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Modeling and simulation for flashover location determination on 150 kV insulator string

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ABSTRACT

The 150 kV Payakumbuh-Koto Panjang transmission line in West Sumatra is located in an area with high lightning activity. Based on Meteorological, Climatological, and Geophysical Agency (BMKG) data (2017-2023), the average number of lightning days per year (IKL: isokeraunic level) reaches 165-173 days/year, and 79% of the transmission towers are located in hilly and rocky areas. This causes contamination of the insulator, which can reduce its performance and cause flashovers in the insulator circuit. However, in the field, finding flash points in insulators is still a challenge. Therefore, simulation must be used as a tool to determine the location of flashover in an insulator circuit that is affected by temperature and humidity. Simulation by modeling flashover provides an effective solution for determining the location of flashover in insulator circuits, which is the novelty of this research. This research compares laboratory test results with manual calculations modeled using Visual Basic 6. The research results show that temperature and humidity have a significant influence on determining the flashover voltage value on the insulator. The flashover locations during the test are the same as the calculated flashover locations, as shown by these simulations and modeling.

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1. INTRODUCTION

In the power system, transmission lines are essential. They serve as a means of economically transmitting electricity. The electrical grid's dependability depends on these lines operating continuously. In the power transmission system, insulators play a crucial role [1]. Insulators are one of the electrical power system equipment used to withstand electrical voltage and mechanical forces [2]. This means that insulators must have a high mechanical strength to weight ratio and a good electrical insulation resistance [3] taking into account that the catastrophic collapse of the entire power system could be caused by a single insulator breakdown [4]. The power transmission system in Indonesia mainly is installed in overhead lines instead of the underground cables. West Sumatra in Indonesia is an area with a high density of lightning strikes. Most outages due to line faults are caused by faulty insulators [5]. An important factor in power system outages is contamination on the surface of insulators, which increases the development of leakage current that may cause flashovers and power system outages [6].

There is a 150 kV transmission line in West Sumatra that is installed through an area where the average number of thunderstorm days per year (IKL: isokeraunic rate) reaches 165 days [7]–[9]. The 150 kV Koto Panjang-Payakumbuh transmission line is 86 km long with a total of 248 towers, of which 63% of the towers are in a hilly environment with 82% flashover, 20% of the towers are in a rice field environment with 16% flashover, and 16% of the towers are in a desert environment with 2% flashover [10]. When it comes to power systems, electrical insulators are among the most crucial components that influence how reliable distribution and transmission lines are. Environmental issues continue to cause flashover failures to occur [11].

Significantly, insulator contamination related to the presence of water vapor degrades the dielectric performance of the insulator. The presence of water vapor in addition to insulator pollution results in the dissolution of salt contaminants, which leads to the formation of a conductive layer on the insulator. The conductive layer, which experiences different voltage values on the insulator, becomes an easy path for leakage current to flow resulting in the formation of dry bands on the insulator [12]. This layer becomes a conductive layer either by itself or as a result of moisture, fog, rain or dew and eventually, this causes leakage currents to pass through and then dry areas on the insulator surface. This current and voltage cause the initiation of small arcs that develop gradually and lead to the phenomenon of electrical discharge. This surface discharge ends up in insulator failure and jeopardizes the transmission line [13]. Insulators must maintain the normal operating voltage, the standard overvoltage, and the mechanical pressure [14]. The unstable environmental conditions will greatly impact the insulator performance for instance, the insulator resistance can decrease due to pollution [15]. Financially, the damage caused by the polluted flashover is higher than that of the natural factors of lightning [16]. A conductive layer forms on the insulator surface when contaminants are present in high humidity [17]. Rain, ultraviolet (UV) rays, temperature changes, and humidity variations are significant weather-related elements that lead to insulator degradation and the formation of a conductive layer that generates flashover on the insulator surface [18]. Based on field experiments, the contaminated insulator surface fails because of increased electrical conductivity caused by condensation of water vapor caused by cooling radiation. When moisture in the form of dew, fog, or light rain falls on an insulator surface, it dissolves electrolytes and dissolved salts, wets the contaminated layer, and leaves behind a thin layer of conductivity [19]. The problem of insulator pollution has become a major threat to the safe operation of power systems [20]. Therefore, in order to ascertain the value of the flashover voltage and the position of flashover on the insulator, modeling and visualization simulation are performed using Visual Basic.

