Analysis of Earth Resistance Effect on The TT-Grounding System Against Electric Shock

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Abstract - ***Based on the General Requirements for the PUIL 2011 (Persyaratan Umum Instalasi Listrik 2011), there are three types of earthing systems, namely the TN system, the TT system, and the IT system. These three types of earthing function to prevent electric shock that is harmful to humans. Earthing part of the equipment namely open conductive part on the TT system is installed separately, where the open conductive part of electrical equipment is connected directly to the earth in order to limit the amount of voltage between the open conductive part and the earth to the allowable limit if a leakage current is caused due to a failure insulation.***

The action taken to minimize the occurrence of indirect touch stress is to use an earthing system with the aim of: Conducting current from the metal parts of the equipment that flows through the leakage to the ground through the earth channel, Minimize potential differences between the metal parts of the equipment and the ground so that it is not dangerous if touched.

Earthing resistance value on the TT system greatly affects the magnitude of the touch voltage that occurs at open conductive part due to a leakage current due to insulation failure. If the resistance value of the earth electrode exceeds the allowable standard, it can cause the touch voltage that occurs in the open conductive part to exceed the maximum standard based on the PUIL 2011 standard and there is no safety of the MCB or ELCB, it will be dangerous if touched by humans because it can cause damage to the human body and can cause death.

Keywords- Earthing system, touch voltage, earthing resistance.

I. INTRODUCTION

An electric shock occurs when a person comes into contact with an electrical energy source. Electrical energy flows through a portion of the body causing a shock.

Victims of electrical shock sustain a wide spectrum of injuries, ranging from a transient un-pleasant sensation from brief exposure to low intensity current to instantaneous sudden death from accidental electrocution. Cardiac arrest due to electrical shock re-quires modification of the standard approach to cardiac resuscitation and necessitates simultaneous application principles of both cardiac and trauma life support [1]. In the literature can be found that the human body resistance ranges from 500 ohms to 1K ohms [2].

To protect against electrical shock the engineer uses two tools: isolation and grounding. Using these he tries to limit the current in a grounded person touching equipment to 5 mA, and the voltage on exposed equip-ment to a few volts above ground. In practically all areas, these standards are adequate. However, under some conditions in medical institutions, voltages and currents less than one per cent of these magnitudes can be fatal [3] .

In many cases, single-phase line-to-ground fault (SLG) currents have an undesired ‘‘leakage’’component circulating through the actual earth. These stray currents, sometimes unavoidable in practical realizations, can produce interferences among electrical systems, which, thus, lose their faultindependence. In addition, they can also transfer hazardous potential rises to healthy systems and trigger corrosion phenomena, involving underground metalwork. To improve this situation, it is desirable to confine the SLG current to a definite and confined metallic return path, by breaking the electrical system into independent ‘‘islands’’ of limited load and supplying them through a separation transformer (with turn-ratio 1:1 or other fitting value), grounded at the secondary winding(s), preferably at the mid-point [4].

Grounding system or commonly referred to as a grounding system is a safety system for devices that use electricity as a power source.

The earth/ground system is described as the relationship between an equipment and electric circuit with the earth. The parts that are connected with the earth are:

a. The neutral point of the transformer or the neutral point of the generator. This is necessary in connection with the needs of protection, especially those involving land disturbance.
b. All parts of the installation are made of metal (conduct electricity) and can easily be touched by humans. This is necessary so that the potential of metals that are easily touched by humans is always the same as the potential soil (earth) where humans stand so it is not dangerous for humans who touch it [5][6] .

All electrical parts are made of metal which normally do not have voltage but when a leakage current occurs due to the failure of insulation to become voltage, it must be connected to earth to minimize the danger to humans due to touch voltage.

Touch voltage directly or indirectly endanger the vital organs of the human body namely the heart, nerve center, and breathing. The amount of risk posed is influenced by the amount of leakage current. Therefore, additional protection is needed to provide protection against the danger of leakage currents/touch voltages, especially for electrical installations using earthing systems[7].

The earthing system is a human security against touch voltages, direct or indirect touch. Direct touch is when we touch the active conductor directly, while indirect touch is when we touch a part of the equipment namely open conductive part which becomes voltage due to a leakage current due to failure / damage to the insulation[8].

