" I hereby declare that I have read through this report entitle "Insulation Monitoring Device" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Mechatronic Engineering with Honours"

Signature : ....

Supervisor's Name : Dr. Muhammad Fahmi Bin Miskon

Date : ....

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

INSULATION MONITORING DEVICE

MOHAMAD HAZRIK BIN ABDUL HAMID

A report submitted in partial fulfillment of the requirements for the Degree of

Bachelor of Mechatronic Engineering with Honours

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UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2015

I declare that this report entitle “Insulation Monitoring Device” 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 : ....

Student’s Name : Mohamad Hazrik Bin Abdul Hamid

Date : ....

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To my beloved mother and father

ACKNOWLEDGEMENT

In preparing this report, I was in contact with many people, researchers, academicians and practitioners. They have contributed towards my understanding and thought. In particular, I wish to express my sincere appreciation to my project supervisor, Dr. Muhammad Fahmi Bin Miskon, for encouragement, guidance, advice and motivation. Without his continued support and interest, this project would not have been same as presented here.

My helpful lecturers should also be recognized for their support. My sincere appreciation also extends to all my friends and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family members.

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ABSTRACT

In the history of surgical procedure, patients have the possibility to bare the side effect of the electrical shock. This electric shock is caused theoretically by electromedical equipment within the medical room surrounding. A primary concern of this electric shock is when there is a micro-shock that passed through the patient while having medical operation and can harm the patient. However, a problem rises when the detection of the leakage current is not accurate. The objective of this project is to design and develop an insulation-monitoring device for detecting the leakage of current in IT electrical network system. The second objective of this project is to test the performance of proposed system in terms of accuracy and precision. For the methodology, the proposed system will be using Arduino UNO and voltage divider theory. Data for this study will be collected using two methods which are from simulation setup and experimental setup. For simulation setup, software Proteus Release 8.0 is used. By employing experimental setup, a circuit contains a decade resistor and a socket for the 100-W lamp to replicate the medical room situation is built. From the experimental setup, the accuracy, precision and sensitivity can be obtained. The finding of the experiment is that the insulation – monitoring device able to detect the leakage of current even though there are error on current measurement from the electrical network system. The average percentage error for accuracy is at 15.683% and the average percentage error for the precision is at 14.59%. On top of that, the sensitivity of the IMD detection is at 37.74%. Thus, for recommendation to increase the reliability of the device, more powerful microprocessor need to be implemented to reduce the error.

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ABSTRAK

Dalam sejarah prosedur pembedahan, pesakit mempunyai kemungkinan untuk menghasilkan kesan sampingan daripada kejutan elektrik. Secara teorinya, kejutan elektrik ini disebabkan oleh peralatan electromedikal di dalam bilik perubatan. Tumpuan utama kesan kejutan elektrik ini adalah apabila adanya kejutan-mikro yang melepasi pesakit semasa operasi perubatan berlangsung; pesakit terdedah kepada serangan jantung dan boleh membahayakan nyawa pesakit. Walaubagaimanapun,pengesanan kebocoran arus elektrik tidak tepat. Objektif utama projek ini ialah untuk mereka dan membina sebuah alat pemantauan penebat untuk mengesan kebocoran arus pada sistem elektrikal IT. Objektif kedua ialah untuk mengkaji keupayaan sistem dalam erti kata ketepatan dan kebolehulangan. Untuk metodologi,sistem cadangan akan menggunakan Arduino Uno dan teori pembahagi voltan. Data untuk kajian ini dikumpulkan dengan menggunakan dua kaedah iaitu dari persediaan simulasi dan persediaan eksperimen. Untuk penggunaan simulasi , perisian Proteus Versi 8.0 akan digunakan. Bagi persediaan eksperimen , litar yang mengandungi perintang dekad , dan soket untuk lampu 100 -W untuk meniru keadaan bilik perubatan akan dibina. Metodologi ini memberi peluang untuk mendapatkan data untuk ketepatan, kebolehulangan dan sensitiviti. Penemuan dalam ujikaji ini menunjukkan alat pemantauan penebat mampu mengesan kebocoran arus elektrik tetapi terdapat ralat dalam mengesan kebocoran arus di dalam rangkaian sistem elektrikal .Purata peratusan bagi ralat ketepatan ialah 15.683% dan purata peratusan bagi ralat kebolehulangan ialah 14.59%. Selain daripada itu,kepekaan untuk pengesanan IMD hanya pada 37.74%.Oleh yang demikian, sebagai cadangan untuk meningkatkan keupayaan alat ini, mikropemprosesan yang lebih berkuasa harus digunakan bagi mengurangkan ralat

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LIST OF ABBREVIATIONS

IT	-	Insulated-terra
IMD	-	Insulation monitoring device
PIM	-	Permanent insulation monitors
N	-	Neutral
PE	-	Protection earth
EME	-	Electromedical equipment

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LIST OF SYMBOLS

I_d	-	Fault current flowing on earth connection resistance of the frame.
C1	-	Earth impedance capacitive component for phase 1.
C2	-	Earth impedance capacitive component for phase 2.
C3	-	Earth impedance capacitive component for phase 3.
Z_N	-	Additional impedance connected between neutral point and earth in IT system.
R_B	-	Resistance of natural earth connection
U_D	-	Contact voltage between frame and earth
G	-	Low frequency generator

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CHAPTER 1

INTRODUCTION

This chapter will discuss about the project background, motivation, problem statement, project objective and scope of work for the insulation-monitoring device.

1.1 Motivation

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Over the past century, deaths from electric shock have been reported in the operation room are caused by three possible mechanism of death [1]. The three possible threats are ventricular fibrillation, respiratory arrest, and asphyxia which happen when there is a long run of shock passed across the patient chest [2][12][15]. By avoiding these three possible mechanisms of death caused by electric shock, operation room safety can be increased. One way to increase the safety of operation room is by using IT system that equipped with insulation monitoring device. This device can provide extra safety to medical environment by alerting the operator if there is a leakage of current, which can lead to electric shock.

A much debated question is whether the insulation-monitoring device able to detect leakage of current in the medical environment in term of accuracy and sensitivity. Others researcher trying to get the value of the leakage current using different method such as differential current between two points [1], technique of the balanced voltmeter [3], direct current (DC) current injection method [3] and many more. Based on the method that being mention before, there are pros and cons for each method in term of accuracy and sensitivity of the detection.

Furthermore, the insulation-monitoring device is meant to help the medical sector by reducing the patient risk towards the electric shock especially in an operation room. From the Malaysian Electrical Installations of Building 2009 standard [16], the medical IT system should be set up with an insulation-monitoring device. Previously from International Electrical Installation of Building for Medical Environment 2002 [13], the usage of insulation-monitoring device should helps the IT system to perfectly detect leakage of current in medical environment. Malaysian government should obligate every hospital and medical clinic to install the insulation-monitoring system in IT system electrical network. Thus, the importance of the device have been studied and researched since 2002 to solve the micro-shock problem especially in an operation room. So, the insulation-monitoring device has the best way to overcome the leakage of current especially in medical environment.

1.2 Project Background

One of the most important events in 1740s was the discovery of Leyden jar's [2], which is the original form of the capacitor and the beginning of electrical era. Investigating electricity is a continuing concern after electric battery invented by Volta, the invention of generators using the study of electromagnetism and the usage of these generators in every major industry in the world. Recently, researchers have shown an increased interest in two types of electrical shock; direct contact to an exposed live conductor and indirect contact. In this report, we will investigate the indirect contact, which happens when leakage of current occurred. Previous studies have reported about death cause by electrical shock during the surgery [2]. Due to these accidents, researchers want to minimize the problems by suggesting their proposals to prevent the leakage of current. IT system in figure 1.1 has the ability to prevent the leakage of current and any power interruption during a surgery. The system in Figure 1.1 namely Insulated and Terra system principles are naturally earthed by the high impedance up to 1500Ω. The neutral port of transformer is not earthed but it is actually unearthed by the capacities of network cables. The system is designed to preclude an electric spark that is not dangerous to human, especially the patient during surgery. To increase the safety for the usage of the system, an isolation transformer will be introduced together with the insulation-monitoring device. The insulation-monitoring device will trigger the alarm and gives the signal if there is leakage of current within the electrical lines. The IT system must be equipped with the insulation monitoring device in order to comply with the Malaysian standard for medical room, IEC 61557-8. Thus, developing an insulation-monitoring device will surely help the medical sector to prevent any electric shock especially in the operation room.

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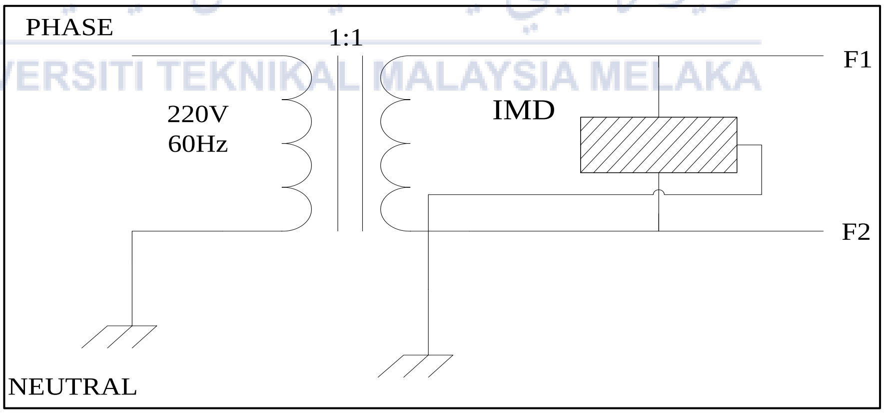

Figure 1.1: The IT (Insulated –Terra) system

1.3 Problem statement

Electric shock is a classic problem in medical sector. In order to solve this problem, researchers are working on to design an earthing system that can prevent electric shock in the operation room. The researchers introduced various standardized earthing systems, which given the international standard for medical room (IEC 60364). IT system is one of the systems that meet the international and Malaysian standard. Figure 1.2 shows that the IT system with no presence of IMD, which can risk the patient if the electro medical equipment having an insulation failure. From figure 1.2, resistance of patient is at 51kΩ, which is not a safe condition for a patient. Micro-shock will be produced when the current induced threshold is at or below 51k and can cause death.

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Insulation monitoring device is a device used to detect leakage of current at medical environment, military sector, server room and many more. This device can alert and gives alarm to the users whenever there is a leakage of current across the electrical line. However, the problem came when the detection of the leakage of current is not accurate. According to IEC 61557-8 standard, an insulation-monitoring device should be able to detect the current induced threshold of below or equal to 51kΩ. Failure to detect the leakage of current can lead the patient to experience the micro-shock. Furthermore, method of detecting leakage of current must be suitable for an insulation-monitoring device as accuracy is the most important factor to detect leakage of current.

Moreover, the most important criteria for the device are the precision of the current measurement. The sensitivity of the device is depending on the resolution of the analog-to-digital convertor (ADC) of the microprocessor. The selection of the circuit to increase the precision also need to be determined as the threshold resistance for the electrical line will be at 51kΩ. The detection of the threshold for the device must be sensitive and precise enough to detect the changes of current every one second. Thus, for solving the problem, the insulation monitoring device design must follow the international electrical standard. On top of that, suitable earthing system and the technique to detect the leakage of current must not be taken lightly as both criteria are the most important part in increasing the accuracy and precision of the device.

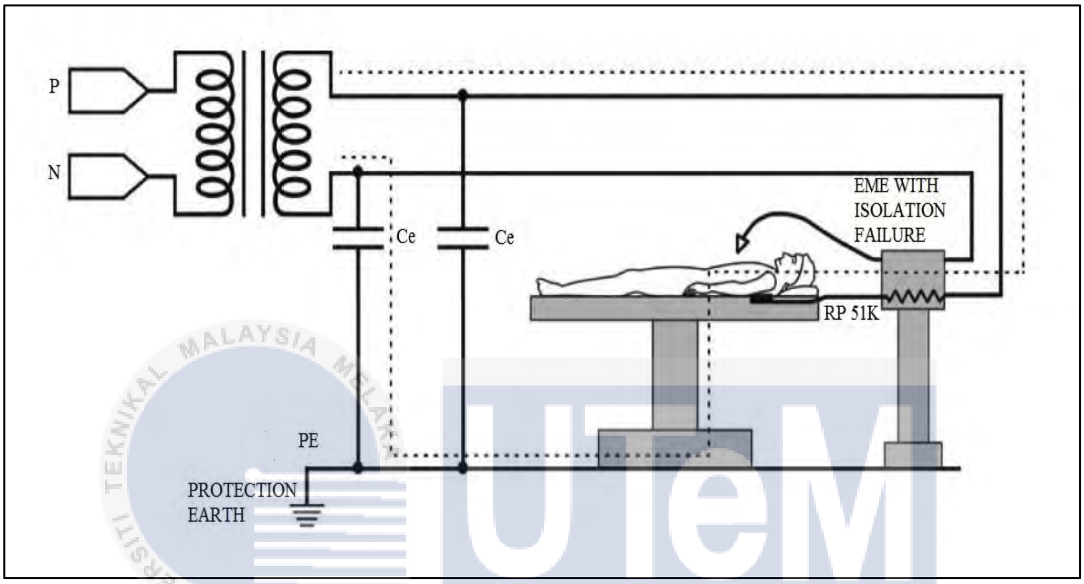

Figure 1.2: IT System used with no presence of IMD [1]

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1.4 Objectives

The objectives of this project are

1. To design and develop an insulation-monitoring device for detecting the leakage current in IT electrical network system.
2. To test the performance of the proposed system in terms of accuracy and precision.

1.5 Scope of Work

1. This project is developed currently to be used in single phase power supply
2. Supply voltage is $200V_{AC}$ with current rating 31.5 kA.
3. This device detects the current leakage in single-phase power supply only.
4. To prove the accuracy and precision of the device, several experiments in the lab are performed.
5. Simulation using Proteus 8.0 software will be used to analyze the hardware functionality and experimental set up.
6. The design and development of the hardware are based on Malaysian Electrical Building Installation 2009.

1.6 Project Development Workflow

For the development of the insulation-monitoring device, the stages of the workflow can be seen in figure 1.3. First of all, the most important aspect to develop an insulation monitoring device is to collect all the information related to the device from any source such as IEEE journal, internet, reference book and many more. Then, after gathering the information from various sources, the simulation design must be acquired in order to propose the best research methodology for testing purpose. After that, the drawing of the desired design of circuit will be tested and verified the performance in terms of accuracy. If the performance of the design of the circuit is not proven, the circuit drawing will be repeated until the circuit can work perfectly. After the circuit has been verified, the hardware development will be started. Later on, after the hardware development, the analysis and data collection can be done. Data analysis and collection will be focused on accuracy and precision of the hardware.

