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DESIGN AND FABRICATION OF A MICROCONTROLLER-BASED OVERCURRENT DETECTION SYSTEM

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Abstract

This paper aims to design and construct a modular automatic overcurrent detection system based on a microcontroller, relay, and other peripheral devices to detect overcurrent fault within an electrical circuit and protect the load. Electrical systems are at the risk of experiencing an overcurrent and need to be protected. Traditional protection devices are slow and require human intervention to reclose the circuit. Thus, a microcontroller-based overcurrent system offers proper fault detection methods and fast tripping times with better performance. The system comprises a current sensor (ACS755), 16 by 2 liquid crystal display (LCD), a suitable microcontroller (ATMEGA 328P), and a switching device (RELAYs) interfaced with sink drivers (ULN2804 IC). The setup of the system was tested with three independent appliances for eight trials. Five out of the eight trials gave a normal working condition for all the loads while the remaining had overcurrent faults. Trial 6 gave one fault for one out of the three loads while Trial 7 gave two fault conditions for two of the loads and Trial 8 had all three faults. The faults were all overcurrent faults and had a timely response from the system. In addition, the circuit automatically closes when the fault is cleared.

Keywords

Overcurrent sensor, Overcurrent Detection device, Overcurrent protection device, Microcontroller-based, ATMEGA328P, Remote Monitoring

Article History

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1. Introduction

A proper operating circuit has the current confined to a safe level. This safe level of current is when the current in a circuit is equal to or less than the normal current level however, at times an electrical circuit may have a higher-than-normal current flow (overcurrent). An overcurrent is a condition that exists in an electrical circuit when the normal load current is exceeded. This condition can be caused by a short circuit, overload situation or ground fault.

An overcurrent protection device (OCPD) is a piece of equipment used to protect electrical systems that are at risk of experiencing overcurrent. In overcurrent situations, an OCPD will re-route or disable current flow through the system to make it safe. The most common of these protection devices are fuses, circuit breakers, and overcurrent relays. The right approach to circuit protection can drastically improve the reliability of a product or design. Unfortunately, not all circuit protection comes in the form of hardware like fuses and transient voltage suppression. Some forms of circuit protection can come from software, and this can create confusion. Hence this study will explore how microcontrollers can play a role in circuit protection. The Distribution Board has circuit breakers which are protection devices used for connecting, protecting and controlling multiple branches of electrical circuits fed from a single primary circuit of wiring installation in a building. They were used to protect devices by allowing individual circuits to draw power from correctly rated breakers. The first generation of distribution boards included several fuses for protecting individual circuits. However, to re-establish the connection, the fuses must be replaced once it is blown. With the advent of circuit breakers, resettable distribution boards with higher load-bearing capabilities were available but again they require human intervention to resume normal operation after a fault condition is cleared. To overcome these limitations, an electronic circuit breaker was proposed. An electronic circuit breaker uses electromagnetic devices to operate when a load current exceeds a pre-set value. Electromagnetic relay (EMR) technology has resulted in circuit breakers that are free from arching and switch bounce, with correspondingly higher reliability and longer lifetime as well as faster switching times. A typical EMR circuit breaker is capable of switching off a faulty line in a matter of microseconds. The work is based on an electronic circuit breaker in which solid-state relays are used as functional replacements for electromechanical relays to provide fast overload protection. The control system of this study consists of an ATMEGA328 microcontroller kit to act smartly and control the systems according to the output of the current sensor. The system would monitor three independent load points in the system for overcurrent. One research in single-fault detection system is an IoT system proposed by Kanchan (2020) and another by Kumar et al. (2015) who fabricated a microcontroller-based online fault detection system to protect overvoltage, overcurrent and Undervoltage faults, while Hameed, et al (2020) designed an overcurrent protection relay using Arduino NANO as a microcontroller, ACS712 current sensor module, solid-state relay, resistor and buttons. These researches have shown the implementation of a detection system of single-fault and overcurrent protection systems that employ Arduino microcontroller. However, Reddy and Vennula (2019) designed a microcontroller-based intelligent protection scheme for heavy DC and AC single and three-phase appliances using the ATMEGA2560 microcontroller. The protection system was designed for safeguarding heavy industrial equipment against all possible faults. The industrial load was a three-phase inductive and resistive load. Also, a microcontroller-based power transformer overload protection system was proposed by Isah, et al. (2020). It had the communication capacity to notify the utility staff in case of abnormalities caused by overloading. The protection system consists of a GSM Module, voltage sensor, buzzer, relay and an ATMEGA328P microcontroller. The system was designed for the continuous faults developed by power system components particularly, power transformers. In a paper by Mafia and Bentabet (2019), a smart RCBO (Residual current circuit breaker with overcurrent protection) device was proposed that mainly comprises ATMEGA microcontroller at the heart of the system, with 2 current sensors and solid-state relays. The system allows for integration with a smart home to provide more convenience for its users.