2. RESEARCH METHOD

This study entails performing a visualization modeling analysis utilizing Visual Basic to precisely compute the flashover voltage value and determine the exact flashover point on the insulator string. Put simply, the objective is to provide accurate and genuine information on the flashover threshold and the most suitable location for flashover on the insulator. Visual Basic is used to visually depict the isolation visualization using flashover occurrences. This technique is carried out by following a sequence of steps detailed as shown in Figure 1.

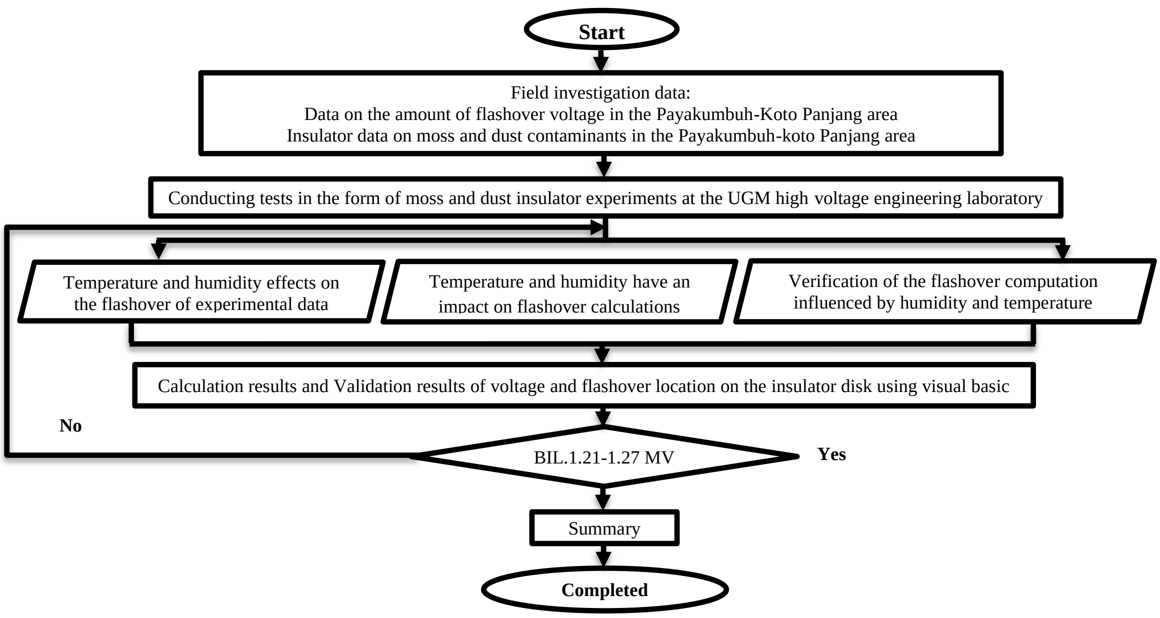


Figure 1. Flowchart

2.1. Correction of test results for air humidity

2.1.1. Air density factor

The main increases in humidity and flashover voltage occur along the surface or across the air gap. The amount of electrons absorbed by water molecules increases with humidity, and the average electron free path decreases. Furthermore, when insulating materials are present in the air gap, the flashover voltage of the gap drops, although the humidity of the surrounding air tends to increase as well [21]. It is important to carefully evaluate these variables related to temperature, pressure, and humidity. Given that temperature might have an impact on a material's overall insulating qualities, consideration must be given careful thought [22]. The typical requirements for air insulation testing are as (1) [23]:

$$\delta = \frac{b}{760} x \frac{273+20}{273+T} = \frac{0.386b}{273+T} \quad (1)$$

p is the measured barometric pressure (mmHg), T is temperature (°C), δ is the relative air density, standard temperature=20 °C, barometric pressure=1,013 mbar (760 mmHg), and absolute humidity=11 g/m^3.

2.1.2. Humidity correction factor

One number that is used to counteract the impact of humidity is the humidity correction factor (19). At the measurement site, the relative humidity and air temperature determine the humidity correction factor used. Significant alterations in the insulation system's performance will occur with a rise in relative humidity, and a drop in flashover voltage may be harmful to the system as a result [24]. IEEE Standard techniques for high-voltage testing, provides a procedure for correcting results obtained under non-standard atmospheric conditions to standard atmospheric conditions. This procedure requires the calculation of air density and humidity correction factors [25].

$$Hc = 1 + 0.010 * [\frac{H}{\delta} - 11] \quad (2)$$

where Hc is humidity correction factor, δ is the relative air density, and H is absolute humidity in grams of water per m^3 of air.

