Smart Residual Current Circuit Breaker with Overcurrent Protection

(Smart RCBO)

By

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Abstract

The protection of users and electrical appliances against the risks of electricity is a major concern. Leakage, overload and short-circuit currents are common types of faulty currents that cause destructive impacts on the users as well as electrical devices. They may cause electrocution or can be the sources of fire. To prevent the effects of faulty currents, conventional electrical protection devices are widely used in electrical systems. Some conventional electrical protection devices do not have proper fault detection methods and fast tripping times.

We present in this study a smart residual current circuit breaker with overcurrent protection (smart RCBO) that is a digital device to protect users and electrical devices against electrical faults. The purpose of this project is to computerize the fault detection of traditional RCBOs based on a microcontroller. This device is fully automated and has adjustable settings to ensure safety while allowing increased flexibility to better match users' needs.

The smart RCBO can be integrated into any smart home to provide more convenience for users. The smart RCBO overcomes the disadvantages of conventional RCBOs and improves their performance. The smart RCBO represents the application of computer science in electrical engineering.

Acknowledgments

I dedicate this study to:

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Notations

A	Ampere
V	Volt
s	Second
ms	Millisecond
mA	Milliampere
AC	Alternating current
DC	Direct current
LC	Leakage current
OL	Overload
SC	Short-circuit
°C	Degree celsius
NO	Normally open
NC	Normally closed
Hz	Hertz
MHz	Mega hertz
ADC	Analog to digital converter
IDE	Integrated development environment
MCB	Miniature circuit breaker
RCD	Residual current device
RCBO	Residual current circuit breaker with overcurrent protection
SRAM	Static random access memory

EEPROM	Electrically erasable programmable read-only memory

Chapter 1

Introduction

1.1 Electrical faults

Human protection against electrical faults is the main concern in electrical systems. Consumption of electricity increases the risk of faulty currents and poses potential dangers for users and electrical devices. Electrocution and electrical fire are common effects of faulty currents. Leakage current, overload, and short-circuit are the main types of faulty currents. The leakage current may lead to an electrical shock in the human body and can harm organs. Meanwhile, the overload and short-circuit currents can cause a fire in electrical circuits.

Under normal conditions, the amount of current on the phase equals the amount of current on the null. The problem arises when the amount of current on the null is less than its amount on the phase. The difference between the phase and null currents constitutes the leakage current. The leakage current can pass inside conductive materials or on the surface of the non-conductive materials. To prevent the transmission of leakage current, the earth wire is used to lead the leakage current to the ground system.

Another technical problem may arise if the earth wire becomes damaged and cannot pass the leakage current. The resistance of the earth wire is normally very low to allow passing the leakage current, but when it is damaged, the current will find another way to go through. Figure 1.1 [1] shows the reactions of the human body to leakage current.

As indicated in this figure, any level of the leakage current may cause serious health issues for users. The problem is that most leakage protection devices have a detection time delay. In general, an increased faulty current must cause a decrease in the tripping time of protection devices to prevent the risk of injury.

As shown in figure 1.1, area AC-1 is the safety margin. No serious health issue threatens users at the maximum current of 0.5 mA. However, area AC-2 bears some health issues. In this case, 30 mA is the threshold current in which the average human body can resist for about 200 ms before experiencing any difficulty in breathing. AC-3 and AC-4 areas have the most dangerous impacts on the human body. For example, any current over 500 mA increases the chance of ventricular fibrillation.

Overload and short-circuit are other types of faulty currents that cause overcurrent faults. They have destructive impacts on wires and electrical appliances. Overload current is an

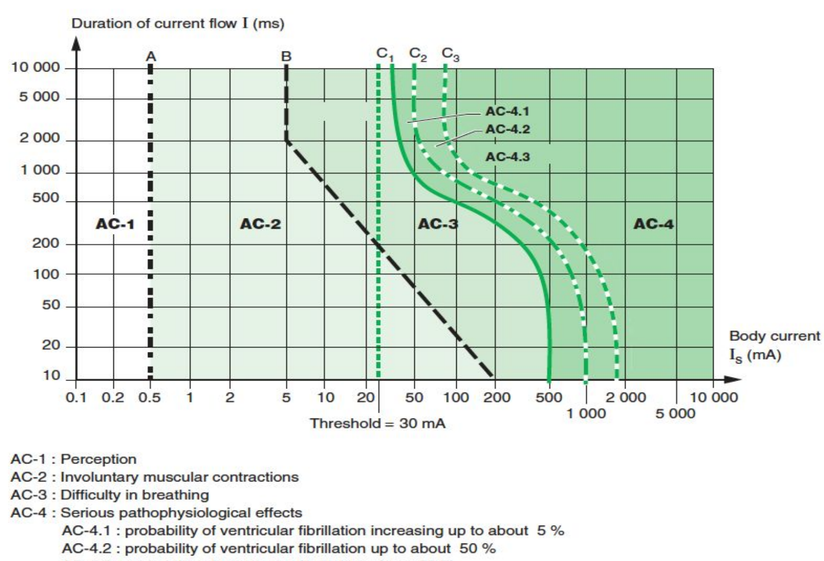


Figure 1.1: Time - current zones for effects of AC current [1]

excessive amount of current that passes through electrical circuits when large numbers of electrical loads are connected to the electrical circuit. In this case, the amount of current that passes through wires exceeds the standard level. The overload current produces extra heating that damages the insulation of wires and may cause an electrical fire. The amount of overload current varies from 1.36 to 6 times the nominal current of the electrical circuit [2].

Short-circuit current occurs under specific conditions when there is a short connection between phase and null wires. This means that the current finds a short way to bypass the electrical loads. The amount of short-circuit current is orders of magnitude higher than the nominal current and can cause critical damages in electrical circuits. Table 1.1 represents a simple comparison between overload and short-circuit faults [3].

The short-circuit current can produce extreme heating that can damage the insulation of electrical devices and cause an electrical fire. According to the US Fire Administration (USFA), 24000 electrical fire accidents were reported between 2014 and 2016 [4].

Comparison	Short-Circuit	Overload
Voltage	Zero	Low voltage
Current	High	High
Occur	Phase and null connection	Large number of devices

Table 1.1: Comparison between the overload and short-circuit faults [3]

1.2 Electrical protection devices

There are a variety of protection devices to prevent negative effects of faulty currents. The fuse is one of the most popular protection devices to protect electrical circuits against the negative effects of overload and short-circuit currents. Figure 1.2 shows the internal components of a cartridge fuse [5]. The main component of the fuse is a metal wire. In the case of overload and short-circuit faults, this wire melts and breaks the path of current. However, the fuse is not a fast tripping protection device in the case of high currents like the short-circuit fault.

Miniature circuit breaker (MCB) is another protection device that protects electrical circuits against overload and short circuit-current currents. It contains thermal and electromagnetic elements to overcome the drawback of the fuse. The thermal element of MCB detects overload fault and its electromagnetic element detects the short-circuit fault. Figure 1.3 shows the internal structure of a conventional MCB [6]. The current passes through the coil of the electromagnetic element and then toward its thermal element [7].

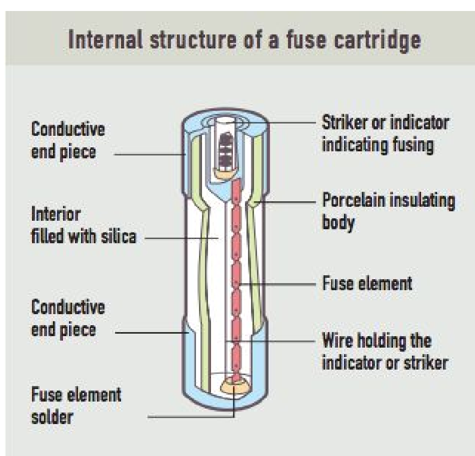


Figure 1.2: Internal structure of a fuse [5]

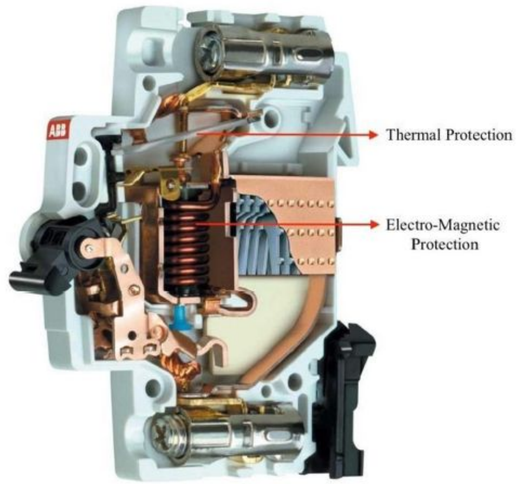


Figure 1.3: Internal structure of a conventional MCB [6]

If the amount of current reaches the overload level, the bimetal part of the thermal element gets hot and moves from its first position to open the contacts of the MCB. If the amount of current reaches to the short-circuit level, it creates an electromagnetic field inside the electromagnetic part. This electromagnetic field produces a force that moves the trigger to open the contacts of the MCB. However, this process makes a short delay to detect faulty currents for sensitive electrical devices like refrigerators. There are different types of MCBs for various protection levels. Type Z is the most sensitive MCB and can be used to protect sensitive electrical appliances. However, types B and C are the most common types for the residential sector. The type B has been suggested to protect lighting electrical circuits while the type C is useful for electrical circuits that include inductive electrical loads like electrical motors. The MCB is unable to protect users against the risk of leakage current. To overcome this limitation, the residual current device (RCD) has been introduced. The RCD protects the users against leakage current when its level exceeds the standard amount. The detection level of RCDs has been categorized into different rates such as 30, 100, 300, and 500 mA. The RCD trips the electrical circuit if the amount of its outgoing current becomes less than its incoming current.