Thus, this study aims to design and construct a modular automatic overcurrent detection microcontroller-based system to detect overcurrent and protect commonly used appliances in the home. Employing current sensors over current and voltage transformers as used in Kumar et al (2015) offer better performance due to thermal isolation which averts the negative impact of the ambient temperature on performance (Mafia and Bentabet 2019). Hence, the overcurrent fault will be detected through the measure of the magnitude of current flowing through an electrical circuit with current sensors, compare the measured current to the rated current for the circuit and thus trigger the relays to isolate the circuit from the mains which will also be displayed to alert the user.

2. Materials and Method

The system consists of five major parts: the power supply unit, a current sensing unit, a control unit, a display unit, and a switching unit. The block diagram of the system is given in Figure 1.

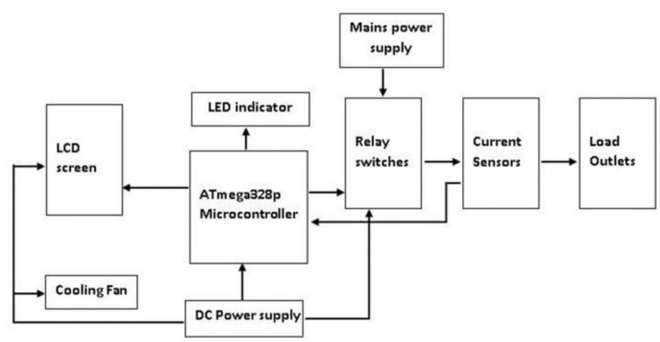

Figure 1 Block diagram of the Overload detection system

The system interfaces the AC mains and the loading outlet through relays and current sensors automated by the ATMEGA328P microcontroller powered by a DC power supply. As faults can linger, it is important to notify the user about the type of overcurrent fault—short circuit, ground or overload fault. A residual microcontroller-based overcurrent detection and protection device should include a display unit for a better user experience. Primarily, this work improves on the smart RCBO architecture on a single-phase fault. The five major parts of the system cover the entire architecture of the system and are discussed as follows:

Power supply unit

All stages in the system require +5volts DC, therefore, the system has to provide a linear power supply that consists of a 220V to 9V step down centre-tap transformer, a bridge rectifier, filtering capacitor and a positive 5volt voltage regulator. The power supply circuit is shown in Figure 2.

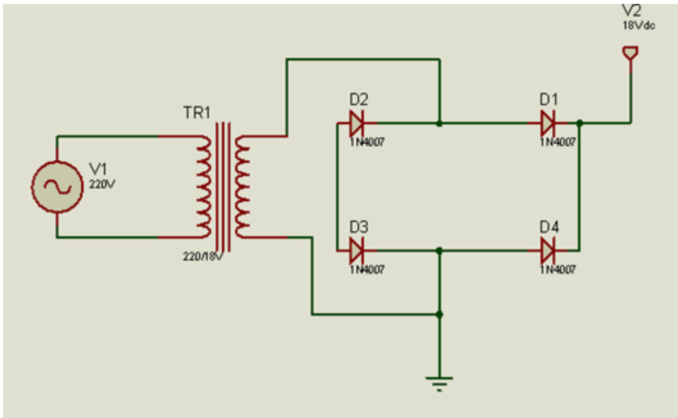

Figure 2 Power Supply Circuit

The calculations for the design of the DC power supply unit start at the transformer. Recall that the voltage transformation ratio is given by the formulae

$$\frac{V_{T2}}{V_{T1}} = \frac{N_2}{N_1} = \frac{I_2}{I_1} = K \qquad (1)$$

Were,

V_{T2} is the secondary side terminal voltage

V_{T1} is the primary side terminal voltage

N_1 is the number of turns in the primary side

N_2 is the number of turns in the secondary side

K is a constant known as voltage transformation ratio

For a step-down transformer, $N_2 < N_1$ i.e., K<1. The transformer would convert an AC main of 220V and produce an 18V voltage (centre-tap) thus;