2.1.3. Flashover voltage by its standard condition

The drop in air density brought on by a rise in temperature reduces the insulating strength of air. The temperature and humidity have an impact on the flashover voltage. The drop in air density brought on by a rise in temperature reduces the insulating strength of air. Temperature and humidity have an impact on the flashover voltage [26] In atmospheric air testing, weather conditions especially temperature, pressure and humidity factors are carefully considered. During the experiment, these parameters are strictly observed by regularly checking the humidity, atmospheric pressure, and atmospheric temperature. If the environmental conditions are not more or less equal to the values mentioned above in point 2.1.1 the formula for air insulation testing is [27]:

$$Vs = V_0 * \frac{Hc}{\delta} \quad (3)$$

where Vs is the flashover voltage under standard conditions, Hc is the humidity correction factor, V_0 is the flashover voltage under actual conditions, and δ is the relative air density.

2.1.4. Basic insulation level (BIL) calculation

Standardization bodies have thought of setting the lowest possible basic insulation level or BIL that is compatible with safety. Lightning impulse voltage is entirely a natural phenomenon and hence highly uncertain. So, it is impossible to predict the shape and size of lightning surges. Payakumbuh-Koto Panjang transmission line uses insulators with the number of insulator spans is 11. The type of insulator used is porcelain type where each insulator unit has a voltage of 110 kV with a basic insulation level (BIL). Weather data is used to calculate the BIL under non-standard atmospheric conditions [28].

$$BIL_A = \delta * Hc * BIL_s \quad (4)$$

where BIL_A is the BIL under nonstandard conditions, δ is the relative air density, Hc is the humidity correction factor, BIL_s is the standard BIL (110 kV).

2.2. The required data

The data in Table 1 are the results of experimental data obtained through Universitas Gadjah Mada (UGM) High Voltage Laboratory experiments. When testing, things that affect the test results will be recorded. Such as voltage, temperature, humidity and air pressure when testing. The test result data is presented in Table 1. When before testing, the type and description of the insulator must first be known. In Table 2 is data from insulators that are tested for flashover. The data is data from the tower insulator tower 17 Payakumbuh-Koto Panjang transmission line.

The polluted insulators were tested for breakdown voltage. The breakdown voltage of polluted insulators was tested at the UGM High Voltage Laboratory using a test scheme as shown in Figure 2. With the 150 kV insulator testing process using a test transformer with temperature and humidity variables that affect flashover voltage, so that each temperature and humidity value can distinguish the results of flashover values.

Table 1. Flashover voltage testing experiment data tower 17

Experimental voltage (kV)	Relative humidity	Temperature °C	Air pressure
350.2	78.6	29.4	747
348.6	77.7	29.9	747
353	76.8	30.5	746
351.4	79	29.1	746
333	80.1	28.9	746.5

Table 2. The insulator specifications [29]

Insulators code material	11 porcelain suspension insulators
BIL	1.21 MV
Diameter (D)	25.4 cm
Total of length	1.6 to 1.87 m