To provide a high level of protection, the RCDs are categorized into general and time-delayed types [8]. The general RCD operates instantaneously to disconnect the electrical circuit. This type of RCD is used widely for human protection to prevent electrocution. However, the time-delayed RCDs provide selectivity in electrical circuits. In this case, the RCD with the nearest level of current to faulty current trips the electrical circuit. Selectivity is an important feature in electrical circuits when we do not need to disconnect the whole electrical circuit . The time-delayed RCDs are not suggested to protect users, but they are widely used to protect electrical equipment. We can install a time-delayed RCD in the upstream of an electrical circuit to minimize the risk of unwanted tripping by the downstream RCD. Also, if the instantaneous RCD fails to detect the leakage current, the selective RCD will protect the whole circuit. Figure 1.4 shows the mechanism of a sample RCD. The RCD uses a current sensor to detect the leakage current fault. Figure 1.5 represents the relationship between the tripping time and the leakage current of a sample RCD [9]. In this case, the instantaneous RCD has faster tripping time compared to the selective RCD. However, the RCD cannot protect the electrical circuits against the risks of overload and short-circuit faults. A residual current circuit breaker with overcurrent protection (RCBO) is the latest electrical protection device that holds the features of the MCB and RCD. Thus, the RCBO can protect electrical circuits against the risks of the leakage current, overload, and short-circuit faults. The RCBO can reduce the size of electrical panels by decreasing the number of MCBs RCDs in an electrical panel. Figures 1.6 represents the operating characteristics of a sample RCBO [10]. The RCBO trips the leakage current of 100 mA in 40 ms, while it needs 5 s to trip an overload that is two times greater than the nominal current.

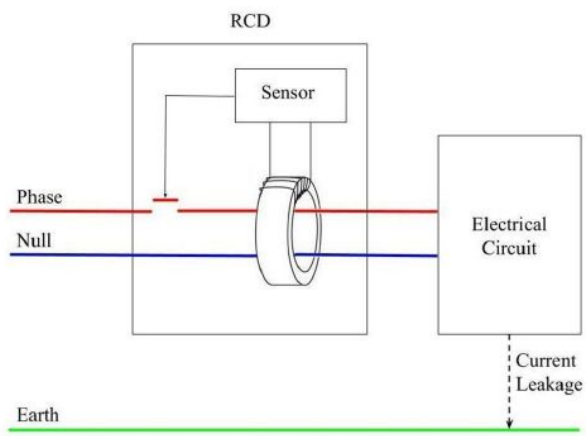


Figure 1.4: Mechanism of a conventional RCD

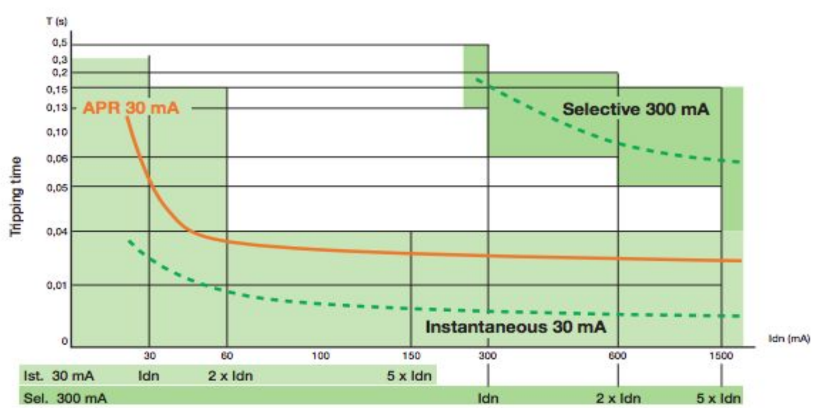


Figure 1.5: Tripping time-current graph of a sample RCD [9]

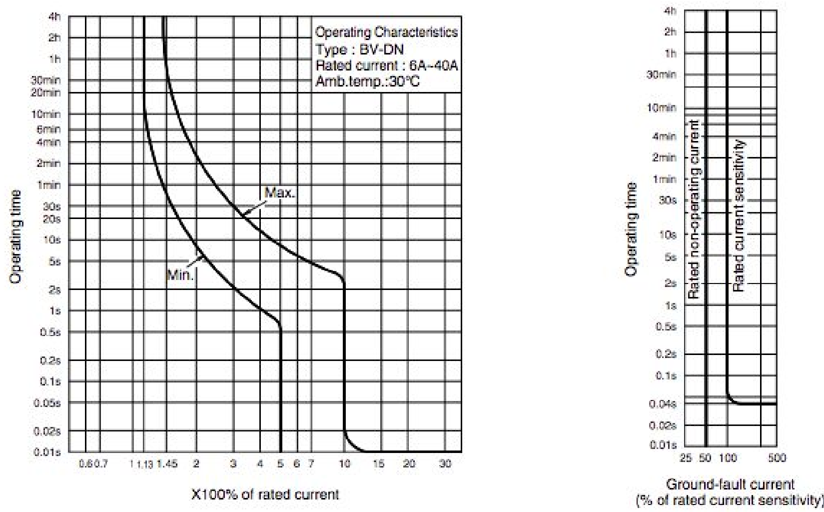


Figure 1.6: Operating characteristics of a sample RCBO [10]

The same RCBO needs 500 ms to trip a short-circuit current that is equal to 5 times the nominal current .

The ground-fault circuit interrupter (GFCI) is another type of electrical protection device. It protects end-users against the risk of leakage current and works similarly to the RCD. The GFCI is popular in TNCS electrical systems because it cannot detect the short-circuit and overload faults like an RCBO. Thus, it should be installed at the user side in the kitchen, laundry rooms, or washrooms. However, the MCB, RCD, and RCBO need to be installed inside the distribution panel.

1.3 Limitations of the existing electrical protection devices

The drawbacks of the existing electrical protection devices are mainly their limitations to detect small faulty currents. Furthermore, some of these devices have slow tripping time to protect sensitive electrical devices against electrical faults.

Many test results have demonstrated that the operating current of a conventional MCB has an inverse correlation with the ambient temperature. Thus, an increase in the ambient temperature decreases the level of fault detection. Figure 1.7 represents the inverse correlation between the current rating and ambient temperature of a sample MCB [10]. In this case, the MCB may have an unwanted trip and fails to detect the real electrical fault.

The thermal and electromagnetic elements of MCBs have time delays to detect electrical faults. The length of the tripping time depends on the technology and materials that have been used to produce the thermal and electromagnetic elements. The physical properties of the material present an obstacle when trying to shorten the tripping time of the existing protection devices. Figure 1.8 [11] denotes the tripping curves of a sample fuse, MCB, and RCD. As shown in the figure 1.8, the fuse and the MCB have similar tripping times against the overload fault. However, the MCB has faster tripping time than the fuse in the case of short-circuit fault.

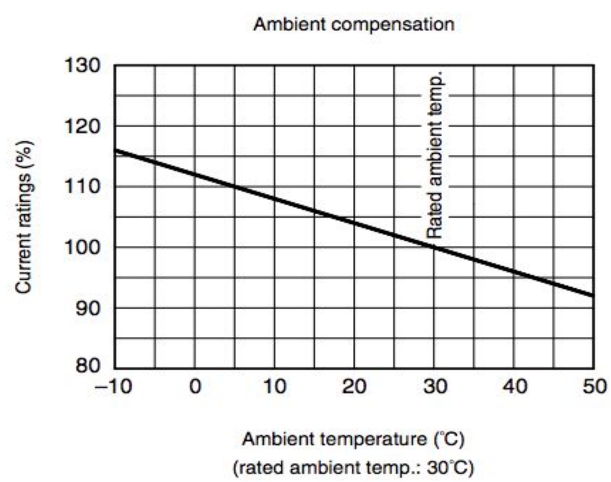


Figure 1.7: Current rating - the ambient temperature of a sample MCB [10]

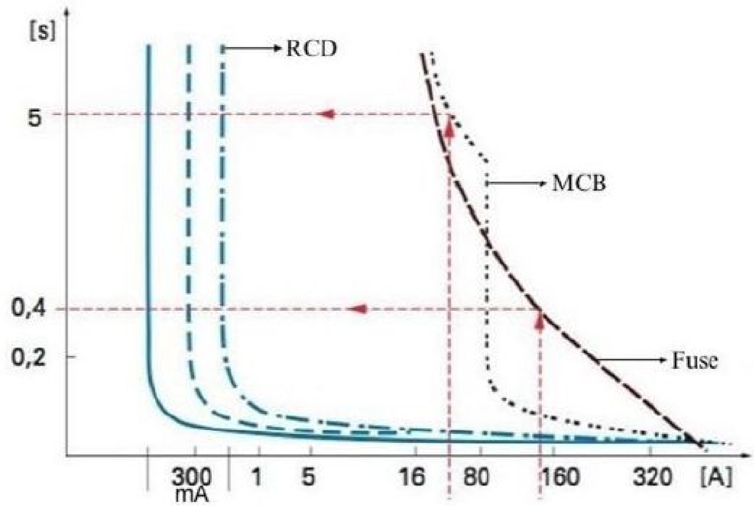


Figure 1.8: Tripping curves of fuse, MCB, and RCD [11]

For example, at the short-circuit level of 160 A, the fuse disconnects the electrical circuit in 0.4 s while the MCB trips the same fault in less than 0.2 s.