Input voltage V_1 = 220V, output voltage V_2 = 18V and operating frequency = 50Hz. Therefore, the transformation ratio is given as from Equation (1).

$$\frac{V_{T2}}{V_{T1}} = \frac{18}{220} = 0.081 = 12:1.$$

The next stage of the process is rectification, the input voltage to the rectifier = 18V RMS

Peak input voltage = $18 \times 1.414 = 25.5V$

Maximum current through the rectifier (load current) = 300mA.

A suitable diode should satisfy the maximum input voltage of 25.5V and current of 0.3A. The 1N4001 diode which has a peak reverse voltage of 50V and maximum current conduction of 1A was chosen.

As a general rule of thumb, the ripple voltage should be no more than 100mV peak to peak. The bridge rectifier ripple voltage is given as:

$$V = \frac{I(Load)}{f \times c} \qquad (2)$$

Where I is the DC load current in amperes.

F is the frequency of the ripple or twice the input frequency in Hertz.

C is the capacitance in Farads.

The capacitance can be calculated from Equation (2) assuming 100mV ripple voltage at a load current of 300mA and frequency of 100Hz;

$$C = \frac{300 \times 10^{-3}}{100 \times 10^{-3} \times 100}$$

It can be seen that the value of the capacitor is so large due to the low ripple percentage needed. A high enough capacitance with a reasonable ripple is a $470\mu F$ capacitor. The voltage regulator used after the capacitor will therefore ensure a smooth output DC voltage.

The microcontroller, LCD, relay, temperature sensor, and menu buttons of the system all require 5V for operation. The LM7805 voltage regulator was chosen since its output is 5V for an input voltage ranging from 8V to 35V.

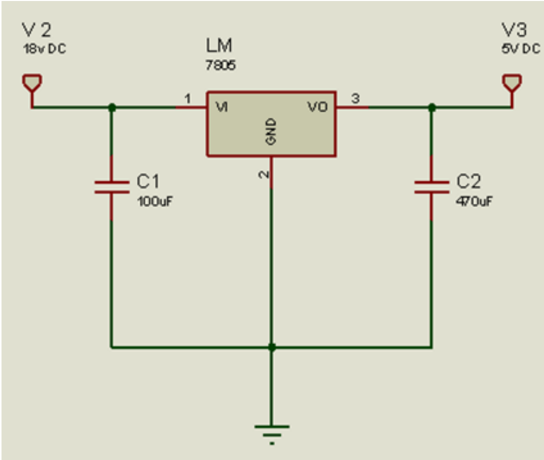

Figure 3 Voltage regulator circuit

The values of the capacitors used in both the input and output of the regulator are standard values from the datasheet of the regulator.

Current sensing unit

To sense the current from the AC mains a current sensing device is needed. The study uses the ACS755 current sensor. It is typically applied in load detection and management, power supplies, and overcurrent fault protection.

