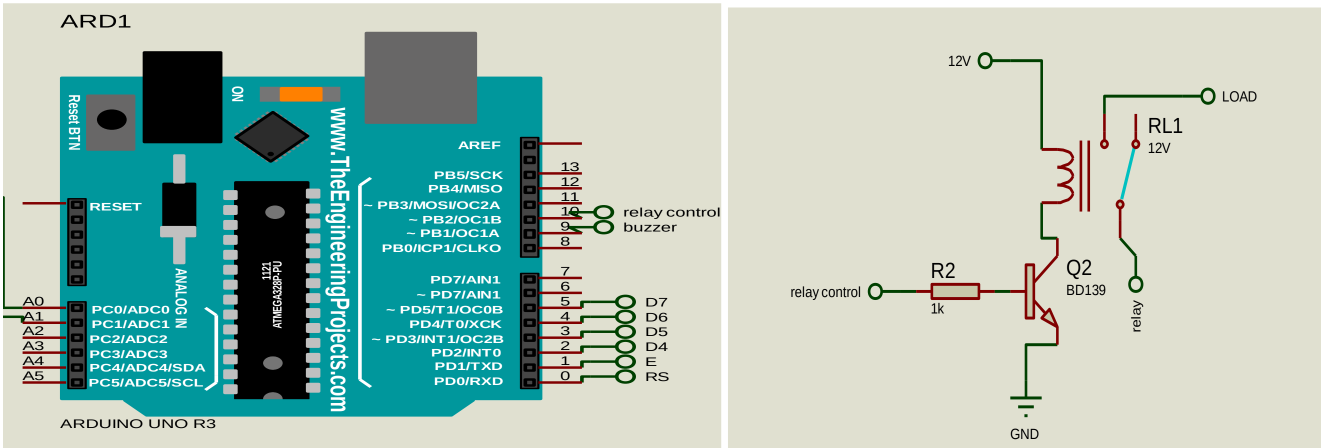

Fig. 4. Arduino UNO Microcontroller - RELAY

D. Loading Unit

The load section consists of four Car bulbs (5W, 12V each) as the loads which are connected to the relay (1.5W, 12V). The relay acts to isolates the load from the transformer if the load current is beyond the rated current (2A) of the transformer used. This is shown in Fig. 5.

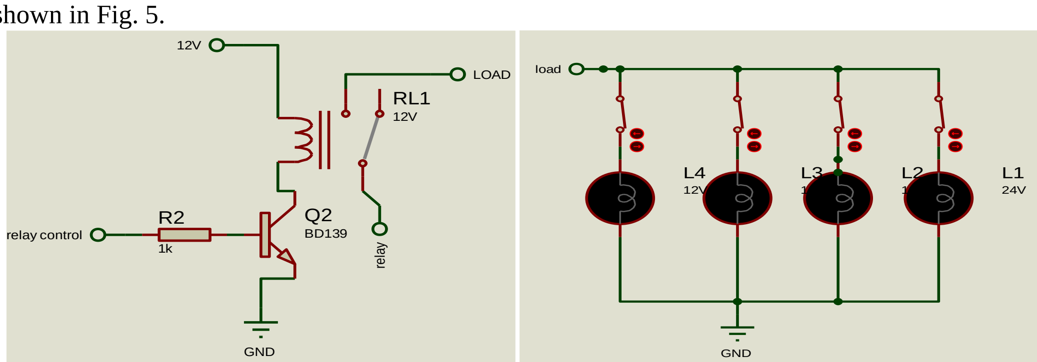

Fig. 5. Relay – Load

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E. Display Unit

The display unit composes of a Liquid Crystal Display (LCD) LM016L module powered by 5V and connected to the Microcontroller using the parallel connection protocol as shown in the circuit of Fig. 6. The logical process utilizes the readings within the 22 pins of the Arduino UNO Microcontroller and displayed on the LCD. For the LCD to light ON, it needs a current of about 20mA. In order to realize the needed current, the 220Ω resistor has been chosen after calculations.

