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Analysis of the Human Body's Resistance to AC Voltage

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Abstract— The economic development of the community affects the widespread use of household electricity. Of course, the development of technology touches every aspect of the activity, whether for entertainment, pleasure or primary needs. Every dry season, the threat of fire is often a scourge for all of us. One of the leading causes is a short circuit of electric current. Electricity is an essential part of this day and age. Everyone needs electricity, whether it is from the lower levels of society to the upper levels of society, both for household, office and industrial purposes. Specifically for household purposes, electricity has become an inseparable part of daily needs. A pandemic has resulted in more extended and varied use of electricity in the home. Another consequence is that it is more prone to short circuits or even fires. The critical criteria that must be met at home are the proper installation of security fuses, the avoidance of sockets with multiple connections, and other items that must guarantee adequate grounding or fulfil the requirements with installations that meet the General Electrical Installation Requirements (in Bahasa Indonesia is abbreviated as PUIL). Problems that can be identified are: What is the average resistance of the student body to AC voltage? Are there any differences in male and female body resistance? The benefits of this research are: Theoretical benefits assessing the average resistance of the human body for planning protection system equipment. Practical benefits it is known as the average student body resistance value. Become a reference in determining the value of a protection system plan. The average measurement results in the range of 5100 Ohm. The results showed a significant difference between the levels of body resistance of male and female students. This is because the number of female students in this study is much smaller than that of male students.

Keywords: resistance of the body, electric voltage

I. INTRODUCTION

The use of electrical energy is increasingly widespread in the community in line with economic growth, followed by an increase in the use of electrical energy, impacting the use of various electrical equipment, specifically household electricity (Kyriakopoulos & Arabatzis, 2016). As a result, it is unavoidable that there will be frequent fires due to carelessness, negligence, or failure of the protection functions possessed by equipment and home installations. The use of electrical energy today is increasingly popular in the community with the success of village electrification in Indonesia, so electricity has been distributed to all corners of the country. The use of electrical equipment is increasingly popular in the community due to the rapidly growing economic level of the community. Electrical energy is increasingly important for people's lives, so its use has fulfilled all strata of society and all age groups. Electricity is an essential part of this day and age. Everyone needs electricity, from the lower to the upper middle level, for household, office and industrial purposes. Specifically for household purposes, electricity has become an inseparable part of daily needs (Kipping & Trømborg, 2017).

Because of the more extended and diversified power usage in the house, the presence of a pandemic has resulted in increased electrical energy consumption (Santiago et al., 2021). Studying and working from home automatically results in increased use of electrical energy as well. Another consequence is that it is more prone to short circuits or even fires. The main requirements that must be met at home are: the installation of security fuses must be correct, avoiding sockets that are installed with many connections, ensuring good grounding, or meeting the requirements with installations made according to the General Electrical Installation Regulations (in Indonesian abbreviated as PUIL). However, it would be wiser to know and be aware of the dangers of electricity so that we are more careful about using electricity in everyday life. The effects of electric shocks vary widely, ranging from physical and psychological disabilities to causing fatalities (Koumbourlis, 2002). Many cases occur in our lives, such as death from electrocution or news about house fires due to short-circuiting currents. Therefore, we need a protection system or electrical installation safety system (Radoglou-Grammatikis & Sarigiannidis, 2019). The application of Earth Leakage Circuit Breakers (ELCB) will increase consumer convenience in using electricity so that at least it can avoid the effects of electric shocks and fires that are increasingly occurring today, which in turn can result in material and immaterial losses (Mehta et al., 2021). Initial data is needed to plan a protection system to determine the allowable current threshold or < 30mA (Kalair et al., 2013). It is necessary to measure the human body's resistance, which in this case is to be measured on students. Based on the background that has been stated previously, several problems can be identified and described, namely: Electrical equipment, which is becoming increasingly popular in the community so that it is often neglected to pay attention to safety factors; increasingly diverse equipment do not all have safety standards in use (LMK, IEEE, and SNI standards); domestic electrical installations that do not meet the requirements according to PUIL; arbitrary usage methods and not paying attention to safety factors; and residential grounding systems often do not meet the requirements.

Through this identification, the problems in this research are formulated: What is the average resistance of the student body to electric voltage? Is there a difference in resistance between male and female students? The objectives of this study are as follows: (i) to find out what the average resistance of the student body to electric voltage is; (ii) to determine whether there are differences in resistance between male and female students. The benefits of this research are that the results can be used as a basis for more considerable research and as a theory to support student learning. Measuring the body's resistance to electrical voltage can be used as a benchmark in planning protection equipment for residential electrical installations (Cadick et al., 2012).