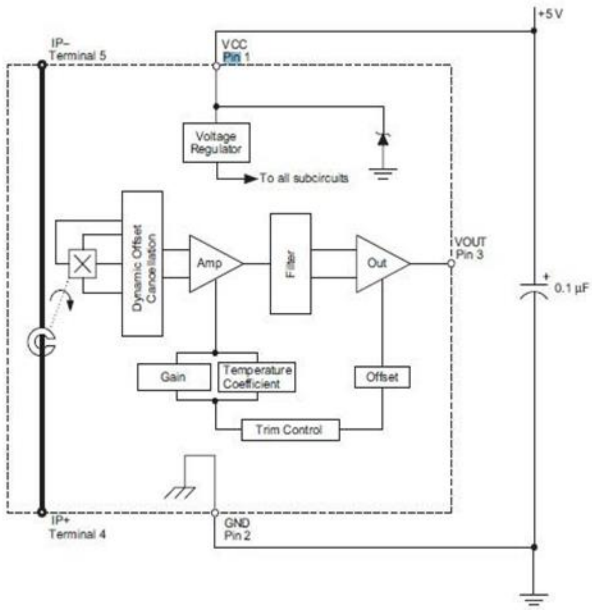

Figure 4: Functional block diagram of ACS755 current sensor

Control unit

The controlling unit is made up of the ATMEGA328P microcontroller which processes the output of the current sensor and performs required actions. It controls the overall operation of the system. To design a device controlled by a microcontroller, it is necessary to have computer software used for compiling the control program (code), and also a device (programmer) for transferring the code from the PC to the microcontroller. Even though this process is quite logical, there are often some queries, not because it is complicated, but for numerous variations. When the microcontroller runs, it does so with a clocking signal which is provided by a crystal oscillator. Figure 4 shows the connection of the crystal oscillator to the microcontroller to produce an electric signal at a constant frequency.

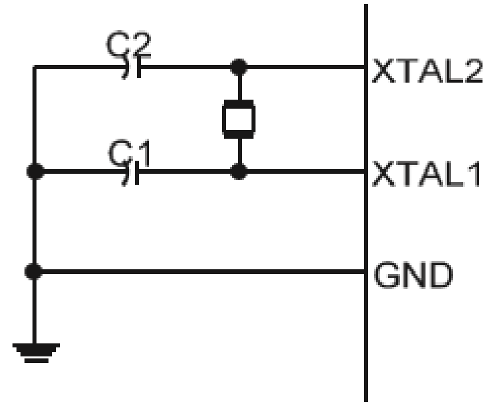

Figure 5 Crystal oscillator connection to ATMEGA328P

The values of capacitors C1 and C2 are equal and it is recommended to be in the range of 12-22 pico Farad.

Control flow code

An important objective of the proposed microcontroller-based overcurrent detection and protection system is to reconnect the electrical circuit after fault disappears. The program of the microcontroller was written in C Language. When using custom software, numerous tools are also installed to aid in the development process. One such tool is the Simulator. This enables the user to simulate/test the code before burning it to the MCU. The simulator used in this project design is the Proteus simulation software. After code development, the program is translated to machine code (HEX code). The machine code is then compiled and simulated for error checking to ensure that all functions and parameters are performing the correct tasks. The compiler used in this design was the Atmel Studio which allows for program development in C language for a variety of AVR microcontrollers. To transfer the "hex code" from the computer to the microcontroller, a cable and a special device called a "programmer" are used with the appropriate software. In this design, the USBasp which is a USB cable and a Programmer were used to load the code through the software 'PROGISP'.

Figure 4 is the flowchart of the control code for the microcontroller.

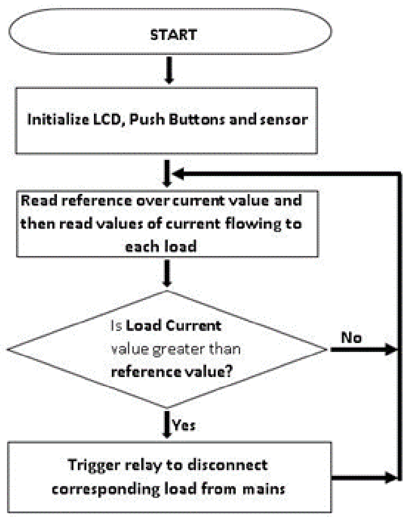

Figure 6: Flow chart

When the system is powered on, the microcontroller initializes the necessary registers and creates variables that would be used when the system is running. It initializes the LCD to ensure communication in the connected mode. When all of the initialization and setups are done, the controller will then begin to read the load current values of each of the outlets and display them on the LCD. While the load current on the outlets is below the maximum value of current before overload/overcurrent occurs, the green LED will be switched on to indicate the normal operation of the system. However, in a situation where the load current on any or all of the power outlets is greater than the reference value, the controller trips the relay and isolates the load then it displays an 'Overcurrent Fault' warning message on the LCD screen to inform the operator and the Red LED indicator is illuminated.

Liquid Crystal Display (LCD) unit

The LCD is the display unit of the system. It is used to display alphanumeric characters. In the study, a 16×2 LCD was used and it has 16 pins. The mode of operation determines the number of pins connected to the microcontroller. The system used a 4-bit mode connection as shown in Figure 5.