Furthermore, the MCB and fuse are unable to detect the leakage current of 300 mA. The RCD has fast tripping time against the leakage current of 300 mA and can trip the electrical circuit in less than 0.2 s.

Given that a regular RCBO shares features with the MCB, its tripping time has an inverse correlation with the intensity of the current. This can change the real fault detection of the RCBO. Besides, the regular RCBOs have time delays to detect electrical faults because of their thermal and electromagnetic elements. This may lead to serious injury in users as well as sensitive electrical devices.

Chapter 2

Problem Review and Related Work

2.1 Issues with the existing electrical protection devices

The conventional RCBOs must detect and trip the electrical faults in the shortest possible time. However, the architecture of conventional RCBOs may cause some delays to trip the electrical faults. Their average time to detect the short-circuit fault is less than the required time to detect the overload fault. Furthermore, regular RCBOs need some time to detect the leakage current. This time can be still greater than the required time to trip the leakage current faults for users and sensitive electrical devices.

Overheating is another problem associated with the use of conventional protection devices. The components of a conventional RCBO are enclosed in a plastic structure that may break or explode because of unexpected heating of overload or short-circuit currents. In this case, the RCBO will be out of order. Thus, we must replace the whole device.

Moreover, a conventional RCBO needs to reset after each fault detection. Therefore, the electrical circuit remains disconnected from the power supply until the user manually resets the RCBO. This process takes some time and may damage sensitive electrical appliances. However, there is maybe an inconvenience for all users to manually reset the RCBO after each fault detection. For example, manual resetting is not a suitable task for most seniors and disabled people. A regular RCBO has limited levels to detect electrical faults.

In this case, we need multiple RCBOs to install in an electrical system for different levels of faults. This increases the size of electrical panels, the number of protection devices, and the amount of wiring. All these factors will increase the cost of electrical protection systems.

2.2 Previous work on the smart electrical protection devices

There are a few efforts to computerize conventional electrical protection devices as described in the literature. These efforts try to improve some disadvantages of conventional devices by adding new features and increasing their performances. Chiranthan et al. proposed a digital MCB using the Raspberry Pi board [12]. The resulting MCB detects electrical faults and disconnects the electrical circuit in the case of overload and short-circuit currents. This digital MCB uses an analog to digital converter (ADC) that transforms the analog signals of current into digital signals to use in the Raspberry Pi. This process decreases the tripping time of this device. The authors used the difference in power traveling to and out of an electrical circuit to identify the location of overcurrent faults. Thus, the digital MCB can trip the electrical circuits in the case of overload and short-circuit faults but it cannot detect the leakage current. This shows the lack of a complete smart device like the RCBO to detect all types of electrical faults.

Some manufacturers have started to commercialize the smart RCBO because of its advantages over conventional protection devices. According to Matismart, the smart RCBO contains a smart breaker with earth leakage protection and an automatic reclosing [13]. It contains a regular breaker used for the tripping of the electrical fault. This smart

RCBO can be remotely controlled through connection to a gateway. The tripping time of this device is less than 0.2 s.

According to Chandraratne et al. [14], smart protection aims to identify and isolate the fault in a short time. This provides more reliability and convenience for users as the purpose of the smart grid. The smart grid is the future of electrical networks and contains smart protection devices as one of its main components. The authors of this study mention that “the smart grid must not only realize a smarter management system but also provide a smarter protection system which can more effectively and efficiently support failure protection mechanisms”. This shows the importance of smart protection devices in modern electrical systems.

The previous work summarized above indicates the lack of an easily programmable and fast tripping smart RCBO as a complete protection device. The smart RCBO must meet all features of the conventional RCBO to be used as a component in a smart grid.

Chapter 3

The smart RCBO architecture and experimental results

3.1 The characteristics of the smart RCBO

To overcome the shortcomings of conventional RCBOs as discussed in previous chapters, we have designed and implemented a new digital device with improved performance compared to the conventional RCBOs. In what follows, we refer to this device as the smart RCBO. The smart RCBO is a computerized electrical protection device that works based on a microcontroller to detect leakage current, overload, and short-circuit faults.

One of the main disadvantages of a conventional RCBO is its delay to trip electrical faults to protect sensitive electrical devices. In this case, a digital RCBO with fast tripping time is essential. It must quickly detect the electrical faults and disconnects the electrical circuit to reduce damages in users and electrical devices.

The smart RCBO contains separated elements. As a consequence, this feature provides a type of thermal isolation. In this case, only some parts of the smart RCBO may be damage because of the high temperature of the short-circuit or overload faults. Thus, users just need to replace the broken parts instead of the whole device. The smart RCBO can reconnect the electrical circuits after each fault detection to avoid the risk of error in fault detection. The regular protection devices may disconnect electrical circuits because of unwanted electrical noises. In this case, they fail to detect the real electrical faults.

The auto reconnection feature of the smart RCBO can reduce the risk of error in electrical circuits. This feature provides more convenience for users as it allows continuing power delivery to electrical devices. However, the smart RCBO will open the electrical circuit after receiving some data about the origin of fault. In this case, it permanently trips the electrical circuit.

The smart RCBO does not contain the thermal and electromagnetic elements of a regular RCBO because it uses electronic sensors to detect electrical faults. Therefore, the risk of unwanted tripping of the smart RCBO is less than the regular devices. The smart RCBO is a multi-task protection device that has different levels of fault detection. This feature allows users to set their desired level of fault detection by making some changes in the smart RCBO. This feature allows the smart RCBO to reduce the number of protection devices in electrical panels. The smart RCBO is a multi-use device because its programming feature allows users to install it either in a single-phase or a three-phase electrical system.

3.2 The architecture of the smart RCBO

The smart RCBO has been designed based on an Arduino board that includes an AVR microcontroller, an analog to digital converter (ADC), analog inputs, digital inputs, and outputs. The AVR microcontroller of the Arduino board is an ATmega type and works as the core of the smart RCBO. The ATmega is the typical microcontroller that is used in most Arduino boards. The smart RCBO receives signals from current sensors and processes them to detect faulty currents. After detecting electrical faults, the microcontroller commands the switches to connect or disconnect the electrical circuit. However, if the faults can be repeated, the smart RCBO permanently disconnects the electrical circuit.

Figure 3.1 shows the flowchart of the smart RCBO. One of the important objectives of the smart RCBO is to reconnect the electrical circuit after an error in fault detection. The smart RCBO examines the existence of electrical faults and temporarily trips the electrical circuit if it can detect an electrical fault. However, the smart RCBO will reconnect the electrical circuit if the number of faults is less than the eligible number for each fault. Otherwise, the smart RCBO will permanently disconnect the electrical circuit.

3.3 The hardware of the smart RCBO

The Arduino board is the heart of this project. It holds an 8 bits ATmega microcontroller that works at 16 MHz. This microcontroller contains three memory types that are flash memory, static random access memory (SRAM), an electrically erasable programmable read-only memory (EEPROM). The flash memory holds programs while the SRAM memory holds dynamic variables. The EEPROM memory retains variables that we do not want to erase after restarting the microcontroller. The ATmega microcontroller contains an ADC unit that continuously transforms analog signals to digital. Most Arduino boards contain either 10 bits or 12 bits ADC. The microcontroller of this study holds a 10 bits ADC. The Arduino board contains a serial port for serial communication with the computer. The serial communication helps users to upload C++ codes into the Arduino board. A power supply 7 - 12 v DC is required to run the Arduino board. The Arduino board includes an onboard voltage regulator that provides a fixed DC voltage of 3.3 or 5 v for internal use of the Arduino board. The smart RCBO tracks changes in the level of current to detect electrical faults. Any change in the amount of current shows the existence of an electrical fault.

