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The Effect of Humidity and Temperature on Flashover in High Voltage Transmission Line Ceramic Insulators

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Abstract **– This research aims to determine the flashover voltage on the surface of porcelain insulators on 150 kV transmission lines located in Payakumbuh, where the insulators are contaminated with dust and moss due to the effects of temperature and humidity. The experiment is carried out with only up to seven insulator plates due to the limitations of the available apparatus. For the further testing, a trend analysis is applied. According to the experimental results, a rise in temperature around the insulator will increase the flashover voltage value and accelerate the potential for a flashover event. This happens because high temperatures can reduce the insulator's dielectric strength and insulation resistance and increase the risk of flashover. The dielectric strength values decreased with an average decrease of 44.62% per insulator plate for dusty insulators and 45.08% for each plate for mossy insulators. The results aim to minimize flashover on transmission lines in hilly areas with relatively high contamination.**

Keywords **– Isolator, dust, moss, flashover, ceramic insulators.**

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1. Introduction

The 150 kV transmission line in Koto Panjang - Payakumbuh has a track length of 86 km and 248 transmission towers [1]. These towers are distributed in several locations: hilly areas at 63%, agricultural land at 20%, and desert areas at 16% [2], [3]. Koto Panjang-Payakumbuh is at coordinates 0.054639 S and 100.75 E (BMKG, 2021-2022). Based on this geographical location, the number of thunder days per year for the Koto Panjang-Payakumbuh area is 174 days per year. According to research related to flashover, 82% of flashovers occur in hilly areas, compared to 16% in paddy fields and 2% in deserts [2]. Since most transmission towers are located in hilly areas, the chance of flashover on insulators is very high, leading to outages. According to the Sumatra Load and Distribution Control Centre (Sumatra P3B), the intensity of outages due to lightning on the Payakumbuh-Koto Panjang transmission line reached 66% [4], [5]. Insulators positioned on hillsides can cause up to 33.3% disruption. In addition to generating power outages, lightning overvoltage surges can destroy transmission line insulation. The trip-out on the transmission lines (Payakumbuh-Koto Panjang) due to the failure of several insulators is due to the high flashover caused by insulator contamination [4], [5], [6].

Insulators are vital in power transmission and distribution [4], [7]. Insulators are required in transmission lines to isolate portions with differing voltages between line and neutral and as mechanical supports [8], [9].

Environmental conditions and long-term use of insulators can create changes in the insulator's physical qualities, which leads to changes in the insulator's electrical properties and has the potential to cause flashover [10], [11], [6]. Aside from that, dust, salt, and other contaminants can adhere to the insulator's surface [12], [13], [14], [15], [16].

Temperature and humidity are two environmental factors that influence the ability of insulators to withstand flashover voltage [7], [15], [17]. They may be less effective at preventing flashover in conditions of high humidity and extreme heat [4], [18] [15], [19]. Contamination and humidity affect the electrical properties of flashover in polluted insulators. Increasing humidity reduces the flashover voltage gradient for all contamination profiles [16], [17]. The flashover voltage will decrease as the ambient temperature rises because an increase in temperature may reduce the resistivity values of a polluted insulator's surface and increase the leakage current. An increase in leakage current can cause degradation on the insulator surface and reduce the insulation strength, resulting in a flashover [8], [15]. The release of gas due to contamination on the surface of high-voltage outdoor insulators can induce a flashover [18]. Leakage current due to flashover can damage insulators and disrupt electrical systems [20], [21].

According to temperature and humidity data collected in Koto Panjang every 6 hours, the average temperature and humidity values at 1 AM were 20°C and 95%, 07.00 AM were 20°C and 90%, 1 PM were 28°C and 65%, and 7 PM were 23° and 95% (source: BMKG, 2021-2022). The data also revealed that the flashover occurred more than four times yearly on Tower Ten (PLN, 2021-2022).

This research aims to investigate the effect of temperature and humidity on the dielectric strength of insulators in a 150 kV transmission line located in mountainous parts of the Koto Panjang using experimental analysis.