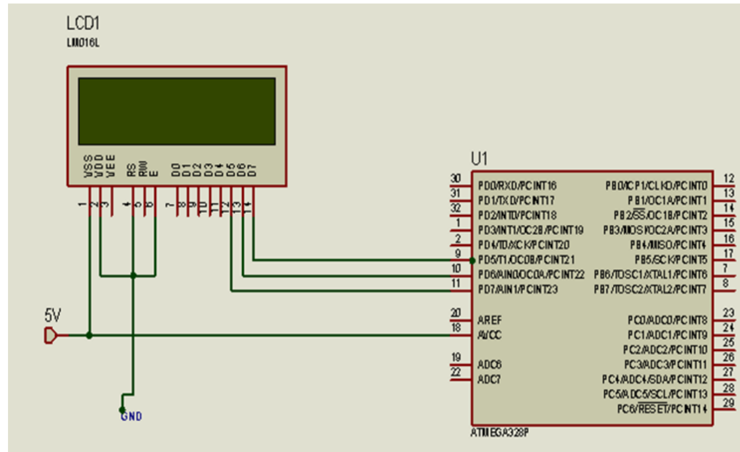

Figure 7: LCD interfaced with ATmega16

Switching circuit

The switching circuit is made of relays which are used to turn off the load unit in the case of an overload. Three relays (JQC3F-05VDC relays) were used to switch on or off the load and they were driven by a Darlington transistor, ULN2804 IC individually. The coil power of 0.45W from the datasheet of the relay and equation (4) shows the relationship between the coil power (P_c), the coil voltage (V_c), and the coil current (I_c) and the coil current is given as;

$$P_c = I_c \times V_c \qquad (4)$$

An important component in the switching circuit is the transistor which is connected between the microcontroller pin and the relay coil. The current that will flow through the transistor used for switching the relay is the same as the coil current and can be calculated from equation (4) at a coil voltage of 5V;

$$I_c = \frac{0.45}{5} = 0.09A = 90mA$$

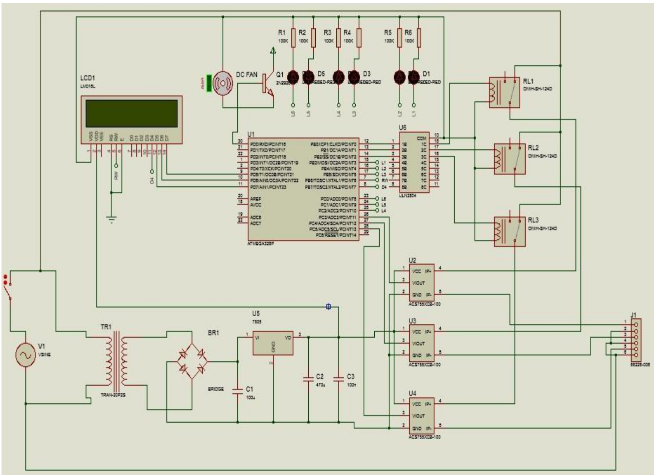

Figure 8 Complete circuit diagram of the overload detection system

As seen in the complete circuit diagram, PORT A and B of the microcontroller interfaces with the LEDs, the relays and current sensors. It also shows the power supply unit and display unit. The three current sensors and relays allows for the protection of three loads which are connected to the junction, J1.

Table 1 is the bill of engineering material used for this research showing the components, number of units and the price of each unit. The total price of the project is also included.

Table 1: Bill of Engineering

S/N	COMPONENT	UNITS	PRICE/UNIT (₦)	TOTAL AMOUNT (₦)
1	220V to12V Transformer	1	1500	1500
2	LM7805 Voltage regulator	1	500	300
3	16 X 2 LCD	1	2000	2000
4	Header pins	2	150	300
5	12MHz Crystal oscillator	1	100	100
6	ATmega328p Microcontroller	1	1000	1000
7	28 Pins IC socket	1	150	150
8	current sensor (ACS755)	1	1000	1000
9	Resistors ($47k\Omega, 150\Omega, 10k\Omega$)	6	30	180
10	Capacitor ($22pF, 10\mu F, 470\mu F$)	6	50	300
11	Diodes(1N4001)	9	50	450
12	Push Buttons	4	40	160
13	ULN2804	1	200	200
14	Relays Module	3	400	1200
15	Vero Board	1	200	200
16	Casing	1	600	600
17	Soldering Iron	1	1500	1500
18	USBasp programmer	1	1200	1200
19	Soldering Lead	1	400	400
20	DC fan	1	500	500
21	Miscellaneous		2000	2000
	TOTAL			₦15,240