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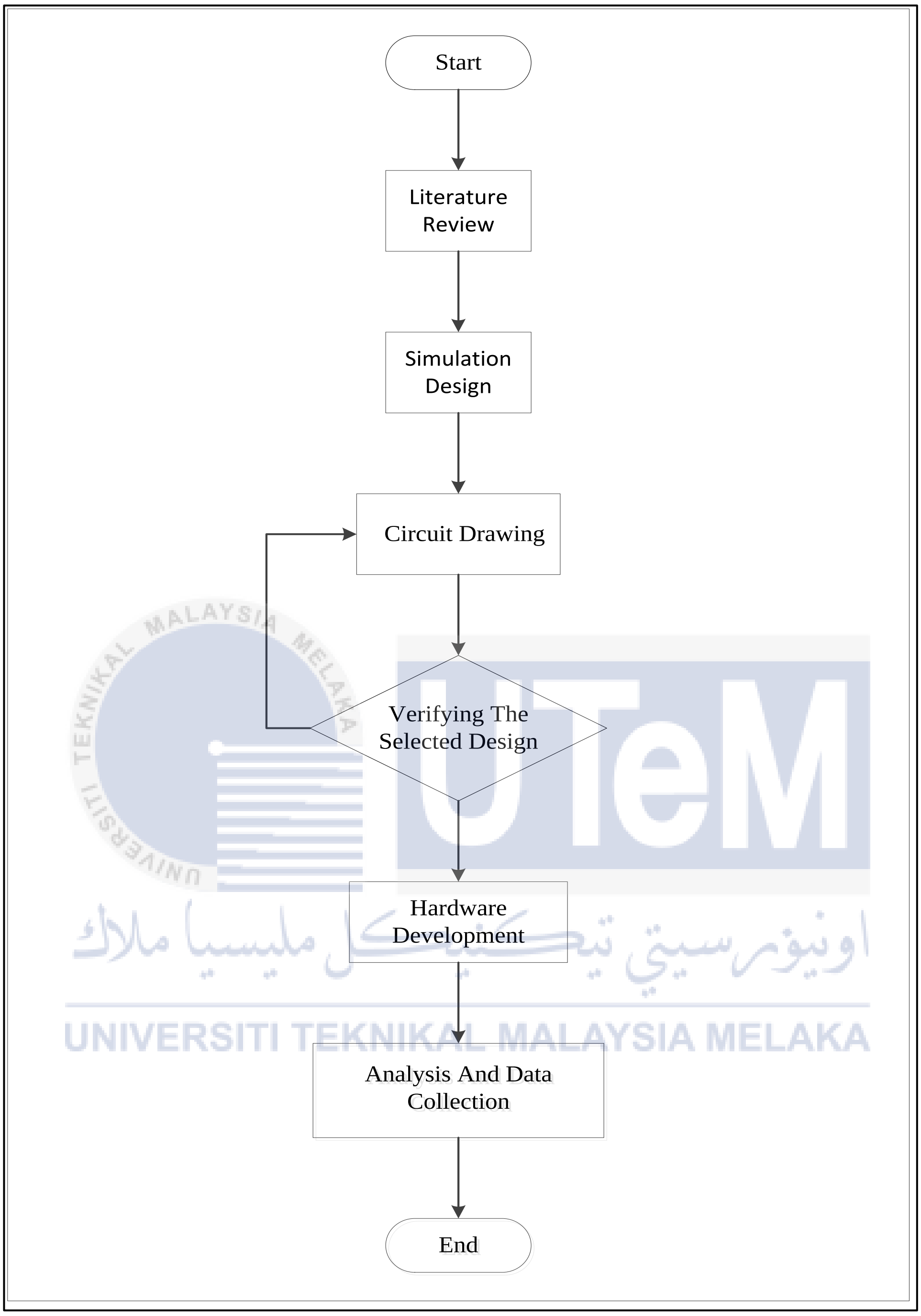

Figure 1.3: Project development workflow

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CHAPTER 2

LITERATURE REVIEW

For this chapter, the collections of information that related to the system development of the insulation monitoring device has been search, evaluate and analysis. Any backgrounds, problems and solution regarding the development of the device will be covered in this chapter.

2.1 Introduction

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As for analysis of information, there are two criteria that going to be studied in the literature review. The most important criterias are the accuracy of the detection of leakage current and the most suitable earthing system to be used with the insulation-monitoring device. Both criteria have been studied thoroughly to develop the most efficient insulation-monitoring device with the highest accuracy. Besides that, calculating fault current and contact voltage are also important criteria that going to be studied in this literature review. From figure 2.1, we can see the general block diagram of the insulation-monitoring device. Generally, the insulation-monitoring device works when there is a leakage of current, which will be detected by a current sensor. After the input of leakage current has been received, the microcontroller will process the input from analog data to digital data and finally will bring out the output. The outputs are in the form of alarm sound and display on a led panel.

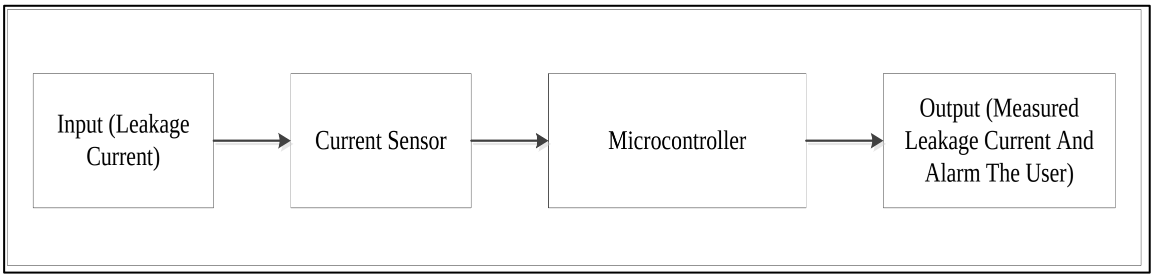

Figure 2.1: Block diagram of the Insulation Monitoring Device (IMD)

2.2 Detecting leakage current

2.2.1 Background

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Previous studies have reported the method to detect a fault by using the first principles of PIM (permanent insulation monitor)[3]. Figure 2.2 is to explains about the first principles of PIM. At A, all the bulbs lit at the same rate of brightness because of the balanced three-phase load supplied throughout the bulbs. That means the current flowing consistently at same value throughout the bulbs[3]. So when the system experiencing the leakage of current, one of the bulbs is not lit and will be connected by the fault impedance, which can be seen at B. Voltage is decreasing at the terminal of the bulb 3 and, the bulb’s brightness for the bulb 1 and bulb 2 are increasing until they reach the maximum voltage phase. Recent developments in fault tracking method have improved the previous method, which are needed to stop the operation of every feeder until the insulation faulty can be found. This new method can detect insulation faulty without power breaking to the system that can save more time to the user to stop each operation of feeder.

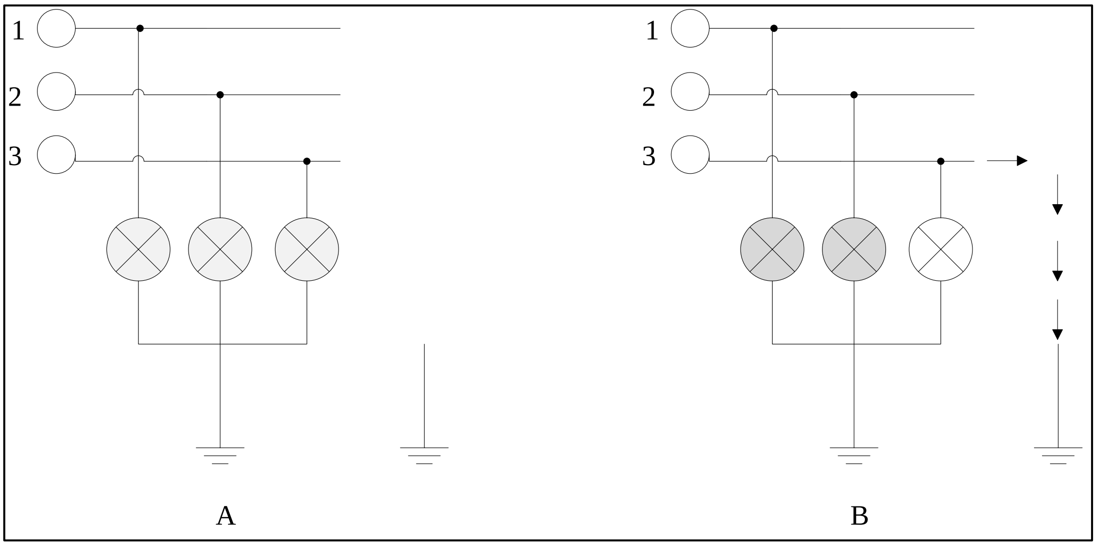

Figure 2.2: Principles of first PIM

2.2.2 Problem on detecting the leakage of current

For tracking an insulation fault, there are two ways to find the fault, which are tracking by successive de-energisation of feeders and live tracking. The operators (users) need to open every feeders starting with the main feeders for the tracking by successive de-energisation of feeder method. By applying the first principles of PIM, whenever the feeder that experiencing the leakage of current is opened, the current injected by the PIM will decrease and drop under the detection level. However, by applying this method, the users need to interrupt the operation of each feeder until the location of the insulation faulty is confirmed.

2.2.3 Solution to available problem

"Live tracking" is the new way to track insulation fault without any power breaking, which mean, the system still can operate even though there is insulation faulty in the system [3]. This system is mainly used in the medical operation room, train control room, military and many more. There are three methods that allow the live tracking, which are detecting the fault current, detecting an injected current and measuring insulation of each feeder [3]. Even though these methods allow live tracking, there are some limitations to the method. Thus, for the new system that is going to be developed, the main criteria for the system must allow live tracking feature.

Table 2.1: Comparison between PIM principles on DC, AC, AC and DC network.[3]

Network	**Principles**	**Limitations**
For DC (Direct Current)[3]	• This network is generated by batteries or by a DC generator • Technique used for this network is by voltmeter balance technique as shown in Figure 2.3	• Not support the live fault-tracking feature.
For AC (Alternating Current)[3]	• The PIMs with AC current injection at low frequency (<10Hz), which will flow through the fault. • This principle uses devices sensitive to the injected pulse only. • This technique is shown in Figure 2.4	• By using this method, the detection can be "misinterpret" by cable capacities that are seen as insulation fault.
For AC and DC[3]	• The new PIMs can monitor leakage of current on all types of networks. • Use squared wave pulses at a very low frequency (≈1Hz) as shown in Figure 2.5.	• The response time is slower than the other two networks.

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By referring to figure 2.3, the needle is pointing out to the faulty polarity of the electrical network. From figure 2.3, the leakage of current happens at negative polarity side. The workflow of the principles is to compare the voltages on the positive or negative polarity with the earth. So, by comparing the voltages with the earth voltage, we can see the difference of voltages whenever there are leakage of current happen either at the positive or negative polarity.

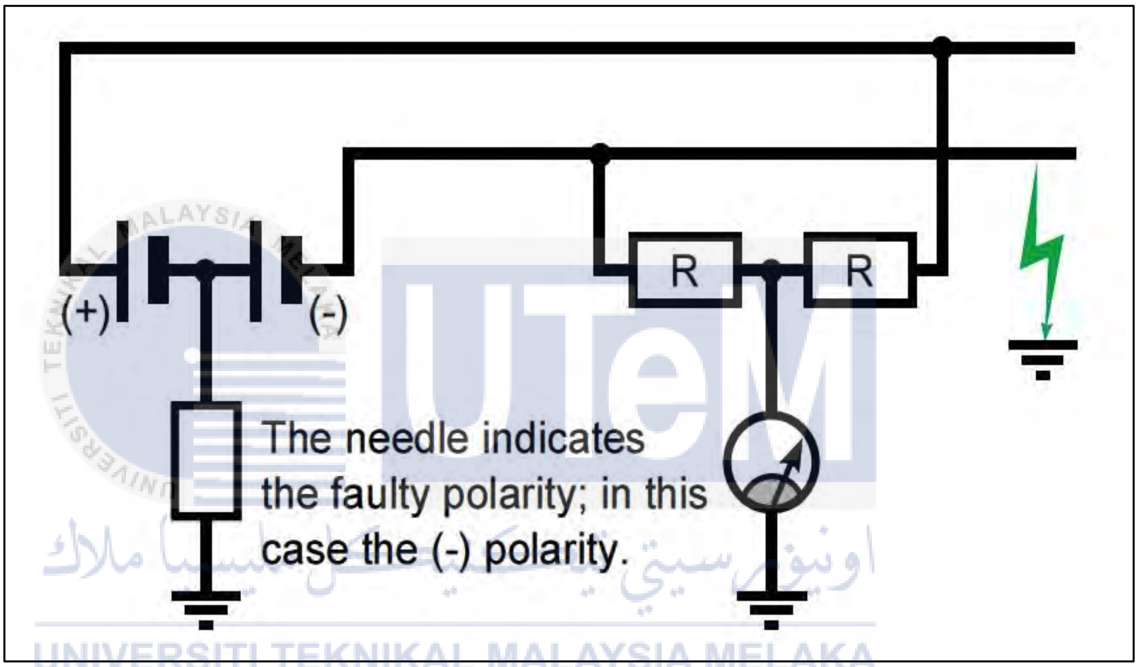

Figure 2.3: Principle of PIM at DC network[3]

From figure 2.4, the low DC current injection will flow through the leakage of current. The first PIM is placed between the network and the earth in order to detect the leakage of current. So, whenever there is a leakage of current, the line where the leakage happens, the circuit will be short-circuited by the impedance. The voltages on the faulty line will be reduced and can be seen by comparing others to the voltage of other lines using voltmeter.

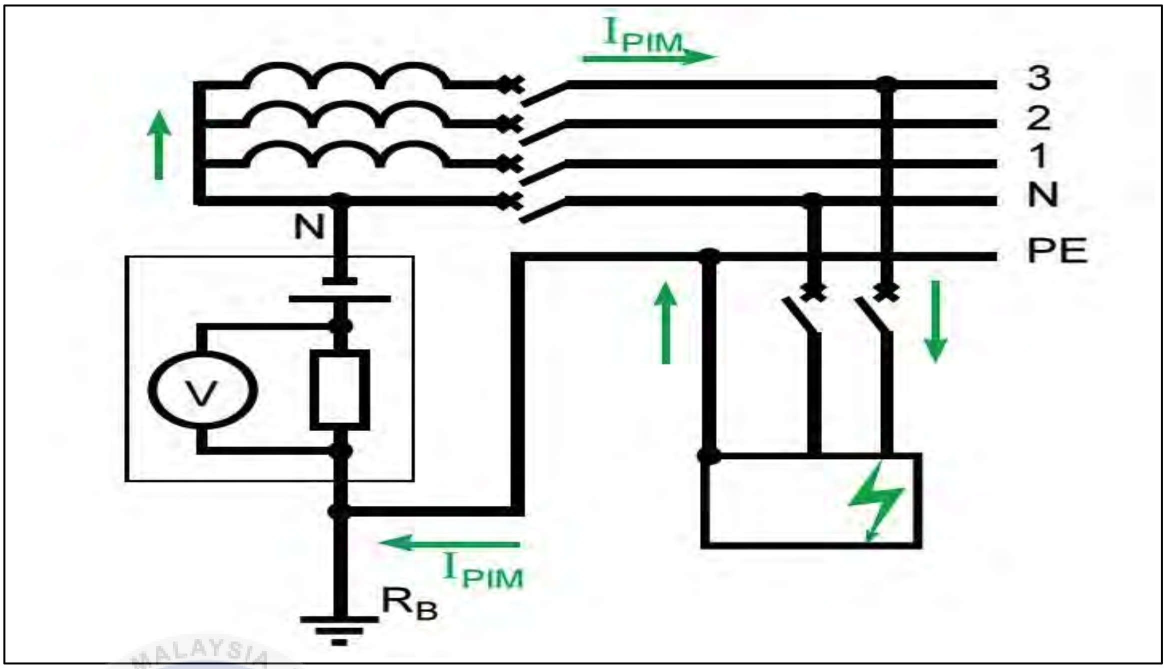

Figure 2.4: Principle of PIM at AC network[3]

From figure 2.5, the principle of the AC and DC network has been discovered to overcome the constraint that occurs when the PIM is applied to long networks. This principle uses low frequency AC current injection in-between the network and the earth. So, the leakage of current can be determined by calculating the voltage-current shift based on the current that flows back through the network impedance. Even though this technique can overcome the constraint of the first PIM, the response time will be longer than the others two network available.