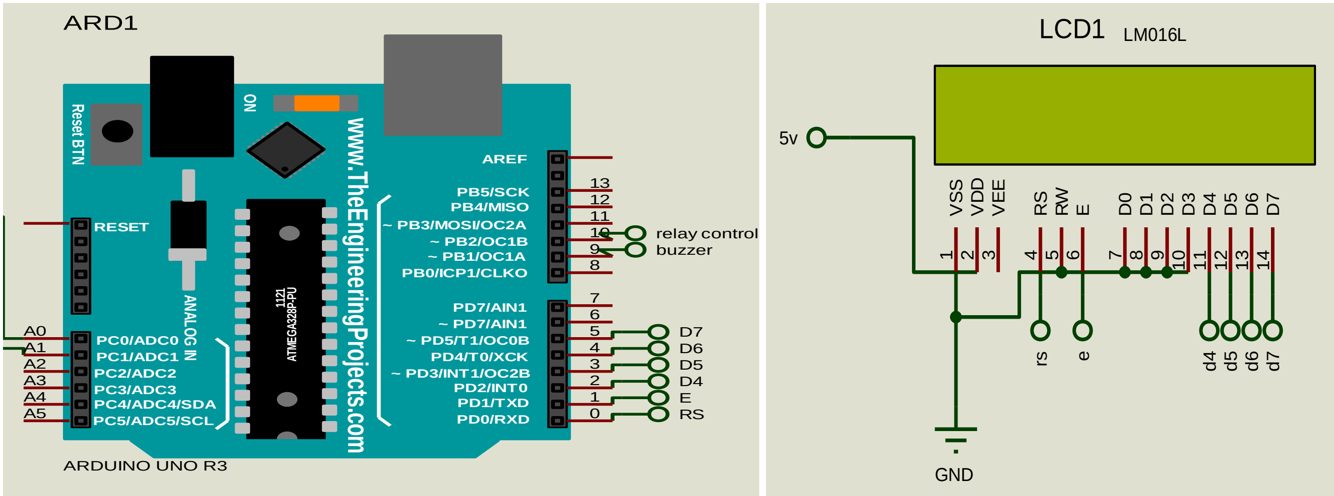

Fig. 6. Arduino UNO Microcontroller – LCD

F. Alarm System

The buzzer in this project is configured to use 12V from the power supply. It is switched ON using a BD139 NPN transistor and connected to pin PB1 of the Arduino UNO Microcontroller as shown in Fig. 7. The Microcontroller powers the transistor thus letting current move in the transistor. It happens anytime the Microcontroller pin running it is set to high. This results because an occasion of a fault current appearing in the system and is dangerous to the transformer. The piezoelectric buzzer provides audio warning to users to halt overloading the transformer or for a relief measure to be administered. It requires about 10mA of current to operate and therefore, the 1kΩ resistor was connected after calculations.