Earthing system plays a very important role in electrical installations. There are two types of earthing systems in electrical installations, namely earthing systems and earthing equipment. Earthing system is the earthing of the neutral point of the distribution transformer connected by a star, while the earthing of equipment is the earthing of electrical equipment which in normal condition is not flowed by current, but if there is disturbance or failure of insulation then the part is flowed by current. The earthing system in electrical installations aims to limit the voltage between the parts of the equipment that are not flowing and between these parts and the ground to a price that

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is safe for all operating conditions, both normal conditions and when interference occurs or failure. There are three types of earthing system, namely TT system, IT system, and TN system (TNS, TNC, TNC-S). Earthing of the TT system is widely applied in industrial electrical installations where many workers must be guaranteed safe from electrical hazards [9].

Earthing System TN (Terra Neutral)

Earthing the TN system consists of three types, namely:

a. Earthing system of TN-S (Terra Neutral-Separated)

In this system the ground and neutral channels are separate, so all systems have two N (neutral) and PE (Protective Earth) channels separately.[10][11][12]

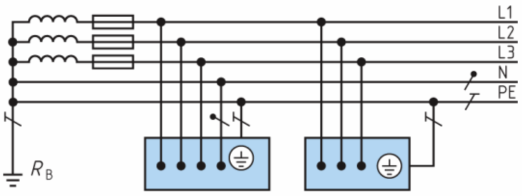

Fig. 1. Earthing of the TN-S system

b. Earthing system of TN-C (Terra Neutral-Combined)

In this system the ground and neutral lines are put together, the neutral and safety lines are put together in the whole system. All parts of the system have PEN (Protective Earth Neutral) channels which are a combination of N and PE channels. Here all parts of the system have the same PEN channel.

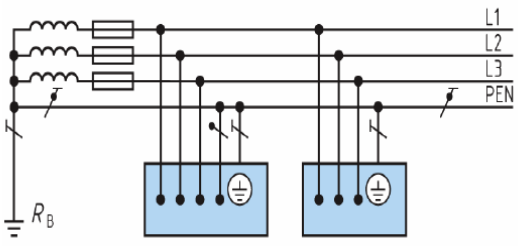

Fig. 2. Earthing of the TN-C system

c. Earthing system TN - C - S (Terra Neutral - Combinated - Separated)

In this system the Land and Neutral canals are united and separated, neutral channels and safety channels are made into one channel in some systems and separated in some other systems [13][14] .

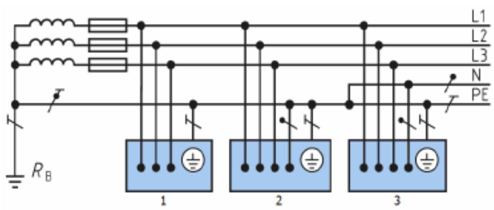

Fig. 3. Earthing of the TN-C-S system

Earthing TT (Terra Terra) System

Terra Terra, which means land, the ground means the earth grounding system and earthing equipment installed separately. In this system the neutral point is connected directly to the ground, but the parts of the conductive open installation are connected to different ground electrodes (independent). Figure 4 shows that the grounding of the equipment is done through a different grounding system with a neutral point grounding [12][13][14].

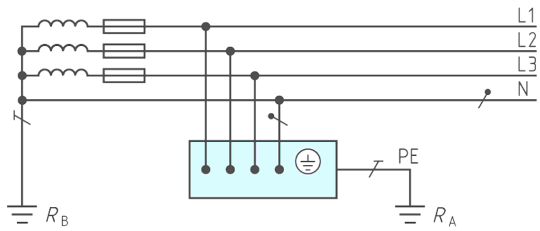

Fig. 4. Earthing of the TT System

Earthing IT System (Impedance Terra)

Impedance Terra means ground line or earthing through impedance. In this system the circuit does not have a direct connection to the ground but through an impedance, while the open conductive part of the installation is connected directly to the earth / ground electrodes separately. This system is also called the impedance grounding system [13][14].