2. Method

The research employs an experimental approach to determine the effect of temperature and humidity on the dielectric strength of insulators contaminated with dust and moss. The experiment data was collected on a laboratory scale, with the discussion focusing on analyzing the influence of temperature and humidity on the flashover voltage on the surface of 150 kV insulators by increasing the test voltage from 0 kV to 400 kV.

The following Equations (1), (2), (3), and (4) will be used to analyze the effect of changes in temperature and humidity on insulator flashover [20].

$$V = \delta . V_s \quad (1)$$

V is the flashover voltage, δ is the air correction factor, and Vs is the flashover under standard conditions. The value of δ can calculated from Equation 2 below.

$$\delta = \frac{b}{760} x \frac{273+20}{273+T} = \frac{0{,}386b}{273+T} \quad (2)$$

According to Equation 2, T is the ambient temperature when the experiment is carried out (°C), and b is the air pressure during the experiment (mmHg). Therefore, the flashover voltage of the insulator at any temperature, pressure, and humidity can be from Equation 3.

$$V = \frac{\delta . V_s}{Kh} \quad (3)$$

To show how humidity and flashover are related, consider Equations (4) and (5), which state that humidity is inversely proportional to flashover, where kh is inversely proportional to v.

$$kh = \left(\frac{p}{760}\right) * \left(\frac{273+T}{273+20}\right) * \left(1 - \left(\frac{RH}{100}\right)\right) \quad (4)$$

P is the air pressure in millimeters of mercury (mmHg), T is the temperature in degrees °C and RH is the relative humidity in percent [22]

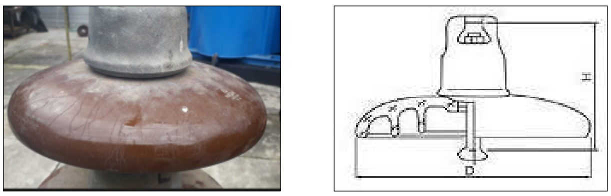
$$Vs = V_0 * \frac{Rh}{\delta} \quad (5)$$

Where V_0 is the actual test voltage and Rh is the humidity correction factor [22]

In this research, the type of insulator used for a test is a ceramic insulator, and its characteristics are illustrated in Table 1 and Figure 1.

Table 1. The insulator specifications

Insulator Code Material	11 Porcelain Suspension Insulator
BIL dalam Mega Volt	1.21
Inner Diameter (D) dalam Centimeter	25.4
Outer Diameter (D) dalam Centimeter	6.7
Unit Spacing (H) dalam Centimeter	14.6
Total Length dalam Meter	1.6 until 1.87



(a) (b)

Figure 1. Samples of ceramic insulator material (a) actual condition of the insulator (b) modeling of the ceramic insulator

The test required 14 pieces of insulators, seven of which were classified as dusty and seven mossy, to observe the differences between the characteristics and effects of dust and moss fouling on insulators.

By testing these two types of fouling, it is possible to identify the influence of temperature and humidity on the level of insulator pollution.

In this study, insulator fouling occurs naturally due to sediment that sticks on the insulator's surface during installation on the tower pole of the 150 kV overhead lines in Koto Panjang. Insulator fouling can be caused by dust, mud, and plants [6], [16], [22]. This contaminated insulator has been used for abaout 2-5 years.

The research step employed in this study is explained in Figure 2.