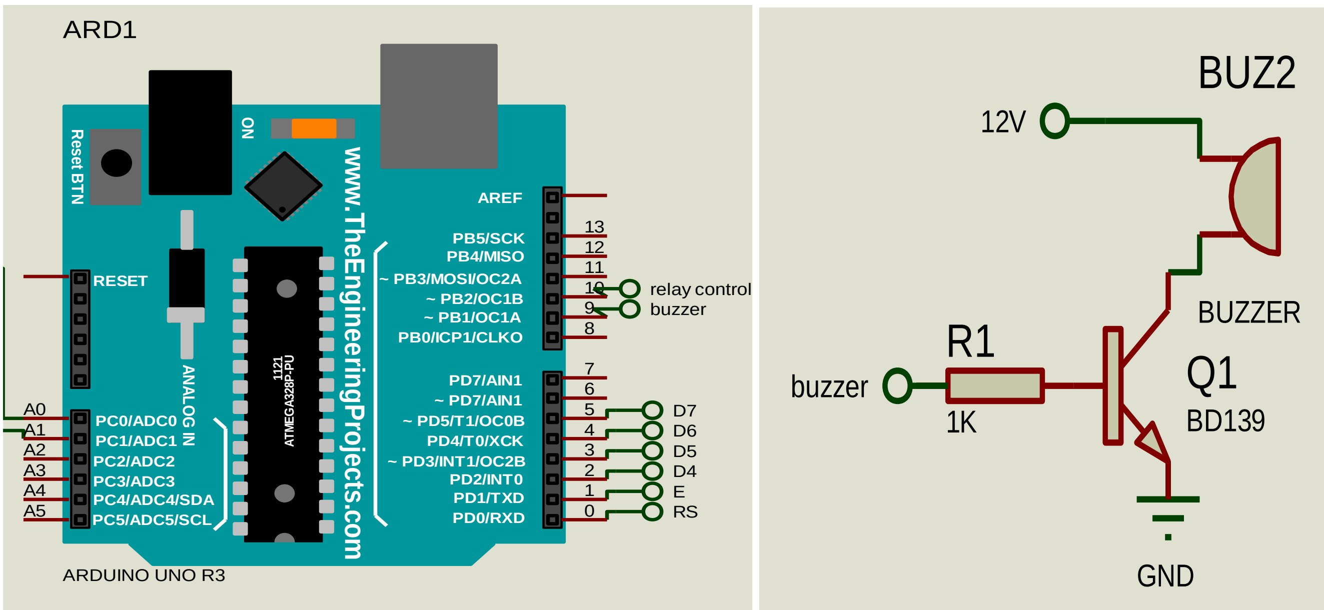

Fig. 7. Arduino UNO Microcontroller – BUZZER

Fig. 8 shows the entire circuit diagram of the transformer overload protection scheme. This comprises sub circuits in Figures 2, 3, 4, 5, 6 and 7.

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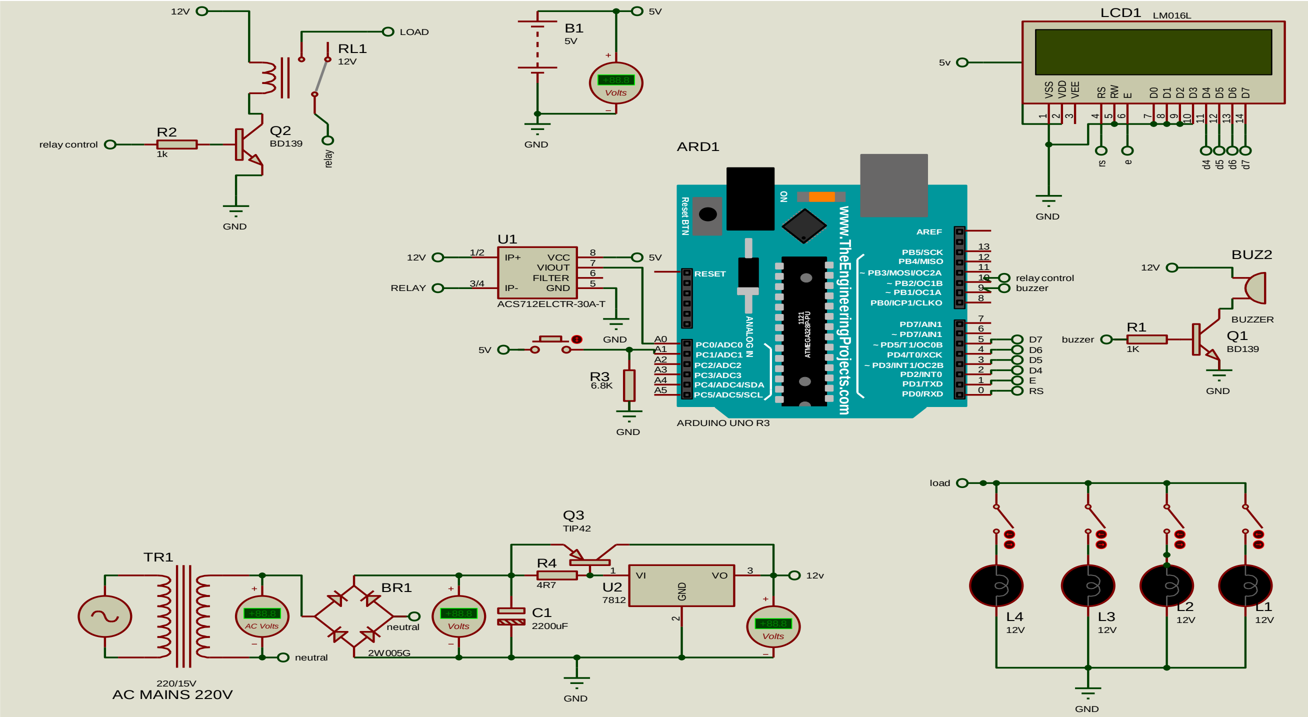

Fig. 8. Circuit Diagram of Over-current Protection of a Transformer

G. Simulations

The flow chart shown in Fig. 9 illustrates the way the work of the system is executed.

