# ANALYSIS OF EARTH LEAKAGE CIRCUIT BREAKER (ELCB) NUISANCE TRIPPING DUE TO EARTHING RESISTANCE VALUE

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"I hereby declare that I have read through this report entitle *"Analysis of Earth Leakage Circuit Breaker (ELCB) Nuisance Tripping due to Earthing Resistance Value"* and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering"

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| Signature | : | ………………………… |
| Supervisor's Name | : | Dr. Farhan Bin Hanaffi |
| Date | : | ………………………… |

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**A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering**



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**JUNE 2018**

I declare that this report entitled *"Analysis of Earth Leakage Circuit Breaker (ELCB) Nuisance Tripping due to Earthing Resistance Value"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : …………………………

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Date : …………………………

To my beloved parents and my siblings

*Thanks for the endless love, kindness, support and encouragement towards me upon completing this project.*

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# ABSTARCT

Protection against leakage current is vital in low voltage system (LV) to protect humans and equipment from electric shocks and fire risk. Residual Current Device (RCD) is a protective device, which is more reliable version of earth leakage circuit breaker (ELCB) used for protection against small leakage current. This device is a current operated device which designed to disconnect the main power supply circuit whenever fault is occurred, where the measured value of phase current and neutral current is different. Also, RCD is made to be very sensitive to the residual current in order to protect equipment and personnel effectively. However, this device is prone to tripping under the non-fault condition due to the high sensitivity and some cases make the device delay to operate. This inappropriate tripping also known as nuisance tripping, where normally the nuisance tripping of RCD is influenced by the improper earthing system, high frequency from power supplied and presence of harmonics in signal waveforms. Besides, the use of resistive and inductive loads changed the behavior of RCD as the high-power consumption delayed the operation of RCD when earth fault current occurred. Hereafter, this report is provided to investigate the residual operating current and operating time of RCD behavior towards the poor earthing resistance value, where the value of resistance is higher than the standard buildings installation. The sensitivity of RCD sample used in this research is 30mA type-AC. The voltage and frequency of circuit tested for RCD sample followed the standard buildings requirement which is 240V with frequency of 50Hz. Meanwhile, the high earthing resistance value is chosen from 1kΩ to 3.5kΩ for this research. The residual operating current of RCD is measured by using current probe (Tektronix A622) and oscilloscope while the operating time of RCD is measured by using RCD Tester (KYORITSU Model 5402D). The results show earthing system with high resistance value affect the operating time of RCD, thus lead to nuisance tripping.

# ABSTRAK

Perlindungan terhadap kebocoran arus adalah penting dalam sistem voltan rendah untuk melindungi manusia dan peralatan dari kejutan elektrik dan risiko kebakaran. Peranti Arus Baki (PAB) adalah peranti perlindungan yang merupakan versi Pemutus Arus Bocor ke Bumi (PABB) yang lebih dipercayai. Ia digunakan untuk perlindungan terhadap arus kebocoran kecil. Peranti ini adalah peranti kendalian arus yang direka untuk memutuskan litar bekalan kuasa utama setiap kali berlaku kesalahan bumi, di mana ukuran nilai arus fasa dan arus neutral adalah berbeza. PAB juga direka sangat sensitif kepada arus baki untuk melindungi peralatan dan pengguna dengan berkesan. Bagaimanapun, peranti ini mudah tersandung kepada keadaan yang tidak salah, disebabkan kepekaannya yang tinggi dan terdapat beberapa kes membuatkan peranti ini lewat berkendali. Keadaan mudah tersandung ini dikenali juga sebagai gangguan tersandung, di mana biasanya hal ini dipengaruhi oleh sistem pembumian yang tidak wajar, frekuensi tinggi dari kuasa yang dibekalkan dan kehadiran harmonik dalam bentuk gelombang isyarat. Selain itu, penggunaan beban rintangan dan beban induktif juga mengubah tingkah laku PAB kerana penggunaan kuasa yang tinggi melewatkan kendalian PAB apabila berlaku kesalahan arus bumi. Selanjutnya, laporan ini disediakan untuk menyiasat arus kendalian baki dan masa kendalian PAB terhadap nilai rintangan bumi yang tinggi daripada pemasangan piawai bangunan. Kepekaan sampel PAB yang digunakan dalam kajian ini ialah 30mA jenis-AC. Voltan dan frekuensi litar yang diuji untuk sampel PAB adalah mengikut keperluan piawaian bangunan iaitu 240V beserta frekuensi 50Hz. Sementara itu, nilai rintangan bumi yang tinggi dipilih untuk kajian ini adalah dari 1kΩ hingga 3.5kΩ. Arus kendalian baki PAB diukur dengan menggunakan alatan arus (Tektronix A622) dan osiloskop. Manakala masa kendalian PAB diukur dengan menggunakan penguji PAB (KYORITSU Model 5402D). Keputusan menunjukkan sistem pembumian dengan nilai rintangan yang tinggi menjejaskan masa kendalian PAB, sehingga mengakibatkan gangguan tersandung.

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# LIST OF ABBREVIATIONS

| | | |
|---|---|---|
| AC | – | alternating current |
| CB | – | Circuit Breaker |
| ELCB | – | Earth Leakage Circuit Breaker |
| GFCI | – | Ground Fault Circuit Interrupter |
| k | – | kilo |
| LV | – | Low Voltage |
| ms | – | mili second |
| PAB | – | Pemutus Arus Baki |
| PABB | – | Pemutus Arus Bocor ke Bumi |
| RCD | – | Residual Current Device |
| SLG | – | Single-Line-Ground |
| V | – | Voltage |
| Ω | – | Ohms |
| ° | – | degree |

# CHAPTER 1

# INTRODUCTION

## 1.1 Research Background

In low voltage (LV) electrical installation, the protection must be provided to ensure the safety for humans and equipment. The most often meant is the over-current protection that must be activated in case of exceedingly high currents in an installation. This protection can be achieved using safety fuses or circuit breakers. However, in order to protect against leakage current, which the current is too small to trip an over-current device, earth leakage circuit breakers (ELCBs) is used. This circuit breaker is used to protect humans from electric shock hazards and fire caused by earth faults. Typically, ELCBs are classified by voltage operated devices and current operated devices, where the current operated devices, also known as residual current devices is more preferable in new buildings installation due to reliability [1].



RCDs which the application is required by the LV electrical installations standard [2] is used to disconnect the circuit when earth fault occur. These devices consist of residual current transformer and electromechanical relay as the main components will open the circuit fast enough to diminish the damage caused by electric shock, thereby protect people effectively against such shocks. The phase and neutral current said to be balanced in normal condition, where the RCDs will not operate. In the meantime, RCDs is operated when there is different between phase current value and neutral current value. The difference in current is caused by fault that happen in the system. At the fault condition, the mechanism in electromechanical relay will triggered and trip the coil of RCDs whenever the residual current reaches the RCDs limit.

For LV system, the frequency from power source supplied shall not more than rated and in sinusoidal waveform to certify the good operation of RCDs. Besides, earthing system must be appropriate according to the standards [3], so that the RCDs will be operated in a correct manner. Therefore, the protection against fault condition that give harmful effect towards human body and equipment can be provided.

## 1.2 Motivation

Nuisance tripping of residual current devices (RCDs) are frequently related to the presence of loads, especially loads with high power consumption. Moreover, without proper earthing system, neutral-to-earth voltage magnitude will become higher than rated value. Consequently, the protection against electric shock will be ineffective.

## 1.3 Problem Statement



In low voltage (LV) distribution system, the protection against leakage current and lightning strikes are essential in any electrical installation to ensure the safety for humans as well for the equipment. Therefore, residual current devices (RCDs) are mostly used to provide the protection for electrical installation in buildings area. These devices are made to be very sensitive to the earth fault current in order to protect the equipment and personnel effectively. However, because of the high sensitivity, RCDs are likely to trip under the non-fault condition and some cases make the device to delay in operation, these also known as nuisance tripping. During nuisance tripping, the protection against electric shock will become ineffective since the disconnection of supply is not occur within the time required. This may cause harmful effects on humans and equipment. Nuisance tripping occur may due to poor earthing systems, where the earthing resistance value is high. The higher the earthing resistance, the higher the possibility of RCD to take time to trigger the coil when earth fault is presented. Also, the used of different types of loads with different power consumption might cause the RCD to change its behavior, considering that the operation is delayed when the power consumption is higher. Hence, it is very important to avoid nuisance tripping since the longest the magnitude of leakage currents flow may cause disastrous effects toward equipment and people who touched the conductor live parts.

## 1.4 Objectives

The objectives for study the earth leakage circuit breaker (ELCB) nuisance tripping due to earthing resistance value are:

- To investigate the residual operating current of residual current device (RCD) due to different earthing resistance value.
- To investigate the operating time of residual current device (RCD) due to different earthing resistance value.
- To investigate the effect of loads towards residual current device (RCD) operating time.



