© Universiti Tun Hussein Onn Malaysia Publisher's Office

IJIE

http://penerbit.uthm.edu.my/ojs/index.php/ijie

The International Journal of Integrated Engineering

Electrical Consumer Panel with Automated Leakage Current Detector System

Muralindran Mariappan[1*], Hiu Fu Shun[1], Karthigayan Muthukaruppan[2]

[1]Faculty of Engineering,
University Malaysia Sabah, Kota Kinabalu, Sabah, MALAYSIA

[2]PG INTSYS SDN BHD
Petaling Jaya, Selangor, MALAYSIA

*Corresponding Author

DOI: https://doi.org/10.30880/ijie.2020.12.02.006
Received 1 March 2019; Accepted 2 January 2020; Available online 28 February 2020

Abstract: In this research work, automated leakage current detector for electrical consumer panel is carried out. Residual Current Device (RCD) is protection equipment that install in the panel for every building where power supply is required. RCD detects leakage current by monitoring the current in both phase and neutral. Mechanical switch has been developed to trip RCD when there are any differences in between these two current. As RCD tripped, power supply cutoff immediately, the developed automated system can detect the Miniature Circuit Breaker (MCB) consists of leakage current. The system will generate instructions to user to open the particular MCB(s) which consist of leakage current and close the RCD to gain back power supply

Keywords: Residual Current Device, leakage current, power

1. Introduction

A building electrical consumer panel is power supply system which basically consists of Molded Case Circuit Breaker (MCCB), residual current device (RCD), Leakage Circuit Breaker (ELCB) and Miniature Circuit Breaker (MCB). Circuit breakers are specially designed switches that automatically open to stop current in the event of an over current condition (Anuar, M.. 2013; Bakhtiar, S, 2009; Beam., 2010; Craig, T, 2010, Jie, C. M, 2010; Kishore, C. M, 2014; ETCI., 2005; Freschi, F. 2012). RCD and ELCB are electrical devices protect against leakage current in a building wiring system. ELCB is the old name of RCD which operate based on earth leakage current. Both devices will cutoff power supply immediately when leakage current is detected. Cut off power supply of a building may cause all the electrical equipment being breakdown. This project is focused on designing and building a unit Electrical Consumer Panel with a system that can detect leakage current automatically after the RCD is tripped and give instruction to the user to gain back power supply.

2. Literature Review

An electrical consumer panel is a component of an electrical supply system which distributes an electrical power feed into subsidiary circuit. It is also providing a protective fuse or circuit breaker to make sure that each of the circuits is protected. Fuse are designed to open circuits when excessive currents are present further damage to the system that might result if the fuse were not present (Singh, R., et.al, 2013). A single phase electrical consumer panel consists of one or more residual-current devices (RCDs) and several of different rated current Miniature Circuit Breakers (MCBs). A Miniature Circuit Breaker is a electromagnet protective device which is used for feeding electricity to houses,

*Corresponding author: murali@ums.edu.my

railways, industries, etc (Kumar, K. A, 2013). Kelvin Boone in the article titled, "A guide to the selection of electrical cable and breakers", concluded that an MCB can usually act as an ordinary switch as well as over-current circuit breaker to protect against two types of over-currents which is overload and short-circuit.

1.1 Residual Current Device (RCD)

Residual current devices (RCDs) are circuit breakers that are able to automatically open the circuit where they are placed when the residual current due to a circuit failure is beyond a predefined threshold (ETCI., 2005). The formal definition from the British Standard for circuit breakers in BS EN 60947-2 is as follows (Jie, C. M, 2010) :

"A mechanical switching device, capable of making, carrying a breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit condition such as those short circuits."

RCD has been also defined as, in BS 7671, as "A mechanical switching device or association of devices intended to cause the opening of the contacts when the residual current attains a given value under specified conditions."

As the RCD tripped, the power supply to the others MCBs is cutoff due to the common connection and arrangement in a electrical consumer panel. Once the RCD has tripped, it can only close back manually by hand just like the other breakers. Somehow, RCD may just keep tripping if the circuit breaker with current leakage circuit remaining close.