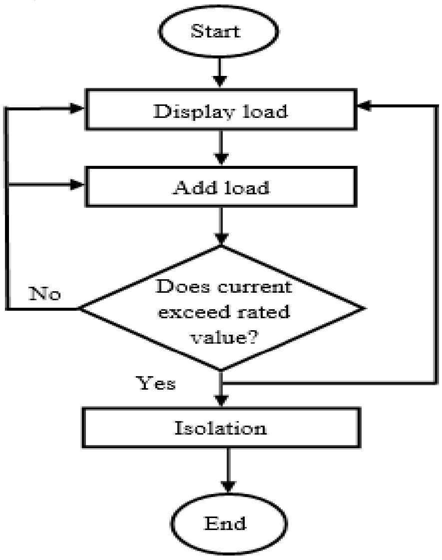

Fig. 9. Flow Chart of the Program

The design topology was simulated using the ***Proteus professional simulation center*** which is included in the **Design Suite.** Simulation of the over current protection system of the transformer shows the current reads by the current sensor which is then displayed on the LCD corresponding to the amount of current consumed by the load. When the load is increased, there is an equivalent increase in value of current consumed by the load. So when the load current outstrips the rated current of the transformer, the Microcontroller activates the relay which then isolates the load from the system and also activates the buzzer which makes an alarm alerting the user(s) of overload situation of the transformer.

III. RESULTS AND DISCUSSION

A. Test and Simulation Results

The designed system is tested by loading it. When the quantity of current flowing in the transformer exceeds the rated value, the relay is excited in order to disengage the transformer until the over current fault is cleared. The relay maintains checking routinely on condition the fault is subsisting and keeps disengaging the transformer until over current fault is cleared. The succeeding results have been acquired from simulating the design system on Proteus Software. When no load is placed on the system, then the no load current displayed as shown in Fig. 10 is 0.00A.

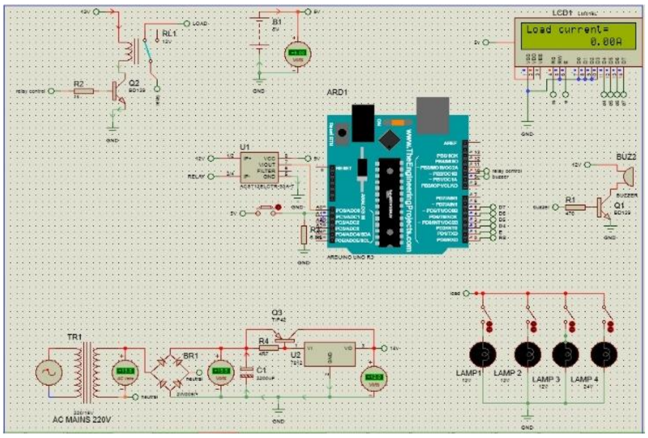

Fig. 10: State of the System at No - load

When the first load is connected, it gives a corresponding amount of current that been consumed by the Bulb. The load current been revealed on the LCD as depicted in Fig. 11 is 0.52A indicating that the first Bulb consumes a current of 0.52A.

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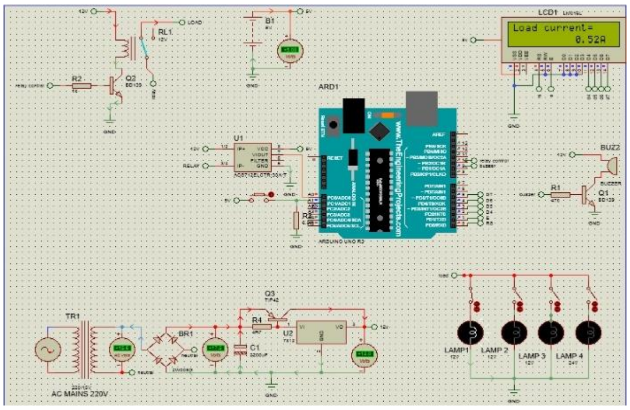

Fig. 11. State of the System for Load Current of 0.52A

When the second load is added, it gives a corresponding higher amount of current that been drawn following the addition of the Bulb. The load current been revealed on the LCD as shown in Fig. 12 is 0.96A indicating that the second Bulb increases load current to 0.96A.