## 1.5 Scopes of Study

The scopes of analysis the earth leakage circuit breaker (ELCB) nuisance tripping due to earthing resistance value are:

- Design hardware of single phase installations with RCD following the Standard MS IEC 60364:2003 ‘Electrical Installation of Building’ at UTeM Electrical Wiring Laboratory.
- TT-system earthing with rated voltage of 240V is used.
- RCD (type-AC) with sensitivity of 30mA is selected as research sample.
- Resistive and inductive loads with different earthing resistance values are used in measurements of both residual operating current and operating time of RCD sample.

- Earthing resistance value is represented by using 10W power resistors with resistance value varied from 1kΩ to 3.5kΩ.
- The residual operating current of RCD is measured using current probe and oscilloscope.
- The operating time of RCD is measured using RCD Tester.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Overview

This chapter will be discussed about several studies that have been done regarding this research earlier. The importance of protection in low voltage system are explained, where there are two types of protection, protection against over-current and protection against electric shock. The protective device against electric shock which is earth leakage current circuit breaker (ELCB) is being deliberated. ELCB is categories in voltage operated device, and current operated device as known as residual current device (RCD). RCD is more preferable in new buildings installation but often leads to nuisance tripping due to some factors. In this chapter, the factors that caused the nuisance tripping will be discussed based on the previous studies, such as poor earthing which high value of earthing resistance, high frequency and presence of harmonics.



## 2.2 Importance of Low Voltage Protection

The most essential in low voltage electrical installation is the protection for the equipment used. The protection can be either protect from overcurrent or protect against electric shock which can be harmful effect of electric current on human body. The overcurrent protection can be pull off using safety fuses or circuit breakers, where the task of protection is to switch out faulty circuits, and thereby protect the loads that are connected to those circuits, thus preventing the consequences of thermal overloading of conductors and fire risk. Meanwhile, the protection against electric shock can be classified as protection against direct contact and protection against indirect contact, where direct contact means when a person is directly touches an energized unprotected part of device, while indirect contact means when a person touches normally dead part of an electrical equipment which has become live due to the insulation failure. For these protections, residual current circuit breaker that detect small earth fault current is used. Therefore, can prevent from disastrous impact towards human body and fire risk.

## 2.3 Circuit Breaker

Circuit breaker is a mechanical switching device used to complete, maintain, and interrupt currents flowing in a circuit during normal operating or faulted conditions. Fault current can cause danger to humans and equipment. Its due to thermal or mechanical effects occur in the circuit or related connection. Hence, the circuit breaker should operate for any fault current flowing in the circuit. The breaking capacity for breaker should be greater than or equal to the possible short-circuit current or earth fault current at the point where the breaker is installed to satisfy the circuit breakers condition. There are some specifications a circuit breaker should fulfil as a mechanical switching device [4]:

- Circuit breaker should be capable of being safely closed in on any load current or short-circuit current within the making capacity of the device.
- Circuit breaker should safely open any current that may flow through it up to the breaking capacity of the device.
- Circuit breaker should automatically interrupt the flow of abnormal currents up to the breaking capacity of the device.
- Circuit breaker should be able to carry continuously any current up to the rated current of the device.

The current that a circuit breaker can carry continuously, typically for a duration of more than eight hours called the rated current ($I_N$). When the ambient temperature is between -5°C to 40°C, the rated current requires not to make a temperature rise in excess of the specified values. The different parts of a circuit breaker specified by different temperature rise limits. According to standard IEC 60947 [5] and IEC 60898 [6], if the current passing through a circuit breaker is 105% to 113% of its rated current, the circuit breaker will not operate (trip). Meanwhile, if the current passing through it is 130% to 145% of the rated current, it will take one to two hours to trip.

A circuit breaker commonly installed in a metal-enclosed cubicle for dead-front or draw out type of construction. Metal barriers between circuit breakers and busbars provide increased safety in service. Also, generally it be equipped with auxiliary contact, alarm contacts, push-button control, position indicator, and key interlock [7]. Table 2.1 shows the different types of circuit breaker and their characteristics. The types of circuit breaker such as Miniature Circuit Breaker (MCB), Moulded Case Circuit Breaker (MCCB), Air Circuit Breaker (ACB), Vacuum Circuit Breaker (VCB), Earth Leakage Circuit Breaker (ELCB), and Residual Current Device (RCD) or Residual Current Circuit Breaker with or without overload have different function and characteristics. As example, MCB and MCCB are used to protect against the short circuit and overload currents, while ELCB and RCD or RCCB used to protect against small leakage current that can cause electric shock.

## 2.4 Earth Leakage Current



The current flowing from the conductive parts of the installation to earth in the absence of an insulation fault is known as earth leakage (residual) current. This current could flow from any conductive part or the surface of non-conductive part to earth such as a human body if a conductive path was available, especially when there is no earthing connection in the installation. Generally, an earthing system is included in electrical installation to provide the protection against shock hazard if there is an insulation failure. The earthing system involved an earthing conductor that bonds the equipment to the earth. If there is fault occur in the insulation between conductor (line) and touchable conductive parts, the voltage is shifted to earth and the resulting current flow will cause a fuse to blow or trip a circuit breaker in order to prevent from shock hazard. Even if there is no insulation failure, there is possible of shock hazard to occur if the interruption of the leakage current currents flowing through the earthing conductor happens, such as someone touching the equipment without earthing system and equipment with earthing system at the same time.

Leakage current split in two different types, AC leakage current and DC leakage current. DC leakage current usually applies only to end-product equipment, not to power supplies, while AC leakage current is caused by a parallel combination of capacitance and DC resistance between a voltage source (AC line) and the earth conductive parts of the equipment. Usually, different from AC impedance of various parallel capacitances, the leakage current caused by the DC resistance is insignificant. The current flowing in earth conductor is measured by connecting a specially designed meter for measuring leakage current in series with the earthing connection. For very low leakage currents, a network consisting of either a resistor or a resistor and capacitor combination is used replacing the meter. Then, voltage drop across the network is measured using sensitive AC voltmeter.

## 2.5 Earth Leakage Circuit Breaker (ELCB)

Earth Leakage Circuit Breaker (ELCB) is one of the types of circuit breakers besides Moulded Case Circuit Breaker (MCCB), Vacuum Circuit Breaker (VCB), Oil Circuit Breaker (OCB) and Residual Current Device (RCD) or Residual Current Circuit Breaker (RCCB). In contrast with other devices which mostly used to protect from overcurrent, this ELCB is used in electrical installation to protect equipment and protect humans from electric shock hazards and fire caused by earth faults that too small to trip an overcurrent device.

Table 2.1: Types of circuit breaker and its characteristics

| Types of Circuit Breaker | Characteristics |
|---|---|
| Miniature Circuit Breaker (MCB) | • Electromechanical device which protects electric circuit from an overcurrent, that may affect from short circuit, overload or imperfect design.<br>• Rated current not more than 100A.<br>• Trip characteristics normally not adjustable.<br>• Thermal or thermal-magnetic operation. |
| Moulded Case Circuit Breaker (MCCB) | • Electromechanical device which protects electric circuit from short circuit and overcurrent.<br>• Rated current up to 1000A.<br>• Trip current may be adjustable.<br>• Thermal or thermal-magnetic operation. |
| Air Circuit Breaker (ACB) | • Breakers often used for main power distribution in large industrial plant, where the breakers are arranged in draw-out enclosures for ease of maintenance.<br>• Rated current up to 10kA.<br>• Trip characteristics often fully adjustable including configurable trip threshold and delays.<br>• Electronically controlled or microprocessor controlled. |
| Vacuum Circuit Breaker (VCB) | • Breakers interrupt the arc in a vacuum bottle.<br>• Rated current up to 3000A<br>• Breakers can also be applied at up to 35kV |
| Earth Leakage Circuit Breaker (ELCB) | • Breakers used to protect the circuit from the electrical leakage.<br>• Notices fault currents from live to the earth wire inside the installation it protects.<br>• Connects the phase, earth wire and neutral.<br>• The working of this circuit depends on current leakage. |

| | |
|---|---|
| Residual Current Device (RCD) or Residual Current Circuit Breaker (RCCB) | • Breakers trip the circuit when there is fault current.<br>• The amount of current flows through the phase (line) should return through neutral. Any unbalanced between those two currents, RCD will trip the circuit.<br>• Most widely used are rated residual current of 30mA and 100mA, which used for electric shock protection.<br>• Rated residual current of 300mA or 500mA used for only fire protection is required.<br>• Do not offer protection against current overloads, overheating and live-neutral shocks. |
| Residual Circuit Breaker with Overload (RCBO) | • The combination of MCB and RCCB.<br>• The principals are the same as MCB and RCCB, but more styles of disconnection are fitted into one package. |

Fundamentally, ELCBs are categories in two types which are voltage operated devices and current operated devices. Voltage operated ELCB operates at a detected potential of around 50V to open a main breaker and isolate the supply from the protected zones. In newer domestic wiring, 50V is still considered as safe voltage for alternating current. So, the voltage operated ELCB is not being used now since it operates at 50V. Meanwhile, current operated ELCB which usually known as residual current device (RCD) is more preferable to be installed in premises due to reliability. The method of operation used is differs from the other one but the function is same, which protects against earth leakage [1].