The broader use of electricity must be followed by attention to the user's safety factor. Human safety is an essential factor and must also be considered in the use of electrical energy. For this reason, it is necessary to correctly understand that consumers of electrical energy are protected from the dangers of electricity itself. One of those dangers is touch voltage, which can threaten human life. For this reason, it is necessary to reduce the risk of electrical hazards such as excessive touch voltage (Barrett et al., 2010). The methods commonly used to reduce these hazards are grouped into two parts, namely: (i) safety measures to prevent the occurrence of touch stresses (Kasim et al., 2017), namely: (a) total isolation, where the equipment is given additional insulation to prevent the enclosure from being energized, in case the essential insulation fails to function; (b) human insulating pads are isolated from the earth and all electrically conducting objects connected to them; (c) safety with electrical equipment separators connected to the main line through a transformer as an isolation transformer (transformation ratio of 1:1); (d) safe extra low voltage, the equipment is fed at a safe voltage (up to 50 V), e.g. from an isolation transformer, battery, or otherwise,; (ii) safety measures aimed at severing the touch voltage hazard, namely: (a) safety measures aimed at severing the touch voltage hazard, the enclosure is connected directly to ground; when there is a short circuit in the frame, the fault current flowing to the ground is so large that the safety is tripped; (b) neutralization (also known as the TN system) is a form of security that is the most common method. From now on, the apparatus's enclosure is linked to a grounded neutral conductor, referred to as the PEN conductor (Yordanova et al., 2016). In the event of a short circuit to the frame, the fault current flowing to the ground is too large, so the circuit breaker or safety equipment falls. In a system of ground fault circuit breakers, if a fault current flows to the ground at any point in the circuit to be secured, the ground fault circuit breaker immediately disconnects the circuit (Mitolo et al., 2019). Touch voltage is the voltage between an object being touched and a point 1 meter away, assuming that the object being touched is connected to a grounding grid below it (see Figure 1).

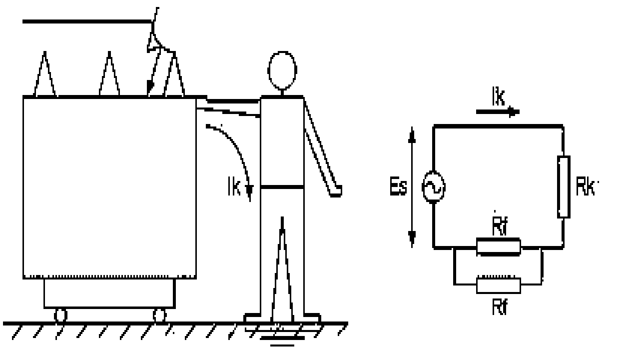

Figure 1. Touch voltage and its equivalent circuit

We get the touch voltage equation from the equivalent circuit in Equation 1.

$$Es = (Rk + \frac{Rf}{2}).Ik \quad (1)$$

Description
ES : Touch voltage
Rk : Human body resistance (Ω)

Rf : The ground contact resistance of one foot on the ground (Ω)
Ik : Current through the body (A)

Touch voltage that is too high must be protected so that it is not dangerous (Kern et al., 2021). Requirements to ensure the safety of humans and livestock and property security from dangers and damage that may arise from the reasonable use of electrical installations (Sni Puil, 2011). Requirements to ensure livestock safety can be applied to locations intended for livestock pens. Protection must be provided against hazards that may arise from contact with live parts of the installation by humans or livestock. In electrical installations, the following hazards may arise (Linsley, 2013), namely:

1. Electric shock current;
2. Excessive temperatures which may result in fire, burns, or other injury effects;
3. Ignition of potentially explosive atmospheres;
4. Undervoltage, overvoltage, and electromagnetic influences that may cause injury or damage;
5. Termination of power supply and termination of safety services;
6. An electric arc of fire, which may cause a blinding effect, excessive pressure, or poison gas;
7. Mechanical movement of electrically actuated equipment. Essential protection for low-voltage installations, systems, and equipment generally relates to protection against direct contact.

Touch voltage arises when a person is connected to a current-carrying conductor, where the conductor and the person are also directly connected to the earth. Some critical piece of equipment to avoid short circuits is MCB (Miniature Circuit Breaker). In the electric power system, it is necessary to provide a protection system to protect electrical equipment from damage due to overload or short circuits, as well as to localize the disturbed area as small as possible. Depending on the needs, many types of protective equipment are commonly used in industry and housing, such as fuses and Miniature Circuit Breakers (MCB). A Miniature Circuit Breaker (MCB) is a form of protective equipment that acts as an overcurrent protector, safeguarding electrical equipment from overload and short-circuit overcurrent (Kasikci, 2018).