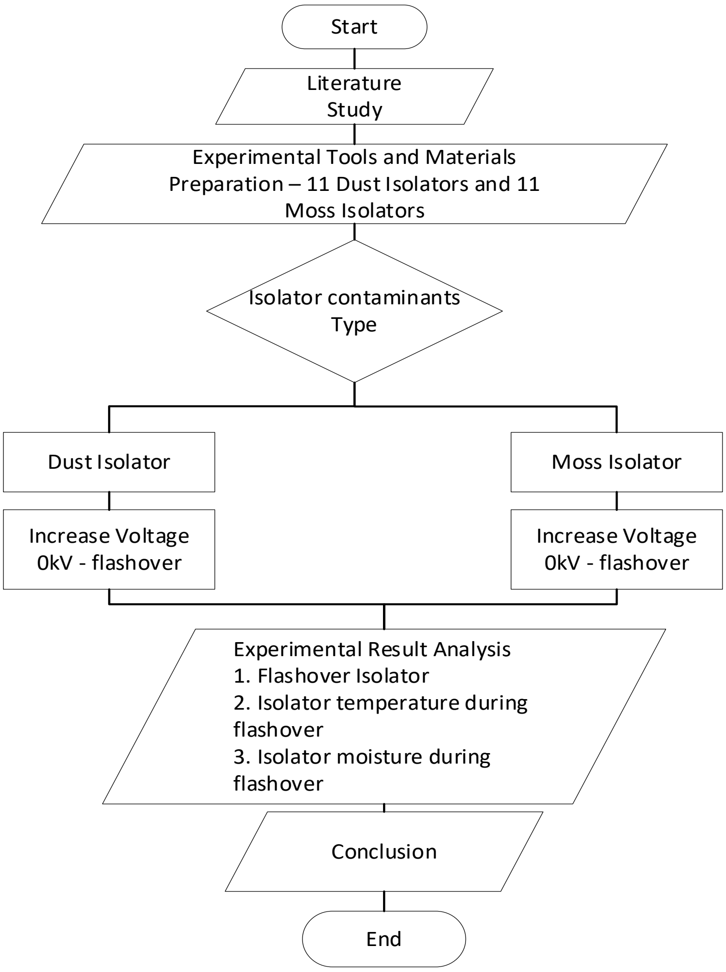


Figure 2. The isolator testing process

The instruments and materials used in the experiment consist of eleven insulators contaminated with dust and eleven insulators contaminated with moss. This study aims to compare dust fouling and moss fouling in terms of their characteristics and effects on insulators. The test is conducted by gradually increasing the voltage from 0 kV until the flashover occurs. Then, data acquisition and analysis were performed.