Table 2.2 below shows the different between voltage operated ELCB and RCD. ELCB is the old name and frequently refers as voltage operated devices that are no longer available in new buildings installations, while RCD is the new name that requires current operated. The different between ELCB and RCD can be recognized by looking for their connectivity, where ELCB is connected with the phase, neutral and earth wire, while RCD connects only the phase and neutral. Besides, the RCD is able to detect any fault current even in equipment without an earth of its own, whereas ELCB is able to detect only earth faults that flow back to the main earth wire. This is because the RCD working based on the difference of phase and neutral current, which normally phase current is equal to the neutral current in single-phase system. If the currents are different, the RCD shall operate. In contrast with ELCB which is working based on earth leakage current.



Table 2.2: Different between ELCB and RCD

| ELCB | RCD |
|---|---|
| Referred as voltage operated devices and no longer available. | Referred as current operated devices. |
| The circuit breaker connects the phase, neutral and earth wire. | The circuit breaker connects only the phase and neutral. |
| The ability is to detect earth faults that flow back to the main earth wire. | The ability is to detect any fault current. |
| Working based on earth leakage current. | Working based on the difference of phase and neutral current, which normally phase current is equal to the neutral current in single-phase system. Hence, circuit breaker tripped when both currents are different. |

## 2.6 Principle Operation of Residual Current Devices

RCDs are essential equipment in modern electrical installation as their application is required by the low voltage (LV) electrical installations standard [2]. These devices also known as residual current circuit breakers (RCCBs), or ground-fault circuit interrupters (GFCIs) [8]. RCDs are designed to disconnect the circuit where they are installed when the earth fault occur. The residual current ($I_{\Delta}$) is the vector sum of the instantaneous values of the current flowing in the main circuit of RCD which expressed as r.m.s value. Also, these devices open the circuit quickly enough to diminish the damage caused by electrical shock, hence protect people effectively against such shocks. The use of RCDs are necessary in some cases such requirements for special installation or locations like swimming pool area, medical locations, earthing requirement, and construction and demolition site installations [9].

Main components of RCDs commonly include a residual current transformer (CT) and electromechanical relay (ER), where both responsible for appropriate detection of a residual current and the tripping. Figure 2.1 shows an illustrative configuration of typically used single-phase RCDs. The primary winding of CT consists of phase and neutral line in opposite direction. The CT produces a secondary current ($I_s$) by transforming a residual current to the secondary side. Then, secondary current flows across the ER contains with a permanent magnet, which keeps the moving armature on the yoke, and the spring pulls the moving armature in the opposite direction [10].

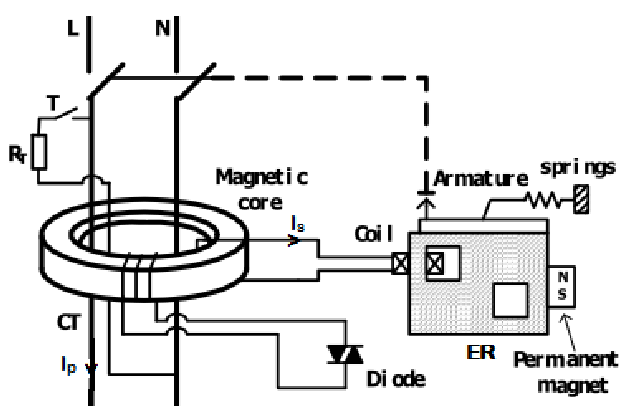



Figure 2.1: An illustrative configuration of RCDs

In normal conditions, when the phase and the neutral current are balanced, the magnetic flux generated is cancelled out in the CT. Thus, the moving armature is kept on the yoke and the main circuit is maintained closed. If an earth fault occurred, the phase and the neutral current imbalanced induces an electromotive force in the secondary circuit. This current transformed, amplifies the magnetic flux of the permanent magnet in one half-wave, but reduces in the other half-wave. When the residual current reaches a predetermined level, the spring pulls the moving armature of ER away as shown in Figure 2.2 due to the magnetic flux produced by that current ($\phi_{I_s}$) is high enough to reduce the magnetic flux produced by permanent magnet ($\phi_{N-S}$), and RCD opens the main circuit [11].

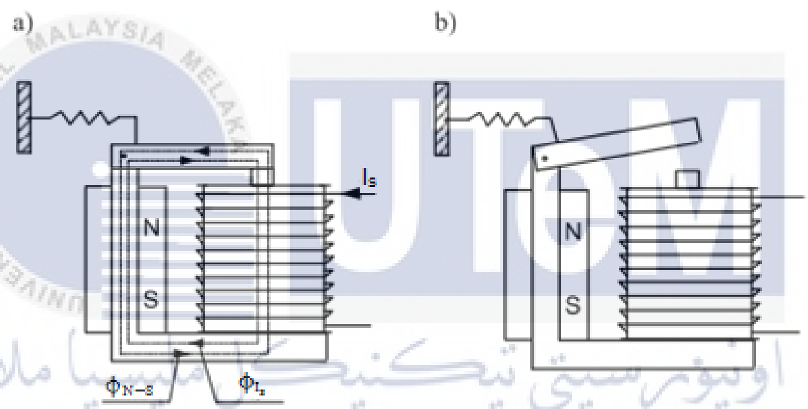



Figure 2.2: Electromechanical relay ER of residual current devices;
a) before tripping, b) after tripping.

According to the standards IEC 61008-1 [12] and MS 60755 [13], RCDs shall operate if the residual current is equal to or greater than $I_{\Delta n}$, while they will not operate if the residual current is equal to or less than $0.5I_{\Delta n}$, where $I_{\Delta n}$ is the rated residual operating current. Correspondingly, the standards state the typical standard values of rated residual operating current, which comprise 6mA, 10mA, 30mA, 300mA and 500mA. There are three different types of RCDs with respect to the sensitivity to the earth fault current waveform, which are AC-type, A-type and B-type.

- AC – for residual sinusoidal alternating currents,
- A – for residual sinusoidal alternating currents and pulsating direct residual currents,
- B – for residual sinusoidal alternating currents up to 1000Hz, pulsating direct residual currents and smooth direct residual current.

RCD type AC for which tripping is ensured for residual sinusoidal alternating currents, whether suddenly applied or slowly rising. Besides, RCD type A for which tripping is ensured for residual sinusoidal alternating currents and residual operating pulsating direct currents, whether suddenly applied or slowly rising. Last, RCD type B for which tripping is ensured for residual sinusoidal alternating currents up to 1000Hz, residual operating pulsating direct currents and residual smooth direct currents whether suddenly applied or slowly rising. The most popular and widely used in LV system are AC-type and A-type [14].

The standard values of maximum break time for earth fault currents (r.m.s values) for general type of RCDs given by IEC 61008-1 [12] is listed in Table 2.3. For any rated current value of RCD type-AC with sensitivity of 30mA, the maximum break time shall equal to 0.3s when the earth fault current is equal to the rated residual operating current (sensitivity of RCD). The earth fault current with two times the rated residual operating current shall operates at maximum break time of 0.15s and the earth fault current more than that shall operates within 0.04s.



Table 2.3: Standard values of maximum break time for general type of RCD

| **$I_n$ (A)** | **$I_{\Delta n}$ (A)** | **Standard values of maximum break time (s) in event of earth fault currents (r.m.s values) equal to** | | | |
|---|---|---|---|---|---|
| | | **$I_{\Delta n}$** | **$2I_{\Delta n}$** | **$5I_{\Delta n}$** | **$>5I_{\Delta n}$** |
| Any value | 0.03 | 0.3 | 0.15 | 0.04 | 0.04 |

## 2.7 Nuisance Tripping of RCD

RCDs are designed to disconnect the circuit where they are installed when the residual current due to a circuit failure is beyond a preset limit. However, these devices are usually prone to nuisance tripping that occur due to non-fault conditions such as extraneous earth leakage path, switching transients and supply voltage spikes. In standards IEC 61008 [12] and MS 60755 [13], state that RCDs shall operate if the residual current equal to or greater than $I_{\Delta n}$, while they will not operate if the residual current is equal to or less than $0.5I_{\Delta n}$, where $I_{\Delta n}$ is the rated residual operating current. Additionally, these standards state that maximum values of break time for type-AC of RCD in the event of alternating earth fault current equal to $I_{\Delta n}$ is 300ms. Meanwhile, in Suruhanjaya Tenaga: Guidelines for Electrical Wiring in Residential Building [15], the operating time should be less than 200ms. In the previous research, there are numerous analysis regarding to the nuisance tripping that occur due to many factors. The nuisance tripping mostly caused by these three factors, which are improper earthing system installation, where the earthing value is high, high frequency and harmonics participation.