The basic principle of operating an MCB is to disconnect the circuit. Suppose there is an overload on the thermal relay due to the current flowing in the MCB continuously exceeding the nominal current (Code, 1993). In that case, the termination system is carried out by bimetallic metal. An electromagnet is used for disconnection in the event of a short circuit that causes a considerable current (Prigmore & Ehlers, 2021). The disconnection of contacts on the arc extinguisher and the opening of the switch on the MCB is due to bimetal or electromagnetic work. MCBs used in residential homes, such as melting safety, are prioritized for short-circuit protection. Therefore, securing the installation or conductor is prioritized in its use. As for the MCB produced by PT Schneider Electric with the Merlin Gerlin brand, it is prioritized as a current limiter with current limiter characteristics and as a safety device from short-circuit currents that work instantly.

Resistors are passive electronic components that have the property of blocking electric current (Olivier, 2018). The unit of value for a resistor is the ohm, usually symbolized according to Ohm's Law (see Equation 2).

$$V = I.R \tag{2}$$

Description
V : The voltage at both ends of the conductor (Volts)
I : Electric current flowing in a conductor (Amperes)
R : The value of electrical resistance (resistance) contained in a conductor (Ohms)

The standard of resistance in the IS (International System) is defined in the basic units of length, mass, and time. IBWM carried out absolute ohms measurements at Sevres, Paris (Mechtly, 1964). The standard resistance is a coil of wire made of manganese alloy with a specific resistance (high electrical resistivity and a low-temperature coefficient of resistance). The coil is placed in a double-walled vessel. Prevent resistance changes due to water vapor conditions outside the air atmosphere (Willyoung, 1892).

The earthing system is one of the factors for securing the electric power system when there is an excessive current or voltage disturbance (Sankaran, 2017). When there is a disturbance in the electric power system, with a grounding system, the current will flow into the ground or be grounded and spread in all directions. An earthing system is a conducting system that connects the body of equipment and electrical installations with the earth so that it can secure humans, equipment, or home electrical installations from the dangers of electric shock or excessive current and voltage. The function of the earth is to drain the fault current into the ground through a grounding electrode planted in the ground. For that, the grounding system's resistance value must follow the conditions applied. The smaller the value of the grounding resistance, the better, but the value of the grounding resistance is influenced by several factors such as soil type, water content in the soil, soil temperature, soil moisture, electrolyte content contained in the soil, and others.

The direct current voltage source is a generator-generated high-voltage source. Voltages might be 100, 250, 500, 1000, or 2000 volts. For 100V and 2000V, the effective measurement area ranges from 0.02 to 20 M. The theoretical framework of this research will create a simple ELCB design that can be installed in residential homes quickly. This tool will be helpful for the reliability of installations at home, especially in preventing the effects of overcurrent or short circuits that harm consumers of electrical energy. Tests are carried out to obtain an accurate picture of when contact and touch occur to ensure the tool's reliability. For this purpose, the trial involved participants with various criteria, such as weight and height (Brenna et al., 2018).

This research aims to determine the average resistance of the human body to AC voltage and whether there is a difference in resistance between male and female bodies.

II. Method

This research method follows the steps shown in Figure 2.

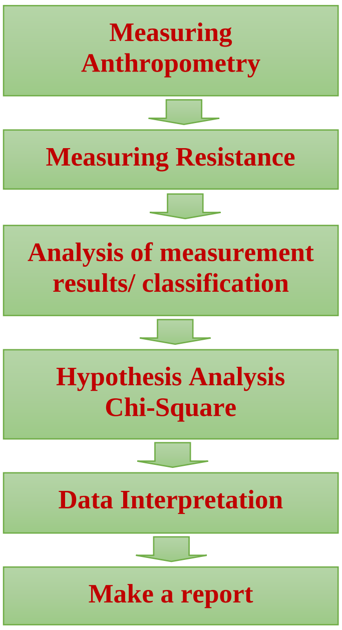

Figure 2. Research Stages

The sensitivity test used several participants classified according to anthropometric data such as weight and height. After the trial, conclusions about the tool's reliability, including the installation, are made. This research was conducted at the Electrical Engineering Education Laboratory of Unima and was tested in front of a group of participating students/volunteers. The research time is from June to August 2022. This study's population is all Electrical Engineering Education Department students registered in the odd semester of 2022/2023. Samples were taken from 30 students, 10% of the total student population. Data analysis techniques are used to test and measure the resistance using a resistance-measuring instrument. The Chi-Square technique's second hypothesis was used to determine the difference between resistance in male and female students. Measurements are made by considering several anthropometric factors, such as height, body weight, and body mass. The analytical technique in this study uses Chi-Square, X^2 analysis to determine the difference in the level of professionalism of teachers. The level of teacher professionalism will be seen for male and female teachers in terms of professionalism and those who are professional and not. The steps are formulating the Ha and Ho hypothesis, testing the truth of both hypotheses, and concluding.