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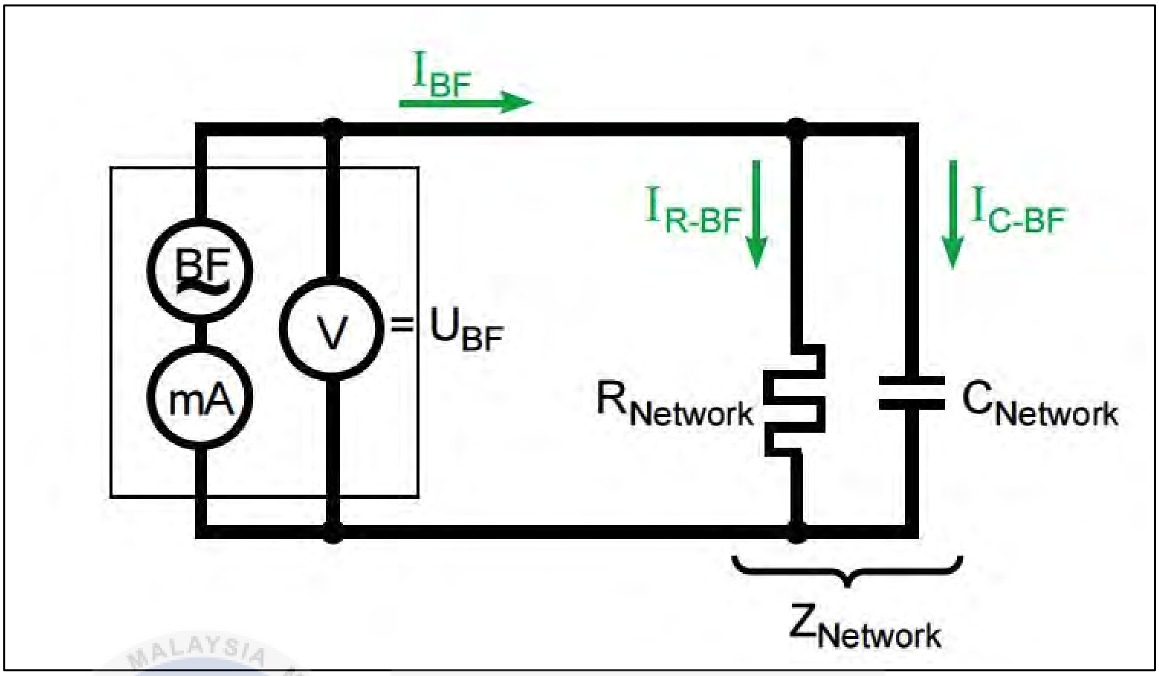

Figure 2.5: Principle of PIM at AC and DC network[3]

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From table 2.1, there are three PIM principles but with different networks. The networks are AC (alternating current), DC (direct current) and for both AC and DC. Every network of the PIM principles has its own advantages and disadvantages. For an example, the DC network does not allow the “live tracking” which considered important nowadays as the “live tracking” method allow the users to detect the leakage of current without any power break. As for AC network, even though the network allows, “live tracking”, there is a problem when the cable capacities are seen as insulation fault. Bigger cable capacities will heavily affected the detection of leakage of current that will decrease the accuracy of the device. Last but not least, the AC and DC network turns out to have a higher response time than the other two networks.

2.2.3.1 Detecting the fault current

This method uses a clamp-on probe to put at each feeder[3]. The clamp-on probe will measure the earth leakage, and the highest measured values are definitely the faulty feeder. This method requires a frequency that similar to the network, which usually at 50Hz or 60Hz[4]. The current I_d flows through the first fault and return to the origin of PIMs through the capacities of other working line. Other option is the current will flow via the neutral impedance if any. Even though this technique allows live tracking, any networks with a large quantity of feeders will not be capable due to its high capacitive value. Plus, this technique will not applicable with network with less capacitive leakage whereas the fault current will virtually unseen.

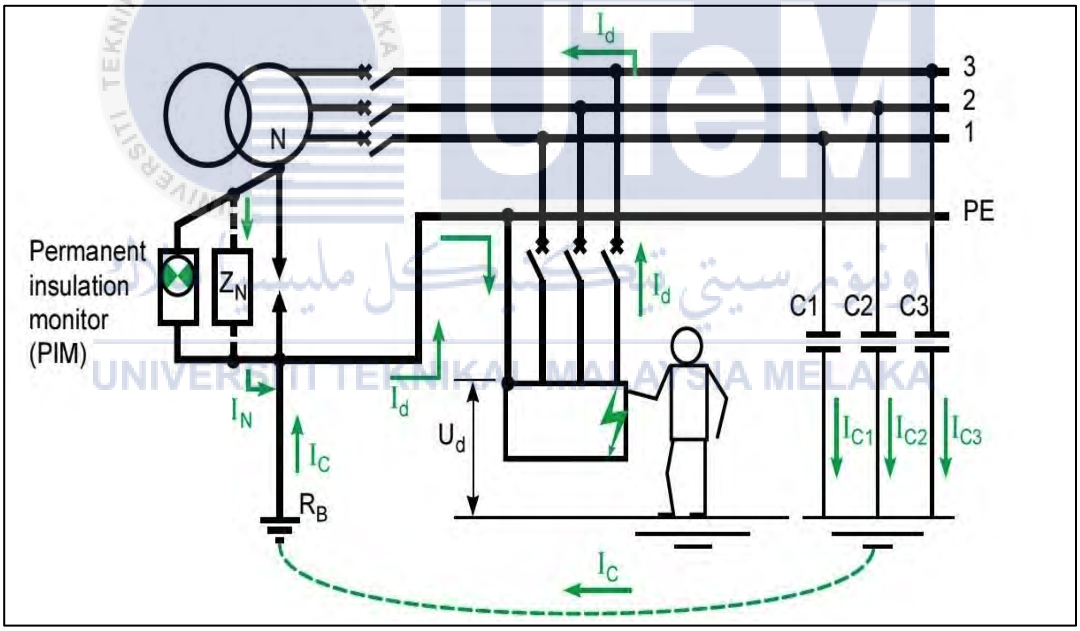

Figure 2.6: IT system network with single insulation fault[3]

In Figure 2.6, low current will be developed whenever the insulation fault occurs due to network of capacities. Even though the fault occurs, only few volts of contact voltage developed at the frame earth connection. The contact voltage then can be calculated after the human, which act as earth connection resistance times with the fault current using simple formula of $V = IR$.

2.2.3.2 Detecting an injected current

For this method, a generator or a PIM is needed to inject the low frequency sinusoidal pulse, which must be less than 10Hz[3][5]. Detection toroid will be positioned at every feeder or a clamp-on probe, where both of the sensitive devices attune to a selected frequency to pinpoint the correct position of the faulty. This method will provide no confusion by the network leakage nonetheless this frequency should stay low as 2.5Hz considering if the value going higher, the magnetic sensor became less sensitive.

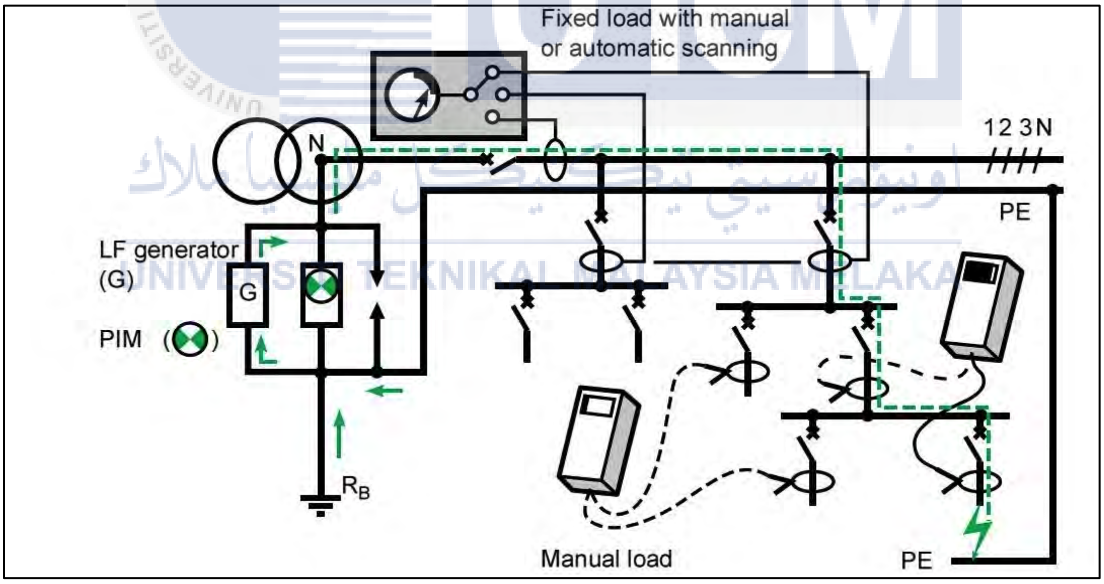

Figure 2.7: Tracking happen by injecting pulse at fixed or portable devices[3]

From figure 2.7, there are two types of load which are manual load and fixed load with manual and automatic scanning. Detection toroid is placed at each feeder but with different load. Fixed load usually used automatic scanning to locate the correct position of the faulty. For manual load, the signal frequency will be set by the users and manually find the faulty at each feeder.

2.2.3.3 Measuring insulation on each feeder

This method allows the user to be prepared one step forward as all data will be taken. The users may not prepared for the first fault to be happen, however the users can programmed the maintenance work and prepared for the faulty feeder[3]. So it is vital to check every change happen to the feeder regularly. The resistive and capacitive insulation components must be precisely determined for the users to program the maintenance schedule. By using this method, same technique will be used from detecting injected current as in figure 2.7 but with the usage of digital techniques for management of electric power distribution[4]. By using this method, the user can control and monitor the insulation fault from one control room. Insulation changes of each feeder can now be supervised, displayed and logged easier. However, this method is expensive as big cost needed to setup an electrical power management system.

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2.3 Earthing systems used

2.3.1 Background

There are several earthing systems which has the official status by the Malaysian standard (MS IEC 60364)[6] which are TN system [7], TT system and IT system [8], where all system shall follow the Electrical Installations of Buildings-Part 7-710: Requirement for Special Installations or Locations-Medical Locations (IEC 60364-7-710:2002, IDT)[1][13]. These standards are to assure the efficiency of industrial and development of Malaysia. In this case, the standard of earthing system can benefit the health and safety of public while at the same time protecting the consumers. The TN system will be divided into three different systems, which are TN-C system, TN-S system and TN-C-S system[3][9]. All systems involved in the medical locations are using different principles with it pros and cons.

2.3.2 Problem on Choosing the Earthing System

To develop an insulation-monitoring device, proper selection of earthing system is needed. This is to make sure the device can work properly and accurately with the environment. Malaysian standard and international standard are used as an important reference on how to pick the most efficient earthing systems. Medical room need to have a high level of dependability to avoid problems due to electric supply and the system can operate for surgical operation and others equipment especially in operation theater [10].

2.3.3 Analysis on choosing the earthing system

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Table 2.2 shows the comparison on several earthing system which suitable with the insulation monitoring device and medical environment. The principles of every system are about the same, which to prevent leakage of current in electrical system. The most suitable system, which suits the insulation-monitoring device, is the IT system. Referring to Table 2.3, IT system scores more than the others three systems with the advantage on the availability of electrical power. As insulation monitoring device involved in electrical environment especially in medical surrounding, IT system is the most suitable system, which can increase the accuracy of the device.

Table 2.2: Table comparing on TN-C, TN-S, TT and IT system[3]

<table>
<tr><th>System</th><th>Principles</th><th>Operation</th></tr>
<tr><td>TN-C [9]</td><td>The neutral and protective conductor share the same conductor</td><td rowspan="3">The leakage of current on the electrical lines becomes short circuit and Short-Circuit Protection Devices will disconnect the faulty part.</td></tr>
<tr><td>TN-S [9]</td><td>The conductor and protective conductor will be separated.</td></tr>
<tr><td>TN-C-S</td><td>The fusion of TN-C and TN-S systems. The neutral and protective conductor separated downstream of part of the installation in the TN-C system[3].</td></tr>
<tr><td>TT [11]</td><td>Neutral line of transformer and the electrical load are earthed</td><td>The current of the leakage part is limited by earthed connection impedance. Protection will be administered by the Residual Current Devices.</td></tr>
<tr><td>IT</td><td>The neutral line of transformer is not earthed, but is theoretically unearthed. It is actually earthed by the high impedances of the stray capacities of the network cables[3]. Not to forget, the electrical load frames are earthed.</td><td>When leakage of current occur, a small current is develops as a result of network’s stray capacities. The contact voltage developed in the frame of earth connection is not dangerous [3].</td></tr>
</table>

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Table 2.3: Summary on the pros and cons of electrical earthing systems[3].

	TT	**TN-C**	**TN-S**	**IT**
Safety when installing the system	3	3	3	3
Safety of equipment				
• Against the fire hazard	3	1	2	3
• For machine protection on leakage of current	3	1	1	3
Availability of electrical power	2	2	2	4
Electromagnetic compatibility	2	1	2	2
For installation and maintenance				
• Skill	2	4	4	3
• Availability	1	2	2	3
Total	16	14	16	21

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4	Excellent
3	Good
2	Average
1	Poor

2.4 Calculating fault current and contact voltage

2.4.1 Background

Dangers can be avoided if the contact voltage on human is less than 50V. This has been issued in international standard IEC 60364 (NF C 15-100)[6]. When the contact voltage is more than 50V, these standards needs automatic opening of the circuit[8]. Fault current, I_d occurs when there is an insulation fault at the circuit. This fault current develops due to the network stray capacities as seen in Figure 2.3. The contact voltage, U_C is voltage between the earths and the faulty device frame. By calculating the fault current, we can calculate the contact voltage for different situation and make comparison to each result.

2.4.2 Problem on calculating the fault current and contact voltage

When there is an electrical insulation faulty, the insulation-monitoring device must capable to calculate and show the user the value of the fault current. However, there is a problem on how to calculate the fault current and contact voltage of the faulty device. Thus, the calculation can be useful to cross check the simulation result with the theoretical result.

2.4.3 Solution to the available problem

<u>General case (resistive fault)</u>

Assume ($C1 = C2 = C3$), so the fault current has the following value:

$$I_d = U_0 \frac{1 + 3jC\omega\, Z_N}{R_d + Z_N + 3jC\omega\, Z_N R_d} \tag{2.1}$$

The capacitive current, I_C is written as:

$$I_C = U_0 \frac{3jC\omega\, Z_N}{R_d + Z_N + 3jC\omega\, Z_N R_d} \tag{2.2}$$

The current in the impedance Z_N:

$$I_N = \frac{U_0}{R_d + Z_N + 3jC\omega\, Z_N R_d} \tag{2.3}$$

The contact voltage, U_C can be calculated by multiplying the fault current I_d flowing to the earth connection resistance R_A of the application frames but both parameters are not connected[3]. If they are connected, R_B will be used. Using simple equation, we can calculate the contact voltage, U_C:

$$U_C = R_A I_d \tag{2.4}$$

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Full fault case

For this full case, there will be a configuration to show the highest contact value, U_C can be achieved. By applying previous formula 2.1, where $Rd = 0$, we get:

$$I_d = \frac{U_0}{Z_N + 3jC\omega} \tag{2.5}$$

$$U_C = R_A \frac{U_0}{Z_N + 3jC\omega} \tag{2.6}$$

The capacitive current is equal to:

$$I_C = +3jC\omega\, U_0 \tag{2.7}$$

While, the current in impedance, Z_N:

$$I_N = \frac{U_0}{Z_N} \tag{2.8}$$

For case study, Z_N (impedance-earthed neutral) have been changeable to two value, which $Z_N = \infty$ and $Z_N = 1k\Omega$, the calculation are made for a network in the IT system. Such condition has been fixed at a value according to this $400\ VAC$ $(U0 = 230V)$, R_A, earth connection resistance equal to 10Ω and R_d, insulation fault value equal to 0 to 10kΩ.

Table 2.4 shows the relationship of fault current and contact voltage within the first fault of the current. This value can be used for crosschecking the value of experiment of the insulation monitoring device hardware. From table 2.4, Case 1, the variables will be representing the low capacity network as in the medical room, which are the most important values for cross checking with the insulation monitoring device. This is because; the insulation-monitoring device is used in a medical environment room.

Case 1 (low capacity network such as operating theatre):

$C1 = C2 = C3 = C = 0.3\ \mu F$ per phase.

Case 2 (power network):

$C1 = C2 = C3 = C = 1.6\ \mu F$ per phase.

Case 3 (very long network up to 40km of cables)

$C1 = C2 = C3 = C = 10\mu F$ per phase.

Table 2.4: Table on relationship of fault current and contact voltages.