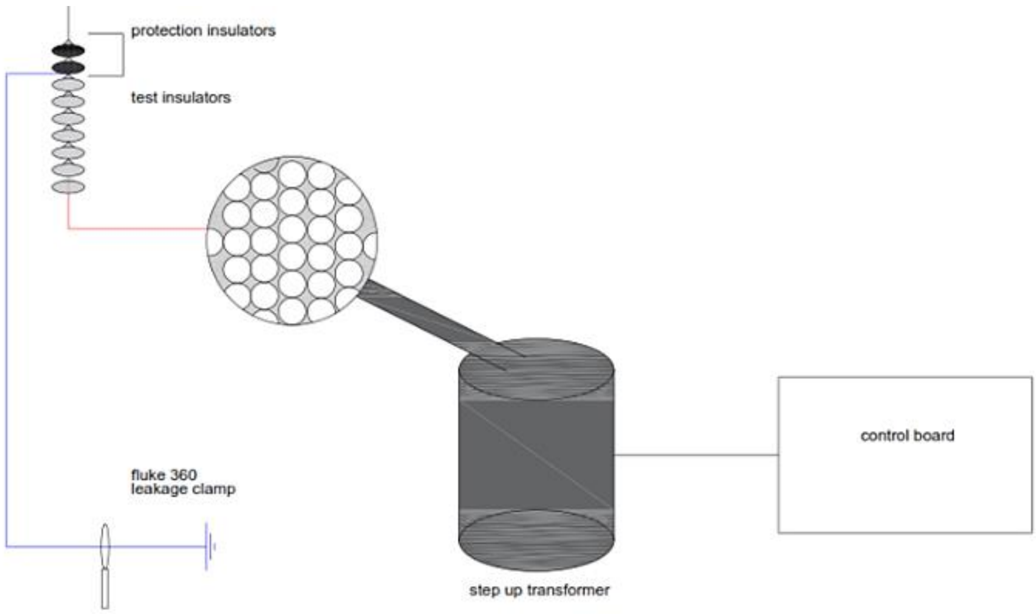


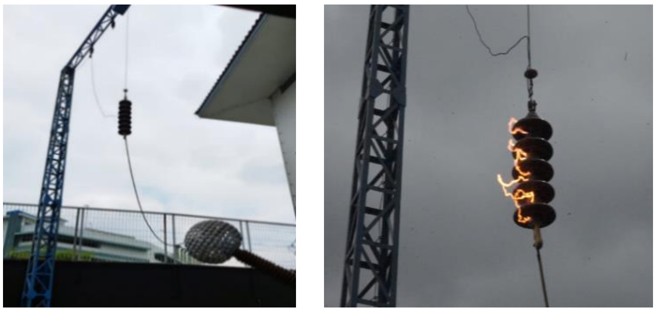
Figure 2. Testing scheme of insulator against flashover at UGM High Voltage Laboratory

In the Figure 2 is the type of insulator on tower 17 that was experimented at the UGM High Voltage Laboratory. The insulator was obtained directly from tower 17 of the Koto Panjang-Payakumbuh transmission line. The insulator was brought in one piece to be tested at the UGM High Voltage Laboratory. Suspension insulator disc is assembly to the suspension insulator set of the transmission lines; it can be said that it is important to support power transmission conductors. Therefore, it is necessary to study the flashover effects on the suspension insulator set that is caused by contaminants in the air and also prevents a breakdown in transmission system [30].

The type of insulator used is the type of ceramic insulator shown in Figure 3. The insulator comes directly from the Koto Panjang-Payakumbuh transmission tower. In Figure 3 it can be seen that the insulator has been covered by so many pollutants that it has the potential for flashover.

Figure 4(a) is the experimental flashover testing process on the 150 kV insulator in tower 17 at the UGM High Voltage Laboratory, and Figure 4(b) is the flashover generated from the 150 kV insulator in tower 17. In Figure 4(a) is a type of ceramic insulator that comes from the Koto Panjang-Payakumbuh transmission tower. With pollutants covering the entire surface of the insulator, flashover occurs throughout the insulator as seen in Figure 4(b).

Figure 3. Ceramic insulator tower 17



(a) (b)

Figure 4. Experiment circuit (a) flashover voltage testing process using a test transformer and (b) insulator experiencing flashover

3. RESULTS AND DISCUSSION

3.1. Experimental of flashover on string insulators

The results were obtained based on experimental data at the UGM high-voltage laboratory, from the experimental results obtained then processed in visual basic software, to calculate and perform modelling of insulators affected by flashover. Figure 5 is the calculation and modelling of flashover voltage on the 150 kV insulator of tower 17, where modelling and calculations were carried out using Visual Basic 6.0 using variables known during experiments at the UGM High Voltage Laboratory. Based on the data obtained in Table 1, calculations can be carried out to calculate the air density, humidity factor, flashover voltage under standard conditions and the calculated base level of the insulator.

Table 3 is the result of the flashover stress value performed during the experiment; the flashover stress value obtained through calculation based on the same temperature value. So, from the data can be described through the trendline in Figure 6. Figure 6, it can be seen that the experimental voltage value and the flashover voltage value of the insulator have the same properties with respect to temperature. Where when the temperature increases, the experimental voltage and flashover voltage of the insulator also increase. Thus, the temperature has a directly proportional relationship with the experimental voltage and flashover voltage of the insulator. In Table 4 is the data from the calculation of flashover voltage against humidity. Humidity has a different effect on flashover compared to the effect of temperature. So that the resulting voltage value will be affected by the value of the existing humidity.