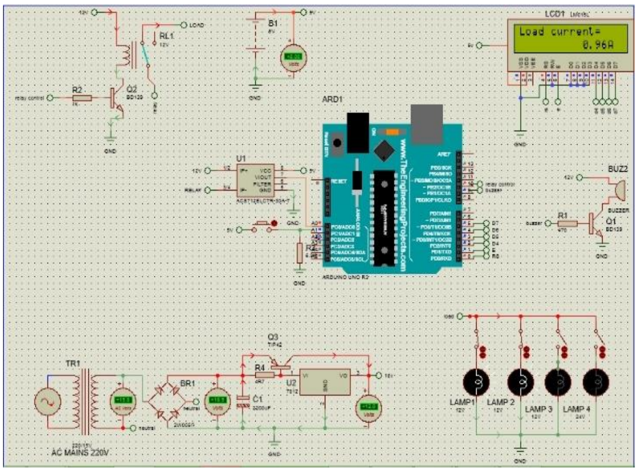

Fig. 12. State of the System for Load Current of 0.96A

When the third load is connected, it gives a corresponding higher amount of current that been consumed as a result of inclusion of the Bulb. The load current been revealed on the LCD as shown in Fig. 13 is 1.48A indicating that the third Bulb raises the current to 1.48A.

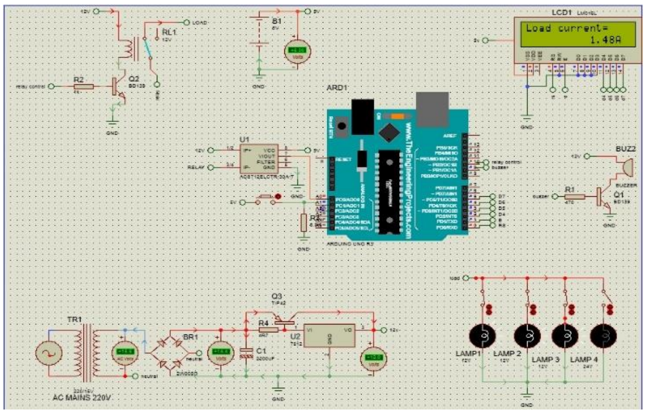

Fig. 13. State of the System for Load Current of 1.48A

Finally, it was observed that when the forth Bulb was connected; the current rose up to level of 2.22A and then the relay as well as the buzzer set off. The buzzer blows an alarm notifying the operators of the Over current fault and concurrently, relay isolates the system from transformer. The LCD shows a report of an OVERCURRENT FAULT as depicted in Fig. 14.

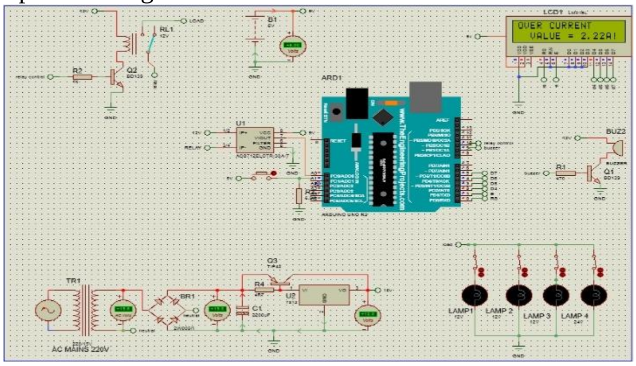

Fig. 14. State of the Relay, LCD at OVER CURRENT FAULT

B. Experimental Results

The Fig. 15 and Fig. 16 show the practical experimentations of the circuit to validate the results obtained during simulations. The current reading on the LCD increases with the increasing load addition up to the preset value point. The experimental performance as depicted closely relates with the simulation. Fig. 15 shows the situation of the system on no load while that of overload is in Fig. 16.