R_d (kΩ)			0	0.5	1	10
Case 1 $Cr = 1\mu F$	$Z_N = \infty$	U_C (V)	0.72	0.71	0.69	0.22
		Id (A)	0.07	0.07	0.07	0.02
	$Z_N = 1k\Omega$	U_C (V)	2.41	1.6	1.19	0.21
		Id (A)	0.24	0.16	0.12	0.02
Case 2 $Cr = 5\mu F$	$Z_N = \infty$	U_C (V)	3.61	2.84	1.94	0.23
		Id (A)	0.36	0.28	0.19	0.02
	$Z_N = 1k\Omega$	U_C (V)	4.28	2.53	1.68	0.22
		Id (A)	0.43	0.25	0.17	0.02
Case 3 $Cr = 30\mu F$	$Z_N = \infty$	U_C (V)	21.7	4.5	2.29	0.23
		Id (A)	21.7	0.45	0.23	0.02
	$Z_N = 1k\Omega$	UC (V)	21.8	4.41	2.26	0.23
		Id (A)	21.8	4.41	0.23	0.02

2.5 Comparison on different method to detect the leakage of current

Different systems will give different performance as well as the behavior of the system. The design is assumed by implementing IT system to insulation monitoring device (IMD). International standard and Malaysian standard of Electrical Installations of Buildings –Part 7-7-10 (IEC 60364-7-710:2002, IDT)[6] obligate to use the medical IT system with the presence of insulation monitoring device. From Table 2.2, the pros and cons of the each earthing system have been simplified. IT system rank the top of all earthing system compared to other earthing systems, which mean the IT system is suitable to pair up with the insulation monitoring device[3]. Table 2.5 shows the comparison on different method to achieve the desired detection of leakage current. Main design parameter of the design, which are accuracy and precision will be discussed to find the most suitable method on achieving the main objective of this project.

Table 2.5: Comparison on different method to detect leakage of current

Method	**Design Parameter**	
	Accuracy	**Precision**
1. Voltmeter Balance Technique	• The accuracy for this method depends on the faulty polarity and the method still being used today. • The major trade off for this method is that no live fault tracking, which is compulsory for today monitoring purpose.	• Precision for this method is unknown, as the faulty current on the circuit will be shown only on the needle indicator as in figure 2.3.
2. Detecting Fault Current	• Accuracy for this method is high, however there are some trade off for this method. • This method is not stable when working with a network with high number of feeders and with network with low number	• Precision for this method can be high if the insulation fault is within the same frequency as that electrical network (50Hz or 60Hz).

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	of capacitive leakage.	
3. Detecting The Injected Current	• No confusion on the capacities leakage network but the accuracy of this method will drop if the frequency is less than 2.5Hz. • The accuracy for this method depends on the magnetic sensor that sensitive to injected pulse only.	• This method uses low frequency injection (<10Hz) on the detection toroid and the precision of the method is high as there are no disturbances of the capacities leakage network. • However, the precision of this method can be affected when the frequency of the electrical system is less than 2.5Hz.
4. Measuring Insulation On Every Feeder	• Accuracy for this method is high but it is costly compared to others method. • For this method, monitoring of every feeders and diagnose the resistive and capacitive insulation component is necessary to allow maintenance before any fault happen.	• This method uses digital buses and the supervision of the leakage current can be monitor remotely. • The advantage of this method is the precision on every reading of the insulation component as digital technique of the management of electrical power

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		distribution being applied.

To detect leakage without less false error, technique of detecting fault current can be used alongside with the AC network. This technique and network allows the ‘live tracking’, which mean the detection of insulation faulty can take place without power breaking. Thus, by designing the insulation monitoring device with IT system by using an AC network with fault current technique can optimize the accuracy and precision of the device but the constraints must be controlled. If the constraint not controlled, the cable capacities can be seen as leakage of current.

Thus, by considering the information from every source, the monitoring device should be able to detect the leakage current with the accuracy and precision criteria being prioritized. Method of detecting the leakage of current will be implemented alongside the IT electrical network system to achieve the most accurate and precise result.

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CHAPTER 3

RESEARCH METHODOLOGY

This chapter will discuss on the setup of the experiment and simulation based on the previous experiment, which are taken from several journal. In this chapter included the design of experiment, presentation of result and interpretation of result

3.1 Objectives of the Simulation and Experiment

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1. To prove the insulation-monitoring device able to detect the threshold resistance of the patient based on the IEC 61557-8 standard.
2. To identify the performance of the device in term of accuracy and precision.

3.2 System Overview

From figure 3.1, the position of an insulation-monitoring device in an electrical network can be seen. When insulation fault or leakage of current happens, the network will be short circuited by the high impedance of the network causing the circuit to be completed. After the circuit has been completed, at point 1 and 2 on the figure 3.1, the insulation-monitoring device starts to operate to detect the leakage of current at the network or circuit.

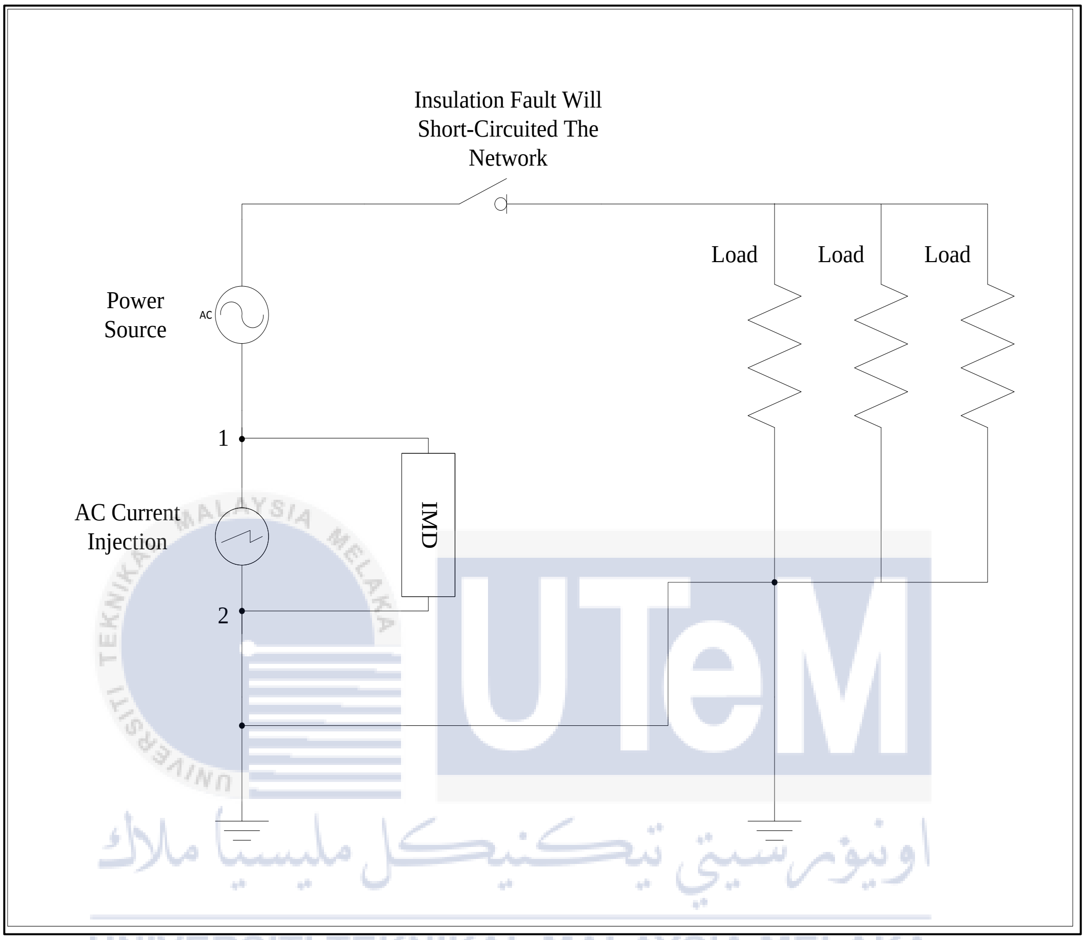

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Figure 3.1: Insulation Monitoring Device position on an IT system

Figure 3.2 is referring to the system overview of the insulation-monitoring device to detect the leakage of current. Current sensor detects the input in term of voltage values, which later on can be calculated to current values of the electric network. Then, operational amplifier to be an amplified analog input will amplify the current values. After passing through the A/D convertor, the analog input converted to digital values, which can be read by microcontroller. Microcontroller will alert the user by give alarm to the user on detected result and display the detected current values if the current induced threshold is at 51kΩ or less.

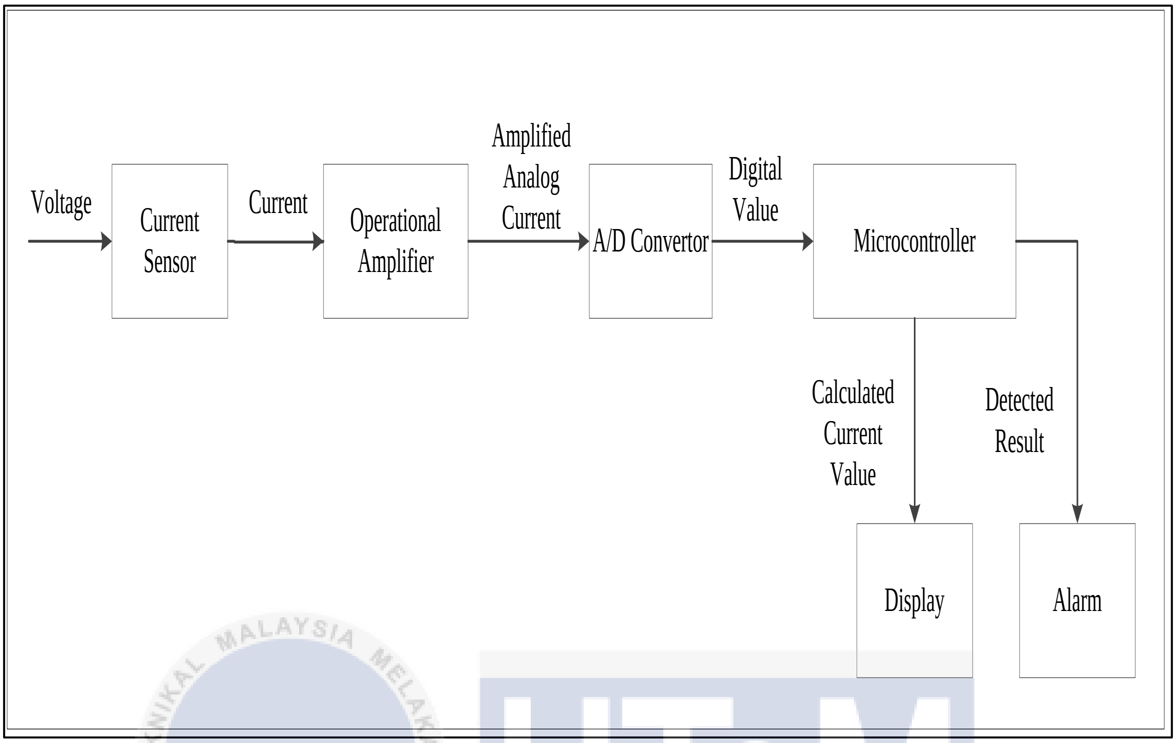

Figure 3.2: System overview of the Insulation Monitoring Device

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3.3 Materials and Equipment

In the development for this project, Proteus software has been used thoroughly to make the circuit and simulation based on the real world model. For the simulation setup, the software that was used is Proteus version 8.0.

Proteus is software to draw schematic capture and microprocessor simulation. Lab Center Electronics is the company that developed the software to help the engineer to verify their circuit before production of the project. The main feature for this software is to check the validity of a circuit that currently being developed. The advantage of this software compare to Pspice is that this software consist variety of component inside the library component.

Previous studies have shown that the IT system that is installed in medical room has permanent electro medical equipment (EME). Due to the fixed equipment, simulation can be done and lab experiment can be developed. Actual parameters from the electro medical equipment and electrical installations will be used for simulation and experiment. Parameters such as capacitances, currents, isolation resistance and parasitic capacitance are the important parameters to achieve valid results.

3.4 Experimental Setup

Recently, simpler and more rapid tests to provoke genuine leakage of current have been developed. The experimental is set up to simulate when the electro medical equipment (EME) is connected to a patient. To replicate the genuine leakage, the voltage at the frequency of $50Hz$ was formed, as though the electromedical equipment connected to the patient because of electrical isolation problems. Figure 3.3a shows the circuit drawing of the experimental setup

In figure 3.3b, the lamp with a resistance of 60W will be used to represent the EME or load which fed by isolation transformer [1] . By placing the decade resistors, the current flows through the resistor can be changeable depend on the resistance set at the decade resistor, which have a small different from what Luiz Eduardo set up to provoke the real leakage [1]. The decade resistor have the resistance value from the range of 1Ω to $1000k\Omega$ while Luiz Eduardo experimental set up uses only two different resistors with $100k\Omega$ and $220k\Omega$ respectively. Besides, real isolation transformer is being used for safety purpose in laboratory environment. Isolation transformer also has an important role on following the Malaysian standard of Electrical Installation Building 2009 [16].

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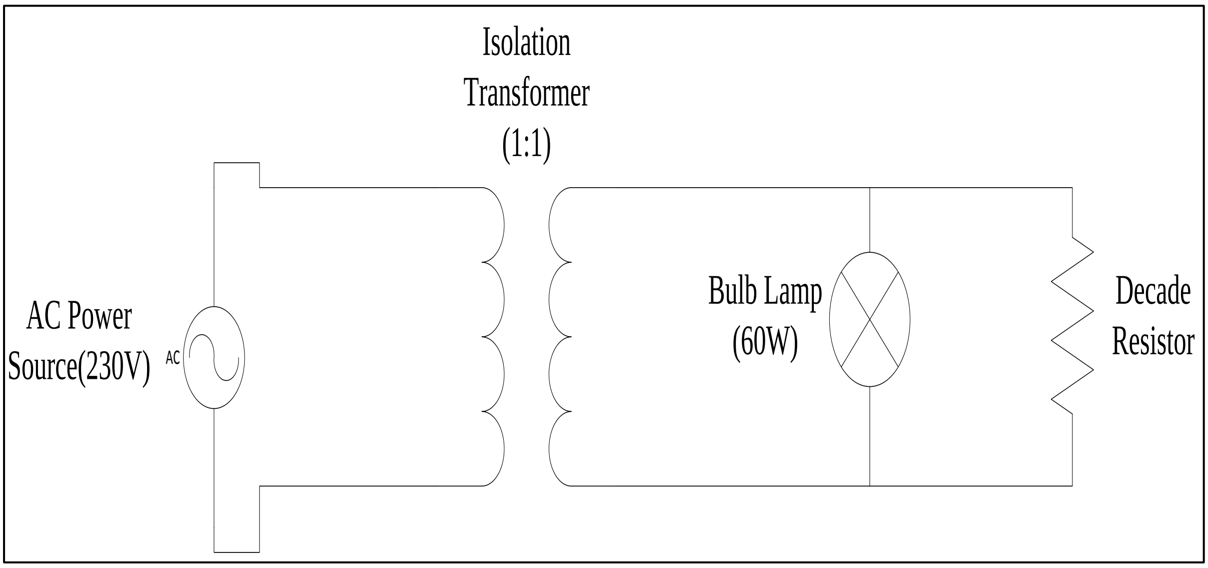