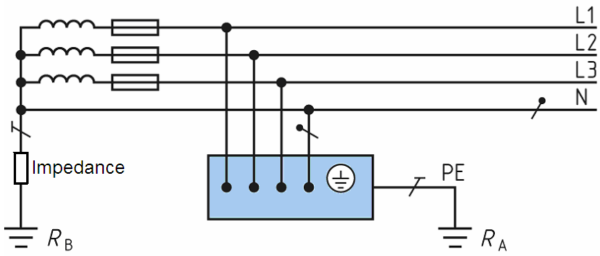

Fig. 5. Earthing of the IT system

Electric Shock Current

Electric shock current or electric touch voltage occurs because of a leakage current in a system. Based on PUIL 2011, the safe voltage limit for humans is 50 V for AC systems and 120 V for DC systems. The process of this electrical touch can occur either directly or indirectly. Direct touch voltage is an event where it directly touches the active conductor. Whereas indirect touch tension occurs when humans hold an open conductive part that is stressed due to failure of isolation.

If the maximum allowable touch voltage is 50 volts, the amount of electric shock that flows to the human body is:

$$I_F = \frac{50Volt}{R_B}\text{m.A} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where R_B is a resistance of the human body.

Table 1. The amount of current and its effect on the human body

Electric current	Influence on the human body
0-0.9 mA	The effect has not been felt, does not cause any reaction
0,9 – 1,2 mA	Just felt an electric current, but did not cause seizures,
1,2 – 1,6 mA	contraction or loss of control
1,6 – 6,0 mA	Begins to feel as though something is creeping in the hand
6,0 – 8,0 mA	Hands up to the elbows feel pins and needles
8,0 – 13 mA	Hands begin to stiffen, tingling sensations increase

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13 – 15 mA	The pain is unbearable, but can still release the conductor.
15 – 20 mA	Muscle no longer able to release the conductor
20 – 50 mA	Can cause damage to the human body
50 – 100 mA	Current limit that can cause death

Table 2. Maximum disconnection times.
(*Source: Schneider Electric, "Electrical installation guide," Chapter F Prot. Against Electr. Shock.*, *2008*)

Grounding system	**50 V < V_{ph} ≤ 120 V**	**V_{ST}**
TT	0.3 seconds	≤120 V
TN	0.8 seconds	≤67 V
Grounding system	**120 V < V_{ph} ≤ 230 V**	**V_{ST}**
TT	0.2 seconds	≤230 V
TN	0.4 seconds	≤100 V

Determinants of Seriousness Due to Electric Shock

Isolation failure in electrical installation equipment can cause a leakage current. This leakage current can cause touch voltage both directly and indirectly which endangers humans.

The factors that cause the seriousness of electrical hazards to humans are as follows:

1) Electric Current

   The flow of current that flows into the human body can damage the vital functions of the human body, namely breathing, nerve center, and heart. The amount of current flowing into the human body is affected by the resistance of the human body, and the magnitude of the touch voltage. Touch voltage that is safe for humans on AC systems is 50 Volts. Meanwhile, according to Hutahuruk (1991), the size of human resistances ranged from 500 ohms to 100,000 ohms. Several studies have been conducted to determine the value of human body resistance.

2) Long time the touch voltage

   The longer the time the touch voltage occurs, the more fatal it is felt. The influence of the magnitude of the current and the length of time the touch voltage has been explained according to IEC 60479-1 which divides the danger zone into four [14].

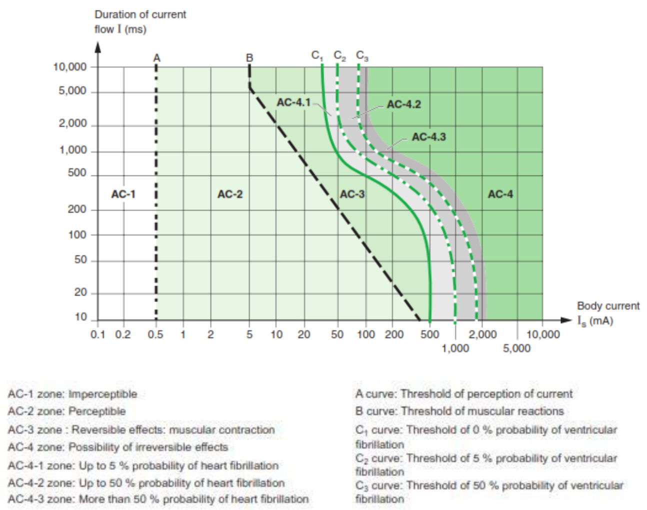

Fig. 6. Time zones and currents.
(*Source: Schneider Electric, "Electrical installation guide," Chapter F Prot. Against Electr. Shock.*, *2008*)