1.2 Earth Leakage Circuit Breaker

An Earth Leakage Circuit Breaker (ELCB) is a device with two earth terminals used to directly detect currents leaking to earth from an installation and disconnect the power (Arduino, 2016). RCD and ELCB are working the same, but the connectivity wise it differs.

The general difference between MCB, MCCB, ELCB, and RCCB", ELCB is the old name and a voltage operated device that is working based on earth leakage current which required an earth connection to detect earth faults that flow back through the main earth wire. RCCB or RCD is the new name that defined itself as a current operated device with the principle of phase current is equal to neutral current in single phase.

1.2.1 RCD Selection Criteria

i. RCD Product Types

RCD is a generic term for a family of products which open automatically in response to a residual current equal to or greater than the rated RCD value. The generic term are Residual Current Circuit Breaker (RCCB), Residual Current Breaker with Over-Current protection (RCBO), Socket outlet RCD (SRCD) and Portable Residual Current Device (PRCD).

RCDs can be differentiated into two: Voltage Independent RCDs (VI) and Voltage Dependent RCDs (VD). VI RCDs are rely on the energy of the residual current to activate the RCD while VD RCDs use the mains supply voltage to power an electronic circuit and tripping mechanism to activate the RCD. Electromechanical RCDs sometimes referred to VI RCDs and Electronic RCDs referred to V. RCDs.

ii. Types of Residual Current

The IEC 60755 standard specifies three different types of RCDs (Medical, R, 2015). RCDs are categorized in term of their ability to sense, properly trip and withstand of different types of residual currents. The three are: Type AC, Type A and Type B. Type AC is the RCDs which can detect full wave AC residual current only. Type A is the RCDs which can detect full wave AC as well as pulsating DC residual currents. Any load incorporating power control devices will produce pulsating DC residual currents. Lastly, Type B is the RCDs which can detect full wave AC, pulsating DC and also pure DC residual currents. This type of RCDs are not commonly used for domestic purposes.

iii. RCD Sensitivity

For every RCD there is normally a choice of residual current sensitivity (tripping current) (Craig, T.,2010). . Sensitivity is all about the level of protection of a RCD afforded. In term of sensitivity, the RCD is divided into two categories: Personal protection and Installation protection. According to BEAM, for personal protection, the RCD operating current is no greater than 30mA to operate to disconnect the circuit within a specified time. This is an additional protection of persons or livestock against direct contact.

On the other hand, RCDs which operate at residual current levels up to 300mA provide the protection for installation. This protection associated with devices that are used to protect against the risk of fire cause by an electric fault.

iv. RCD Operating Times

In termS of processing time taken to respond, RCDs fall into two categories: General Type and S Type.

For General Type RCDs have specified maximum response times but have no specified minimum response time [6]. The response times are stated as IΔN ≤ 300mS and 5 IΔN ≤ 40mS.

For S Type RCDs, as known as delayed types, have specified on both minimum and maximum response times. The response times are stated as follows.

$I_{\Delta N}$ 130mS - 500mS
5 $I_{\Delta N}$ 50 - 150mS

The application of General Type RCDs are commonly for downstream of S Type which refers to proximity to the load, but S Type RCDs are used for upstream of General type. The upstream is refers to the proximity to the origin.

v. RCD Applications

It is important to select a correct device for the particular application. Serious consequences may happened such as electric shock or fire if a wrong RCD is chose to use. According to the regulation in BS7671:2008, table below conclude the examples of particular applications of RCDs.

Table 1 - Example of particular applications of RCDs.