3. Results and Discussion

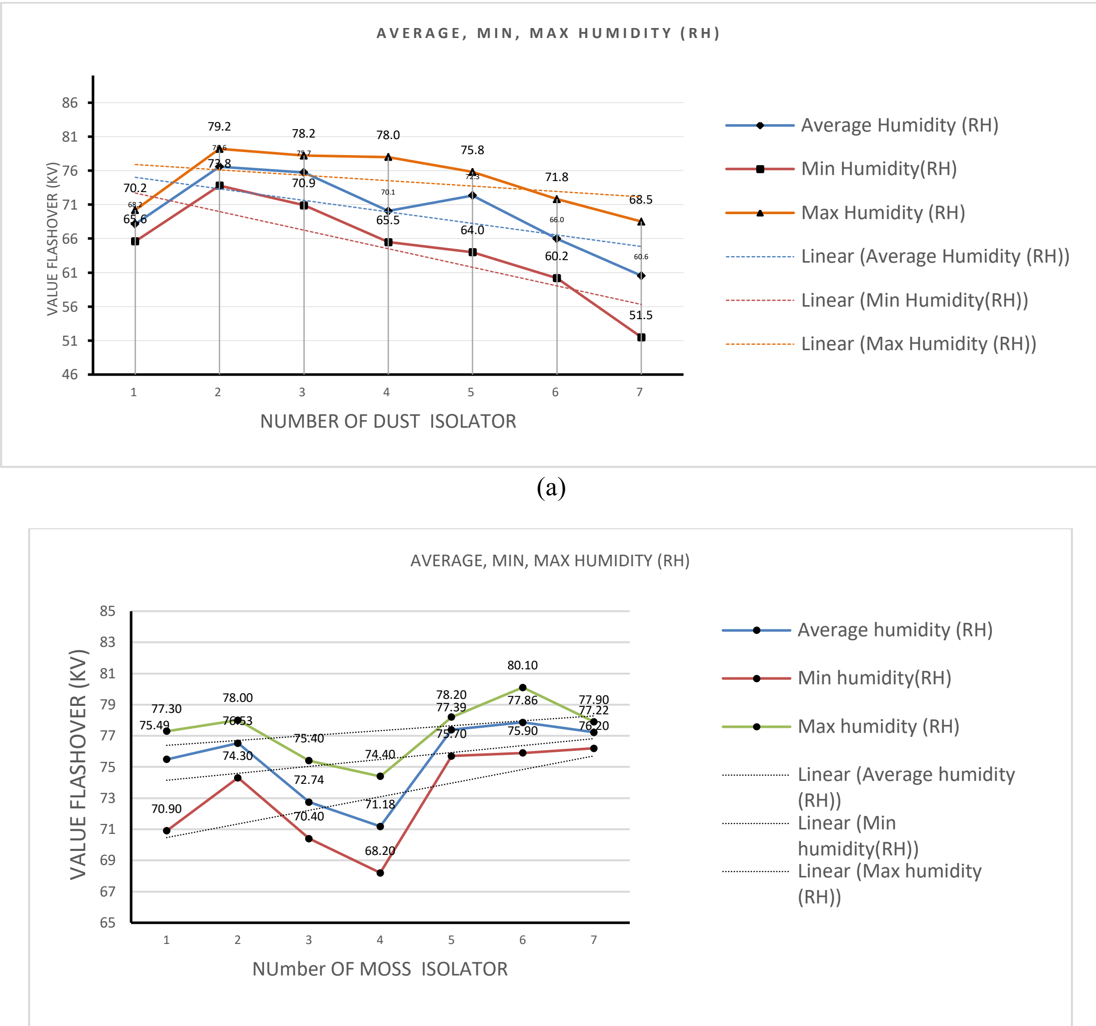
According to the test, it is possible to identify the insulator's dielectric strength level that affects its performance. Figure 3 depicts the implementation of the breakdown voltage test under two distinct circumstances when the insulator has been contaminated with moss and dust after being used for 2 to 5 years. In this test, there were several challenges, one of which was the limited capacity of the transformer equipment at a voltage of 400 kV. As a result, the flashover test can only be performed on a maximum of seven insulator plates. The process of insulator fouling occurs naturally as a result of sediment sticking on the insulator's surface. In contrast, insulators are installed on the tower pole of a 150 kV overhead transmission line in Koto Panjang [6], [16], [22].

Figure 3. Flashover test chain insulator circuit

The breakdown voltage test for plates 8 to 11 was carried out by analyzing trend values from the test results of the previous seven plates. This implies that the test results of the seven plates are used to evaluate the condition of other similar plates (plates 8 to 11). Thus, breakdown voltage testing is performed on several insulator plates that can be physically tested.

In contrast, other plates with similar characteristics are evaluated by analyzing trends based on previous plate test results. This method is widely employed in testing high-voltage insulators when equipment capacity is limited. It can help to monitor and analyze the reliability of these insulators during their use over a more extended period.

3.1. The Measurement of Dust and Moss Isolator Humidity



(a)

(b)

Figure 4. Humidity value based on number of isolators (a) dust isolator, (b) moss isolator

Figure 4 depicts the test results of seven dusty and mossy insulator plates. These insulators have been tested ten times to acquire data on the average, minimum, and maximum humidity values measured when flashover occurs on each insulator plate.

The graph in Figure 4 (a) shows the test results for variations of insulators with dust contamination. There is a decreasing linear trend in the change in humidity values on the dusty insulator plates. The results show that the highest humidity value occurred on insulator plate two, with 79.2 kV, while the lowest was on insulator plate seven, with 51.5 kV.

The first, third, fourth, fifth, and sixth insulator plates have humidity values of 68.2 kV, 75.7 kV, 70.1 kV, 72.3 kV, and 66 kV, respectively.