III. Results and Discussion

The study results can be presented in several tables related to the measured sample data, namely anthropometry, measuring the length of the participant's range, and the results of measuring resistance at specific points. At the time of measurement, the human body's resistance is measured at two points on the human body that are different from the variables of height, weight, and distance between the two measurement points. The following is the procedure for data collection to be carried out:

1. Measuring height to determine the respondent's height.
2. Weighing to find out the respondent's weight.
3. Measure the distance between the measurement points.
4. Wipe the skin's surface to be measured with a tissue to ensure dryness.
5. Measure body resistance using a digital multimeter with a direct current injection of 9 volts at the fingertips between points 1–2, 1–3.1–4, 2–3, and 2–4, as shown in Figure 3.

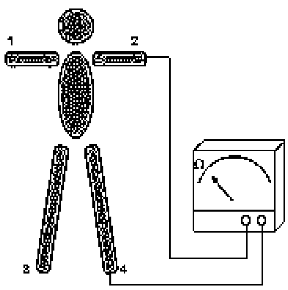

Figure 3. Body Resistance Measurement

Anthropometric data measured included height and weight and general data from respondents, namely age and gender, for 30 participants who became respondents (see Table 1).

Table 1. Anthropometric data for female and male participants

No	Height/Cm	Weight/Kg	Age	Gender
1	165	60	26	M
2	166	70	25	M
3	155	44.9	21	M
4	171	67	21	M
5	174	68	20	M
6	170	57	21	M
7	166	55.6	18	M
8	150	53	20	F
9	150	53	21	F
10	155	51	21	F
11	161	59.9	24	F
12	169	51.5	18	M
13	167	61	18	F
14	162	59	24	F
15	156	45	19	F
16	157	55	18	F
17	147	45	20	F
18	152	53	18	F
19	149	51.8	23	F
20	150	50	22	F
21	174	68	20	M
22	170	57	21	M
23	166	55.6	18	M
24	150	53	20	F
25	150	53	21	F
26	155	51	21	F
27	155	44.9	21	M
28	171	67	21	M
29	174	68	20	M
30	170	57	21	M

Measurement of the length of the body point, the results of the distance between points that follow the respondent's height, so that the tendency of the distance obtained follows how tall the body is measured (see Table 2). When comparing female and male respondents, the measuring distance tends to be longer for males than for females.

Table 2. Average body R in the experiment using a multimeter for 5 points

No	1–2 (Ω)	1-3 (Ω)	1-4 (Ω)	2-3 (Ω)	2-4 (Ω)	Average (Ω)
1	412	600	750	1276	1800	967.6
2	78	550	1120	258	357	269.4
3	790	963	1167	960	2500	1276
4	350	2200	1300	3400	3100	2070
5	325	446	317	1050	1530	733.6
6	832	570	665	580	611	651.6
7	575	5670	4300	2080	3010	3127
8	1700	1900	6600	13900	12800	7380
9	6200	9700	17700	9600	12700	11180
10	1200	4900	2100	1400	2080	2336
11	14100	6100	8700	11300	10600	10160
12	2200	2100	1600	1500	1600	1800
13	932	1300	5800	2200	3300	2706.4
14	1500	665	731	1300	1800	1199.2
15	271	583	593	2473	3250	1431.2
16	2100	6290	8100	9700	5100	5238
17	1410	3320	3500	8030	2680	3788
18	1490	4210	6560	1800	651	2942.2
19	6570	10440	9140	7050	10430	8726
20	6510	7150	4550	7060	9760	7006
21	325	446	317	1050	1530	733.6
22	832	570	665	580	611	651.6
23	575	5670	4300	2080	3010	3127
24	1700	1900	6600	13900	12800	7380
25	6200	9700	17700	9600	12700	11180
26	1200	4900	2100	1400	2080	2336
27	14100	6100	8700	11300	10600	10160
28	2200	2100	1600	1500	1600	1800
29	932	1300	5800	2200	3300	2706.4
30	1500	665	731	1300	1800	1199.2

The next step is to make a classification for a sample of 30 students, as follows: < 2000 (low), 2000-6000 (medium), and greater than 6000 in the high classification.