II. RESEARCH METHOD

The action taken to minimize the occurrence of indirect touch stress is to use an earthing system with the aim of:

a. Conducting current from the metal parts of the equipment that flows through the leakage to the ground through the earth channel.

b. Minimize potential differences between the metal parts of the equipment and the ground so that it is not dangerous if touched.

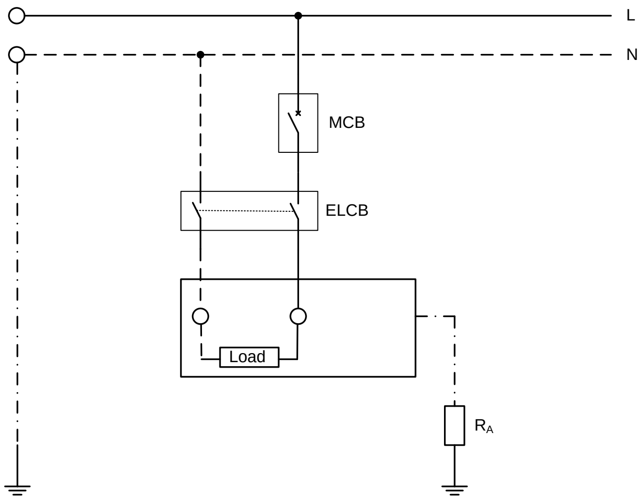

Fig 7. Protection against indirect contact

In figure 7 under normal circumstances (no leakage current occurs) then no current flows to the open conductive part (I_F = 0). If a leakage current occurs due to failure of insullation then there is a current that flows to the open conductive part so that the voltage touches on the open conductive part [15]. The amount of the touch voltage depends on the amount of I_F leakage current and the amount of earth resistance at the open conductive part (R_A). The earth resistance value is maximally equal to 5 Ohms. When the amount of touch voltage on the open conductive part exceeds 50 Volts, the ELCB works to open the circuit.

III. RESULTS AND ANALYSIS

3.1. Experiment Circuit

In this study, using the existing facilities in the Electrical Installation laboratory, Department of Electrical Engineering, Bandung State Polytechnic. At this stage a series of designs is made which will be used for experiments. Components and equipment that are not in the laboratory must be held with the purchase of tools / components to complete the creation of a series of touch voltage experiments on the earthing system of the TT.

Figure 8, is a series of experiments used in research to obtain data. A variable resistor is used to regulate the amount of leakage current to the open conductive part and a leakage current protector using a 30 mA ELCB. Electric load using incandescent 100 Watt lamps, with safety using MCB 2A. Earthing electrodes on open conductive part use ceramic resistors whose values vary, namely 1Ω, 2 Ω, 3 Ω, 4 Ω, 5 Ω, 6 Ω, 7 Ω, 8 Ω, 9 Ω, 10 Ω. The value of the ground electrode resistance is varied to prove

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the resistance of the ground electrode resistance to the amount of touch voltage on the open conductive part.