RCD ($I_{\Delta N}$)		Application	Regulation
10mA	i.	Used to protect socket-outlets of laboratory benches in school.	415.1.1
30mA	i.	Mobile electrical appliances used outdoor.	411.3.3(ii) 514.1.1
	ii.	Bathroom or shower location. Must be protected by one or more RCDs not exceeding 30mA.	701.411.3.3
	iii.	Ordinary socket-outlets for general purpose.	411.3.3(i)
100mA	i.	Used when the earth fault loop impedance is too higher for fault protection.	411.5.3
300mA	i.	Fire protection purposes in agriculture	705.422.7

1.2.2 Effects Leakage Current On Human Body (at 50Hz)

Leakage current at certain level would kill human life. Leakage current more than 10mA flows through the human body cause effects such as experience several pain and shock. At the current over 20mA the victim may experience breathing difficulties with asphyxia if current flow is uninterrupted (Craig, 2010). . The effects are more significant at higher value of current and time. At 100mA to 200mA leakage current flowing through human body, victims may experience serious burns and muscular contraction of such a degree that the thoracic muscles constrict the heart (Microchip, 2014).

3. Methodology

Several hypotheses have considered to select suitable methods in designing the automated system.

3.1 AC Current Measurement Approach

This project needed to measure AC current in both Live and Neutral by using ACS712. The ACS712 can measure current in two directions. This component reports with a voltage output when a current measurement has made. The sensitivity of the ACS712ELCTR-05B-T is 185 mV/A.

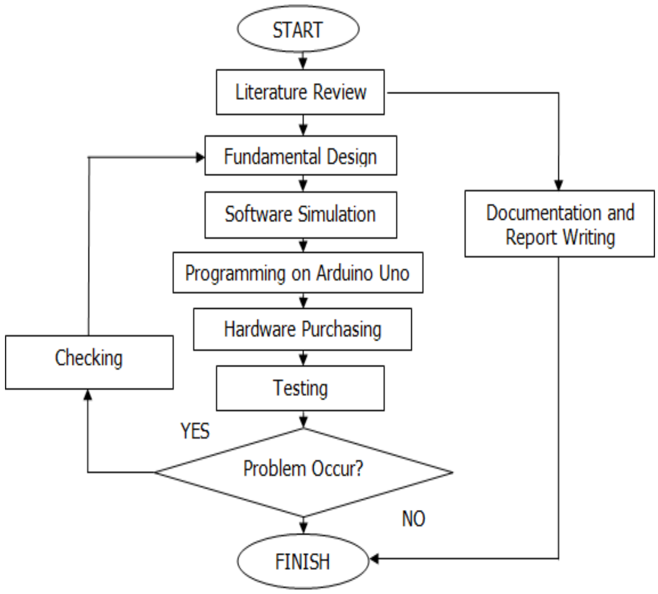

Fig. 1 - Project Flow Chart

3.2 Hardware Configuration

Uno is a microcontroller board based on the ATmega328P. This microcontroller has 14 digital input/ output pins, 6 analog inputs, a 16 Mhz quartz crystal, a USB connection, a power jack, an ICSP header and a reset button (Bakhtiar, S, 2009).

The main purpose of the analog input pins are used to read the analog value from ACS712 current detectors whereas the digital output pins can be used to control the relays as the actuator. Uno board also capable with LCD display function to display the status of the system. The Uno board in this system is power up with an external power supply.

ACS712 is offered with full scale values of 5A, 20A and 30A. It is designed to be capable with microcontrollers such as Arduino. This current sensor measures current and reported with a DC voltage. A +5VDC power supply is need to power up the interface circuit. A 9V battery is the best option for this project. In order to produce a +5VDC power supply, a voltage regulator like LM7805 is needed.

Arduino relay module as the selector has standard interface that can be controlled directly by microcontroller. The 5V 4-Channel Relay interface board as shown as Figure 3.4.4 is equipped with high-current relay with the rated value of AC250V 10A and DC30V 10A. The relay modules are use as the actuator and selector in the system to control the on off of the RCD and MCBs.

3.3 Software Configuration

The software program is use to develop the program algorithm is Arduino Software (IDE). Arduino Software is an open-source prototyping platform based on easy-to-use hardware and software (Arduino, 2016). In this project, a circuit board work with Arduino UNO board used to control the automated system. The program written in Arduino Software will uploaded to the UNO board via the USB connection.