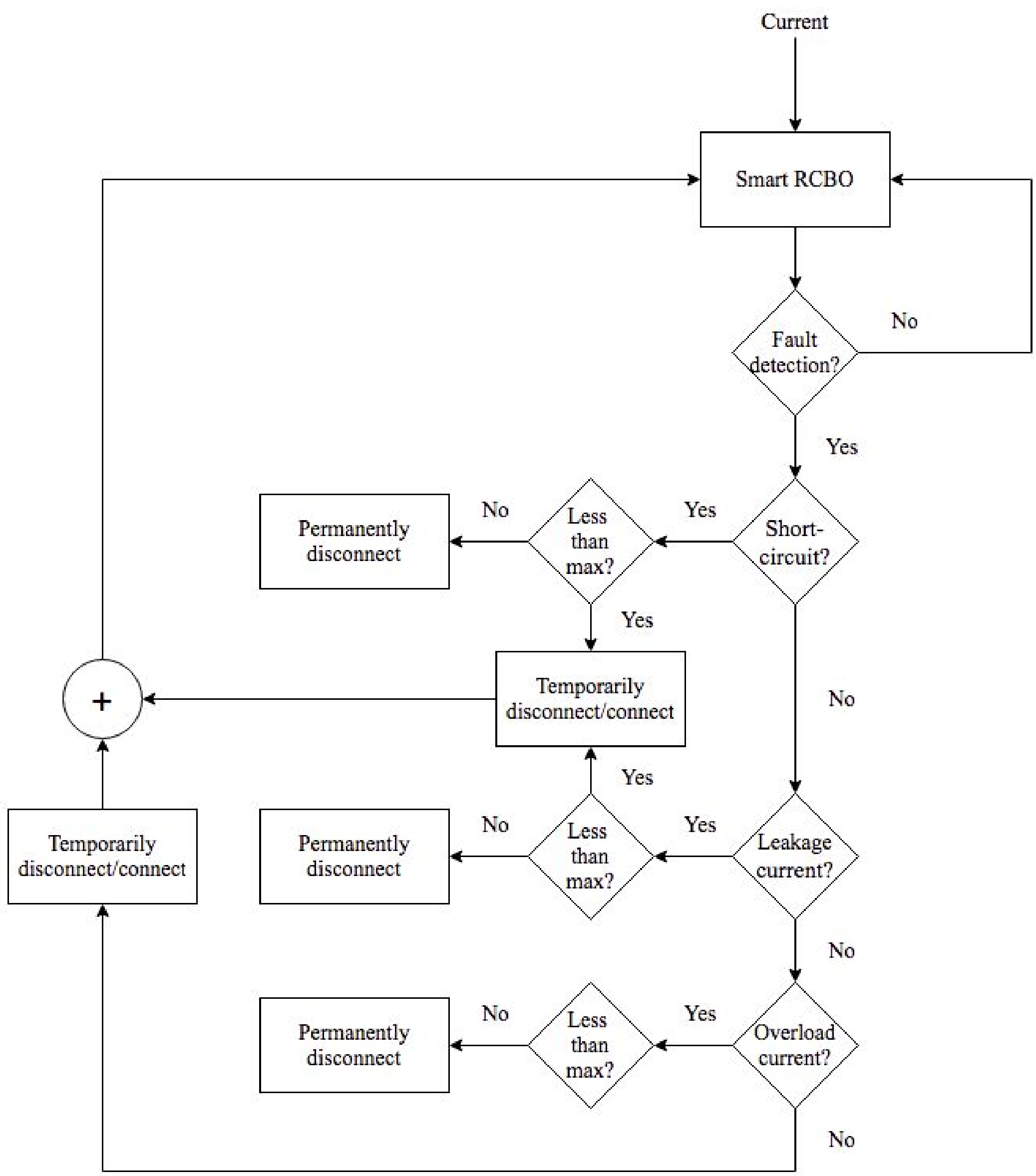


Figure 3.1: The flowchart of the smart RCBO

For example, if the amount of current on the phase becomes greater than the set value for overload and short-circuit, the smart RCBO detects either overload or short-circuit fault and trips the electrical circuit. However, if the amount of current on the phase becomes greater than the amount of current on the null, the smart RCBO detects the leakage current fault and trips the electrical circuit. To measure any change in the level of current, we need to use current sensors that are analog and work based on changes in voltage. Generally, most analog sensors are voltage based and measure the changes in voltage. The current sensors of this study measure change in current of phase and null and send analog signals to the microcontroller. The microcontroller computes the level of current on the phase and null based on the changes in their current.

The smart RCBO contains an electromagnetic relay to trip the electrical circuits in the case of electrical faults. The electromagnetic relay holds two modes that are normally open (NO) and normally closed (NC). We can choose either NO or NC mode. The microcontroller sends a signal to the electromagnetic relay to connect or disconnect the electrical circuit. The electromagnetic magnetic relay also needs a power supply of 5 v DC that can be supplied by the Arduino board or an external DC power supply. The smart RCBO operates in a single-phase electrical system with 120 or 220 v AC to provide an advantage to most regions of the world. However, we can develop this device to use it in a three-phase electrical system. This requires some changes in the hardware and software of the Arduino board. Figure 3.2 shows the block diagram of the smart RCBO while figure 3.3. The complete electrical diagram is given in Appendix 1.

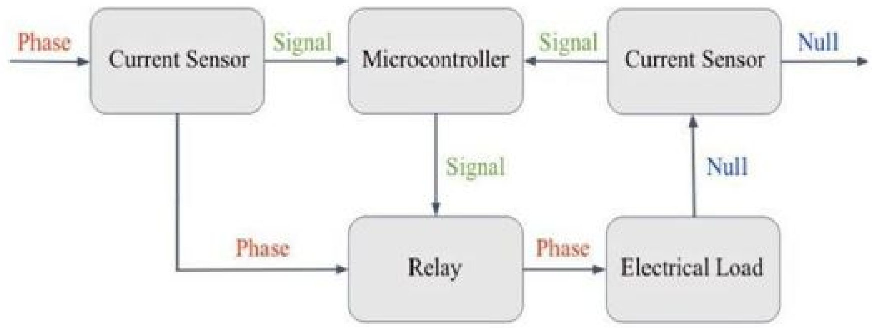


Figure 3.2: The block diagram of the smart RCBO

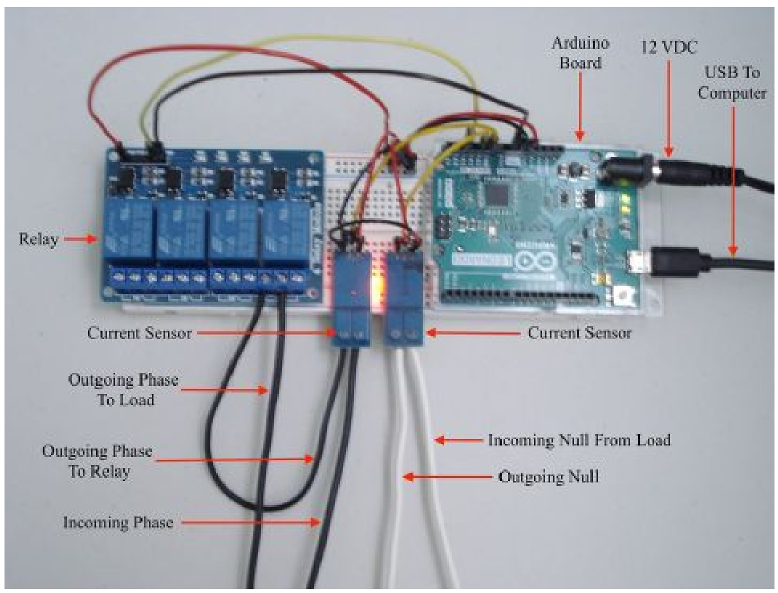


Figure 3.3: The hardware of the smart RCBO

3.4 Programming of the smart RCBO

The ATmega microcontroller is a single task device that is programmable through an AVR compiler (like CodeVisionAVR) or the Arduino integrated development environment (Arduino IDE). To program the AVR microcontroller, we need to set up extra hardware such as an AVR programmer. However, the smart RCBO of this project has been programmed through the Arduino IDE. The codes have been written in C++

which is the common programming language for Arduino boards. The Arduino board transforms the C++ code into machine code to use in the microcontroller.

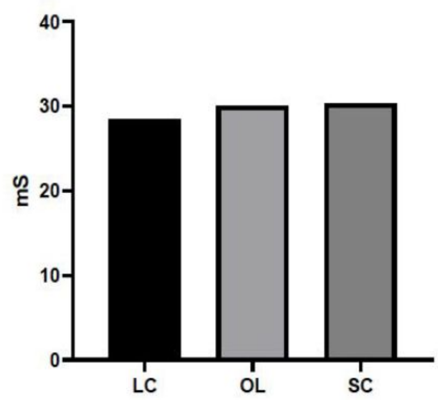
3.5 Experimental Results

To provide a real-world scenario for testing, the smart RCBO is connected to a 120 v AC electrical circuit. The ambient temperature was about 20 °C and the electrical load was about 150 mA. To provide real faults, we simulated overload and short-circuit conditions by adding extra loads to the electrical circuit. To simulate the leakage current condition, we split the null current to decrease the level of current on the null wire. The device performed according to the defined scenario and successfully disconnected the electrical circuit in the case of leakage current, overload, and short-circuit faults. Table 3.1 shows the test results.