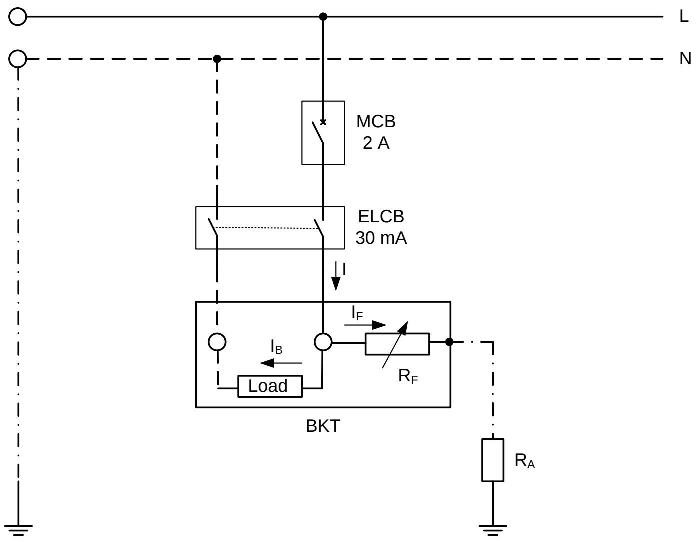

Fig. 8. Experiment circuit on earthing system TT

3.2. Experiment Data

A. Experiment I

In Experiment I, used a 30 mA ELCB leakage current protector as shown in Figure 9 with 10 mA, 20 mA, 30 Ma, and 40 mA respectively. Setting the leakage current by adjusting the R_F variable resistor. Earth electrode resistance values ranging from 1 Ohm to 10 Ohm, and the measurement results table starting from table 1 to table 4.

Table 3. Experimental data I with a leakage current of 10 mA.

R_A (Ohm)	I_F (mA)	I_B (A)	I (A)	Touch voltage (Volt)	ELCB 30 mA
1	10	0,45	1,83	0,01	Not trip
2	10	0,45	1,83	0,02	Not trip
3	10	0,45	1,83	0,03	Not trip
4	10	0,45	1,83	0,04	Not trip
5	10	0,45	1,83	0,05	Not trip
6	10	0,45	1,83	0,06	Not trip
7	10	0,45	1,83	0,07	Not trip
8	10	0,45	1,83	0,08	Not trip
9	10	0,45	1,83	0,09	Not trip
10	10	0,45	1,83	0,10	Not trip

Table 4. Experimental data I with a leakage current of 20 mA.

R_A (Ohm)	**I_F (mA)**	**I_B (A)**	**I (A)**	**Touch voltage (Volt)**	**ELCB 30 mA**
1	20	0,45	1,84	0,02	Not trip
2	20	0,45	1,84	0,04	Not trip
3	20	0,45	1,84	0,06	Not trip
4	20	0,45	1,84	0,08	Not trip
5	20	0,45	1,84	0,10	Not trip
6	20	0,45	1,84	0,12	Not trip
7	20	0,45	1,84	0,14	Not trip
8	20	0,45	1,84	0,16	Not trip
9	20	0,45	1,84	0,18	Not trip
10	20	0,45	1,84	0,20	Not trip

Table 5. Experimental data I with a leakage current of 30 mA.

R_A (Ohm)	**I_F (mA)**	**I_B (A)**	**I (A)**	**Touch voltage (Volt)**	**ELCB 30 mA**
1	30	0,45	1,85	0,03	Trip
2	30	0,45	1,85	0,06	Trip
3	30	0,45	1,85	0,09	Trip
4	30	0,45	1,85	0,12	Trip
5	30	0,45	1,85	0,15	Trip
6	30	0,45	1,85	0,18	Trip
7	30	0,45	1,85	0,21	Trip
8	30	0,45	1,85	0,24	Trip
9	30	0,45	1,85	0,27	Trip
10	30	0,45	1,85	0,30	Trip

Table 6. Experimental data I with a leakage current of 40 mA.

R_A (Ohm)	**I_F (mA)**	**I_B (A)**	**I (A)**	**Touch voltage (Volt)**	**ELCB 30 mA**
1	40	0,45	1,86	0,04	Trip
2	40	0,45	1,86	0,08	Trip
3	40	0,45	1,86	0,12	Trip
4	40	0,45	1,86	0,16	Trip
5	40	0,45	1,86	0,20	Trip
6	40	0,45	1,86	0,24	Trip
7	40	0,45	1,86	0,28	Trip
8	40	0,45	1,86	0,32	Trip
9	40	0,45	1,86	0,36	Trip
10	40	0,45	1,86	0,40	Trip

B. Experiment II

In this experiment without installing a leakage current protection ELCB but still installing the MCB with the aim to find out whether the MCB can secure the danger of indirect touch electric shock currents or not. MCB used is MCB 2 A with a load of 100 Watt.