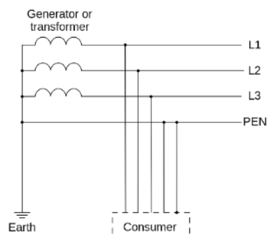
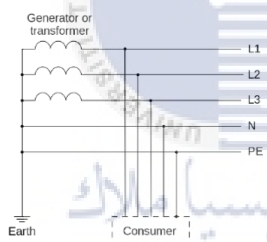
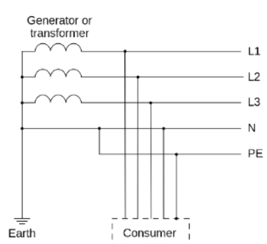
Different experiments have been conducted in order to study the behavior of RCD towards poor earthing system, high frequency and harmonics present which high-order harmonics, low-order harmonics and non-sinusoidal waveform, also the effect of loads. From research [8], [16]–[19] nuisance tripping is occurred caused by the high frequency generated from the power supply. The high frequency affects the sensitivity of RCD, where it was found that the higher the frequency, the higher the level of RCD sensitivity, which also means the RCD becomes insensitive towards high frequency. Besides, findings in [8], [10], [16]–[20] state that the presence of harmonics affect the sensitivity of RCD. The RCD becomes less sensitive if there is presence of high amplitude of high order harmonic, while more sensitive with low amplitude of high order harmonic. The presence of low order harmonic such as $3^{rd}$ order with angle also increase the RCD sensitivity. Moreover, nuisance tripping of RCD has been traced to high level of residual currents through electronic loads present in the power supply system [21]. The connections and disconnections of loads produced high frequency voltage transients in RCD tripping that will makes RCD insensitive [19], [22]. Thus, the loads influence the RCD operation which caused the nuisance tripping. In addition, poor earthing which have high earthing resistance values influence the operation of RCD, especially operating time. The higher the earthing resistance value, the longer the time for RCD to operate [23], [24]. Hence, leads to nuisance tripping. Overall, these factors mentioned above will trigger the RCD to nuisance tripping. However, there are not much stress on nuisance tripping regarding the improper earthing system effect. Albeit, this effect gives the same disastrous damage towards equipment as well to person touched the live part when earth fault occurred. Thus, the factor of improper earthing system will be discussed more in the next section.

## 2.8 Earthing System

Generally, the main function of earthing is to allow a system or equipment to be disconnect from the supply in order to avoid the effects of excessive currents produced under earth fault conditions. Most of the electrical equipment should be earthing, so that the protective gear can operates effectively when the earth fault currents occur. Otherwise, it will cause damage to property and danger to life through shock due to installation metalwork being maintained at a dangerous potential relative to earth [3].

BS 7671 has adopted the internationally agreed classification of low voltage system types as shows in Table 2.4. A TN system has one or more points of the source of energy directly earthed and the exposed and extraneous-conductive-parts of the installation are connected only by means of protective conductors to the earthed point(s) of the source. This system is subdivided into TN-C system where the neutral and protective conductor are combined in a single conductor throughout the system, TN-S system where there are separate neutral and protective conductors throughout the system and TN-C-S system where the neutral and protective conductor are combined in a single conductor but only in a part of a system. Meanwhile, a TT system has one or more points of the source of energy directly earthed and the exposed and extraneous-conductive-parts of the installation are connected to a local earth electrode or electrodes that are electrically independent of the source earth(s). Next, an IT system has the source either unearthed or earthed through a high impedance and the exposed-conductive-parts of the installation are connected to an electrically independent earth electrode.

Table 2.4: The earthing system types and characteristics

| Type of System | Characteristics of System Types |
|---|---|
| *TN-C system*<br><br>Figure 2.3: Illustration of TN-C system | • The neutral and protective earth conductor functions are combined both in the supply and installation, also known as PEN conductor.<br>• The exposed-conductive-parts of the installation are connected by PEN back to the source.<br>• PEN provides a return path both for the neutral conductor current to flow under normal conditions and for the earth fault current to flow for the duration of a line-to-earth fault current occurring in the installation. |
| *TN-S system*<br><br>Figure 2.4: Illustration of TN-S system | • The neutral conductor and the protective earth conductor (PE) functions are separate both in the supply and in the installation.<br>• The exposed-conductive-parts of the installation are connected by the PE back to the source.<br>• PE provides a return path for earth current to flow for the duration of a line-to-earth fault current occurring in the installation. |
| *TN-C-S system*<br><br>Figure 2.5: Illustration of TN-C-S system | • The neutral and PE functions are combined in the supply and separate in the installation.<br>• The exposed-conductive-parts of the installation are connected by this separate PE in the installation to the combined neutral and PE of the supply back to the source.<br>• This installation protective conductor provides a return path for earth fault current to flow for the duration of line-to-earth fault occurring in the installation.<br>• The combined neutral and PE of the supply provides a return path both for the neutral conductor current to flow under normal conditions and for the earth fault current to flow for the duration of a line-to-earth fault occurring in the installation. |

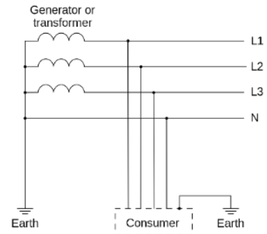
<table>
<tr>
<td>TT system<br>


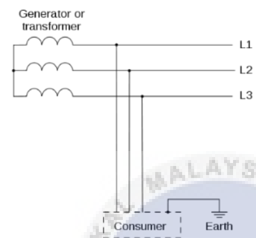
Figure 2.6:Illustration of TT system</td>
<td>
<ul>
<li>The exposed-conductive-parts of the installation are connected by a protective conductor in the installation to the main earth terminal then to the installation earth electrode which is electrically independent of the source earth.</li>
<li>These components of the installation provide a path for the earth fault current to flow back to the source during a line-to-earth fault in the installation.</li>
</ul>
</td>
</tr>
<tr>
<td>IT system<br>


Figure 2.7: Illustration of IT system</td>
<td>
<ul>
<li>The exposed-conductive-parts of the installation are connected by a protective conductor in the installation to the main earth terminal then to the installation earth electrode which is electrically independent of the source earth.</li>
<li>These components of the installation provide a path for the earth fault current to flow back to the source during a line-to-earth fault in the installation.</li>
</ul>
</td>
</tr>
</table>

### 2.8.1 Importance of Earthing System and Factor Involved in Effective Earthing

Earthing system shall properly design and installed to provide means to carry electric currents into the earth under normal conditions without exceeding any operating and equipment limits or adversely affecting continuity of service. Also, a safe earthing system is to assure that a person in the area of earthed facilities is protected to the danger of critical electric shock. The improper earthing system may cause the disastrous effect towards human body when earth leakage current passing through the body, besides damage the equipment.

Besides, earthing system connection should have a resistance not greater than the design value and should be capable of carrying the expected maximum fault current. Therefore, various factor need to be considered which affect the resistance to earth and fault current capacity of the buried conductor, designated the earth electrode. The factors involved include the size and shape of the earth conductor, the soil in which it is buried and the connection of the system to it.

### 2.8.2 Effect of Resistance Value to Earth on RCD

The requirements for smaller distributions stated in IEEE Std 80-2000 [25], the usually acceptable range is from 1Ω to 5Ω depending on the local conditions. For RCD with sensitivity of 30mA, the resistance of the earth connection should not be greater than 100Ω since a resistance in excess of this value may be unstable and therefore be unsuitable [3]. From previous research, earthing system with high resistance values influence the operation of RCD, especially the operating time. The operations of RCD will take longer time to energize the trip coil after receiving signal as the grounding resistance increases. The delay in operation of RCD can have terrible effects on the equipment when earth fault leakage occurs [24]. Thus, it is important to ensure the proper earthing with low resistance to provide good operation of protection devices during earth fault. Proper grounding can minimize noise interferences in electronic, control and instrumentation, thus provides a high operational performance of the equipment [23].



## 2.9 Impact of Delay Operation of RCD

Magnitude and duration is one of factors that affect an electric current flowing through the vitals parts of a human body. Ventricular fibrillation which a heart condition ensuing in immediate arrest of blood circulation is the most dangerous consequence of such an exposure. According to IEC 60479-1, in order of increasing current magnitude, threshold perception, muscular contraction, unconsciousness, fibrillation of the heart, respiratory nerve blockage, and burning are the most common physiological effects of electric current on the body. Table 2.5 listed the range of current that possible pass through a person body and its effects when earth fault current occurs [25]. Generally, for current 1mA is familiar as the threshold of perception which a person able to sense a small tingling sensation in hands or fingertips at this current magnitude that passing through. Meanwhile, currents of 1 to 6mA known as termed let-go currents, normally when a person hold an energize object of these currents still can control his muscles and release it, though these currents are unpleasant to sustain. In the range of 9 to 25mA, it is difficult or impossible to release energized object grasped by the hand and these currents may be painful to handle. Also, these higher currents muscular contraction could make a person difficult to breath. Unless the contraction is very dangerous and breathing is stopped for a long time, these effects are not long-lasting and vanish when current is interrupted. The worst case is the current in range of 60 to 100mA, which it reached that ventricular fibrillation, the heart may stop, or inhibition of respiration might occur and cause injury or death. Therefore, it is very important to carefully designed the earthing system to keep the range value of shock currents lowest, so the injury or death may be avoided.