Proteus 8 Professional is the software program to simulate and design the electronic circuit involves in this project. Proteus PCB design combines the schematic capture and ARES PCB layout programs to provide a powerful, integrated and easy to use suite of tool for PCB Design (Proteus, 1988-2016). Proteus Schematic Capture is the core to ensure the designed circuit is workable by simulation before any further steps.

4. Results and Discussions

The system flow chart is initializing followed by checking the RCD condition which indicates that if leakage current has been detected. If RCD is not tripped, the LCD will display the message of "Status: RCD IS RUNNING". However, if the RCD is tripped, the system will continue with activating the detector and followed by health checking on MCB1 and MCB2. The detector is deactivated after MCB health check is done. The system will give instruction to user to open certain MCB(s) consists of leakage current and reclose back the RCD. A manual restart is needed to re-initialize the system.

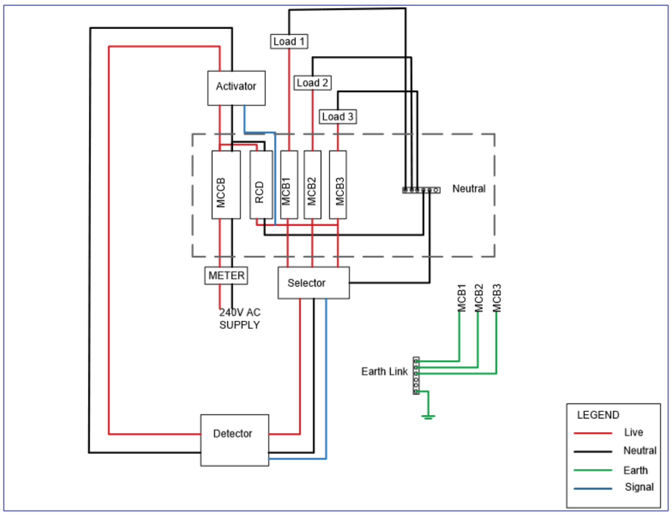

Fig. 2 - Pre-designed block diagram

4.1 Pre-designed Block Diagram

The pre-design of the system consists of Activator, Selector and Detector as shown as Figure above.Selector is controlled by a microcontroller, Arduino Uno. The Selector is operates to feed 230V AC supply to each MCB to allow the detector to verify the circuit health. It has communication with the detector to changeover after a MCB is done with verification. The selector consists of a 230V ac, 5V relay module controlled by the Arduino Uno microcontroller.

Activator is a unit to activate the automated system by receiving a I/O signal from RCD outgoing live cable. Activator is a 230 VAC-to-5 VDC converter, which converts the RCD live outgoing voltage to 5 VDC I/O signal. This I/O signal is to trigger the system when the RCD is tripped.

Detector is another unit function as leakage current detector. It is the idea of the current in live must be equal to the current in neutral to verify the presence of earth leakage or short circuit.

4.2 Simulation Results

i. Measuring AC Current with Voltage Output Display

In the beginning stage of simulation, a single ACS712ELCTR-05B-T is tested by measuring an AC current. The ACS712 is connected with Arduino Uno and a LCD display device. Table 2 below shows the simulation result with varies sensed AC current.

Table 2 Simulation result of output DC voltage

Sensed AC Current (A)	Output DC Voltage (V) Maximum	Minimum
3.93	3.61	1.39
3.47	3.48	1.52
2.94	3.33	1.67
2.46	3.20	1.80
1.94	3.05	1.95
1.56	2.94	2.06
0.99	2.78	2.22
0.53	2.65	2.35
0.00	2.50	2.50

ii. Measuring AC Current Using ACS712

After the peak to peak voltage, Vpp is found, the peak to peak voltage is divided by two to obtain peak voltage, Vp. The peak voltage, Vp is then divided by 1.4142 to yield rms voltage, Vrms. The Vrms is converted to rms current, Irms by the sensitivity of ACS172ELCTR-05B-T, 185 mV/A.