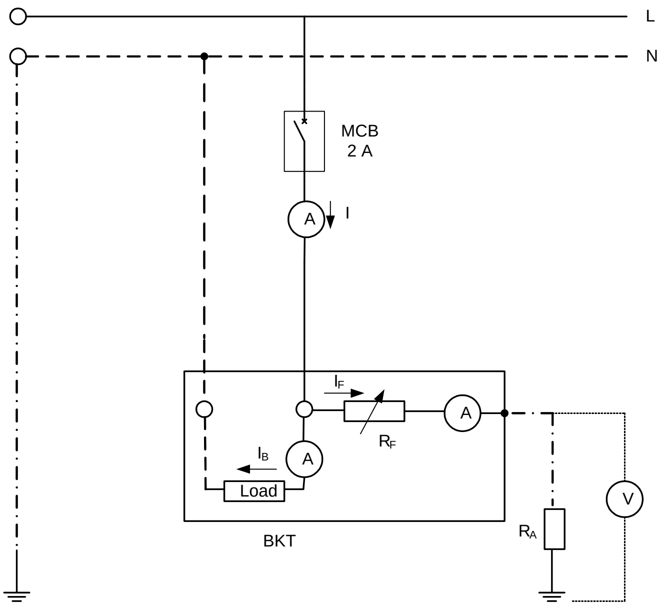

Fig. 9. Experiment circuit II

Table 7. Experimental data II with a leakage current of 1000 mA

R_A (Ohm)	I_F (mA)	I_B (A)	I (A)	Touch voltage (Volt)	MCB 2A
1	1000	0,5	2,8	1	Trip
2	1000	0,5	2,8	2	Trip
3	1000	0,5	2,8	3	Trip

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4	1000	0,5	2,8	4	Trip
5	1000	0,5	2,8	5	Trip
6	1000	0,5	2,8	6	Trip
7	1000	0,5	2,8	7	Trip
8	1000	0,5	2,8	8	Trip
9	1000	0,5	2,8	9	Trip
10	1000	0,5	2,8	10	Trip

Table 8. Experimental data II with a leakage current of 2000 mA

R_A (Ohm)	I_F (mA)	I_B (A)	I (A)	Touch voltage (Volt)	MCB 2A
1	2000	0,5	3,8	2	Trip
2	2000	0,5	3,8	4	Trip
3	2000	0,5	3,8	6	Trip
4	2000	0,5	3,8	8	Trip
5	2000	0,5	3,8	10	Trip
6	2000	0,5	3,8	12	Trip
7	2000	0,5	3,8	14	Trip
8	2000	0,5	3,8	16	Trip
9	2000	0,5	3,8	18	Trip
10	2000	0,5	3,8	20	Trip

Table 9. Experimental data II with a leakage current of 3000 mA

R_A (Ohm)	I_F (mA)	I_B (A)	I (A)	Touch voltage (Volt)	MCB 2A
1	3000	0,5	4,8	3	Trip
2	3000	0,5	4,8	6	Trip
3	3000	0,5	4,8	9	Trip
4	3000	0,5	4,8	12	Trip
5	3000	0,5	4,8	15	Trip
6	3000	0,5	4,8	18	Trip
7	3000	0,5	4,8	21	Trip
8	3000	0,5	4,8	24	Trip
9	3000	0,5	4,8	27	Trip
10	3000	0,5	4,8	30	Trip

Table 10. Experimental data II with a leakage current of 4000 mA

R_A (Ohm)	**I_F (mA)**	**I_B (A)**	**I (A)**	**Touch voltage (Volt)**	**MCB 2A**
1	4000	0,5	5,8	4	Trip
2	4000	0,5	5,8	8	Trip
3	4000	0,5	5,8	12	Trip
4	4000	0,5	5,8	16	Trip
5	4000	0,5	5,8	20	Trip
6	4000	0,5	5,8	24	Trip
7	4000	0,5	5,8	28	Trip
8	4000	0,5	5,8	32	Trip
9	4000	0,5	5,8	36	Trip
10	4000	0,5	5,8	40	Trip

Table 11. Experimental data II with a leakage current of 5000 mA

R_A (Ohm)	I_F (mA)	I_B (A)	I (A)	Touch voltage (Volt)	MCB 2A
1	5000	0,5	6,8	5	Trip
2	5000	0,5	6,8	10	Trip
3	5000	0,5	6,8	15	Trip
4	5000	0,5	6,8	20	Trip
5	5000	0,5	6,8	25	Trip
6	5000	0,5	6,8	30	Trip
7	5000	0,5	6,8	35	Trip
8	5000	0,5	6,8	40	Trip
9	5000	0,5	6,8	45	Trip
10	5000	0,5	6,8	50	Trip