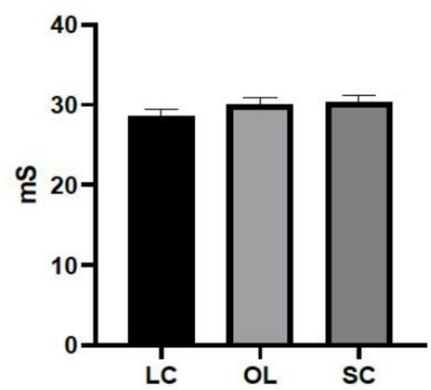
Mode	**Current difference (mA)**	**Average tripping time (ms)**
Overload current	100	31.5
Short-circuit current	210	31
Leakage current	70	28.5

Table 3.1: Test results for our electrical circuit

As shown in Table 3.1, the smart RCBO has shorter tripping time than a conventional RCBO. For example, according to [11], a regular RCBO with 100 mA current sensitivity does not trip the leakage current at 50% of its current sensitivity and needs about 40 ms to trip at 100 mA. However, the test result indicates that the smart RCBO needs 28.5 ms to trip the leakage current of 70 mA. Also, the smart RCBO can trip overcurrent faults faster than other RCBOs. Figure 3.4 (a) illustrates the mean bar of tripping times for the leakage current (LC), overload (OL), and short-circuit (SC) faults. The tests are repeated for three individual experiments and each bar represents the mean of each trial. The tests are repeated twenty times for each individual experiment. Figure 3.4 (b) shows the recorded data as individual bar graphs with the standard deviation. The test results show that the standard deviation is 0.513 ms for the leakage current, 0.510 ms for the overload, and 0.605 ms for the short-circuit faults.



(a)



(b)

Figure 3.4: The mean bar with a standard deviation of tripping times

Chapter 4

Smart RCBO integrated into a smart home

4.1 The architecture of the integrated system

Energy management is an important concern and correlates with economic and environmental issues. The demand for electricity increases as the population grows. The smart home is an effective method to reduce electricity consumption in households and can cut the cost of electricity bills.

A typical smart home does not include electrical protection devices. The electrical protection systems and smart homes have separate electrical platforms. To create a new smart system, the smart RCBO is added to the smart home. The new system includes all features of the smart RCBO in addition to some features of a sample smart home. Thus, the smart RCBO and the smart home control the electrical circuit through a unified communication platform as a single device.

Figure 4.1 shows the block diagram of the integrated smart RCBO into the smart home. This system includes an Arduino board, a digital motion sensor, analog current sensors, an analog photocell sensor, and electromagnetic relays. As shown in figure 4.1, the microcontroller receives digital and analog signals from sensors. The first part of signals come from the current sensors to monitor electrical faults. These signals will be processed in the smart RCBO module of the microcontroller.

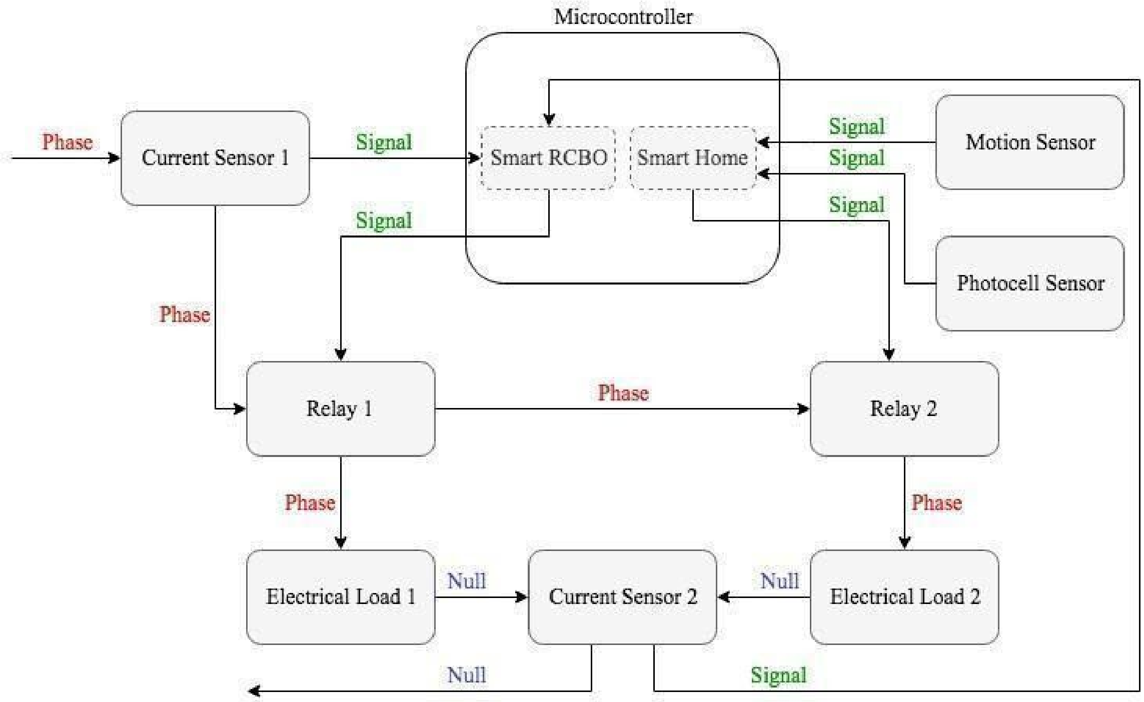


Figure 4.1: The block diagram of the smart RCBO integrated into the smart home

In the case of faulty currents, this module sends signals to Relay 1 to trip the electrical circuit. This module operates similar to the smart RCBO device. In the absence of an electrical fault, the smart home module controls the smart home system based on the received signals of motion and photocell sensors. In this case, the smart home module can connect or disconnect the electrical loads through Relay 2.

4.2 The hardware of the integrated system

The new smart system contains analog sensors, a digital sensor, electromagnetic relays, and an Arduino board. The current and photocell sensors are voltage-based analog sensors. The current sensors perform similar to the current sensors of the smart RCBO. The photocell sensor holds a variable resistance that has an inverse correlation with the ambient light. If the level of illumination increases, the amount of the variable resistance decreases, which leads to an increase in the output voltage of the photocell. However, if the level of illumination decreases, the amount of the variable resistance increases and will lead to a decrease in the output voltage. The photocell works like a switch that connects or disconnects the electrical circuits based on the level of its output voltage. The photocell sensor needs a power supply of 5 v DC that can be provided by the Arduino board.

If the motion sensor detects a moving object in its area, it sends 3.3 v DC to the Arduino board. Otherwise, it sends 0 volts. The motion sensor requires a 5 v DC that can be supplied by the Arduino board. The electromagnetic relays are similar to the relay of the smart RCBO and are used for switching of electrical loads.

The main issue may arise when the number of connected devices to the Arduino board increases. This decreases the level of voltage in the smart system. In this case, a DC-DC power supply can be used to stabilize the level of voltage in the smart RCBO integrated into the smart home.

Many different communication methods are used in smart home systems containing wired and wireless networks. The purpose of the communication methods is to exchange data between commanders, actuators, and control units in a smart system. The main advantage of the wired network is the safety of signals compared to the wireless network. The smart home of this study has been implemented based on a wired communication network to connect sensors and relays to the Arduino board.

4.3 Implementation and test

To implement the new smart system, a scenario is defined to control ventilation and lighting systems. The photocell and motion sensors are the commanders of the smart home and have been used to control ventilation and lighting systems. The electromagnetic relays are actuators and have been used for switching of ventilation and lighting systems. The microcontroller on the Arduino board works as the control unit of the system. It sends controlling signals to the actuators. The Arduino disconnects the ventilation system if the photocell detects the day mode. However, the Arduino board connects the ventilation system to the power if the photocell detects the night mode. The Arduino board connects the lighting system if the motion sensor detects a moving object. Otherwise, the Arduino board disconnects the lighting system. Figure 4.2 shows the flowchart for the scenario of the smart RCBO integrated into the smart home. The complete electrical diagram is provided in Appendix 2.

Figure 4.3 shows the used hardware of the smart RCBO integrated into the smart home. This system was tested and worked according to the defined scenario. However, the smart home system can perform any desired scenario according to the user’s needs. In this case, extra hardware is required in addition to some changes in the programming based on the new scenario.