Figure 3.3a: Circuit drawing of experimental setup to provoke real leakage

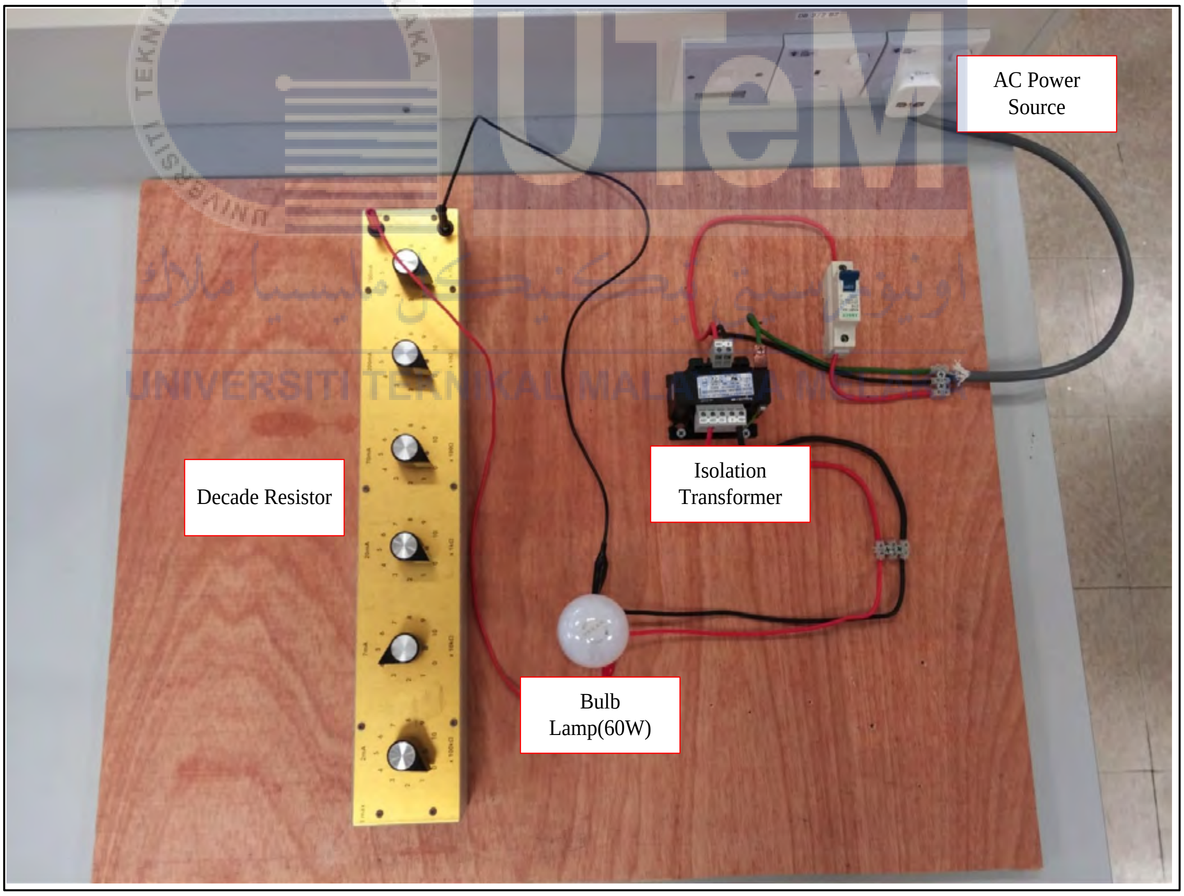

Figure 3.3b: Laboratory experimental set up to provoke real leakage

3.4.1 Parameter for the Initial Experimental Setup

The parameters listed in table 3 are to replicate the IT system parameter within the medical room environment. The parameters such as isolation transformer, load and decade resistor are being controlled as below to replicate the electrical leakage in the medical room. While, the high accuracy multimeter will be used as the theoretical value reading to be refer to when calculating the error.

Table 3.1: Parameter that will be used to replicate the medical room environment

Parameter	**Value**
Isolation transformer	• Input voltage = 230V • Output voltage=200V
Bulb lamp	• 60W/100W
Decade resistor	• Changeable to differentiate different resistance • Tolerance 0.5%
GW Instek multimeter GDM 354A Multimeter	• DC voltage range=199.9mV • AC voltage range=199.9mV • Resistance reading up to $2000M\Omega$ • Frequency reading up to 15MHz

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3.4.2 Precautions to Prevent Invalidity

In order to prevent invalidity, the length of the wire used must not be at optimum length. This is because; longer wire can increase the resistance of the circuit. Furthermore, the hardware must be tested in terms of accuracy, so that the result will not be affected. Next, the power source connected to the device should be controlled at 5V as the microprocessor, display, current sensor and alarm used at least 5V. More over, before any experiment is set up, the input voltage and output voltage from isolation transformer need to be taken by using the multimeter as we need to know the voltage loss within the transformer. The reading of output voltage from the transformer is important due to the threshold resistance for the medical environment will be changed after receiving different value of voltage.

For example, from figure 3.4, the transformer input voltage is at 236.2 V while referring to figure 3.5; the transformer output voltage is at 200.9 V. There is a drop of voltage from the primary and secondary coil of the transformer based on the reading from the multimeter. So, to reduce the invalidity, before start every experiment, the transformer input and output voltage need to be recorded.

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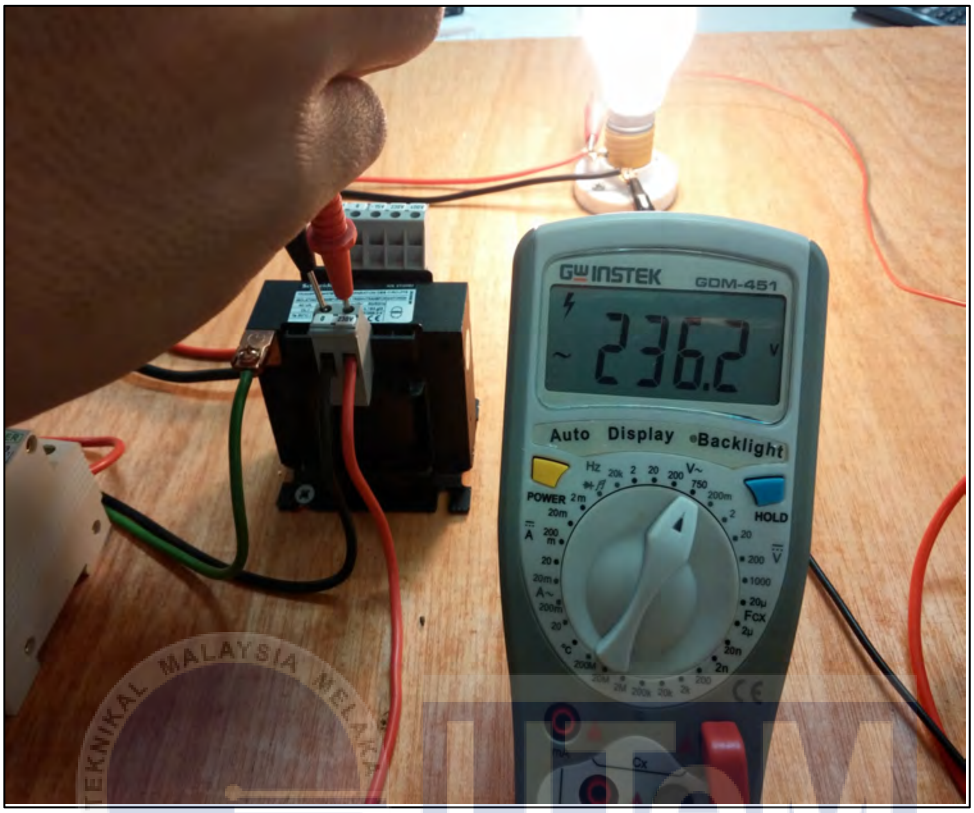

Figure 3.4: Checking the transformer input voltage

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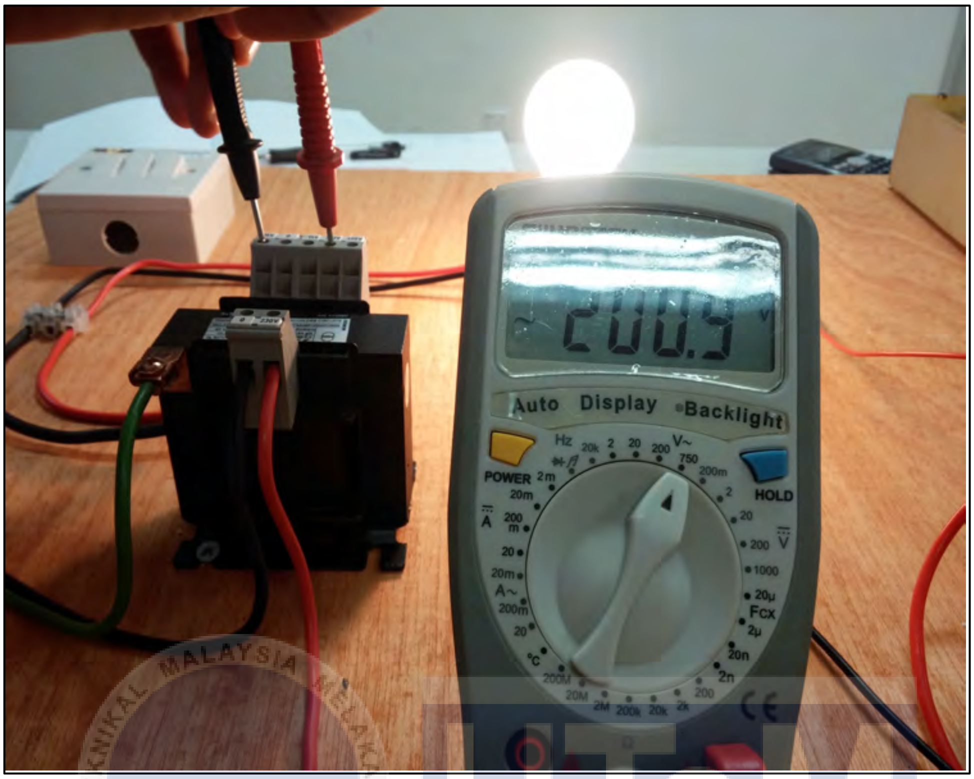

Figure 3.5: Checking the transformer output voltage

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3.5 Procedure

3.5.1 Simulation

IT system has been developed and improvises to prevent any accidents that occur due to passing current across patient[2]. Even though the system are built for safety inside the medical room, there are cases which, the IT system incapable to prevent current-provoked accidents. Thus, standard that being issued by the Malaysian government requires that one separate IT system must be included with an insulation-monitoring device.

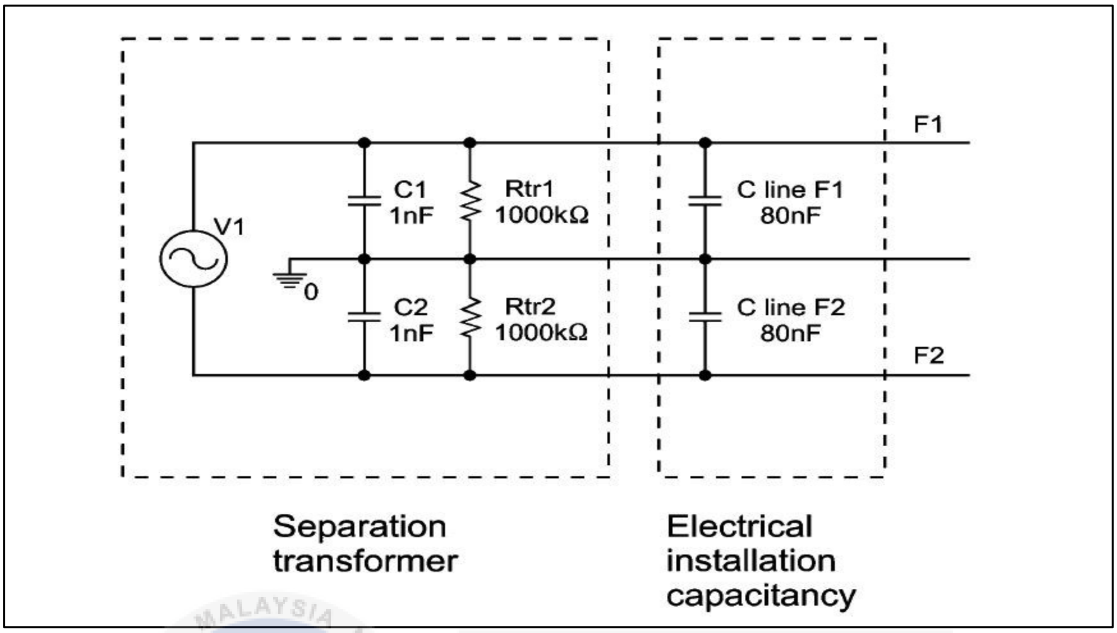

Figure 3.6: IT system parameters[1]

IT system has been developed and improvised to prevent any accidents that occur due to passing current across patient[2]. Even though the system are built for safety inside the medical room, there are cases which, the IT system incapable to prevent current-provoked accidents. Thus, standard that being issued by the Malaysian government requires that one separate IT system must be included with an insulation-monitoring device. Software Proteus is used for the simulation and mathematical calculation. The parameters of C1, C2, Rtr1 and Rtr2 are approximately taken from genuine measurement in the transformer[1]. While for the C line F1 and C line F2, the values are approximately taken from medical operation theater and it will represent the capacitances that included in the installation of conductor. By using this method, it is mandatory to calculate the differential current at point F1 and F2[1]. From the figure 3.4, the F1 and F2 will be put resistive component (R1 and R2) with a small resistance of 0.001Ω.

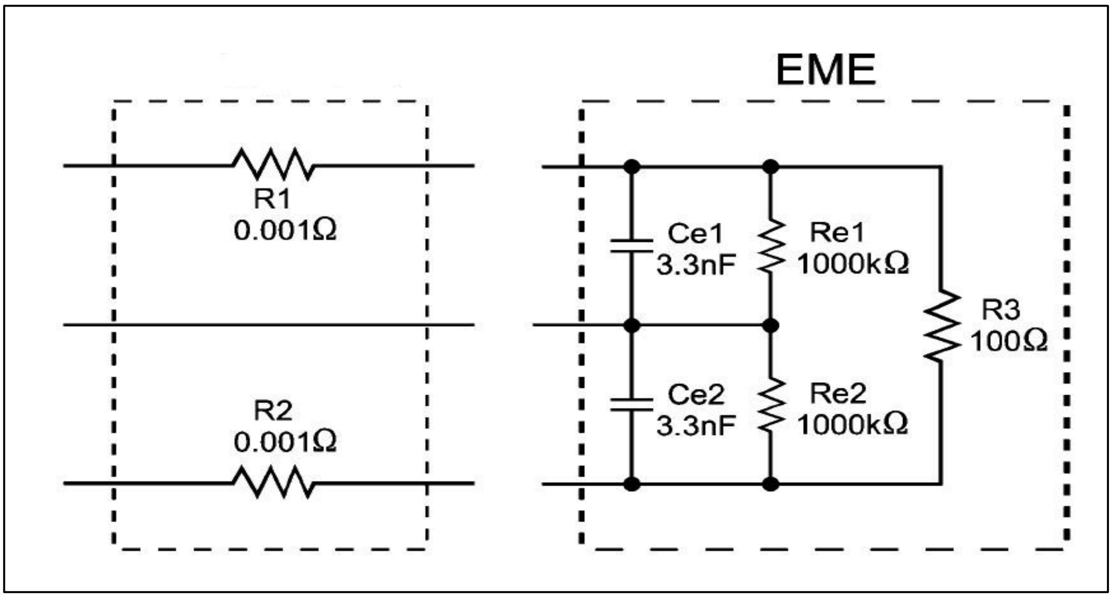

Figure 3.7: Current measurement and EME simulated by software[1]

As the differential current measuring will be representing by R1 and R2, the electro medical equipment is represented by filter capacitors of 3.3 nF. The capacitance however will have a big effect on the load production in F1 and F2. The electro medical equipment isolation resistance (Re1 and Re2) are $1000k\Omega$[1]. The load resistance of 100Ω will produce a load current of $230V/100\Omega = 2.3\,A$ which are the characteristic for electromedical equipment. The main purpose of the simulation is to acquire whether there is a current pass through patient whenever the resistance on the body changes from 1000Ω to $51k\Omega$ and to check whether the differential current measurement can be calculated.

3.5.1.1 Experiment to find the relationship between theoretical current with measured current and relationship of voltage drop with the resistance

For this experiment, ammeter is placed in series between the load and the decade resistor. Decade resistor will provide the different resistance value from 46 kΩ to 55kΩ, which will detect the threshold value at 51kΩ. The experimental setup follows the figure 3.3 but adding extra ammeter for the current flow reading. The isolation transformer provides 200 V_{AC} to the circuit as shown in figure 3.8 and the when the switch is turn on; the bulb is lit to indicate that the voltage supply flows through the circuit.