Figure 3 shows the graph of Comparison of Ammeter Reading and ACS712 Current Reading. The error percentage can be calculated as below:

$$\left|\frac{Measurement\ value - exact\ value}{exact\ value}\right| \times 100\% \quad (1)$$

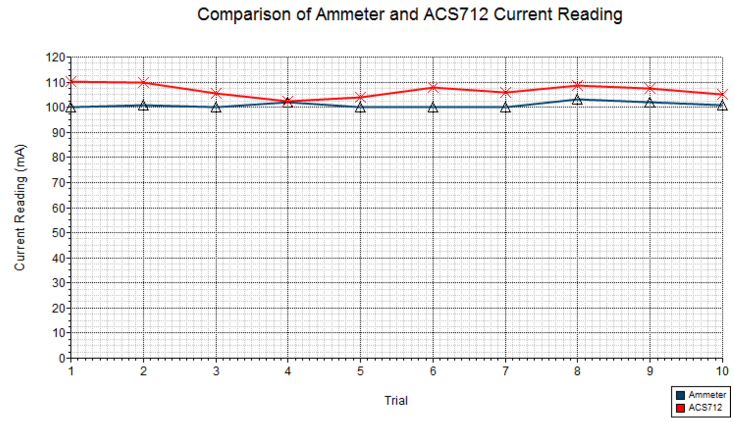

Fig. 3 - Comparison of Ammeter and ACS712 Current Reading

iii. Measuring AC Leakage Current

Two ACS712 current sensors are used to measure the Live current and Neutral current. These two currents are then compared to see the difference between them. Figure 4 shows the graph of Comparison of Ammeter Reading and ACS712 Leakage Current Reading.

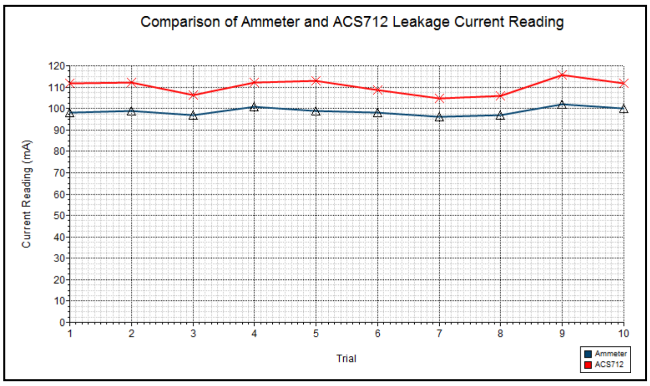

Fig. 4 - Comparison of Ammeter and ACS712 Leakage Current Reading

4.3 Hardware development

Figure 5 shows the overview of the prototype. A 18W fluorescent light is connected to MCB1 whereas two 25W light bulbs are connected to MCB2 in parallel.

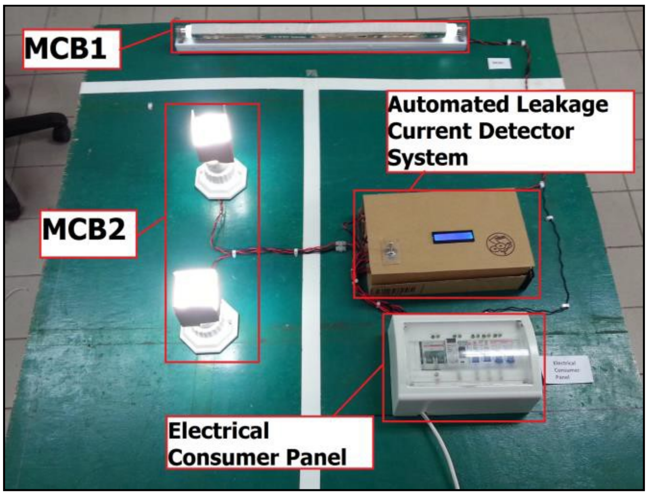

Fig. 5 - Overview of the prototype

4.4 Software development

The software development is started since the simulation stage. The Arduino Uno board programming is the main focus in software development. A flowchart is drawn to represent the programming flow of the written coding.