Table 2.5: The effect of current range passing through body

| **Range of Current Passing through Body** | **Effect of Current Range** |
|---|---|
| 1mA | • A person touched this current sense a small tingling sensation in hands or fingertips. |
| 1mA – 6mA | • Unpleasant to sustain.<br>• Do not harm the ability of a person holding an energized object to control his muscles and release it. |
| 9mA – 25mA | • The touched currents may be painful.<br>• Difficult or impossible to release energized object.<br>• High currents muscular contractions could make difficult to breath.<br>• Effects are temporary and disappear if the current is interrupted. |
| 60mA – 100mA | • Reached ventricular fibrillation, stoppage of the heart.<br>• Might occurred the inhibition of respiration and cause injury or death. |

Moreover, the permissible current value may be based on the clearing time of protective devices. The fast clearing of earth faults is advantageous for it will reduce the probability of exposure to electric shock as well as reduced the chance of severe injury or death if the duration of a current flow through body is very short-term. In previous research by U. G. Biegelmeier and W. R. Lee [26], provides evidence that when the time of current passing through body is approaching the heartbeat period, a human heart becomes increasingly prone to ventricular fibrillation. However, the danger is much smaller if the time of exposure to current is in the range of 0.06s to 0.3s. Hence, the use of suitable protective device is significant to eliminate the fault according to the time range allowed, so the chance of severe injury or death can be prevented.

## 2.10 Conclusion of Literature Review

In this chapter, from all the previous studies can be concluded as nuisance tripping frequently occurred due to poor earthing resistance value, which the earthing resistance value is high, power supplied with high frequency and the presence of harmonics component. Installation in earthing system has been investigated, where they conclude that electrocution and power quality problems will occur if the earthing system is improper such as high neutral-to-ground voltage at LV distribution system. High neutral-to-ground voltage occurs when there were connections and disconnections events of the load as well as lightning induced impulse. Besides, the high value of earthing resistance delayed the operation of RCD to disconnect the power supply when earth fault occurred. The RCD should be operated below than 200ms according to Suruhajaya Tenaga, or else it may cause dangerous effect toward equipment and person touched the exposed conductive object during earth fault. Asides from that, the residual operating current increased when there is presence of high frequency. The higher the frequency, the higher the level of residual operating current. If the frequency is too high, they might reach to the unacceptable values of residual operating current. As well, residual current with high amplitude of high order harmonics will increase the residual operating current, while it will decrease when residual current with low amplitude of high order harmonic. In the conclusion, beside the harmonics that could be the factor of nuisance tripping, poor earthing system installation also may lead to nuisance tripping of RCD. The higher the resistance values of earthing system, the longer time taken for RCD to operate, thus the higher the chance of a person and equipment to be harmed.

# CHAPTER 3

# RESEARCH METHODOLOGY

## 3.1 Overview

This chapter will discuss about the method used and the flow of the analysis regarding the project study. The tripping characteristic of RCDs can be determined by measuring their residual operating current and operating time. From previous studies, RCDs tripping characteristic, especially operating time is affected by earthing resistance values. To investigate more about this matter, several experiments have been analyzed. The experiments involved the measuring of residual operating current and operating time of RCD with different earthing resistance values. The standard buildings voltage and frequency are used to run the system as well as different loads are used to analyze the influence towards RCD tripping characteristic. The experiments purposes are to recognize the level of RCD residual operating current and operating time whether acceptable or not acceptable if the value of earthing resistance is high. The results of the experiments will be explained on the next chapter.

## 3.2 Measuring Residual Operating Current and Operating Time of RCD with Different Earthing Resistance Value

In this section, the behavior of RCD residual operating current and operating time toward different earthing resistance values are investigated. Figure 3.1 shows the flowchart from starting the experiment to running the experiment and doing the analysis. The RCD type-AC with 30mA of sensitivity is used as sample in this experiment. This type of RCD is appropriate for the final circuit such as 13A socket outlets. The system is feed in according to the standard building, which the voltage of 240V with frequency of 50Hz. Meanwhile, power resistors of 10W with different value of resistance are represented as earthing system resistance value. The earthing resistance value were varied from 1kΩ to 3.5kΩ with different value of 100Ω. Afterward, the unbalanced current is then applied to the RCD to record the residual operating current and operating time. The current probe and oscilloscope are used to measure the residual operating current and RCD Tester is used to measure the operating time of RCD. The data obtained are analyzed by changing the load with different loads, such as resistive load bank, synchronous motor and induction motor. The results of the analysis will be discussed on the next chapter.

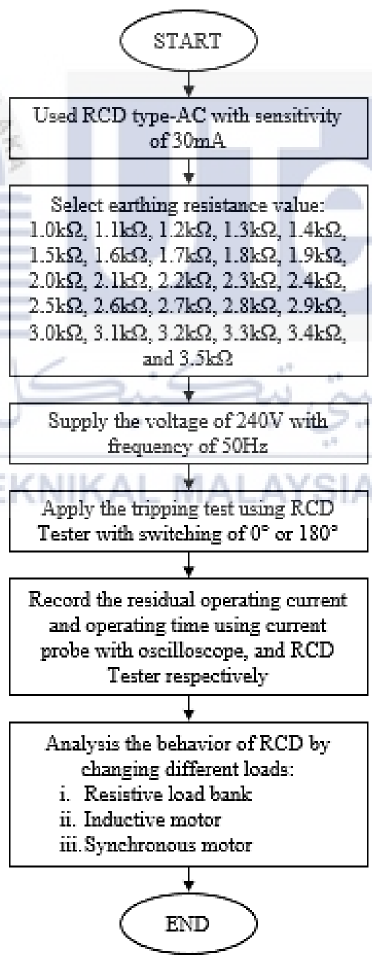





Figure 3.1: Flowchart of measuring residual operating current and operating time of RCD with different earthing resistance values

## 3.3 The Equipment Used

This section will discuss in details about the equipment used and how they operated in this research. Figure 3.2 shows the block diagram of the equipment setup for this research from applying the standard voltage AC source to the system being earthed. The main equipment involved in this study are type-AC of RCD with sensitivity of 30mA, RCD Tester (KYORITSU Model 5402D), current probe (Tektronix A622), oscilloscope, synchronous motor, induction motor, and power resistor (10W).

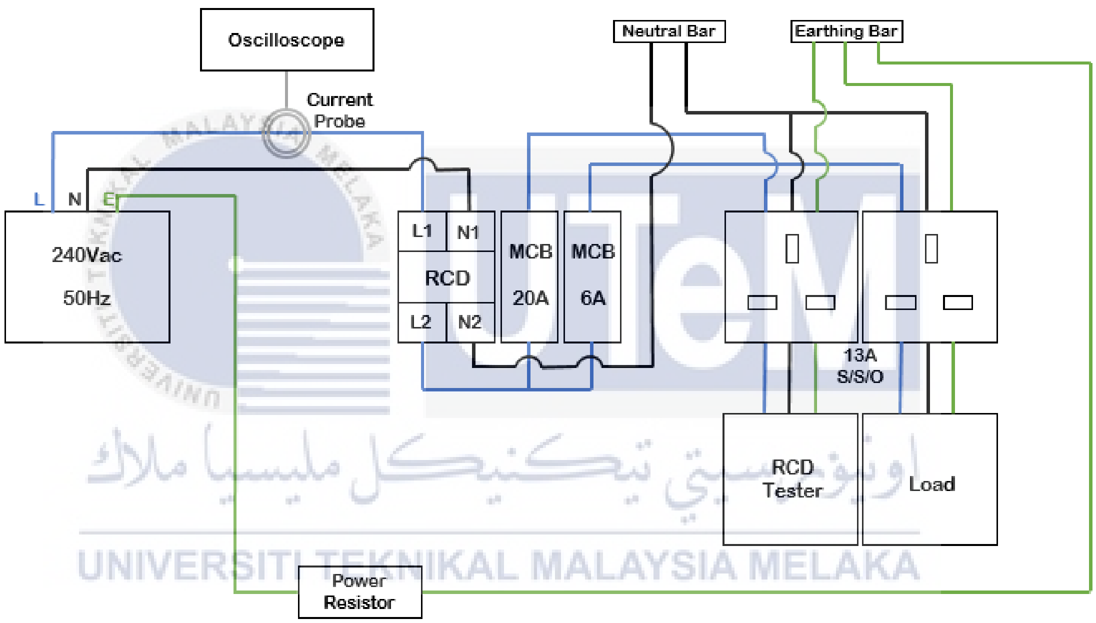





Figure 3.2: The block diagram of the analysis of RCD

### 3.3.1 Residual Current Device (RCD)

Residual Current Device (RCD) in Figure 3.3 shows the type-AC which for pure AC current and suitable for the load used in this experiment. The 30mA sensitivity of RCD is the maximum value permissible for personal shock protection and is appropriated for the final circuit such as 13A of switch socket outlet. This device is the main equipment for this research, which RCD will instantly break the electric circuit when leakage current of 30mA and above is presented. When the energized (line) conductor and the return (neutral) conductor is not balanced, supposedly the devices should trigger the tripping coil to disconnect the circuit quickly.