3. Results and Discussion

After designing and testing the system it was discovered that the device protected the load against overcurrent using a microcontroller-based overcurrent relay using a current sensor, relays, and a liquid crystal display. Table 2 shows the test result of 8 trial tests to measure the performance of the microcontroller-based overcurrent relay.

Table 1 Test results

Trials	Resistance(Ω) (R1, R2, R3)	Display on LCD Current(A)	State of Relay 1	State of Relay 2	State of Relay 3	LED state L1, L2, L3	System state displayed
1	440,660,880	I_1=0.5, I_2=0.33, I_3=0.25	OFF	OFF	OFF	Green, Green, Green	
2	220,330,400	I_1=1.0, I_2=0.660, I_3=0.55	OFF	OFF	OFF	Green, Green, Green	
3	110,150,200	I_1=2.0, I_2=1.46, I_3=1.1	OFF	OFF	OFF	Green, Green, Green	
4	55,80,100	I_1=4.0, I_2=2.75, I_3=2.2	OFF	OFF	OFF	Green, Green, Green	
5	25,40,50	I_1=8.8, I_2=5.5, I_3=4.4	OFF	OFF	OFF	Green, Green Green	
6	12,20,25	I_1=18.3, I_2=11.0, I_3=8.8	ON	OFF	OFF	Red, Green, Green	Fault
7	12,10,20	I_1=18.3, I_2=22.0, I_3=11.0	ON	ON	OFF	Red, Red, Green	Fault
8	12,10,10	I_1=18.3, I_2=22.0, I_3=22.0	ON	ON	ON	Red, Red, Red	Fault

Calculated current for the eight trials assuming 220Volts is given from Ohms law;

$$I = \frac{V}{R} \qquad (5)$$

The results of currents for the eight trials are given in Table 3.

Table 2: Current values for the eight trials flowing through the loads

Trials	I_1	I_2	I_3
1	0.5A	0.33A	0.25A
2	1.0A	0.66A	0.55A
3	2.0A	1.46A	1.10A
4	4.0A	2.75A	2.20A
5	8.80A	5.50A	4.40A
6	18.3A	11.0A	8.80A
7	18.3A	22.0A	11.0A
8	18.3A	22.0A	22.0A

For trial 1 using equation 5:

$$I_1 = \frac{220}{440} = 0.5A$$

$$I_2 = \frac{220}{660} = 0.33A$$

$$I_3 = \frac{220}{880} = 0.25A$$

Figures 9 and 10 are the relay module and current sensors circuit soldered onto the Veroboard. The complete system is shown in Figure 11 in a plastic enclosure.