Figure 7 it can be seen that the experimental voltage value and flashover voltage value of the insulator have different properties to the relative humidity value, where when the temperature increases, the experimental voltage and flashover voltage of the insulator will decrease, thus temperature has an inversely proportional relationship with the experimental voltage and flashover voltage of the insulator. The graph illustrating the correlation between humidity and flashover voltage is shown by the trend line above, where there is a decrease in the value of flashover voltage as a result the value of humidity increases which was experienced by flashover voltage during testing and flashover voltage during the calculation; therefore, it can be seen from the graph above in the calculation of (3) that flashover voltage is inversely proportional to the humidity correction factor; however, it is directly proportional to the air correction. In other words, when the value of humidity is higher, there will be a decrease in flashover voltage. In this case, contaminants such as moss or dust adhering to the surface of the insulator can reduce the insulator's ability to withstand electrical stress and accelerate flashover to occurrence. This is in line with a study conducted by [29], which found that as the amount of contamination on the surface of the insulator increased, it made the electric field on the insulator surface even larger. Eventually, there would be a voltage drop in the insulator above the critical voltage and would cause flashover in the insulator.

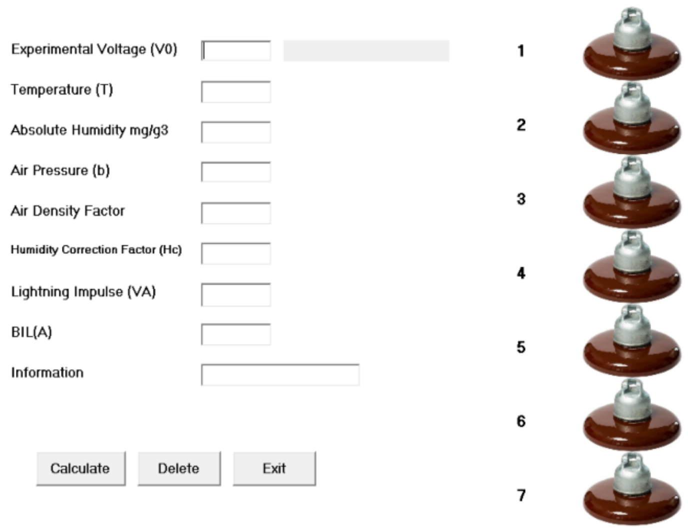


Figure 5. Modelling of insulator flashover based on the location of flashover on the insulator

Table 3. Calculation flashover stress and experimental flashover stress

No	Experimental voltage	Flashover voltage calculation	Temperature
1	350.2	369.64	29.4
2	348.6	369.21	29.9
3	353	375.38	30.5
4	351.4	370.16	29.1
5	333	350.28	28.9

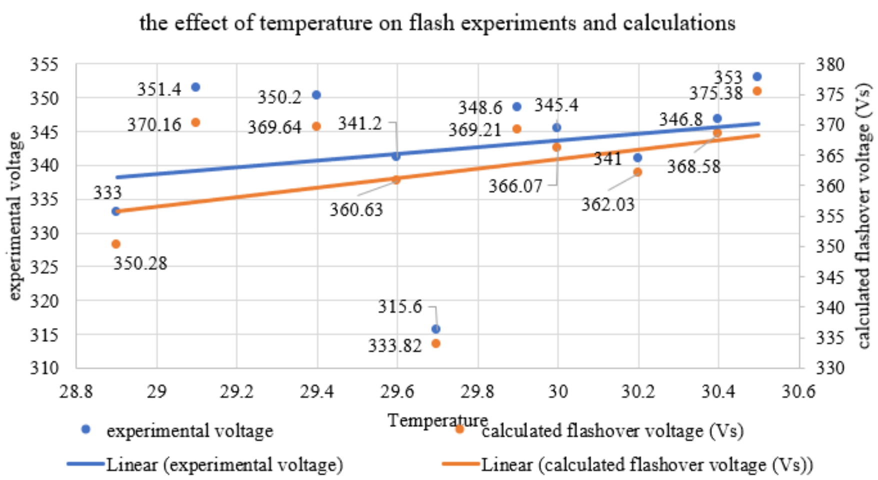


Figure 6. Trendline of experimental voltage and flashover of insulator against temperature value