Figure 3.3: RCD type-AC with sensitivity of 30mA

### 3.3.2 Miniature Circuit Breaker (MCB)

Miniature Circuit Breaker (MCB) is used for overcurrent protections. In this experiment, 20A and 6A current rating of MCBs are used for RCD Tester and loads respectively as shown in Figure 3.4 and Figure 3.5. MCB operates as an automatic switch that opens in the event of excessive current flowing through the circuit and once the circuit returns to the normal, it can be reclosed without any replacement. Since the function of RCD is only protects for small leakage current, MCBs are used to ensure the safety in the system to protect against the overcurrent for the loads.


Figure 3.4: MCB 20A rated current


Figure 3.5: MCB 6A rated current

### 3.3.3 RCD Tester (KYORITSU Model 5402D)

RCD Tester as shown in Figure 3.6 equipped with 13A plug to connect with 13A socket outlet. The sensitivity of the RCD will be selected on the equipment which is the same as RCD that will be tested. The time taken for RCD operating time will be estimated using this equipment which consist of 0° (negative wave) and 180° (positive wave). Moreover, the test button on the device can be represented as the unbalanced current whenever the button is pressed. The residual current at the phase terminal will increase when the test button is pressed, thus make the current between phase and neutral terminal become unstable. Magnetic flux will be created within the core which then open the contact of the RCD.


Figure 3.6: RCD Tester (KYORITSU Model 5402D)

Also, this device works by inducing the earth leakage fault into the electrical system. The steps for this method are shown as follows:

a) Set the trip current range switch same as the rated residual current of the sample RCD used: 30mA
b) Connect the RCD Tester to the 13A switch socket outlet, make certain that both P-E and P-N lamps are illuminated (disconnect the instrument and check the wiring if not illuminate).
c) Set function switch to No Trip position.
d) Press and hold down the Test Button. A half (50%) of the rated trip current selected will pass through the breaker for 2000ms. The RCD should not trip at this step. P-N and P-E lamps should continue illuminated.
e) Reverse 0°/180° selector position and repeat step d).
f) Set function switch to Trip position.
g) Press and hold down the Test Button. The rated trip current (100%) of the rated selected will pass through the circuit breaker for 2000ms maximum. At this test the breaker should trips and all lamps go out.
h) Reverse 0°/180° selector position and repeat step g).

### 3.3.4 Current Probe (Tektronix A622) and Oscilloscope

Both equipment, Tektronix A622 current probe and oscilloscope are used for measuring the residual operating current of RCD. A622 current probe as shown in Figure 3.7 enables a general-purpose oscilloscope to display AC current signals up to 100A peak (70A r.m.s). The oscilloscope will read the input current and should displayed the value of residual operating current in peak-to-peak or r.m.s value. The results obtained will be tabulated and analyzed. The steps to obtained the results are as follows:

a) Connect the probe BNC connector to the oscilloscope input. Start by setting the oscilloscope channel vertical coupling to DC volts, the vertical deflection to 0.1 V/div.
b) Move the OFF/Range switch to the 10mV/A or 100mV/A position to power on the probe. The A622 current probe has a green LED power/battery indicator (replace the battery if the LED does not light).
c) Use the ZERO adjustment to zero or offset the probe input
d) Connect the probe to the circuit by opening the jaws and clamping around the conductor.
e) Adjust the probe and channel on oscilloscope as necessary to get clear view of the result obtained.



Figure 3.7: Tektronix A622 current probe

### 3.3.5 Loads

For loads used in this research shall have different in power rating to analyze the impact of load power consumption towards tripping characteristics of RCD. Hence, the use of resistive load bank which consumed pure power, and inductive loads such as induction motor and synchronous motor, which consumed reactive power are required. Figure 3.8 shows 5kW Resistive Manual Load Bank which is able to convert or dissipates the resultant power output of the source, applies the load to an electrical power source and developed an electrical load. Asides from that, a load bank is projected to imitate the operational of actual load which a power source will see in real application. Also, this load bank provides a contained, fully controllable and organized load. In this experiment, 200W is selected to analyze the behavior of RCD.




Figure 3.8: 5kW resistive manual load bank

Meanwhile, induction motor, the most commonly used type of motor in industry is reliable, simple and high efficiency. Induction motor generally rely on the use sets of winding in a fixed stator to generate a rotating magnetic field to drive a rotor which provides the mechanical output. This motor cannot operate from direct current supplies because the stator can only generate a rotating field if supplied with alternating current. Figure 3.9 shows the four-pole squirrel-cage induction motor is a 0.2kW induction machine mounted in a full-size EMS module. The stator windings are independently connected (six jacks), allowing connection in either wye or delta configuration. The connections to the motor are made through color-coded safety banana jacks located on the front panel on the module.

Figure 3.9: LabVolt Series 8221-05 four-pole squirrel-cage induction motor

Synchronous motor shown in Figure 3.10 is a 0.2kW three phase synchronous machine mounted in a full-size EMS module. This motor module can be operated either as three-phase or single-phase motor. Each phase of the motor stator windings is independently terminated and identified on the front panel to allow operation in either wye or delta configuration. Also, the rotor is equipped with a squirrel-cage damper and the connections to this motor are made through color-coded safety banana jacks located on the front panel of the module.

Figure 3.10: LabVolt Series 8241-05 synchronous motor

### 3.3.6 Power Resistor

Power resistor shown in Figure 3.11 is represented as the earthing resistance value for the system analysis. 10W power resistors with resistance values between 1kΩ to 3.5kΩ with different of 100Ω are chosen for this research. The power resistor will be connected in between the building earthed and earthing wire from the circuit. The current will flow through this resistance to the earth. The effect of the value of earthing resistance on RCD is investigated and the data obtained is recorded using RCD Tester and oscilloscope.


Figure 3.11: Power resistor 10W

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Overview

In this chapter, the results for analysis of earth leakage circuit breaker (ELCB) nuisance tripping due to earthing resistance value will be discussed. The analysis consists of two experiments. First experiment is measuring the residual operating current and operating time of RCD with different value of earthing resistance, while second experiment is measuring the operating time of RCD with different types of load as earthing resistance value increased. The results are recorded using RCD Tester, current probe and oscilloscope. Then, the data obtained is tabulated and displayed on the graph. These results discussed is related with the previous studies.



## 4.2 Residual Operating Current and Operating Time of RCD with Different Values of Earthing Resistance

Power resistors of 10W with different values of resistance are chosen in order to investigate the behavior of RCD. These power resistors represent as the actual earthing resistance value. The values of resistance used in this research are from 1kΩ to 3.5kΩ with different value of 100Ω. Besides, the residual operating current and operating time are measured without the presence of the power resistor as the reference value of this research. Then, the unbalanced current is applied for 2000ms maximum by using the RCD Tester trip test.

The sample of RCD's residual operating current shall equal to the rated residual operating current, $I_{\Delta n}$ which is 30mA, while the operating time shall not more than 200ms. The results in Figure 4.1 shows that the reference value of the residual operating current of the RCD sample measured is approximately equal to 30mA which is 29mA with the earthing resistance measured of 0.07Ω, which is nearly 0Ω. Next, for the presence of power resistor, the sample of RCD's residual operating current measured for 1kΩ till 3.4kΩ of earthing resistances are also about 30mA. However, for earthing resistance value of 3.5kΩ and above, the RCD sample does not trip for maximum of 2000ms applied unbalanced current.

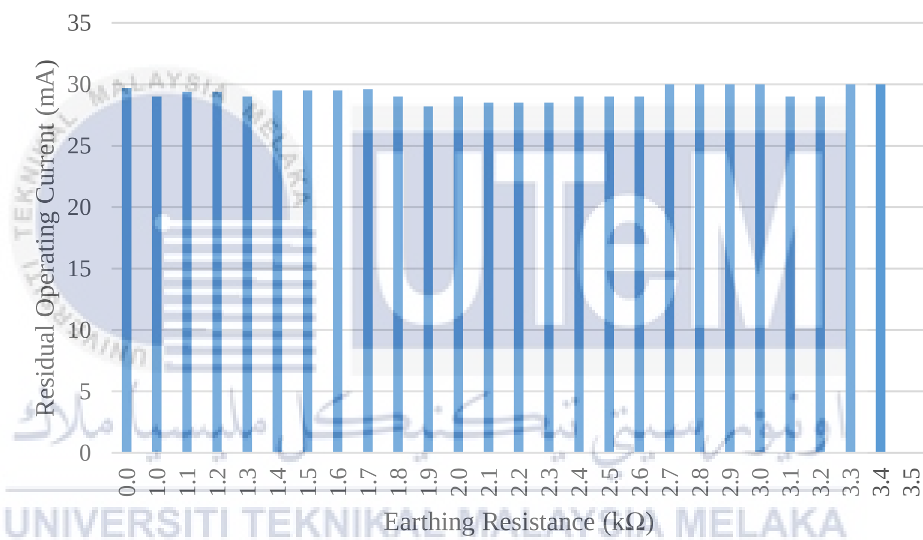



Figure 4.1: Residual operating current (mA) of RCD type-AC with different values of earthing resistance (kΩ)

The highest value measured for operating current is 30mA at earthing resistance value from 2.7kΩ to 3kΩ, 3.3kΩ and 3.4kΩ, while the lowest operating current measured is 28.2mA which earthing resistance value of 1.9kΩ. The data recorded above prove that earthing resistance below than 3.4kΩ does not affect the operating current of the RCD sample as the value measured is almost the same which is approximately equal to 30mA.