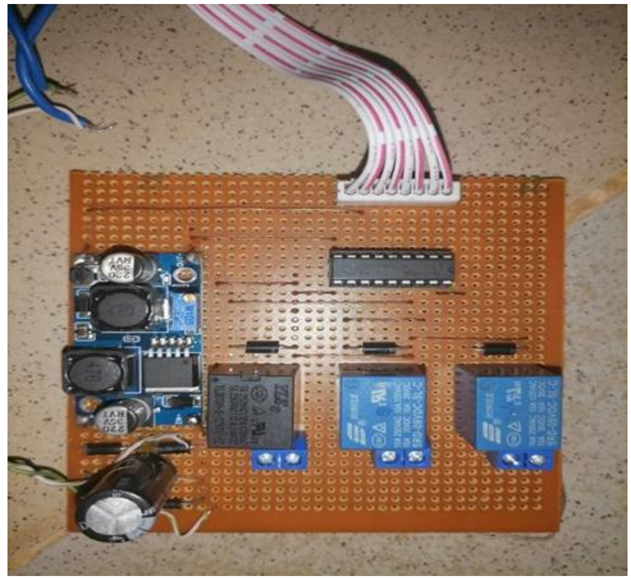

Figure 9 Relay Module

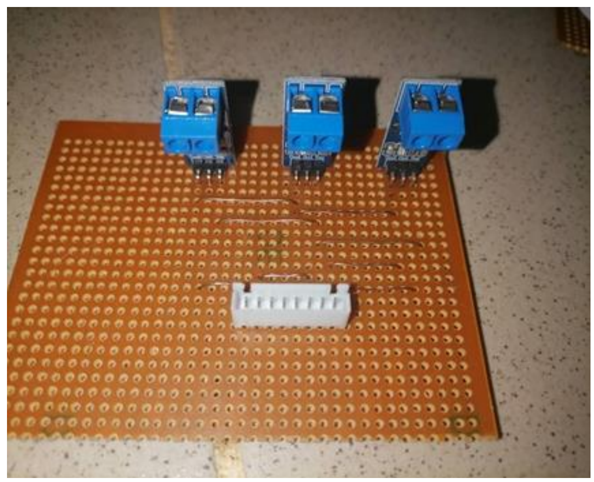

Figure 10 Current sensors

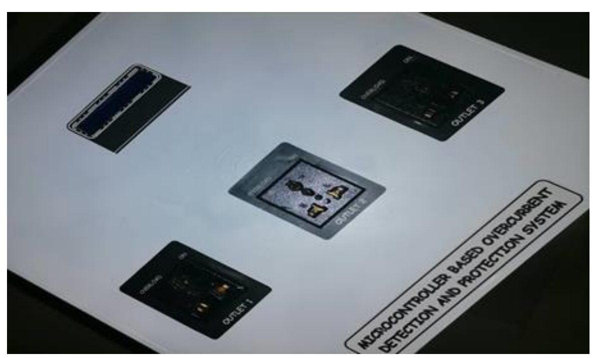

Figure 11 Complete system design

The developed system was observed to achieve the function of an overcurrent relay that automatically detects overcurrent fault and uses the microcontroller to record the fault, isolate the load in the affected zone and report the fault occurrence so that the system operator. Thereafter the overcurrent relay closes the circuit once the fault is cleared. Particularly, when the circuit is closed, there is an in-rush current and this was taken care of in the proposed system through a delay of $255\mu s \times 4$. This delay allows the inrush phenomenon to clear so that the loads come back to normal operation before the relay starts its work. On powering on the system and testing, it was observed that when the current drawn by the load is beyond the maximum allowed current of 11.5A and as the microcontroller switched the appropriate relay to disconnect the corresponding load from the power source. This was possible as a result of the feedback formed by the current sensor to the controller, enabling it to process the current values and then send out the appropriate command signal to the relay unit. Finally, it was observed that when the current was varied up to the pre-set level, of 11.5A, the relay, and the red LED were triggered. The relay isolated the corresponding load from the system, and the red LED blinked to signify that the current level was too much for the load. The LCD displayed the notification when there was a fault. As a residual protection system, implementation with a smart home is noteworthy to improve the experience for residents. This study considered a simpler model to show the relevance of a display unit in the implementation to help the operator address the overcurrent fault. Thus, a more sophisticated design should clearly implement a display to alert users and the use cases with a smart system implementation can extend on.

4. Conclusion

The study successfully designed and implemented a system that uses a microcontroller to detect an overcurrent fault and thus acts to protect the appliances. The experimental setup was successful at prototyping the real-life electrical systems when an overcurrent fault. This was done with eight tests (trials) on three different loads. The electrical circuit was closed whenever the current was below the pre-set value (11.5A) and was opened (trigger to the relay) when the current exceeded the threshold. In addition, the overcurrent fault message was visible from the display unit and the indicator was lit when there was a fault. Such a system offers better performance than the conventional protection due to thermal isolation among the components of the system which therefore mitigates the adverse effects of temperature on accuracy of current values. The system can be used in AC and DC electrical systems. It can also automatically disconnect and reconnect any electrical circuit to provide convenience for users.

5. Acknowledgement

The authors wish to acknowledge the assistance and contributions of the project students of the Department of Electrical/Electronic Engineering, University of Benin, Benin City toward the success of this work.

6. Conflict of Interest

There is no conflict of interest associated with this work.

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