Table 4. Calculation flashover stress and experimental flashover stress

No	Experimental voltage	Flashover voltage calculation	Relative humidity
1	350.2	369.64	78.6
2	348.6	369.21	77.7
3	353	375.38	76.8
4	351.4	370.16	79
5	333	350.28	80.1

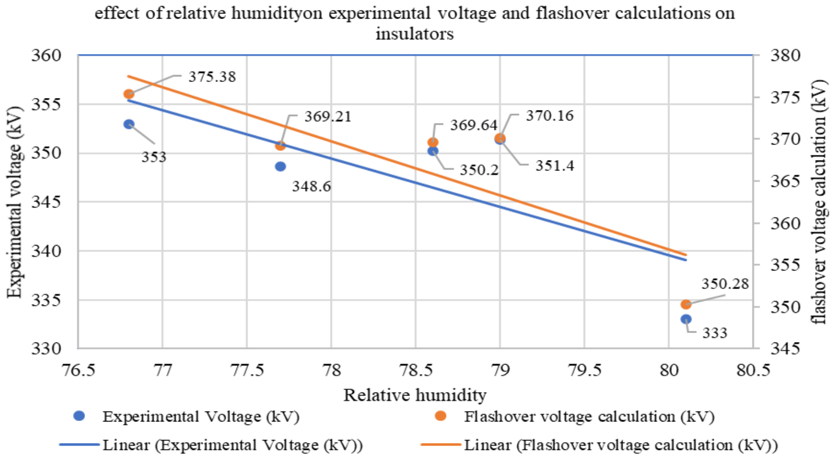


Figure 7. Trend line of experimental voltage and flashover of insulator against relative humidity value

3.2. Modelling flashover on insulators using Visual Basic 6.0

To get the results according to (1) to (4), it must be made into a Visual Basic 6.0 algorithm to calculate the flashover voltage value, and model the insulator under test. Equations (1) to (4) are entered into the visual basic algorithm, so that it can be run in the program. As shown in Figure 8, are the equations used in the calculation, which are entered into the algorithm of visual basic.

The equations (1) to (4) also includes the variables of temperature, humidity, air correction factor, and humidity correction factor used to calculate the flashover voltage value. To determine the algorithm for determining the location of the insulator experiencing flashover, the peak voltage values from each test scenario are entered into the algorithm. The following are the results of modelling and calculation of flashover of 150 kV insulators on tower 17.