RCDs shall not operate if the r.m.s value of the earth fault (residual) current is equal to or less than $0.5I_{\Delta n}$ and shall operate if the residual current is equal to or larger than $I_{\Delta n}$, where $I_{\Delta n}$ is the rated residual operating current. For this research, $I_{\Delta n}$ of the sample of RCD type-AC used is 30mA. The residual operating current of RCD sample is considered passed for earthing resistance below than 3.4kΩ since the results obtained is higher than $0.5I_{\Delta n}$. However, the earthing resistance above 3.5kΩ is failed the requirement because RCD sample does not operate for applied earth fault current of 30mA. According to M. Z. Abdullah and R. Ariffin [23], the improper installation of earthing system may cause the power quality problems and electrocution in the system. Also, this problem led to nuisance tripping of RCD due to large neutral-to-earth voltage and large earth fault current. In addition, disruption of sensitive loads might cause the RCD to operate suddenly. Their past researched also found that in the event of connection and disconnection of loads activity such as computers, there were several neutral-to-earth voltage impulse recorded due to generation of intermittence single line to ground fault (SLG). Hereafter, it is recommended to improve the earthing system which must get the resistance value as low as possible to avoid the nuisance tripping of RCD, thus reduced the neutral-to-earth voltage.

Figure 4.2 shows the different earthing resistance value against the operating time of RCD sample. The reference value for 0.07Ω of earthing resistance gave the operating time of RCD sample measured approximately 30ms for 0° (negative waveform) and 20ms for 180° (positive waveform). At phase angle of 0°, the value of operating time is increased as the value of earthing resistance increases. The fastest operating time of RCD sample is 30ms which at the reference value and the slowest operating time is 195ms which at the value of earthing resistance of 3.3kΩ. The sample of RCD does not trip for maximum of 2000ms applied unbalanced current with earthing resistance value of 3.4kΩ and above at 0° phase angle. Meanwhile, the operating time of the RCD sample measured for earthing resistance values from 1kΩ to 3.4kΩ at 180° phase angle are almost the same as the reference value which is 20ms. Then again, at the value of earthing resistance of 3.5kΩ and above, the sample of RCD does not trip for 2000ms of maximum applied unbalanced current at phase angle of 180°.

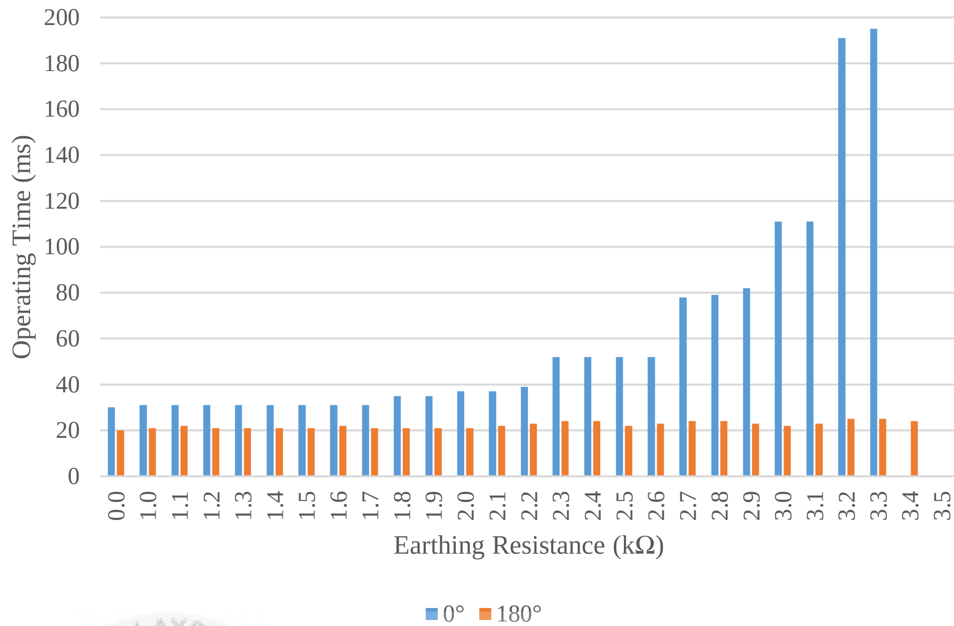



Figure 4.2: Operating time (ms) of RCD type-AC with different earthing resistance value (kΩ)

The time for RCD to operate is very important because delay in operation of circuit breaker can have disastrous effect on the equipment as well to persons touching the live parts when earth leakage occurs. According to Suruhanjaya Tenaga: Guidelines for Electrical Wiring in Residential Building [15], the operating time should be less than 200ms, while BS EN 61008-1:2012 [12] states that limit values of break time for type-AC of RCD in the event of alternating residual current is equal to 300ms for rated residual current, $I_{\Delta n.}$ The results obtained above shows that RCD type-AC still maintain their protection function for earthing resistance values reached 3.4kΩ, which RCD operated below 200ms. However, for the highest earthing resistance values above 3.5kΩ, RCD failed to operate for maximum applied unbalanced current for 2000ms. This shows that the RCD cannot maintain their protection function if the earthing resistance is further increase above 3.5kΩ. In earthing system, it is very important to have proper installation and have the lowest value for earthing resistance, so that the effectiveness of clearing the fault current to earth is improved. As the earthing resistance values increase, RCD takes longer time to energize the trip coil after receiving the signal. Thus, the operating time may increase to an unacceptable value. The effect of delay in RCD time operation may cause the damaged towards equipment also may harm the persons touching the live parts when earth fault is happened. Hence, this prove that it is very important to have proper earthing system and low resistance value of earthing.

Additionally, alternating current (AC) comprises of positive and negative half cycles with respect to zero reference point, so an AC fault current flows to earth may at any point during either half cycle. Usually, type-AC of RCD will only trip in response to either positive or negative half cycles of an AC earth fault current. This type of RCD is blind to either the positive or negative half cycles of an AC fault current, thus the fault current could flow for up to 10ms before the RCD thoroughly detect the fault current. This 10ms will be added to the response time of the device. In general, RCD Tester is provided with switch that enable the test current to start flow in the circuit at phase angle of 0° or 180°, in other word the test current may start to flow on a negative going or a positive going half cycle respectively. The maximum of RCD operating time can be determined by testing the RCD at both settings of the test current phase angle. Therefore, the result obtained shows that the maximum operating time for RCD sample is determined by referring to the negative wave current, 0° phase angle. This is because the switching of 0° take the longest time for RCD sample to operate than switching of 180°.



## 4.3 RCD Operating Time with Different Values of Earthing Resistance for Different Loads

In this section, different load with different power consumption is used to investigate the effect of loads towards the operating time of RCD sample. Three different loads, such as resistive load bank, induction motor and synchronous motor are used in this research. Also, the earthing resistance for this system is varied from 1kΩ to 3.5kΩ. As usual, the reference value which is pure earthing resistance, without the presence of the power resistor is measured first as the unbalanced current is applied for 2000ms maximum by using the RCD Tester trip test to the system.

Figure 4.3 shows the results obtained for operating time of RCD sample for different loads as the earthing resistance value increased. The reference value for all the loads and without load show nearly same operating time measured which is within 30ms and 31ms. As the resistance of earthing increased, the operating time of RCD sample for all loads and without load are increase. Besides, the pattern shows that the induction motor load increases the RCD sample operating time higher than other loads, which at 388ms for earthing resistance value of 3.4kΩ. This value is already exceed the time requirement to operates an RCD as stated in Suruhanjaya Tenaga: Guidelines for Electrical Wiring in Residential Building [15] and BS EN 61008-1:2012 [12] which are 200ms and 300ms respectively.