Table 12. Experimental data II with a leakage current of 6000 mA

R_A (Ohm)	I_F (mA)	I_B (A)	I (A)	Touch voltage (Volt)	MCB 2A
1	6000	0,5	7,8	6	Trip
2	6000	0,5	7,8	12	Trip
3	6000	0,5	7,8	18	Trip
4	6000	0,5	7,8	24	Trip
5	6000	0,5	7,8	30	Trip
6	6000	0,5	7,8	36	Trip
7	6000	0,5	7,8	42	Trip
8	6000	0,5	7,8	48	Trip
9	6000	0,5	7,8	54	Trip
10	6000	0,5	7,8	60	Trip

3.3. Analysis

From the results of experiment I in table 3 when there is a leakage current of 10 mA the safety of the leakage current ELCB does not trip but the touch voltage that occurs in the open conductive part is relatively small so it is not harmful to humans who touch it, as well as in table 4 with a leakage current of 20 mA.

In table 5 with a leakage current of 30 mA the safety of the leakage current ELCB trip even though the touch voltage occurring at the open coctive part is still relatively low and not harmful to humans who touch it, as well as in table 6 with a leakage current of 40 mA.

From tables 3 to 6 the touch voltage that occurs in the open conductive part is the largest is 0.40 Volts. With this touch voltage when touched by humans, the current flowing into the human body is 0.4 mA assuming the resistance of the human body is 1000 Ohms. With a current of 0.4 mA flowing into the human body, according to table 1 the effect has not been felt and does not cause any reaction for humans who touch it.

From the results of experiment II where no ELCB leakage current protector is installed but still installing MCB, in table 7 if there is a leakage current of 1000 mA then the MCB trip because the current flowing through the MCB is greater than the nominal rating of the MCB. Likewise in Tables 8 through 12 with a leakage current greater than 1000 mA, the MCB will trip.

From tables 7 to table 12 prove that the MCB can also function as a safety guard against indirect electric shock currents due to leakage currents due to damage to the cable insulation if the current passing through the MCB exceeds the nominal rating of the MCB.

In table 12 when there is a leakage current of 6000 mA with an earth electrode resistance of 9 Ohms and 10 Ohms, the touch voltage that occurs in the open conductive part exceeds the maximum standard according to PUIL 2011, however the touch voltage that occurs in the open conductive part will not endanger humans because it has been secured by MCB.

In these conditions the MCB trip because the current through it exceeds the MCB nominal. If there is no safety MCB or ELCB and the touch voltage on the open conductive part is 60 volts due to a leakage current of 6000 mA and the earth electrode resistance value is 10 Ohms, so if the open conductive part is touched by humans the amount of current flowing into the human body is 60 mA , and based on table 2 it can cause damage to the human body. Current limit that can cause death.

From the results of experiment I and experiment II obtained data that the magnitude of the resistance value of the ground electrode (RA) greatly affects the amount of touch voltage in the open conductive part when a leakage current occurs due to damage to a failure of cable insulation. The greater the grounding electrode resistance value, the greater the touch voltage value that occurs in the open conductive part when a leakage current occurs to that part.

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IV. CONCLUSION

From the results of experiment I and experiment II on the earthing system of TT can be concluded as follows:

Earthing resistance value on the TT system greatly affects the magnitude of the touch voltage that occurs at open conductive part due to a leakage current due to insulation failure. If the resistance value of the earth electrode exceeds the allowable standard, it can cause the touch voltage that occurs in the open conductive part to exceed the maximum standard based on the PUIL 2011 standard and there is no safety of the MCB or ELCB, it will be dangerous if touched by humans because it can cause damage to the human body and can cause death. If the grounding electrode resistance value is smaller than the maximum standard permitted, the touch voltage that occurs in the open conductive part is relatively small and below the maximum touch voltage standard according to the PUIL 2011 standard so that it does not serve if touched by humans.

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