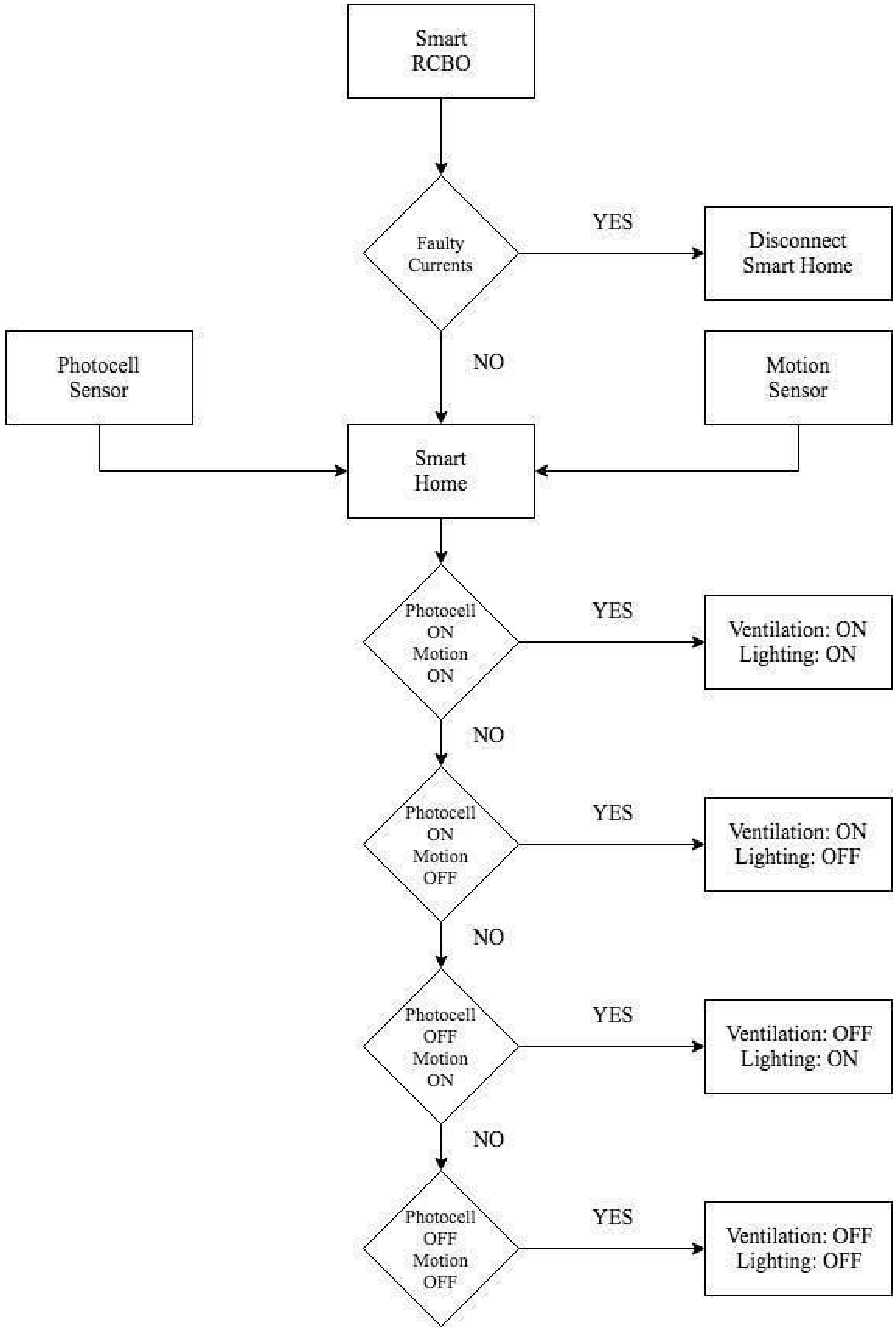


Figure 4.2: The flowchart of the smart home module

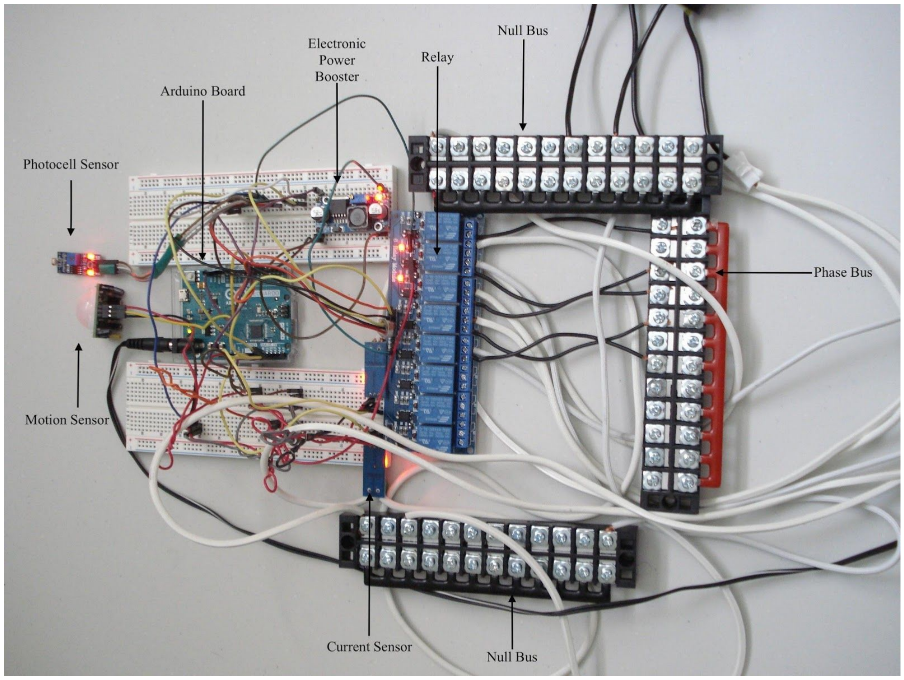


Figure 4.3: The hardware of the smart RCBO integrated into the smart home

Chapter 5

Conclusion

The purpose of this project was to design, program, and test a smart residual current circuit breaker with overcurrent protection (smart RCBO). The smart RCBO is a computerized version of a conventional RCBO. This device provides enhanced safety by using digital technology to detect electrical faults.

The smart RCBO has adjustable settings to ensure the safety of users and electrical devices. It has been designed and simulated to work at different voltage levels to meet the needs of different electrical systems. The smart RCBO can be used in AC and DC electrical systems. It can automatically disconnect and reconnect any electrical circuit to provide convenience for users.

The performance of the smart RCBO is better compared to regular protection because it does not contain thermal and electromagnetic sensors. Therefore, changes in the ambient temperature will not have negative impacts on the performance of the smart RCBO. The elements of the smart RCBO have thermal isolation because they are not located in a plastic package. This feature decreases the risk of an explosion that is a common failure.

The smart RCBO has been designed based on an Arduino board and it has been programmed through the Arduino IDE. The Arduino IDE contains a user-friendly environment that allows users to reprogram the smart RCBO based on their needs.

The smart RCBO is integrated into a smart home to centralize the electrical protection and the home automation systems. This can reduce the scale of electrical circuits. This project is developed based on ICT (Information and Communication Technology) in the field of electrical engineering to computerize the traditional electrical protection devices to improve the performance of the whole electrical systems.

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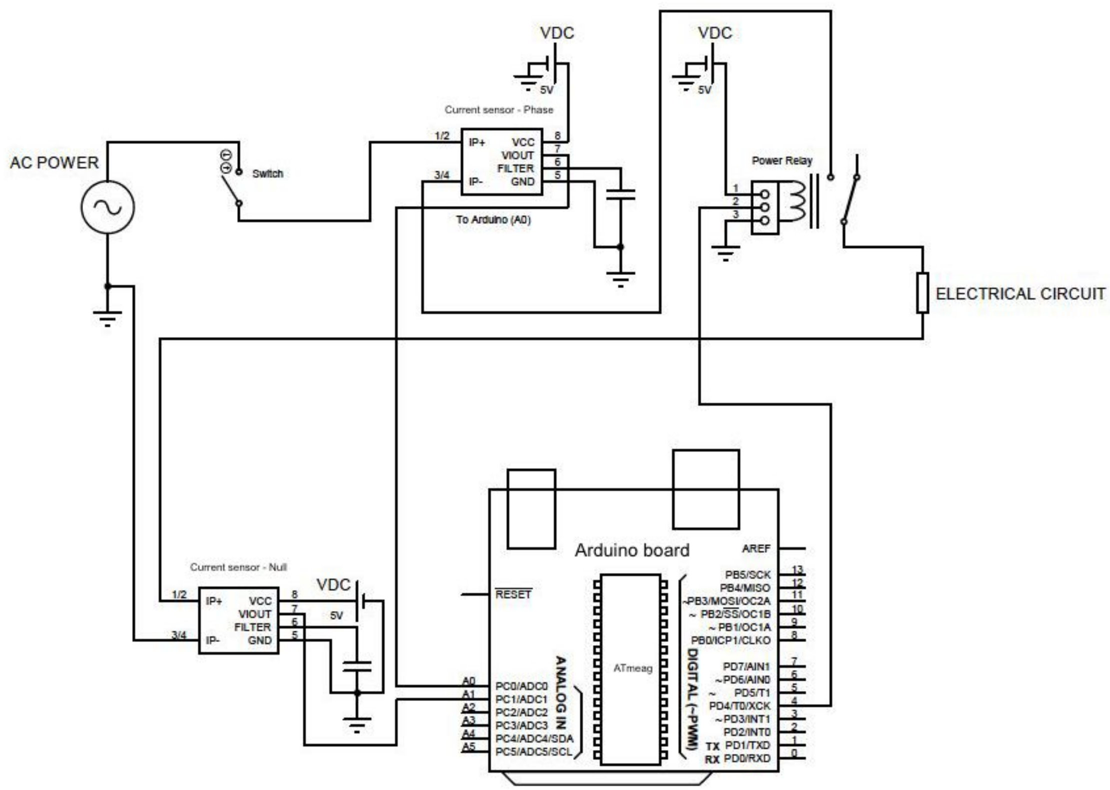
Appendices