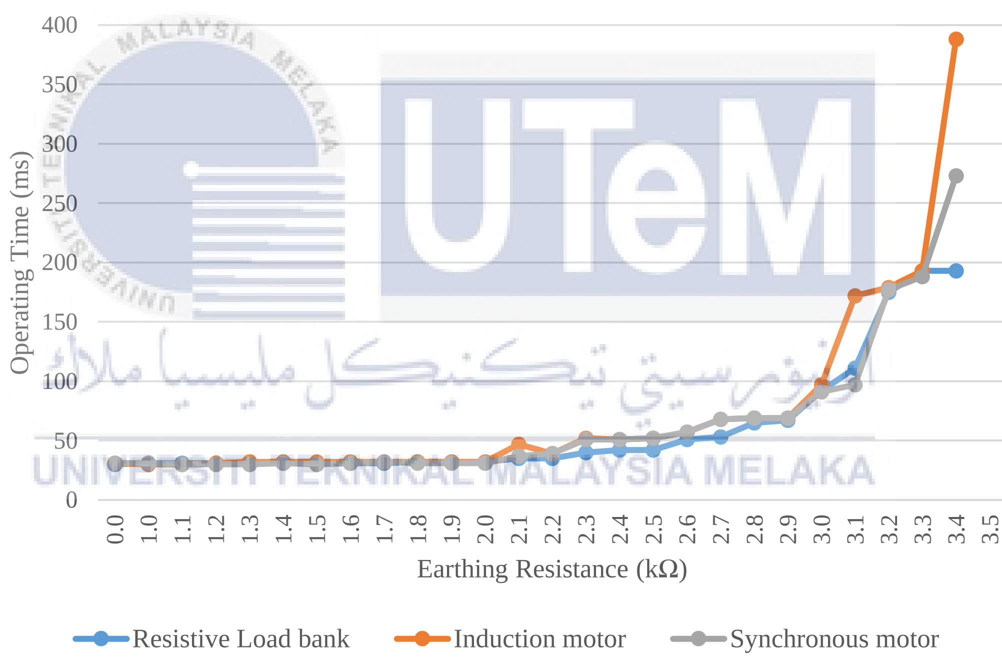




Figure 4.3: Operating time (ms) of RCD type-AC for different load at 0° phase angle

The results show equipment that contain resistive and inductive loads took longest time for RCD to trigger the coil to break the circuit when earth fault occur than equipment that only comprise with resistive load. The type of load depends on how the wave for the voltage and the wave for current line-up. In resistive load such as load bank, the voltage and current waves are in phase, while inductive load such as an electric motor, the voltage wave is ahead of the current wave. This two waves difference create a secondary voltage that moves in opposition to the voltage from energy source, also called as inductance. Therefore, the inductive loads tend to experience power surges when they are turned on and off, contra with resistive load, which never seen in this phenomenon. On the other hand, the total power consumption of inductive load is higher than resistive load. As the fact that inductive load produced reactive power and the total power consumption of this load is equal to the summation of active power and reactive power, thus makes inductive load power consumption greater than resistive load, which is in phase and does not produce reactive power.

M. H. Suhailee [24] stated the RCD operation is affected by the total power consumption of the loads, which the value of operating time is higher when the power consumption of the load is larger. Hence, the induction motor and synchronous motor, which both are combination of resistive and inductive load, took the longest time to trip the RCD sample compare to load bank which is resistive load. As the value of earthing resistance increased to 3.4kΩ, the operating time of RCD reached the unacceptable value, which 388ms for induction motor and 273ms for synchronous motor. Both values of operating time exceed the allowable value of standard for type-AC RCD, whereas the RCD shall break the circuit not more than 200ms when the earth fault is occurred. This is to avoid the equipment from damage as well as to avoid the electric shock if the persons touched the enclosed body of the equipment. So, it is important to ensure the earthing system is properly installed according to the standards. Likewise, the earthing resistance value should be in low resistance to make the RCD operates in the right time.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

In low voltage power system protection, value of earthing resistance is one of the vital element needs to be considered to ensure the proper earthing system installation. In this research, different value of earthing resistance from 1kΩ to 3.5kΩ have been tested to analysis the characteristic of RCD in terms of residual operating current and operating time. From the results obtained, the earthing resistance does not affect the residual operating current of the RCD sample as the residual operating current measured for all value of earthing resistance tested show approximately equal to 30mA. The RCD is required to operate when residual current is higher than $0.5I_{\Delta n}$, where $I_{\Delta n}$ is the rated residual current. As the earthing resistance is increased, the RCD sample is still operated as per required. So, the RCD sample is considered passed in terms of its residual operating current. In the meantime, the RCD supposedly operates below than 200ms when residual current flow through it. The results show that the operation of RCD sample delayed as the value of earthing resistance increased. Besides, it does not operate for value of earthing resistance above than 3.4kΩ when residual current is applied at maximum of 2000ms. Thus, this conclude that if the earthing resistance value is increase, the RCD take some time to energize the trip coil after receiving the signal and it will not trip for the earthing resistance value above than 3.4kΩ. In addition, RCD sample took the longer time to operate for inductive loads than resistive loads. The operating time of RCD sample measured for inductive loads such induction motor and synchronous motor reached the unacceptable value as it is operated more than 200ms when the earthing resistance value passed 3.3kΩ. Also, the results obtained show the RCD sample does not trip for earthing resistance value above than 3.5kΩ for applied residual current maximum of 2000ms. Hence, the high-power consumption loads take more time for RCD to trigger the coil when residual current is presented and the value of earthing resistance above than 3.5kΩ caused the RCD to not function.

## 5.2 Recommendation for Future Works

There are few recommendations that have been suggested. In the future research for the analysis of RCD nuisance tripping due to earthing resistance value, the residual operating current and operating time can be investigated by changing the frequency range of low voltage system instead of 50Hz. Furthermore, the system can be analyzed in the presence of harmonic distortion. Moreover, the low voltage circuit tested can used different rated residual current or sensitivities of RCD such as 10mA, 100mA and 300mA. Therefore, the nuisance tripping of RCD issue can be studied further.

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# APPENDICES

A. Gantt Chart of Project

| Year | 2017 | | | | 2018 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Tasks \| Months** | **9** | **10** | **11** | **12** | **1** | **2** | **3** | **4** | **5** |
| Literature research | | | | | | | | | |
| - Research on protection in LV system | | | | | | | | | |
| - Research on ELCB | | | | | | | | | |
| - Research on nuisance tripping | | | | | | | | | |
| - Earthing resistance value effect on RCD | | | | | | | | | |
| - Loads effect on RCD | | | | | | | | | |
| Design hardware | | | | | | | | | |
| - Preparation of equipment used | | | | | | | | | |
| - Designing LV system circuit for analysis | | | | | | | | | |
| Analysis the nuisance tripping effect on RCD | | | | | | | | | |
| - Effect on residual operating current | | | | | | | | | |
| - Effect on operating time | | | | | | | | | |
| Report writing | | | | | | | | | |

B. Effect of Earthing Resistance Value Results

| Earthing Resistance (kΩ) | Operating Time (ms) | | Residual Operating Current |
|---|---|---|---|
| | 0° | 180° | |
| 0.0 | 30 | 20 | 29.7 |
| 1.0 | 31 | 21 | 29 |
| 1.1 | 31 | 22 | 29.4 |
| 1.2 | 31 | 21 | 29.4 |
| 1.3 | 31 | 21 | 29 |
| 1.4 | 31 | 21 | 29.5 |
| 1.5 | 31 | 21 | 29.5 |
| 1.6 | 31 | 22 | 29.5 |
| 1.7 | 31 | 21 | 29.6 |
| 1.8 | 35 | 21 | 29 |
| 1.9 | 35 | 21 | 28.2 |
| 2.0 | 37 | 21 | 29 |
| 2.1 | 37 | 22 | 28.5 |
| 2.2 | 39 | 23 | 28.5 |
| 2.3 | 52 | 24 | 28.5 |
| 2.4 | 52 | 24 | 29 |
| 2.5 | 52 | 22 | 29 |
| 2.6 | 52 | 23 | 29 |
| 2.7 | 78 | 24 | 30 |
| 2.8 | 79 | 24 | 30 |
| 2.9 | 82 | 23 | 30 |
| 3.0 | 111 | 22 | 30 |
| 3.1 | 111 | 23 | 29 |
| 3.2 | 191 | 25 | 29 |
| 3.3 | 195 | 25 | 30 |
| 3.4 | - | 24 | 30 |
| 3.5 | - | - | - |

C. Effect of Earthing Resistance Values with Different Loads Results

| **Earthing Resistance (kΩ)** | **Operating Time of 0° Phase Angle (ms)** | | |
|---|---|---|---|
| | **Resistive Load Bank** | **Induction Motor** | **Synchronous Motor** |
| 0.0 | 30 | 31 | 31 |
| 1.0 | 31 | 30 | 31 |
| 1.1 | 31 | 30 | 30 |
| 1.2 | 31 | 31 | 30 |
| 1.3 | 31 | 32 | 30 |
| 1.4 | 31 | 32 | 31 |
| 1.5 | 31 | 32 | 30 |
| 1.6 | 31 | 32 | 31 |
| 1.7 | 31 | 32 | 32 |
| 1.8 | 32 | 32 | 31 |
| 1.9 | 32 | 32 | 31 |
| 2.0 | 32 | 32 | 31 |
| 2.1 | 35 | 47 | 37 |
| 2.2 | 35 | 39 | 39 |
| 2.3 | 40 | 52 | 51 |
| 2.4 | 42 | 51 | 51 |
| 2.5 | 42 | 52 | 52 |
| 2.6 | 51 | 57 | 57 |
| 2.7 | 53 | 68 | 68 |
| 2.8 | 65 | 69 | 69 |
| 2.9 | 67 | 69 | 69 |
| 3.0 | 92 | 97 | 91 |
| 3.1 | 111 | 172 | 97 |
| 3.2 | 175 | 179 | 177 |
| 3.3 | 193 | 193 | 188 |
| 3.4 | 193 | 388 | 273 |
| 3.5 | - | - | - |