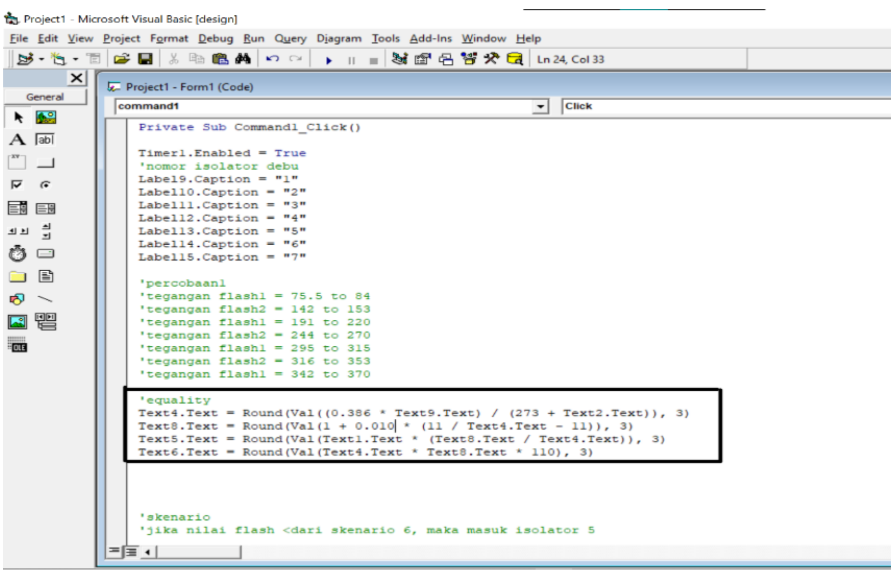


Figure 8. Equations (1) through (4) used in Visual Basic 6.0

Figure 9 is the modelling and calculation of flashover voltage on the insulator. Input experimental voltage variables based on Table 2, namely at 350.2 kV, temperature 29.4 °C, humidity 76.8% and air pressure 747 mmHg. This illustrates the modelling of flashover occurrence in insulators 1, 2, 3 and 6. Figure 10 is the modelling and calculation of flashover voltage on the insulator. Input experimental voltage variables based on Table 2, namely at 348.6 kV, temperature at 29.9 °C, humidity at 77.7% and air pressure at 747 mmHg. Thus, illustrating the modelling of flashover occurrence on insulators 1, and 6. Figure 11 is the modelling and calculation of flashover voltage on the insulator. Input experimental voltage variables based on Table 2, namely at 353 kV, temperature at 30.5 °C, humidity at 76.8% and air pressure at 746 mmHg. Thus, illustrating the modelling of flashover occurrence on insulators 1, 5, and 6. Figure 12 is the modelling and calculation of flashover voltage on the insulator. Input experimental voltage variables based on Table 2, namely at 351.4 kV, temperature at 29.1 °C, humidity at 79% and air pressure at 746 mmHg. Thus, illustrating the modelling of flashover occurrence on insulators 1, 4, and 6. Figure 13 is the modelling and calculation of flashover voltage on the insulator. Input experimental voltage variables based on Table 2, namely at 333 kV, temperature at 28.9 °C, humidity at 80.1% and air pressure at 746.5 mmHg. Thus, illustrating the modelling of flashover occurrence on insulators 1 and 6.

Figure 9. Modelling and calculation results of insulator flashover with temperature 29.4 °C, relative humidity 76.8%, air pressure 747 mmHg and experimental voltage 350.2 kV

Figure 10. Modelling and calculation results of insulator flashover with temperature 29.9 °C, relative humidity 77.7%, air pressure 747 mmHg and experimental voltage 348.6 kV

Figure 11. Modelling and calculation results of insulator flashover with temperature 30.5 °C, relative humidity 76.8%, air pressure 746 mmHg and experimental voltage 353 kV

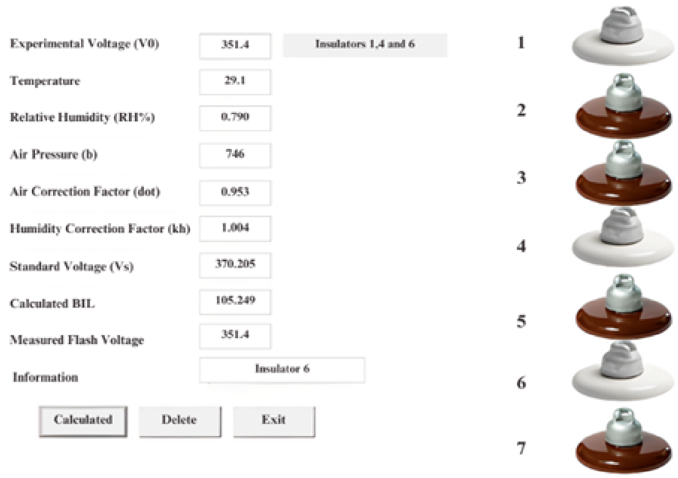


Figure 12. Modelling and calculation results of insulator flashover with temperature 29.1 °C, relative humidity 79%, air pressure 746 mmHg and experimental voltage 351.4 kV

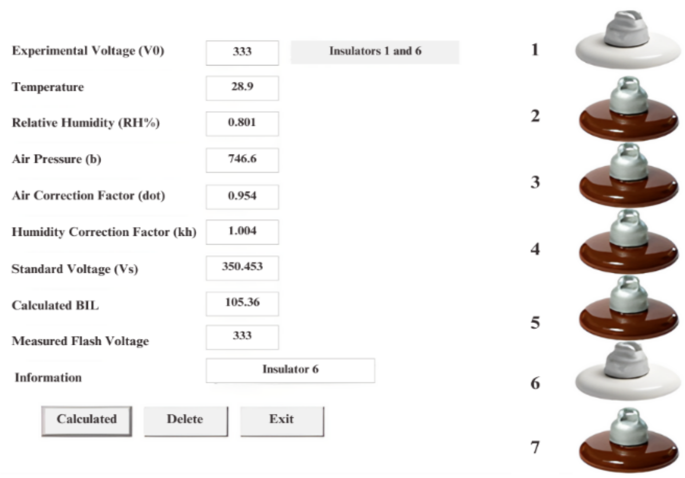


Figure 13. Modelling and calculation results of insulator flashover with temperature 28.9 °C, relative humidity 80.1%, air pressure 746.5 mmHg and experimental voltage 333 kV

Table 5 is the result of each calculation, experimental voltage, insulator flashover voltage, and calculation in Visual Basic 6.0, for modelling the 150 kV insulator on tower number 17. The results are obtained based on (1) to (4). The equation is done by calculating, and entering into the algorithm of visual basic to get modelling.