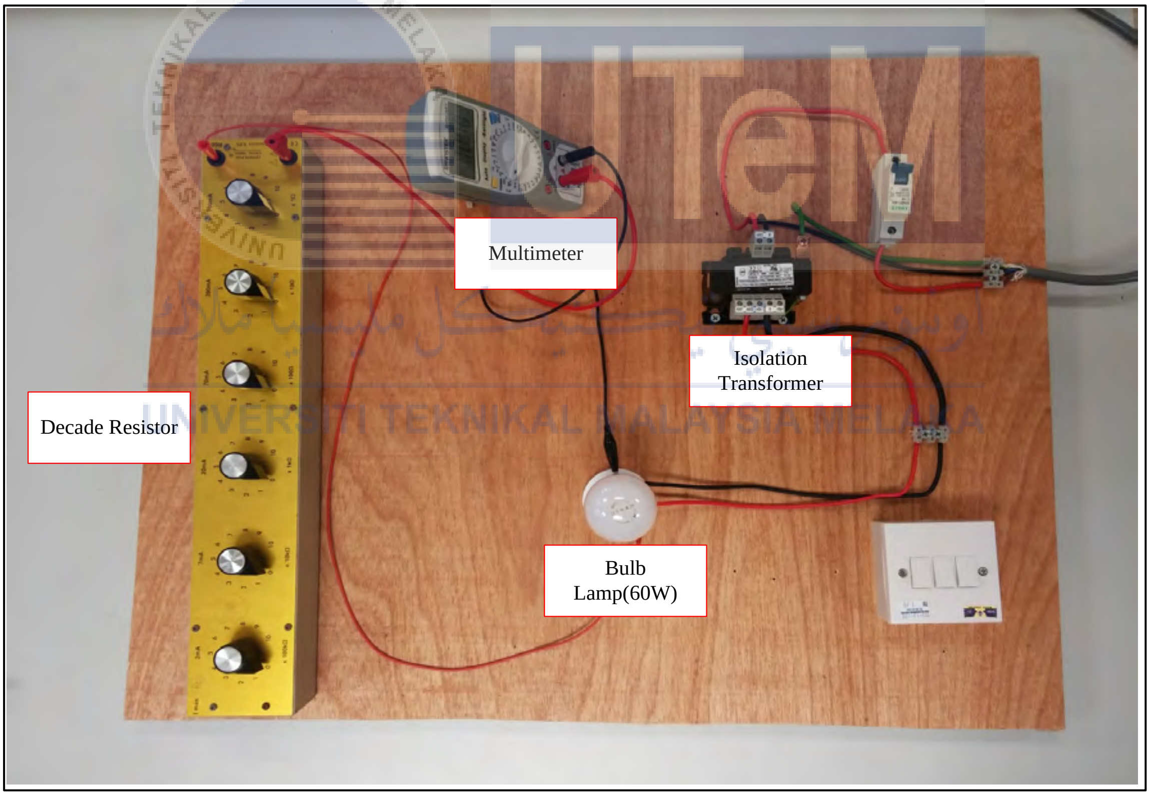

Figure 3.8: Experimental setup for the relationship between the theoretical current with measured current.

Next, this experiment is meant to find the relationship between voltage drop with the resistances of the decade resistor and fixed resistor on the device. By using a voltmeter, which connected parallel with the decade resistor, the voltage drop can be easily obtained. This experiment will be using an AC (alternate current) function generator, which is set initially at 5V. The resistor of 10kΩ will be used as fixed resistor to the device and the decade resistor is connected in series with the fixed resistor. Any addition of resistance using the decade resistor is actually showing the internal resistance of the circuit increases and can affects the voltage. The experimental set up for this experiment is the same with figure 3.8 but the power will be supplied by the function generator.

3.5.2 Lab experiment

3.5.2.1 Experiment to find the accuracy and the precision of the IMD detection

For the accuracy experiment to detect the leakage of current, the device uses the voltmeter theory to firstly find the voltage drop after the decade resistance, which represent the leakage. So, the hardware of the device is placed after the decade resistance in series. The device detects the changes of voltage drop after the decade resistance. By referring to figure 3.3a and 3.3b, the insulation-monitoring device (IMD) is placed after the decade resistance and a multimeter will be placed in parallel with the insulation-monitoring device to show the exact value of voltage drop after the resistance. This experiment figures out the accuracy by subtracting the real value and the device value after changing the decade resistor value. Figure 3.9 shows the connection of IMD to the electrical network system, which is crosschecked with the multi-meter reading.

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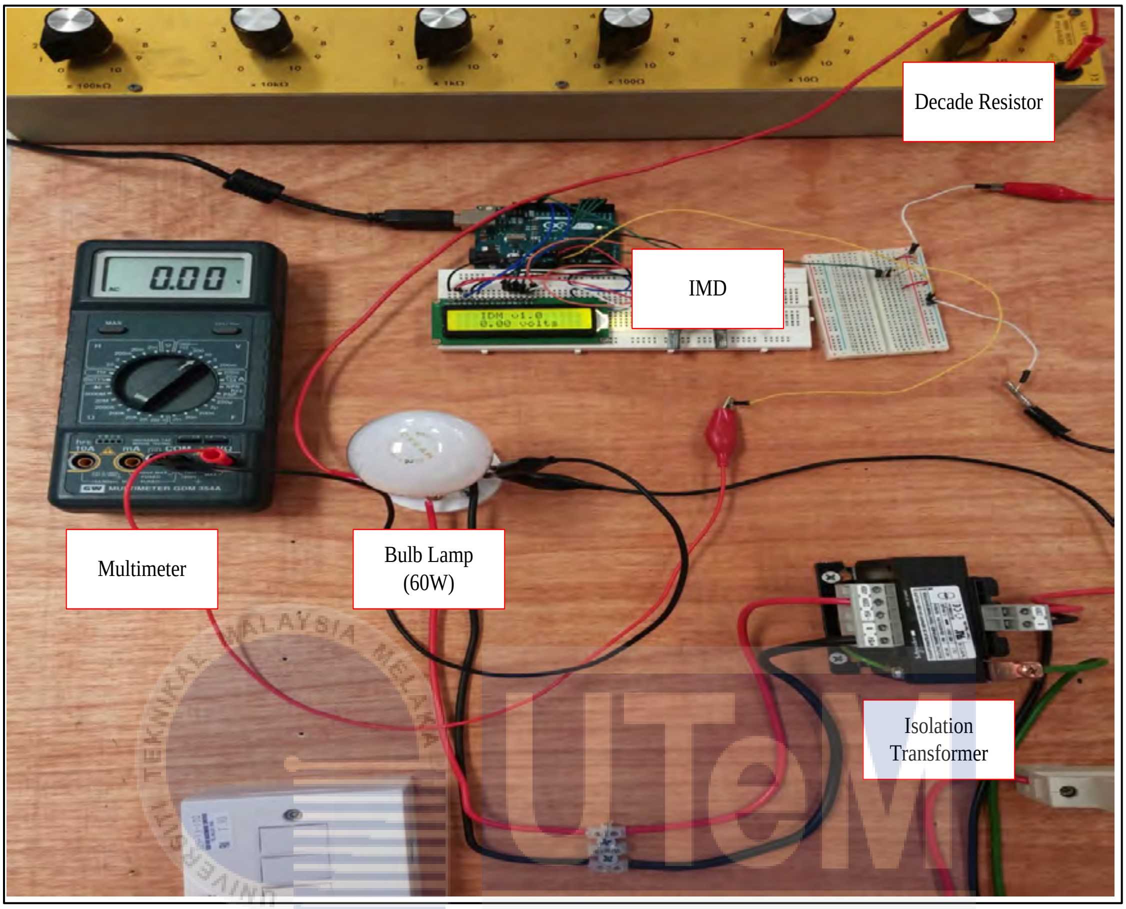

Figure 3.9: Experimental set up for accuracy and precision test

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We perform similar experimental set up for the precision experiment as shown in figure 3.9. However, the precision experiment tends to find the repeatability of the correct measurement. By using the same experimental set up, the device will be exposed to the leakage of current for two minutes and from the reading, the precision formula is applied to find the precision of the device. There will be 120 data from the device after two minutes, as the device will be detecting the leakage of current every one second. The precision of the device will be calculated by using the data received.

3.5.2.2 Experiment to find the sensitivity of the IMD detection

For this experiment, the experimental set up is the same as figure 3.9. However, the specific objective is to find the sensitivity of this device, the resistance to replicate the leakage of current is set at 44.35kΩ and 47.85kΩ. The 44.35kΩ represents the value of current threshold of leakage while the 47.85kΩ represents the value of current in a safe condition. For both resistance, the repetition is set to 50 times and the result for every repetition are recorded in the table of sensitivity. By using equation 3.3, the sensitivity of the device can be calculated.

3.6 Method to analyze

3.6.1 Accuracy experiment on IMD reading and detection

For the accuracy experiment on the IMD reading, the method to take the data is by taking both multi-meter reading and IMD reading after the resistance being changed. For each resistance from 40kΩ to 47.85kΩ, the reading of the IMD is taken despite the time taken to get the reading. Then, tabulate the data in the graph for further analysis of the data. From figure 3.10, at the resistance of 40kΩ, the multi-meter reading is at 1.82V while the IDM reading is at 1.84V. Thus from both reading, the multi-meter reading is set as the theoretical value and the IMD reading is the experimental value or the reading value. Analysis for accuracy of the IMD device will be based on absolute error and percentage error formula:

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$$Absolute\ error = \left| \frac{Experimental - Theoretical}{Theoretical} \right| \quad (3.1)$$

$$Percentage\ error\ (\%) = \left|\frac{Experimental - Theoretical}{Theoretical}\right| \times 100 \qquad (3.2)$$

By using both formulas, we can analyze the data from the IMD reading and make improvement on every aspect that can increase the accuracy of the device. From the formulas, the experimental value is the value from the IMD reading while the theoretical reading is the value from the reading of the multi-meter.

Figure 3.10: Method on taking data for accuracy experiment

3.6.2 Sensitivity experiment on IMD reading and detection

To analyze all the data that being considered, sensitivity and specificity play big roles on verify the effectiveness of the system. Therefore to analyze the data, diagnostic test is used. Sensitivity is the ability to consider a condition correctly. Mathematical expression for sensitivity is given by:

$$Sensitivity = \frac{number\ of\ true\ positives}{number\ of\ true\ positives + number\ of\ false\ negatives} \tag{3.3}$$

Where true positive, the situation is when it is correctly identified while false positive is a situation when it is incorrectly identified and true negative, the situation is when it is correctly rejected while false negative is when it is incorrectly rejected.

For sensitivity test, we refer to table 3.2 in order to calculate the percentage of sensitivity and specificity. Parameters such as true positive, false positive, false negative and true negative are important in order to find the sensitivity and specificity. By setup the fixed number of test for the software simulation and hardware simulation, the parameter of the test outcome is cross check with both simulations. Each repetition of hardware simulation is cross check with software simulation in order to find out the result. By cross checking each repetition, number of each parameter such as true positive, false positive, false negative and true negative can determined easily. Thus, sensitivity can be calculated.

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Table 3.2: Sensitivity and Specificity Table

	Condition		
	Condition positive	Condition negative	
Test outcome positive	True positive (TP)	False positive (FP)	Positive predictive value= $TP/(TP + FP)$
Test outcome negative	False negative (FN)	True negative (TN)	Negative predictive value= $TN/(FN + TN)$

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CHAPTER 4

RESULT AND ANALYSIS

For developing this project, few testing have been done on Proteus software and laboratory. This result is based on the insulation-monitoring device, which developed to detect the changes of current on the medical room environment. The accuracy and precision of the device are recorded for further analysis and improvement.

4.1 Introduction

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For the result and analysis chapter, there is discussion on finding the best method and using it to build the insulation-monitoring device. The experiment will be key point to achieve the objective of the project. Furthermore, the result from the experiment can be useful further study on the insulation-monitoring device. Accuracy and precision will be the key factor on producing the best insulation-monitoring device. As we know, the device has an important role on helping the medical environment to reduce the risk of micro-shock. Micro-shock happens when there is a leakage of current on the medical equipment. Thus, the result and analysis below will help to gather more information on designing the accurate and precise insulation-monitoring device.

4.2 Simulation result

4.2.1 Relationship between theoretical current with measured current on 230V condition

For the first experiment to simulate micro shock for medical environment, the voltage will be set accordingly to single-phase voltage distribution provided by Tenaga Nasional Berhad (TNB). The voltage is set to $230V_{AC}$ and divided into the resistance from 46kΩ to 56kΩ in order to verify the alarm threshold for this device. The alarm threshold should be at 51kΩ**.** Current produced for the resistance will be calculated first and the will be verified with the reading of the ammeter.

From appendix 1, when the resistance of the circuit is going down, the current produced is increasing to a value, which can bring hazard to patients in the medical environment. The threshold for the device, at the resistance of 51 kΩ will produce 4.51 mA. Any current produced bigger than 4.51 mA is dangerous especially, to the patients that being exposed to medical equipment.

In order to show the potential risk of micro shock, threshold of resistance 51kΩ will represent the first fault or leakage of current in the medical environment. The device should detect the first fault as if when a second fault occurs and the first fault is being ignored, the fault current will be fatal to patients. First fault or first leakage of current can developed contact voltage, but with minimum values and does not dangerous to healthy human. Even though the contact voltage is at minimum values, the patient at medical environment can be affected with the first fault.

Figure 4.1 shows the relationship between the resistance and current produced when the input voltage to be maintained at $230V_{AC}$ according to TNB single-phase distribution. From the graph, the calculation is calculated using Ohm's Law where

$$V = IR \tag{4.0}$$

In the Ohm's Law, the 'V' represents the voltage, 'I' represents the current and lastly the 'R' represents the resistance. The voltage value, V_{AC} is equal to $230V_{AC}$ and the resistances, R are being change decreasingly from 55 kΩ to 46 kΩ. The resistances for the experiment are decreasing 1Ω for each repetition to show the differences of current produced before and after threshold point at 51 kΩ. Current produced for each different resistance is being calculated by using Ohm's Law formula.

From Figure 4.1, there is a clear trend of current produced increased when the resistance value fall off. The results, as shown in Figure 4.1, indicate that the relationship of resistance with the current produced on circuit. In real life situation, the leakage of current is available when there are current leak on the frames of the electro-medical equipment (EME) to separate earth connection. By referring to Ohm's Law, as the voltage provided by TNB is to be maintained at $230V_{AC}$ and considering no power loss at that stage, the current produced will increase gradually whenever the resistances drop off from bigger value to a smaller value.

There were no significant differences between the current produced at highest resistance value and lowest resistance value from Figure 4.1. Current produced at 55kΩ is 4.18 mA while current produced at 46kΩ is 5 mA. The difference between both current produced is 0.82 mA for 9 kΩ difference in resistance. The value for current difference is small but can impact the patient in medical environment. Thus, having the insulation-monitoring device is vital precaution to every hospital or other medical environment.