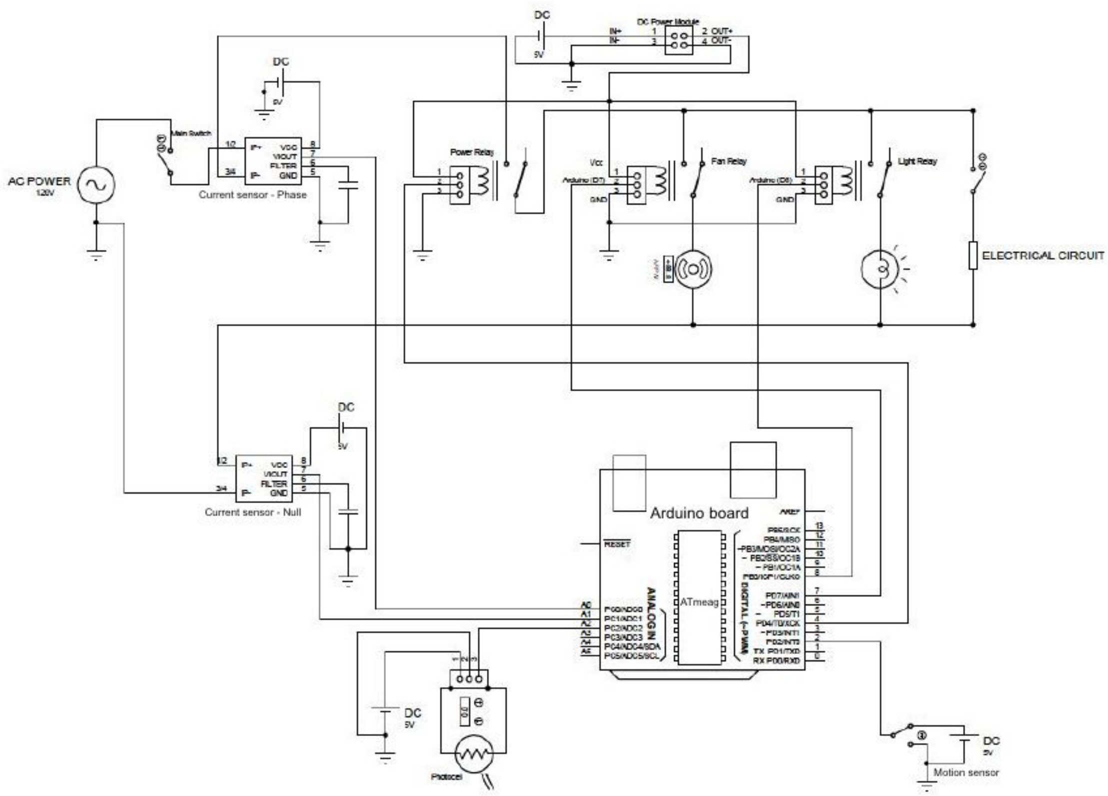
Appendix 1

The electrical diagram of the smart RCBO



Appendix 2

The electrical diagram of the smart RCBO integrated into the smart home



Appendix 3

Technical data of Arduino boards [15]

Name	Processor	Operating/Input Voltage	CPU Speed	Analog In/Out	Digital IO/PWM	EEPROM [kB]	SRAM [kB]	Flash [kB]	USB	UART
101	Intel® Curie	3.3 V/ 7-12V	32MHz	6/0	14/4	-	24	196	Regular	-
Gemma	ATtiny85	3.3 V / 4-16 V	8 MHz	1/0	3/2	0.5	0.5	8	Micro	0
LilyPad	ATmega168V ATmega328P	2.7-5.5 V / 2.7-5.5 V	8MHz	6/0	14/6	0.512	1	16	-	-
LilyPad SimpleSnap	ATmega328P	2.7-5.5 V / 2.7-5.5 V	8 MHz	4/0	9/4	1	2	32	-	-
LilyPad USB	ATmega32U4	3.3 V / 3.8-5 V	8 MHz	4/0	9/4	1	2.5	32	Micro	-
Mega 2560	ATmega2560	5 V / 7-12 V	16 MHz	16/0	54/15	4	8	256	Regular	4
Micro	ATmega32U4	5 V / 7-12 V	16 MHz	12/0	20/7	1	2.5	32	Micro	1
MKR1000	SAMD21 Cortex-M0+	3.3 V/ 5V	48MHz	7/1	8/4	-	32	256	Micro	1
Pro	ATmega168 ATmega328P	3.3 V / 3.35-12 V 5 V / 5-12 V	8 MHz 16 MHz	6/0	14/6	0.512 1	1 2	16 32	-	1
Pro Mini	ATmega328P	3.3 V / 3.35-12 V 5 V / 5-12 V	8 MHz 16 MHz	6/0	14/6	1	2	32	-	1
Uno	ATmega328P	5 V / 7-12 V	16 MHz	6/0	14/6	1	2	32	Regular	1
Zero	ATSAMD21G18	3.3 V / 7-12 V	48 MHz	6/1	14/10	-	32	256	2 Micro	2
Due	ATSAM3X8E	3.3 V / 7-12 V	84 MHz	12/2	54/12	-	96	512	2 Micro	4
Esplora	ATmega32U4	5 V / 7-12 V	16 MHz	-	-	1	2.5	32	Micro	-
Ethernet	ATmega328P	5 V / 7-12 V	16 MHz	6/0	14/4	1	2	32	Regular	-
Leonardo	ATmega32U4	5 V / 7-12 V	16 MHz	12/0	20/7	1	2.5	32	Micro	1
Mega ADK	ATmega2560	5 V / 7-12 V	16 MHz	16/0	54/15	4	8	256	Regular	4
Mini	ATmega328P	5 V / 7-9 V	16 MHz	8/0	14/6	1	2	32	-	-
Nano	ATmega168 ATmega328P	5 V / 7-9 V	16 MHz	8/0	14/6	0.512 1	1 2	16 32	Mini	1
Yún	ATmega32U4 AR9331 Linux	5 V	16 MHz 400MHz	12/0	20/7	1	2.5 16MB	32 64MB	Micro	1
Arduino Robot	ATmega32u4	5 V	16 MHz	6/0	20/6	1 KB (ATmega32u4)/ 512 Kbit (I2C)	2.5 KB (ATmega32u4)	32 KB (ATmega32u4) of which 4 KB used by bootloader	1	1
MKRZero	SAMD21 Cortex-M0+ 32bit low power ARM MCU	3.3 V	48 MHz	7 (ADC 8/10/12 bit)/1 (DAC 10 bit)	22/12	No	32 KB	256 KB	1	1

1Mhz = 10^6 Hz

Appendix 4

Technical parameter of Matismart smart RCBO [13]

Technical Parameter

	Poles		MT61SR-sinple phase	MT61SR-Three phase
	Pictures			
Electric Features	Approvals:		CE,CCC	
	Standards		IEC50557, IEC61009	
	Rated voltage Ue	Vac	230	400
	Rated current In	A	16,20,25,32,40,50,63,80,100,125	
	Rated frequency	HZ	50/60	
	Mini. operating voltage	Vac	85% Ue	
	Max. operating voltage	Vac	110% Ue	
	Rated insulation voltage Ui	Vac	500	
	Rated breaking capacity	A	6000	
	Dielectric strength test voltage between pole and earth	V/Min	2500	
	Pollution degree		2	
	Rated residual current (I∆n)	mA	30,50,100,300	
	Type of associated residual current circuit breaker		A,AC	
	Thermo-magnetic release characteristic		C	5-10In
			D	10-20In
	Trips time		<0.2	
	Over/under voltage Protection		270/170+-5	
Mechanical features	Electrical life	s	5000	
	Mechanical life	Vac	10000	
	Protection degree	times	IP20	
	Width in Din modules	times	72	108
	Reference temperature for setting of thermal element	°C	30	
	Ambient temperature (with daily average<=35 .C)	°C	-25---+55	
	Storage temperature	°C	-40---+70	
Functions	Protection		Overload	
			Short Circuit	Residual current
			Auto Reclose	Phase loss
			Over/Under voltage	Phase unbalance
	Characteristic set up		Over/under voltage Action time	
			Over/under voltage value	
			Reclose trips & time	
			Time setup/Language	
	Measurement & Monitor		Voltage	
			Earth leakage	
	Communiction port		RS485	
	Others		Event reord and checkup	

Appendix 5

Technical specification of Spectrum smart RCBO [16]

Technical specification of iRCBO

Smart RCBO may be used as main switch and line protection in Smart Breaker SPCT10 system. It is also the necessary part for Smart Breaker SPCT10 system as main switch.