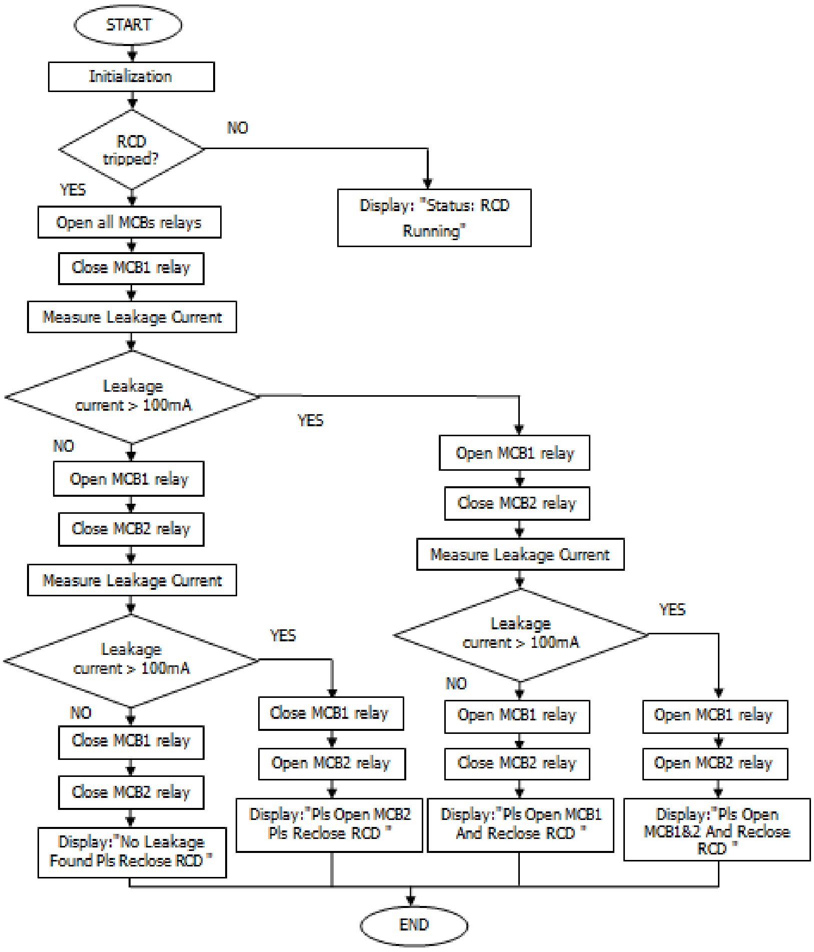

Fig. 6 - Software programming flow

4.5 Discussion and Finding

The ADC in the Uno board has a 10-bit resolution, it allows us to differentiate to 2^10, which is equal to 1024 different levels for an analog input. As mentioned earlier, the current detector ACS712 measuring AC current with an analogy DC voltage output. The analog DC voltage output is read by the Uno board as the resolution as shown below:

5 V / 1024 bit = 4.883x10-3 V/bit

From the datasheet ACS712, the sensitivity is 185 mV/A = 0.185 V/A

(4.883x10-3 V/bit) / (0.185 V/A) = 0.0264 A/bit
= 26.4 mA/bit

From the calculation above, every each bit is represent to 26.4 mA. Since 512-bit is represent zero current reading, the current measured by the ACS712 can be obtained by

current (mA) = (analog_VDC - 512) bit * 26.4 mA/bit

In order to improve the sensitivity of the current detector, the only way is to improve the 10-bit ADC resolution by replacing Uno board with a 32-bit microcomputer, Beagle Bone Black (BBB). If 12-bit ADC resolution is used, the sensitivity of current detector is:

5 V / 4096 bit = 1.221x10-3 V/bit
(1.221x10-3 V/bit) / (0.185 V/A) = 0.0066 A/bit
= 6.6 mA/bit

Every each bit represent only 6.6 mA. The sensitivity has been improved around 75% by using 12-bit ADC resolution.