Table 3. The Contingency of Resistance Levels by Gender of Students

Gender	Resistance Level Classification			Total
	Low	Medium	High	
Male students	7	8	6	21
Female students	2	4	3	9
Total	9	12	9	30

The measurement data was then made into a chi-square table to determine how much body resistance the respondents measured and whether there was a difference in resistance between female and male participants. The analysis is carried out with the following steps: make a hypothesis that there is no difference in the level of body resistance of male and female students (Ho), or accept (Ha) an alternative that there is a significant difference between the levels of body resistance of male and female students.

Table 4. Percentage of Resistance by Gender

Gender	Percentage of Resistance			Total
	Low	Medium	High	
Male students	23.33%	26.66%	20%	70%
Female students	6.67%	13.33%	10%	30%
Total	30.01%	39.99%	30%	100%

The next step is calculating each cell's Fe value (see Table 3 and Table 4) with Equation 3.

$$Fe = \frac{Total\ of\ row\ x\ Total\ of\ column}{Total\ of\ percentage} \quad (3)$$

In the first cell = 21 x 9/ 30 = 6.3
In the second cell= 9 x 9/ 30 = 2.7
In the third cell = 21 x 12/ 30 = 8.4
In the fourth cell = 9 x 12/ 30 = 3.6
In the fifth cell = 21 x 9/ 30 = 6.3
In the sixth cell = 9 x 9/ 30 = 2.7

Chi-square value = $X^2 = \Sigma$ ki = 1 (fo-fe)^2 fe
$(7- 6.3)^2/7 + (2- 2.7)^2/2 + (8- 8.4)^2/8 + (7- 6.3)^2/7 + (9- 3.6)^2/9 + (21- 6.3)^2/21 = 0.07 + 0.245 + 0.02 + 0.07 + 3.24 + 10.29 = 13.935$

$X^2 = 13.935$ number of rows = 2 (r) and number of columns = 3 (c)

Df = (r-1) (c-1) df = (2-1)(3-1) = 2 critical values of the table = 5.991 for 5% and 9.210 for 1% so that the results obtained > from the table that can be interpreted reject Ho there is no significant difference between the level of resistance in male and female students. There are different levels of resistance or acceptance of alternative hypotheses.

Anthropometric data is needed to present size data from various parts of the human body in percentiles, which will be very useful for designing a product or work facility. Therefore, in measuring the body to determine the level of resistance, as a basis, height and weight are measured by the length of the distance from each point, namely the point of the left shoulder to the right, the shoulder to the end of the hand, and from the shoulder to the toe. Measure body resistance; it depends on several factors or indicators, namely skin moisture, touch area, and tension. The body's resistance is a combination of the skin's and the human body's internal resistance.

In this study, Ho: There is no significant difference in measuring the level of body resistance to AC voltage between male and female students, and Ha: There is a significant difference in the results of measuring student body resistance to AC voltage for male and female students. The results showed that there was a significant difference between the levels of body resistance of male and female students. The number of female students in this study is much smaller than that of male students. When the test is carried out on a relatively balanced number of research results, the results are likely to be almost the same, or there are no differences. Significant differences can also be explained by the aspect of anthropometry, where the measuring distance or length of the limbs of male students tends to be longer than female students. The weight factor also affects the amount of body resistance, although it needs a more in-depth study. The interpretation of the results of this study is that the resistance of each student's body is different, especially when viewed from a gender perspective with differences in height and weight.

This research is still straightforward and limited in terms of time and sample. Therefore, more extensive research regarding samples and adequate time are needed. This research needs more participants or students to produce more reliable research.

IV. CONCLUSION

The conclusions obtained from this study are to determine the average resistance level of students majoring in Electrical Engineering Education. The average body resistance measurement to AC voltage is 1000 to 10,000 or an average of 5100. This result is almost the same as the results of previous studies in the range of 3000. In the results of the chi-square analysis, it was also found that there was a significant difference between the amount of resistance of male and female students. This difference is influenced by whether the number of samples is limited or minor. Besides that, the number of sampled students is too small compared to male students. Of course, some of these factors cause differences, so more comprehensive studies must be carried out to obtain more precise data. Suggestion, The research results can be used as a basis for more extensive research and as a theory to support student learning. The results of measuring body resistance to electrical voltage can be used as a reference in planning protection system equipment for residential electrical installations or other research purposes. Some suggestions in this research are:

1. The need for expanded research, both in the number of samples and the time provided.
2. Anthropometric measurements are still essential to consider before resistance measurement.
3. It is necessary to involve students both as active participants and in participating as test objects in research.
4. Equipment for measuring instruments should use at least two instruments, namely conventional and digital multimeters/avometers.
5. Other measuring instruments must be prepared in a unique laboratory for more complete and precise anthropometric measurements.

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