Item Code:		SPCT10 - RC2	SPCT10-RC4
Picture			
Poles		2P	4P
Rated voltage Ue	Vac	230	400
Frequency (HZ):	Hz	50/60	
Rated current	A	16,20,25,32,40,50,63,80	
Type (wave form of the earth leakage sensed)		AC	
Rated residual current (IΔn)	mA	30	
Rated insulation voltage Ui	Vac	500	
Rated Breaking capacity acc.to IEC61009 ultimate Icn	A	6000	
Breaking time under IΔn		<=0.1 S	
Breaking time under Icn		<=0.04S	
Triping characteristic		C (5-10In)	
Other functions		Over/under voltage protection , warning and alarm Max.power and current setting Auto test of earth leakage current High temperature protection, warning and alarm Monitor of current, power and voltage in real-time Arcing fault protection, warning and alarm Remote control Timer Meter Event record and notice	
Breaking time when voltage is over 265Vac		10S	
Over/undder voltage warning		when voltage is higher than 250Vac or lower than 190Vac	
Breaking time when the current reach the max.current or power setup		5s	
The time for switching on automatically after auto-test of earth leakage current		5s	
Electric life	Times		
Mechanical life	Times		
Conductor cross-sections	mm²	38	
Pollution degree		2	
Numbers of modules(1 module=18mm)		3 (54mm)	5 (90mm)
Ambient temperature:	°C	-15 - +40	
Storage temperature:	°C	-25---+70	
Humidity		< 95%	
Altitude:	m	<=2000	
Terminal connection		Cable/Pin-type busbar	
Mounting		Din rail En60715(35mm) by means of fast clip device	
Connection		From top to bottom	

Appendix 6

List of components

Product #	Description
ATmega microcontroller	Arduino board
ACS712	Current sensor
Electromagnetic relay	NO/NC
LM2596	DC-DC power supply
LDR	Photocell sensor
HC-SR501	Motion sensor

Appendix 7

Technical specification of ACS712 [17]

Type	Part Number	Measurement Range (A)	Isolation Voltage (VRMS)	Bandwidth (kHz)	Vcc	Temperature Ranges	Packages
Bidirectional	ACS720*	±15, ±35, >±50	3600	120	5	K	SOIC
Bidirectional, Unidirectional	ACS724LC	<±10, ±20, ±30, >±50, 10,20,30,40	2400	120	5	L	SOIC
Bidirectional, Unidirectional	ACS724MA	±20, ±30, >±50, 30, 50	4800	120	5	K, L	SOIC
Bidirectional, Unidirectional	ACS725LC	<±10, ±20, ±30, ±40, >±50, 10, 20, 30	2400	120	3.3	L	SOIC
Bidirectional, Unidirectional	ACS725MA	±20, ±30, >±50, 30	4800	120	3.3	K, L	SOIC
Bidirectional, Unidirectional	ACS730	±20, ±40, >±50, 40, >50	2400	1000	5	K	SOIC
Bidirectional, Unidirectional	ACS732LA	±20, ±40, >±50, >50	3600	1000	5	K	SOIC
Bidirectional	ACS732MA	>±50	4800	1000	5	K	SOIC
Bidirectional, Unidirectional	ACS733LA	±20, ±40, >50, 40	3600	1000	3.3	K	SOIC
Bidirectional	ACS733MA	>±50	4800	1000	3.3	K	SOIC
Bidirectional, Unidirectional	ACS70331*	±2.5, ±5, 2.5, 5	120	1000	3.3	E	QFN
Bidirectional, Unidirectional	ACS70331OL*	±2.5, ±5, 2.5, 5	120	1000	3.3	E	SOIC
Bidirectional	ACS71020*[1]	±15, ±30, >±50	4800	8	3.3,5	K	SOIC
Bidirectional, Unidirectional	ACS71240EX	<±10, ±30, 50	120	120	3.3,5	K	QFN
Bidirectional, Unidirectional	ACS71240LC	<±10, ±30, ±45, 50	2400	120	3.3,5	L	SOIC

Appendix 8

Technical description of relay [18]

DESCRIPTION REVIEWS (0)

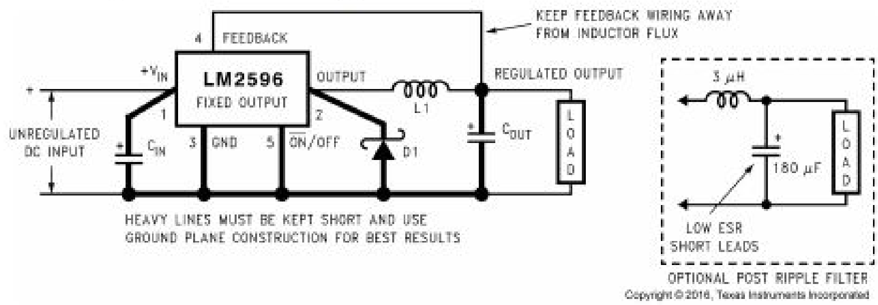
- This relay module is 5V active low. Relay output maximum contact is AC250V 10A and DC30V 10A.
- Standard interface can be directly connected with microcontrollers.
- Working status indicator lights are conducive to the safe use
- 4-channel relay interface board, which can be controlled directly by a wide range of microcontrollers such as Arduino, AVR, PIC, ARM, PLC, etc. It is also able to control various appliances and other equipments with large current.
- Widely used for all MCU control, industrial sector, PLC control, smart home control.
  4-channel relay output modules, relay output contacts 250A 10A.
  Input IN1, IN2, IN3, IN4, the signal line LOW effective.
  VCC, GND power input, can relay a separate power supply relay power input of JD-VCC.

Uses:
1, support all MCU control.
2, the industrial sector;
3, PLC control;
4, smart home control;

Appendix 9

Technical specification of LM2596 [19]

9.2.1 LM2596 Fixed Output Series Buck Regulator



C_{IN} — 470-µF, 50-V, Aluminum Electrolytic Nichicon *PL Series*
C_{OUT} — 220-µF, 25-V Aluminum Electrolytic, Nichicon *PL Series*
D1 — 5-A, 40-V Schottky Rectifier, 1N5825
L1 — 68 µH, L38

Figure 32. Fixed Output Voltage Version

9.2.1.1 Design Requirements

Table 2 lists the design parameters for this example.

Table 2. Design Parameters

PARAMETER	EXAMPLE VALUE
Regulated Output Voltage (3.3 V, 5 V or 12 V), V_{OUT}	5 V
Maximum DC Input Voltage, V_{IN}(max)	12 V
Maximum Load Current, I_{LOAD}(max)	3 A

Appendix 10

Technical specification of LDR photocell [20]

Model	Vmax (VDC)	Pmax (mW)	Ambient Temp (°C)	Spectral Peak (nm)	Photo Resistance (10Lx) (KΩ)	Dark Resistance (MΩ) Min.	γ Min.	Response Time (ms)	
								Rise	Decay
PGM5506	100	90	-30 ~ +70	540	2 ~ 6	0.15	0.6	30	40
PGM5516	100	90	-30 ~ +70	540	5 ~ 10	0.2	0.6	30	40
PGM5526	150	100	-30 ~ +70	540	8 ~ 20	1.0	0.6	20	30
PGM5537	150	100	-30 ~ +70	540	16 ~ 50	2.0	0.7	20	30
PGM5539	150	100	-30 ~ +70	540	30 ~ 90	5.0	0.8	20	30
PGM5549	150	100	-30 ~ +70	540	45 ~ 140	10.0	0.8	20	30
PGM5616D	150	100	-30 ~ +70	560	5 ~ 10	1.0	0.6	20	30
PGM5626D	150	100	-30 ~ +70	560	8 ~ 20	2.0	0.6	20	30
PGM5637D	150	100	-30 ~ +70	560	16 ~ 50	5.0	0.7	20	30
PGM5639D	150	100	-30 ~ +70	560	30 ~ 90	10.0	0.8	20	30
PGM5649D	150	100	-30 ~ +70	560	50 ~ 160	20.0	0.8	20	30
PGM5659D	150	100	-30 ~ +70	560	150 ~ 300	20.0	0.8	20	30

Appendix 11

Technical specification of motion sensor [21]

Product Details

Product Description
SODIAL(R) HC-SR501 Human Sensor Module Pyroelectric Infrared Blue
Color: Blue
Delay time: 5-200S (adjustable) the range is (0.xx second to tens of second)
Block time: 2.5S (default) Can be made a range (0.xx to tens of seconds)
Board Dimensions: 32mm*24mm
Angle Sensor: Less than 100 cone angle
Operation Temp: -15 - +70 ¡æ
Lens size sensor: Diameter:23mm(Default)