5. Conclusion

5.1 Overview

An automated system has also been developed which can identify the fault MCB with a control system platform using Arduino Uno Board. Programming is performed on Arduino Uno Board as the control platform of the automated system. The automated system consists of leakage current detector monitoring current up to 100mA. The automated system is designed to give proper instruction to user to reclose RCD and open certain MCB(s) which consists of leakage current. Incase if there is difference in the current, it will automatically end the power supply on the source part.

At the end of the project, a prototype is built in small scale for demonstration purposes. The demonstration shows the full functionality of the work. Further improvement is needed in future time to achieve the complete prototype.

5.2 Future Work

In order to perform in a big scale electrical consumer panel (more than two MCBs), microcontroller is needed to replace with a 32-bit microcomputer, Beagle Bone Black (BBB). BBB has more digital output pins which are required to control numbers of relays of the MCBs. BBB has higher ADC resolution compare to the Arduino Uno Board only has 10-bit resolution. Higher ADC resolution improves the sensitivity of the leakage current detector in thesystem.

Besides, BBB is able to implement radio frequency connection with NRF24L01 and allow to send data online using wifi connection. In other words, user can always view the status of the Automated Electrical Consumer Panel.

Last but not least, a great improvement can be achieved if system can turn on and off the RCD and MCB automatically. Pneumatic system or servo motor can be suggested in the design of the push-pull mechanism.

Acknowledgment

This research was supported by the Faculty of Engineering Project Grant. We thank our colleagues from the Electrical & Electronic Engineering Program who provided insight and expertise that greatly assisted the research.

References

[1] Anuar, M.. (2013).”Automatic Earth Leakage Circuit Breaker with Backup Supply”.Thesis. Unviersiti Tun Hussein Onn, Malaysia.,

[2] Arduino. (2016).Arduino UNO & Genuino UNO. Retrieved from Arduino & Genuino Products: https://www.arduino.cc

[3] Bakhtiar, S. (2009). “Development of Auto-Reclosure Earth Leakage Circuit Breaker (AR-ELCB)”. Thesis, Unviersiti Malaysia Pahang, Malaysia,

[4] Beam.. (2010). “The RCD Handbook - BEAM Guide to Selecction and Application of Residual Current Devices”.

[5] Craig, T. (n.d.). (2010). “ Safe Switchgear Specifications Application of Low Voltage Moulded Case Circuit Breakers”,Terasaki Electric Europe Ltd.

[6] ETCI., (2005). “Guide to the Selection & Use of Residual Current Devices” ET214:2005 Edition 1. Ireland: Electro-Technical Council of Ireland Limited,

[7] Freschi, F. (2012) “High frequency behaviour of residual current devices”. *IEEE Transactions Power Deliviery, 27 n.3*, 1629-1635.

[8] Jie, C. M,(2010) Intelligent Earth Leakage Circuit Breaker,

[9] Kishore, C. M, (2014). “Concept And Working Of Different Types Of Fuses - Protection From Short Circuit Damages - A Bird's Eye View”, *IOSR Journal of Electrcal and Electronics Engineer (IORS-JEEE), 9*(5 Ver. 1), 44-49.

[10] Kumar, K. A. (2013). *Guidance on Proper Residual Current Device Selection for Solar Inverters*.

[11] Medical, R. (2015). A Practical Guide to IEC601.

[12] Microchip, (2014). *MPL ThesisAB X*. Retrieved from microchip: http://www.microchip.com/pagehandler/en-us/family/mplabx/

[13] Proteus. (2016) *roteus PCB Design Packages*. Retrieved from Labcenter Electronics: http://www.labcenter.com/products/pcb/pcb_overview.cfm

[14] Singh, R., & Singh, B (2013). “Evalution and Calibration of Miniature Circuit Breaker”. *Internationnal Journal of Computers & Technology, 4 No. 1*.

[15] Tarzimi, M. (2009). “Development of Earth Leakage Circuit Breaker with an Auto Re-closer Unit”, Thesis, University Malaysia Pahang, Malaysia,

[16] Wiles, J. (1998) (*Focusing On Fuses.* Retrieved from Home Power Magazine #671998). www.nmsu.edu_~tdi_pdf-resources_cc67