Fig. 15. Picture of the Implemented System at No-load

Fig. 16. Picture of the Implemented System with Load 4 showing the Over-current Value

The system shown in the Fig. 16 indicates the LCD display of OVER CURRENT, meaning that the current circulating in the transformer exceeds the rated value. At this time, the buzzer is activated to notify the system operator of the fault occurrence in the particular transformer. A signal is also directed to the relay to isolate the load from the transformer. A comparison of the results obtained from simulations and those of the experiment is shown in Table I.

Table- I: Comparison of the Simulation and Experimental Results

No. of connected loads	Simulated load current (Amp)	Experimental load current (Amp)	State of relay	State of buzzer
None	0.00	0.08	OFF	OFF
1	0.52	0.62	OFF	OFF
2	0.96	0.99	OFF	OFF
3	1.48	1.43	OFF	OFF
4	2.22 (OC)	2.28 (OC)	ON	ON

OC = Over Current

C. Discussion

It was noted that as the load increases, the current flowing in the transformer also rises. This is portrayed in the Table 1 and an increment in the sensor output voltage prompted a comparable rise in the current value presented on the LCD. The plot in Fig. 17 shows the trend of current on loading the system.

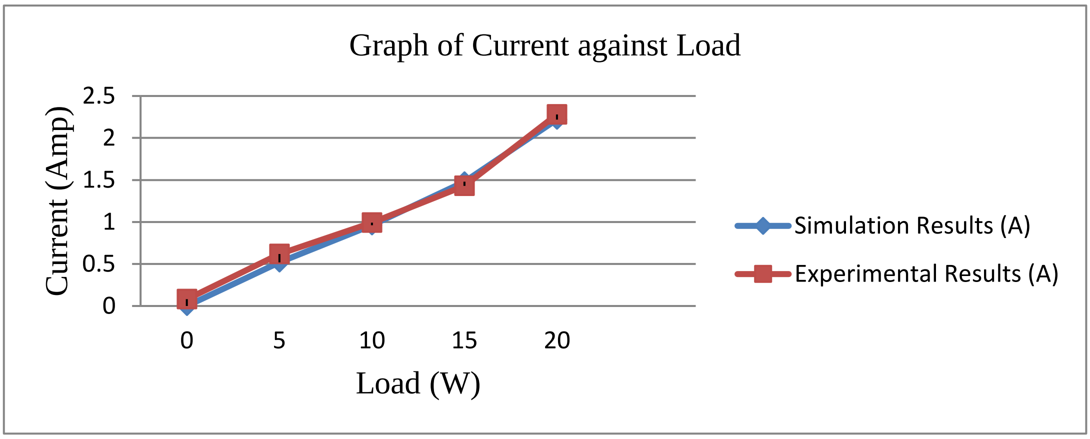

Fig. 17. Graph of Currents against Connected Loads

As the load increases, the current increases and is displayed on LCD to a certain extent where the relay trips and isolates the transformer. This attests that the system can perform the function for which it is designed.

From the results, the system accomplishes the task of automatic detection over current fault and uses an Arduino UNO Microcontroller to record the load current and detach the transformer from the affected zone. The alarm reports the fault incident to the system operator. The superiority of this system above analogue over current relay is that it immediately recloses just after the fault is cleared. The measure of precision of the system is also marvelous in contrast to analogue operated over-current relay. Delay of 5 seconds was used to allow the inrush experience to clear in order that the transformer returns to normal operation before the relay could function.

IV. CONCLUSIONS

In this paper, a new designed topology of sustainable overload protection of distribution transformer has been implemented and presented. The relay is the main switching component in the system. When electrified, it opens its contacts and deactivates the contactor thus cut off the system from overloading the transformer to safety. The other marginal accessories make up media of delivering cautioning notes should an over current fault crops up.

The cost of executing the system is somewhat economical as the elements utilized are handful and sourced in local market. This makes the overall project cost effective. Generally, findings reveal a means for modesty and veracity of the fad design topology to use handy and soon accessible constituents and substances to build the invention. In comparison to variant arrangements in literature, this topology here was able to incorporate an alarm complement together with display element to immediately create awareness. This makes it better than the existing analogue design.

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