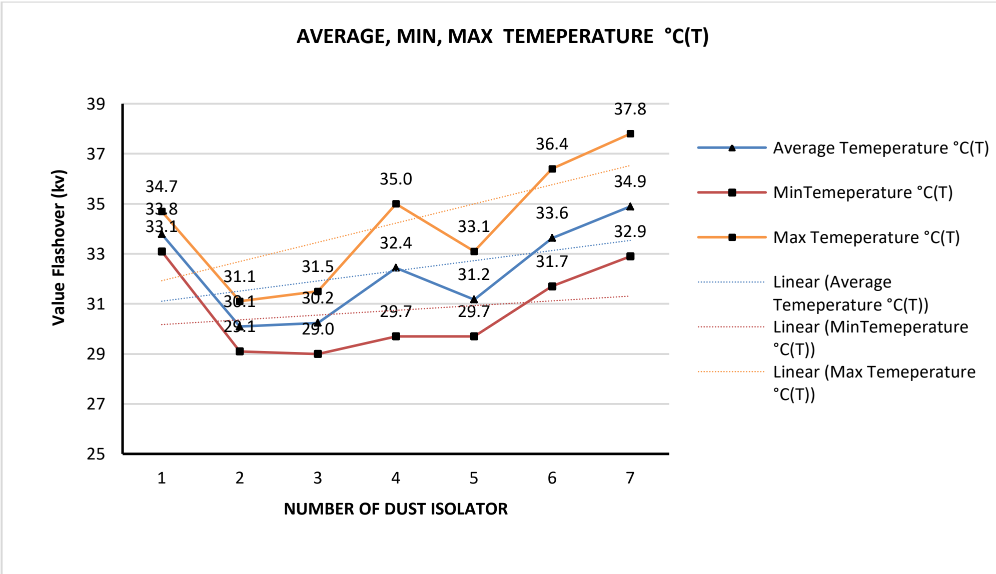
In the meantime, Figure 4 (b) shows the test findings for several moss-contaminated insulators. According to these results, insulator plate six has the maximum humidity value of 80.10 kV, while insulator plate four has the lowest humidity value of 68.20 kV. The humidity values for the first, second, third, fifth, and seventh insulator plates are 75.49 kV, 76.53 kV, 72.74 kV, 77.39 kV, and 77.22 kV, respectively.

The graph demonstrates that the change in humidity levels on the mossy insulator disk has an increasing linear trend.

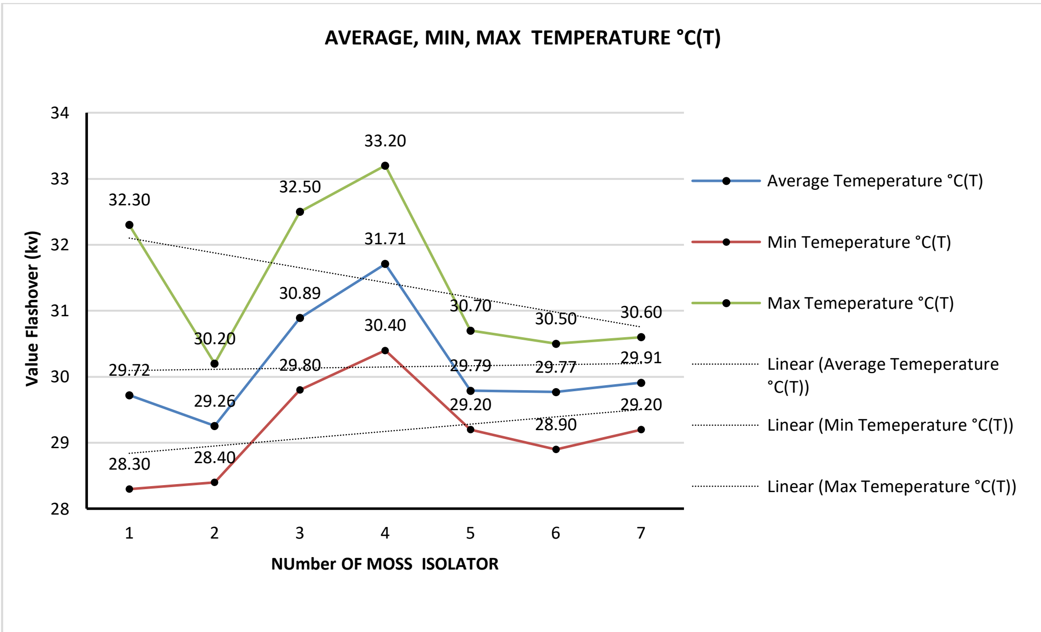
The test results indicate that dust contamination tends to reduce the humidity of the insulator, while moss contamination tends to increase it.