Figure 14 shows the calculation and modelling values of flashover voltage simulation based on flashover voltage simulation modelling using visual basic. The calculation is influenced by the same temperature and humidity values, with the object of the 150 kV transmission line insulator on tower 17. With the results showing the trendline of the flashover voltage calculation results and the calculation results based on the modelling algorithm using visual basic.

Table 5. Calculation flashover stress and experimental flashover stress

Experimental voltage	Flashover voltage calculation (kV)	Flashover voltage by visual basic 6.0 (kV)	Insulators exposed to flashover
350.2	369.64	369.288	1,2,3,6
348.6	369.21	369.106	1,6
353	375.38	375.318	1,5,6
351.4	370.16	370.205	1,4,6
333	350.28	350.453	1,5

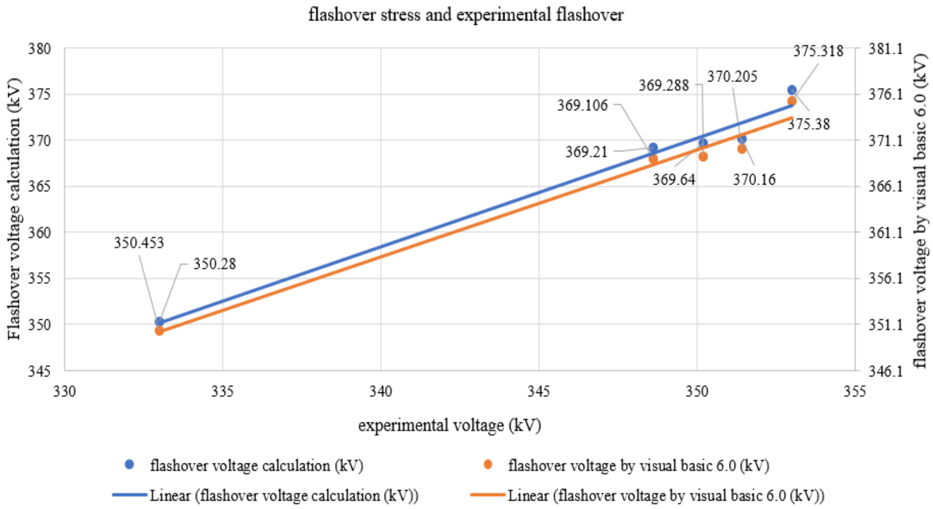


Figure 14. Graph of calculation and modelling results of flashover stress simulation using visual basic 6.0

4. CONCLUSION

Based on the results of calculations and experiments that have been carried out, it shows that at a temperature of 30.5 °C the flashover voltage can reach the highest voltage value from the data obtained; 353 kV for the voltage experiment, 375.38 kV for computing voltage and 375,318 kV for validation with visual basic. Then the lowest temperature point is at 28.9 °C, where the flashover voltage can only reach the lowest voltage value; The flashover voltage experiment at 333 kV, and the calculated flashover voltage at 350.28 kV, while the validation with basic visuals is at 350.43 kV. The conclusion can be made that the higher the temperature value, the higher the flashover voltage is, because high temperature can reduce the dielectric resistance. However, in the humidity variable the opposite happens, where the highest humidity reaches to 80.1% causing the flashover at its lowest value of 333 kV the voltage experiment, and 350.28 kV for the flashover voltage calculation, and 350.43 kV for the visual basic validation. Meanwhile, at the lowest humidity value of 76.8%, the highest flashover voltage is obtained at 353 kV for flashover voltage experiment, at 375.28 kV for the flashover voltage calculation and at 375.318 kV for the visual basic validation. So, it can be concluded that if the humidity value is higher, it will reduce the flashover voltage value, but if the humidity value decreases, it will increase the flashover voltage value. Based on the trend line graph, it can be concluded that the trend line pattern for temperature against the flashover voltage in the experiment and calculation has the same pattern, just as the humidity value for flashover voltages also has the same trend line pattern between the flashover voltage in the experiment, calculation and visual basic validation visualization.

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