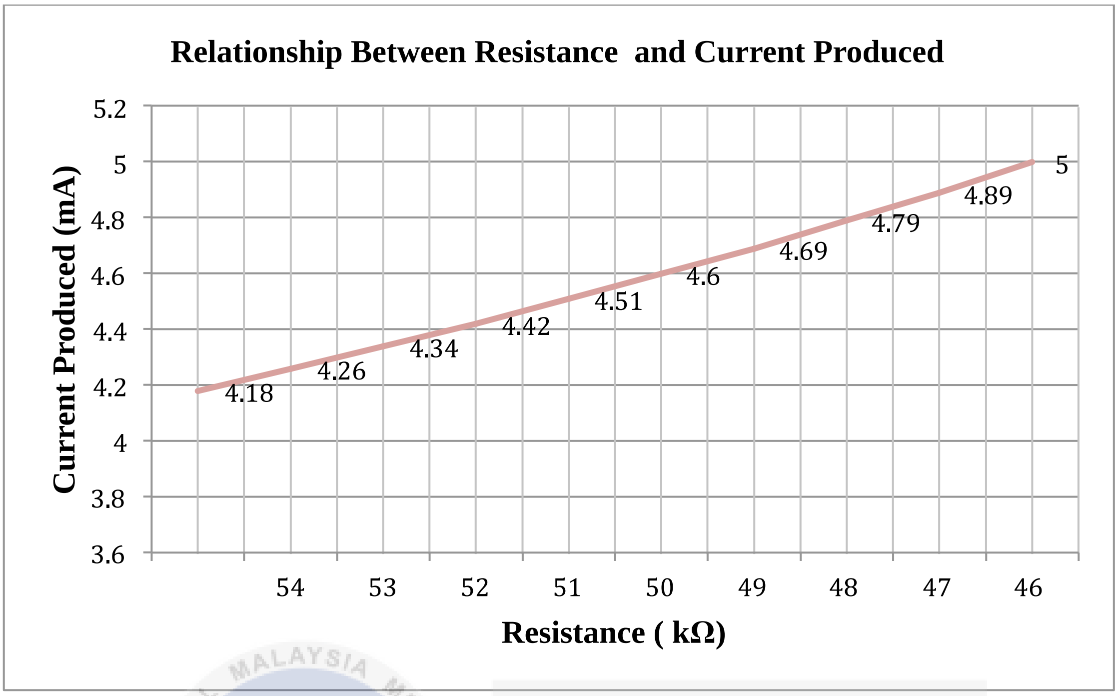

Figure 4.1: Relationship between resistance and current produced

4.2.2 Relationship between theoretical current with measured current on 200V condition

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Based on Malaysian standard for medical room, IEC 61557-8, the usage of isolation transformer is compulsory for the safety of medical environment. Isolation transformer is a transformer, which have no connection between ground (earth) with live and neutral lines. Therefore, by considering the safety of the patient, isolation transformer is compulsory to be install at the medical environment.

For the experiment to verify the current produced with the ammeter reading, real isolation transformer is being used. The isolation transformer input voltage is measured and the reading is 236.2 V_{AC}, while the output voltage that being read from the isolation transformer is 200 V_{AC}. The voltage drop of the isolation transformer needs to be considered in the calculation, as the resistance value for each current produced need to be the same with the calculation from appendix 1.

As the voltage is different from the early calculation, which is 230 V_{AC} to 200 V_{AC}, the current produced must be calculated again using Ohm's Law to provide a theoretical result. The theoretical result will be used to calculate error later on. From appendix 2, the I_{Theory} or I_{Th} represents the current produced after using new parameter of voltage and resistance by applying the Ohm's Law. So, the I_{Theory} from appendix 2 and current produced from appendix 1 are similar. The $I_{Measured}$ or I_m represents the current reading using ammeter, which to calculate the error when using the ammeter theory on the device.

From Figure 4.2, I_{Theory} and $I_{Measured}$ result follows the Ohm's Law and the trend of the graph is the same with the graph on Figure 4.1. When the resistance is at 40 kΩ, which is the lowest resistance, the current produced will be at the highest value compared to others resistance. The resistance value is at different value from previous resistance value, which can be refers at table 4.1 as; the output voltage from the isolation transformer is 200 V_{AC}.

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The resistance of 44.35 kΩ is the new threshold to be set on the device after the output voltage from isolation changing from 230 V_{AC} to 200 V_{AC}. Ohm's Law plays an important role to calculate the correct resistance value, which will be used to minimize the error reading of current reading. From appendix 2, there is slightly difference in the value of calculation and the reading of the current. Thus, to minimize the risk of the device not be able to detect the threshold resistance, the sensitivity of the device should be at optimum condition.

Further analysis on the reading of the ammeter and the calculation using equation 3.1 show the percentage error on every different resistance. From Figure 4.2, the green line, represents the I $_{Measured}$ and red line, represents the I $_{Theory}$. As the percentage error for the ammeter reading is at low value, the green line is overshadowing the red line in the graph. This shows that the percentage error for every resistance is low. The lowest percentage error for the ammeter reading can be seen when the resistance is at 40kΩ with 0.60% of error and the highest percentage error can be seen when the resistance is at 47.85kΩ with 1.20% of error.

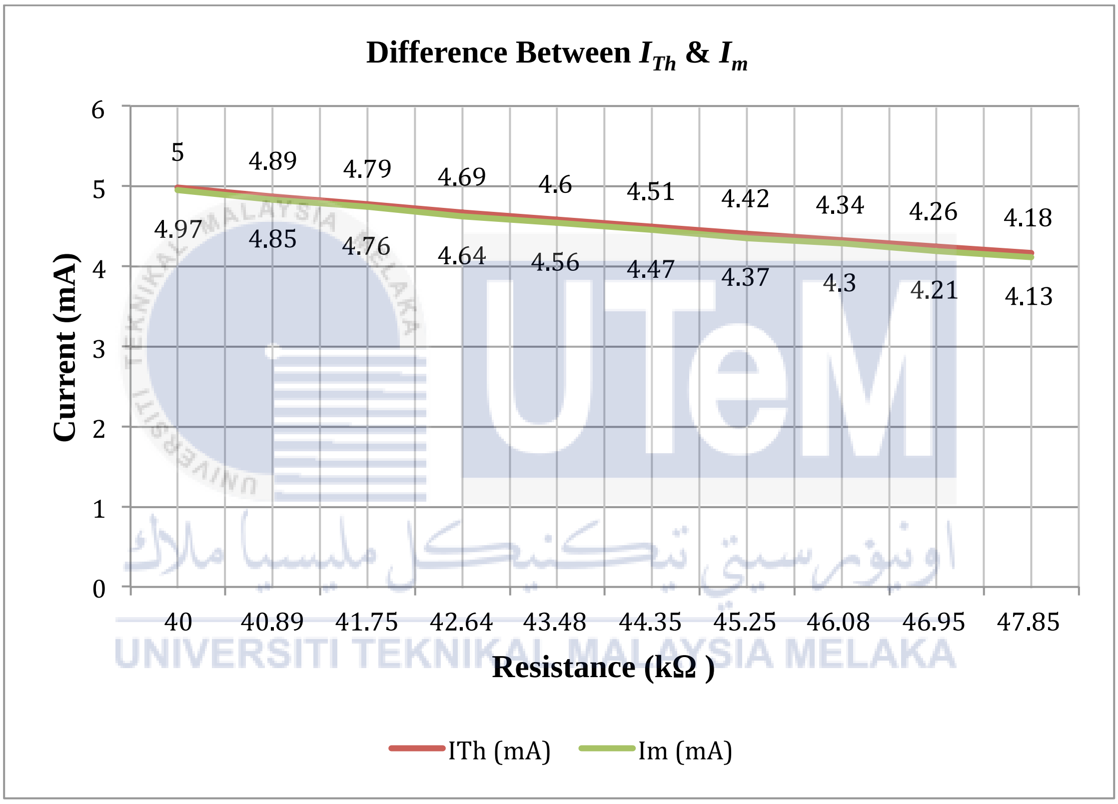

Figure 4.2: Relationship between I $_{Theory}$ and I $_{Measured}$

The graph in Figure 4.3 is quite revealing in several ways. First, the linear trend-line of the graph, which represent by the black line is increasing from the lowest resistance to the highest resistance. The percentage error from the graph is not consistent but still follows the linear trend of the graph. Besides, the percentage errors made by the ammeter are directly proportional to the increment of resistance. As the lowest percentage error is 0.6% and the highest percentage error is 1.2%, the difference between both errors is just

0.6%. The difference value, which is 0.6 %, does not bring significant effect on the reading of the ammeter.

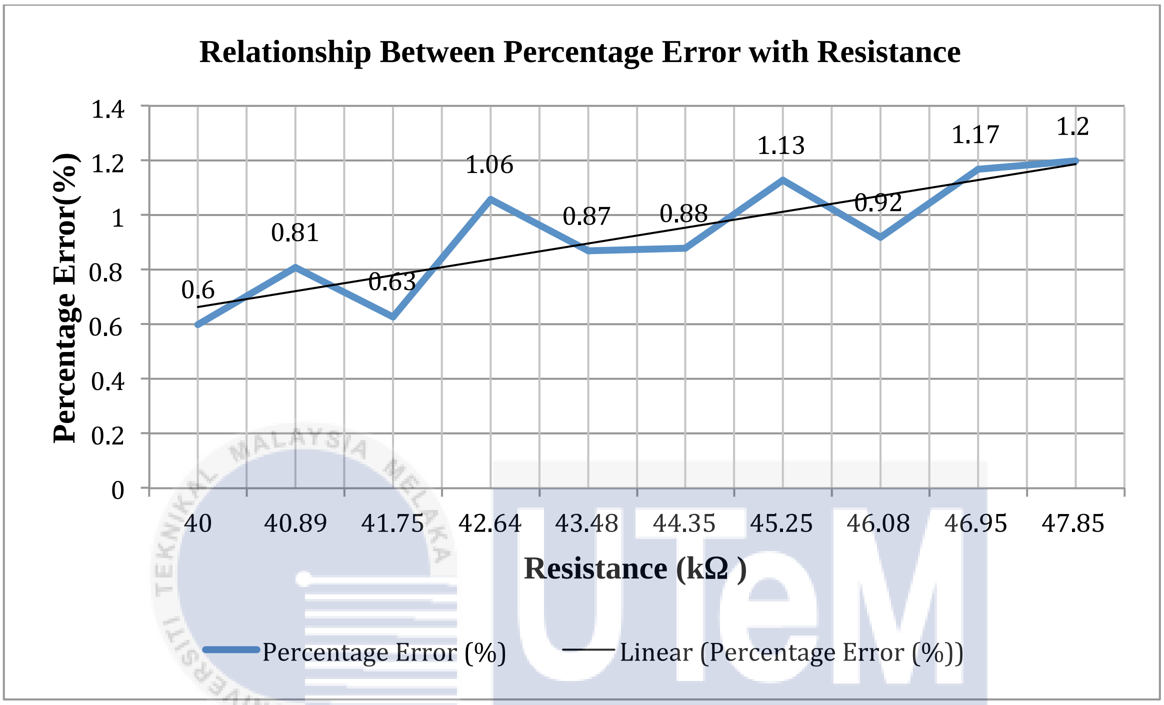

Figure 4.3: Relationship between percentage errors against resistance

Furthermore, from the graph of the percentage error, we can calculate the arithmetic mean of the percentage error by using this mathematical equation below:

$$Arithmetic\ Mean = \frac{\Sigma \text{ Percentage Error}}{Number\ of\ Data\ Points\ (n)} \tag{4.0}$$

So, the mean score or average value for the percentage error is 0.929%. On average, the reading shown to be a sensitive result with less than 1% error. When the resistance is at threshold position at 44.35 kΩ, the percentage error recorded was 0.88%. The statistical tests revealed that when the most critical point of this monitoring device has the percentage accuracy of 99.2%. The accuracy for the monitoring device in medical environment is vital as it does involve people life. Thus, The experiment is successfully achieved the accuracy test with less than 1% average error on every resistance condition.

4.2.3 Relationship between the voltage drops with the resistances.

As the Arduino UNO can only receive 0V to 5V only as analog input, this experiment meant to lower down the high output voltage from isolation transformer of 200 V_{AC} to 5 V_{AC}. Arduino UNO has a built in analog-to-digital convertor (ADC) with the capacity of 10 bits. To calculate the resolution of the Arduino UNO, the following formula has been used:

$$Quantization\ Levels = 2^{Bits} \tag{4.1}$$

Since the Arduino UNO can encode the analog input with capacity of 10 bits, therefore the quantization levels of the Arduino UNO is:

$$2^{10} = 1024 \tag{4.2}$$

$$ADC\ Voltage\ Resolution = \frac{Measurement\ Range}{Quantization\ Levels} \tag{4.3}$$

$$ADC\ Voltage\ Resolution = \frac{5V - 0V}{1023} = 4.88mV \tag{4.4}$$

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From equation 4.4, the ADC voltage resolution is equal to 4.88 mV, which mean when a bit of analog input increment; the voltage increase will be equal to 4.88mV. The voltage resolution is sensitive and can be used to calculate the voltage drop every time the resistance is changing.

Referring to appendix 4, the resistance value is using decade resistor to simulate the resistance of patient in medical environment. For this experiment, the voltage is lowered down using the voltage divider theory and calculates the voltage drop in order to find the current in the circuit. Furthermore, there is a fixed resistor of 10kΩ as a reference value for calculation part.

The resistances values are between 10kΩ and 100kΩ produce interesting result on the voltage reading on the multimeter. When the resistance increases, the voltage reading on multimeter also increasing. The voltage reading on the multi-meter is the reading of the voltage drop on the circuit of the device.

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From the graph at Figure 4.4, the trend is gradually increasing. The voltage reading from the multi-meter is actually the voltage drop happen on the circuit of the device. By using the Ohm's Law with voltage drop, V and the fixed resistor, R of 10kΩ, we can calculate the current within the circuit. For the resistance of 10kΩ, the voltage drops is 2.556V and the value of voltage reading increasing gradually from low resistance to a higher resistance. The highest voltage drop from the graph is at 100kΩ resistances with 4.632 voltage drop.

The difference value for highest and lowest resistance is 90kΩ with voltage drop difference of 2.076V. As the threshold for the IMD to alert the users is at 51kΩ, voltage reading at Figure 4.4 will be used to provide a significant value for the Arduino to monitor the leakage of current. The IMD will be using this reading as, the voltage drop from 230 V_{AC} to 5 V_{AC} is only occurs in the device itself. So, the outside voltage on the electromedical equipment is still maintained at 230 V_{AC}. Thus, by using 5V as a voltage reference inside the device, the device still can monitor the leakage of current through the medical environment.

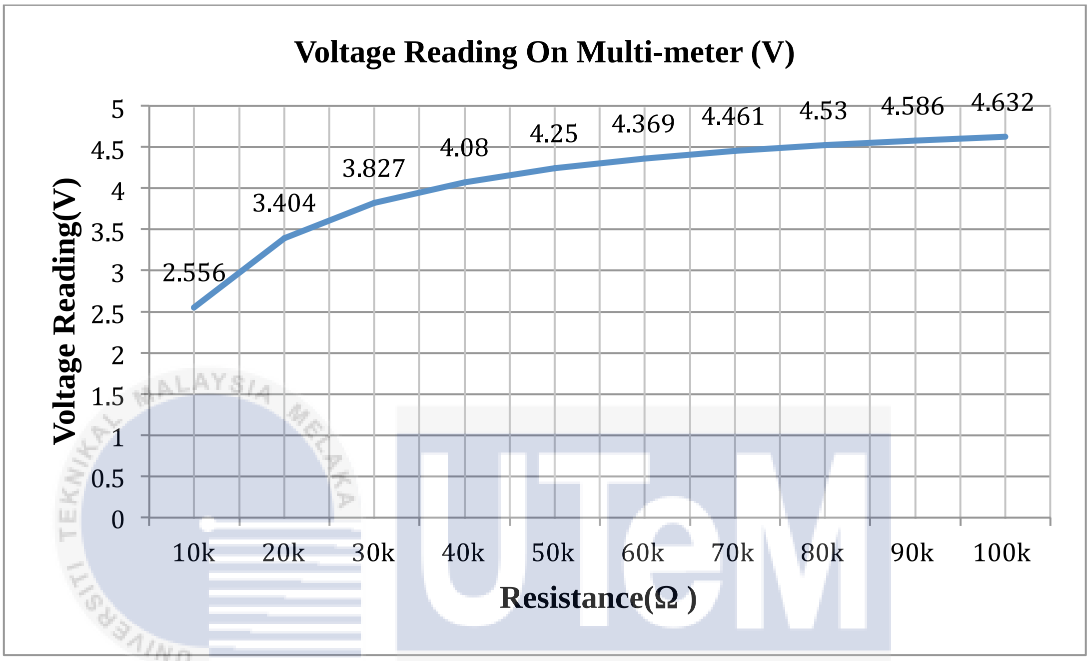

Figure 4.4: Relationship between resistance and voltage reading

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4.3 Experimental result

4.3.1 Accuracy result on the insulation-monitoring device

For this experiment, the main purpose is to calculate and compare the insulation-monitoring device (IMD) reading accuracy on voltage. The voltage readings from the IMD are very important on giving the alarm and warning light in the medical environment. The voltage later on will be used to calculate the current leakage based on the voltage divider current on the device. All parameter on the device is useful to calculate the current on the experimental setup of the experiment.

Table 4.1 shows the result on the voltage reading from the hardware and being compared to the reading of high precision multimeter. By comparing the different hardware, we can determine the percentage error of the insulation-monitoring device based on formula 4.2 and using the reading from the multimeter as the theoretical value. Besides that, the voltage input from the transformer is $200V_{AC}$, but after passing the decade resistor, the voltage going down from $200V_{AC}$. The input voltage before the insulation-monitoring device is important, as the voltage drop caused by the leakage of current will be processed by the microcontroller to give alarm and notify the leakage.

Table 4.1: Reading from voltmeter with no load, voltmeter with load and IMD

Resistance (kΩ)	**Voltage input before IMD device (V)**	**Voltmeter reading with no load (V)**	**Voltmeter reading with load (V)**	**IMD reading (V)**
40.00	110.4	2.72	1.82	1.84
40.89	109.3	2.71	1.80	1.71
41.75	108.4	2.68	1.79	1.85
42.64	107.3	2.65	1.77	1.87
43.48	106.4	2.63	1.76	1.10
44.35(Threshold)	105.3	2.60	1.75	1.25
45.25	104.4	2.58	1.74	1.27
46.08	103.3	2.55	1.72	1.40
46.95	102.1	2.53	1.70	1.34
47.85	101.1	2.50	1.68	1.53

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For the accuracy experiment, the device shows that the mean error is still big and lot of noises can be detected. The total average error for the accuracy experiment is at 15.683%. From appendix 5, the detection of the voltage before the threshold and after the threshold has the three highest value of error on the table. The device should be able to detect the threshold changes of the resistance, however the detection error is big compared to the voltmeter reading. At the threshold resistance, the device percentage error is at 28.57% and the error is too dangerous to the medical environment. The lowest percentage of error can be seen at the resistance of 40kΩ with the value 1.09%. 40kΩ is the resistance, which will produce highest current value on the electrical line. From figure 4.5, the percentage error happens to reducing to a more stable value after the threshold point. The error of the device still can be reduced and improved after taking all the consideration on the device circuit. More powerful processor can be used to overcome the processing error for the circuit. Powerful processor should be able to detect the reading more faster and often than current processor.

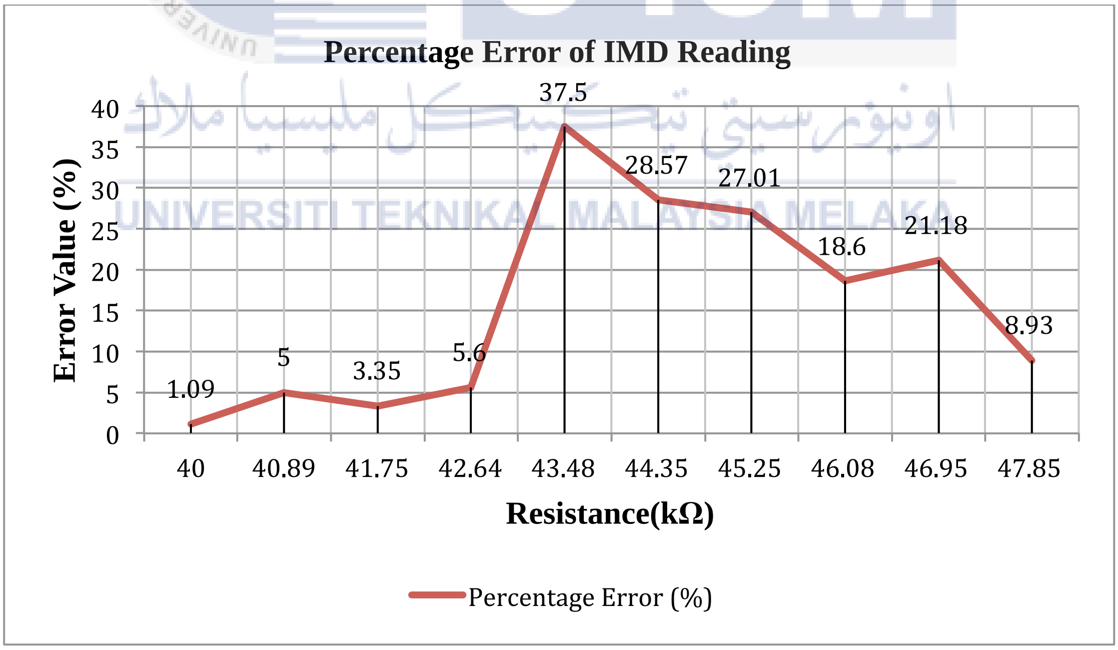

Figure 4.5: Percentage Error of accuracy of IMD reading

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4.3.2 Precision result on the insulation-monitoring device

The main objective for this experiment is to find out whether the hardware precision level is at optimum level. Precision is important as the value of current is changing every second and the detection for the device should be precise all the times. Thus, this experiment is to find the precision of the IMD detection and later on the data will be used for analysis and further development of the device. The IMD current reading on the table is the average value of current reading over 120 data collections. The multimeter current reading will be assumed as theoretical data for this experiment. The tabulated data can be seen at appendix 6.

From figure 4.6, there will be several aspects that going to be analyzed and discussed. Firstly, the lowest percentage error can be seen at 40kΩ resistance with the error of 0.66. The highest percentage error with 36.98% is at 43.48kΩ. The difference from the highest and the lowest percentage error is 36.32%, which is very high for a safety-monitoring device. Graphs from figure 4.5 and 4.6 are quite similar in shape but have different value on each point. Surprisingly, the percentage error at 44.35kΩ, which is the threshold point experiencing the second highest percentage error. The percentage error is at 28.27% and the error will absolutely affect the reading accuracy. Precision for the device is still low and the hardware needs to be improved in all aspects.

After getting a high error on 43.48kΩ resistance, the error suddenly decreases and stable with a low percentage error. The decrement of the percentage error maybe because of the microcontroller being able to read the analog input more accurately. Total average precision error for the device is at 14.59%. Even though the percentage error is a bit high, the reading for every resistance can be stable but time taken for an accurate reading will be longer. When the average percentage error for accuracy and precision experiment is being compared, the difference is 1.093%. Somehow from both result, we can observed that the error decreases if the time taken to read the leakage current is longer.

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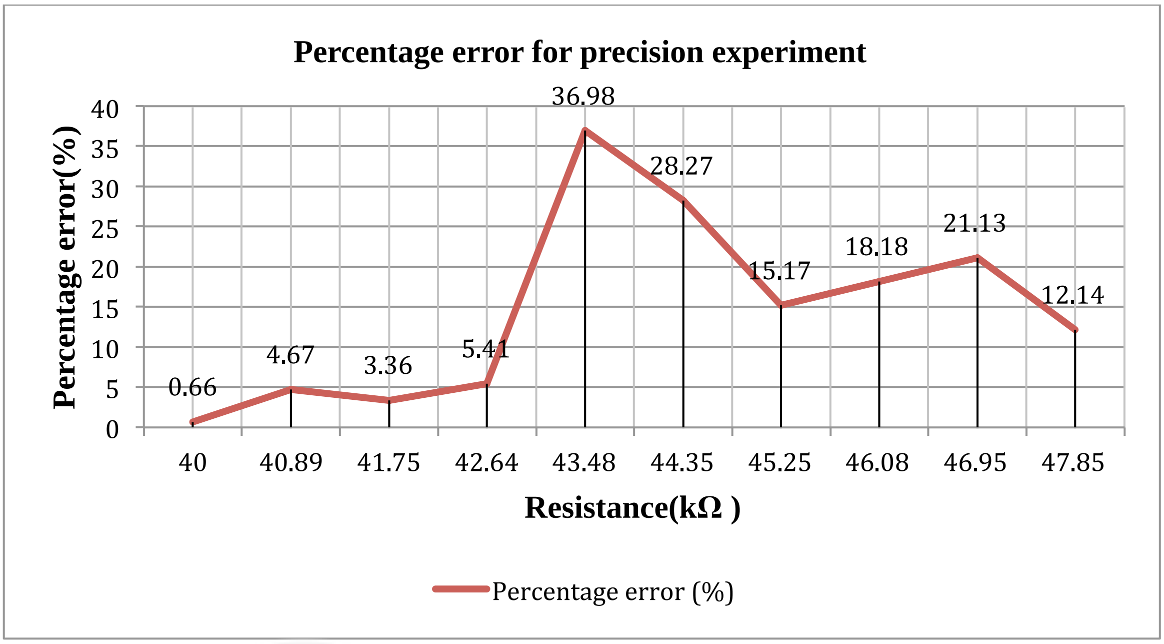

Figure 4.6: Percentage error for precision experiment

4.3.3 Sensitivity result on the insulation-monitoring device

By referring to table 3.2, the result for this experiment can be obtained. Before that, several condition of the table needs to be determined. Condition positive is when the test outcome should be true and the condition showing same result as the positive test outcome. Condition negative is when the test outcome should be true but the condition negative shows the wrong outcome. By repeating the same condition for 50 times, we can get the sensitivity value for this device. From table 4.2, we can now calculate the sensitivity for the IMD detection. By using formula 3.3, the sensitivity for the IMD detection is 37.74%. The value, which is clearly at a low sensitivity, must be improved in order to detect the leakage of current in medical environment.

This low sensitivity detection came from drawback of the hardware. This can be proved as the microcontroller for this project, namely ARDUINO Uno has only 10bits of resolution. The disadvantages if using this microcontroller is that for every bit increment, only 4.88mV will increase and the precision for every repetition will decrease. The sensitivity of the device is 37.74% and the device still need to improve by approximately 62.26% to achieve the objective of this experiment. When the outcome of the experiment should be positive, the device only detect 20 times of leakage current, which is less than half and the device does not detect the leakage for 30 times. Moreover, when the outcome of the experiment should be negative, the device only detect 17 times of the correct condition while 33 times detect the incorrect condition. By analyzing all the data, the detection sensitivity is worrying especially the device was developed to help the medical environment in detecting the leakage of current. If the device cannot detect the leakage of current, the patients in the hospital still have the potential to experience the micro-shock or leakage of current.

To overcome this problem, the microprocessor needs to have a bigger and better processing unit and the sensor for the device should be able to capture the changes on the electrical network system. Furthermore, the frequency for the system must be maintained at 50Hz to 60Hz to match the sensor frequency range. By using formula 3.3, we calculated the sensitivity of the insulation-monitoring device.

$$Sensitivity = \frac{number\ of\ true\ positives}{number\ of\ true\ positives + number\ of\ false\ negatives} \tag{3.3}$$

$$Sensitivity = \frac{20}{20 + 33} = 0.3774 \tag{4.5}$$

$$Sensitivity = 0.3774 \times 100 = 37.74\% \tag{4.6}$$

Table 4.2: Sensitivity result on the IMD detection

	Condition	
	Condition positive (alarm is on)	Condition negative (alarm is off)
Test outcome positive (Threshold value at 44.35kΩ)	20	30
Test outcome negative (Safe condition at 47.85kΩ)	33	17

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Insulation monitoring device is an important as it has huge contribution to the medical field. This device will provide a new alternative to reduce the problems due to electric shock, which can harm the patient during medical operation. This project was undertaken to design an insulation monitoring device and able to find the insulation faulty at power line. Taken together, these results suggest that the method to detect leakage current can be useable in developing the insulation-monitoring device. Furthermore, these findings enhance our understanding on relationship between patient resistances with the current produced.

Both patient resistances and current produced have play major role in investigating the insulation monitoring device architecture. Further research regarding the role of the insulation-monitoring device would be worthwhile as international standard organization have been issued a standard, which obligate every medical room need to have an insulation monitoring device. Thus, this project will help the medical sector especially in developing country such as Malaysia. This development of insulation monitoring device will shows that Malaysia is concern on the safety of patient and aware that this device can help to decrease the probability on harming the patient during the medical operation.

Thus referring to result at chapter 4, the objective of the project has been achieved. The objective of the experiment has been achieved as the device able to detect the threshold value of current when different resistance is being applied. However, the average percentage error for accuracy is still high at 15.683% while the average percentage error for precision is at 14.59%. As for sensitivity error, the value is 37.74% and the value is considered high for an insulation-monitoring device. Even though the error for all experiment is high, improvement can be made and the error can be reduce.

5.2 Recommendation

Both errors can be improved by using a more powerful microprocessor that can process the data faster than Arduino UNO. Furthermore, new design of the device hardware can step down the voltage to a value that can be read and process by the microcontroller. The stability and the accuracy of the device also can be improved from time to time by using more powerful microprocessor and the monitoring system can be improved by using instrumentation amplifier. Lastly, the performance of the device will help the medical environment to reduce the death or accident regarding the leakage of current by alarming the leakage efficiently.

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APPENDIX 1

Calculation of current value when V_{AC}=230V

Number	Voltage (V)	Resistance (kΩ)	Current produced (mA)
1	230	46	5
2	230	47	4.89
3	230	48	4.79
4	230	49	4.69
5	230	50	4.6
6	230	51(Threshold)	4.51
7	230	52	4.42
8	230	53	4.34
9	230	54	4.26
10	230	55	4.18

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APPENDIX 2

Result when V_{AC} = 200V as voltage output from isolation transformer.

Number	**Resistance (kΩ)**	**$I_{CALCULATE}$ (mA)**	**$I_{AMMETER}$ (mA)**
1	40.00	5.00	4.97
2	40.89	4.89	4.85
3	41.75	4.79	4.76
4	42.64	4.69	4.64
5	43.48	4.6	4.56
6	44.35	4.51	4.47
7	45.25	4.42	4.37
8	46.08	4.34	4.30
9	46.95	4.26	4.21
10	47.85	4.18	4.13

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APPENDIX 3

Percentage error of ammeter reading

Resistance (kΩ)	**$I_{CALCULATE}$ (mA)**	**$I_{AMMETER}$ (mA)**	**Percentage Error (%)**
40.00	5.00	4.97	0.60
40.89	4.89	4.85	0.81
41.75	4.79	4.76	0.63
42.64	4.69	4.64	1.06
43.48	4.6	4.56	0.87
44.35	4.51	4.47	0.88
45.25	4.42	4.37	1.13
46.08	4.34	4.30	0.92
46.95	4.26	4.21	1.17
47.85	4.18	4.13	1.20

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APPENDIX 4

Result when using voltmeter theory

Resistance (Ω)	**Voltage Reading On Multi-meter (V)**	**$I_{CALCULATE}$ (mA)**	**I_{IMD}(mA)**
10k	2.556	0.250	0.244
20k	3.404	0.167	0.159
30k	3.827	0.125	0.117
40k	4.080	0.100	0.092
50k	4.250	0.083	0.075
60k	4.369	0.071	0.063
70k	4.461	0.063	0.054
80k	4.530	0.056	0.047
90k	4.586	0.050	0.041
100k	4.632	0.045	0.037

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APPENDIX 5

Percentage error on IMD reading compared to voltmeter

Voltmeter Reading With Load (V)	IMD Reading (V)	Percentage Error (%)
1.82	1.84	1.09
1.80	1.71	5.00
1.79	1.85	3.35
1.77	1.87	5.60
1.76	1.10	37.50
1.75	1.25	28.57
1.74	1.27	27.01
1.72	1.40	18.60
1.70	1.34	21.18
1.68	1.53	8.93

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APPENDIX 6

Precision experiment and error of the device.

Resistance (kΩ)	**Voltage input before IMD device (V)**	**Multimeter current reading (mA)**	**IMD current reading (mA)**	**Percentage error (%)**
40.00	110.4	1.52	1.53	0.66
40.89	109.3	1.5	1.43	4.67
41.75	108.4	1.49	1.54	3.36
42.64	107.3	1.48	1.56	5.41
43.48	106.4	1.46	0.92	36.98
44.35(Threshold)	105.3	1.45	1.04	28.27
45.25	104.4	1.45	1.23	15.17
46.08	103.3	1.43	1.17	18.18
46.95	102.1	1.42	1.12	21.13
47.85	101.1	1.40	1.23	12.14

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