This information is essential for further analysis of the dielectric strength value of a fouled insulator and for isolator maintenance in managing contamination in order to maintain the reliability of the electric power system.

3.2. The Measurement of Dust and Moss Isolator Temperature



(a)



(b)

Figure 5. Temperature value based on number of isolators (a) dust isolator, (b) moss isolator

Figure 5 (a) illustrates the test results for variations of insulators with dust contamination. These results show that the highest temperature value occurs on the insulator plate seven when the voltage reaches 37.8 kV. At the same time, the lowest temperature value occurs on the insulator plate three when the voltage reaches 29.0 kV.

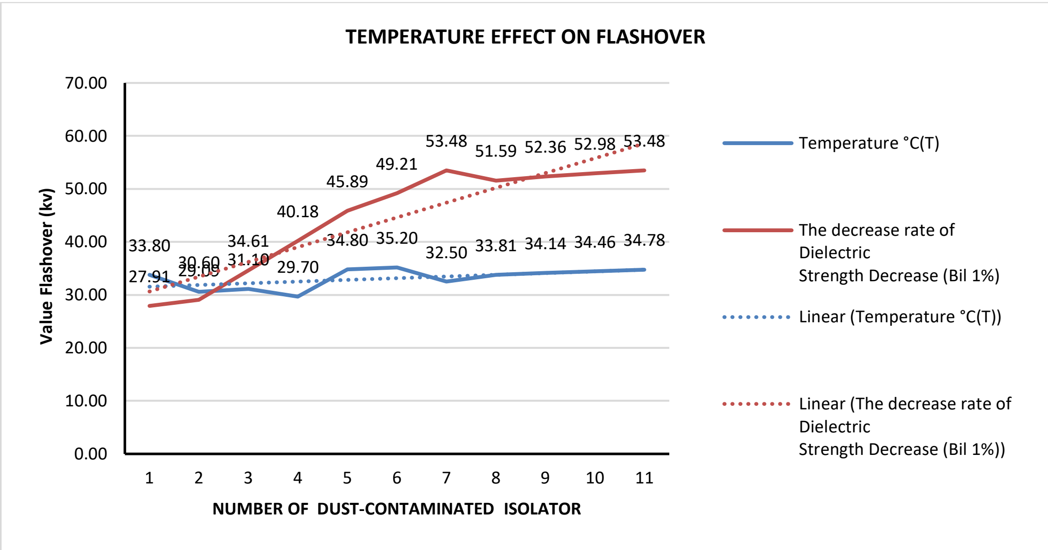
The first, second, fourth, fifth, and sixth insulator plate temperatures are 32.8 kV, 30.1 kV, 32.4 kV, 31.2 kV, and 33.06 kV, respectively. The graph shows a linear increasing trend in the temperature change of the dusty insulator plates as the voltage increases.

Meanwhile, Figure 5 (b) depicts the test results for variations of moss-contaminated insulators. These results show that the highest temperature value occurs on the insulator plate four when the voltage reaches 33.20 kV. At the same time, the lowest temperature value occurs on the insulator plate two when the voltage reaches 28.40 kV. The first, third, fifth, sixth, and seventh insulator plates have temperature values of 29.72 kV, 29.80 kV, 29.79 kV, 29.77 kV, and 29.91 kV, respectively.

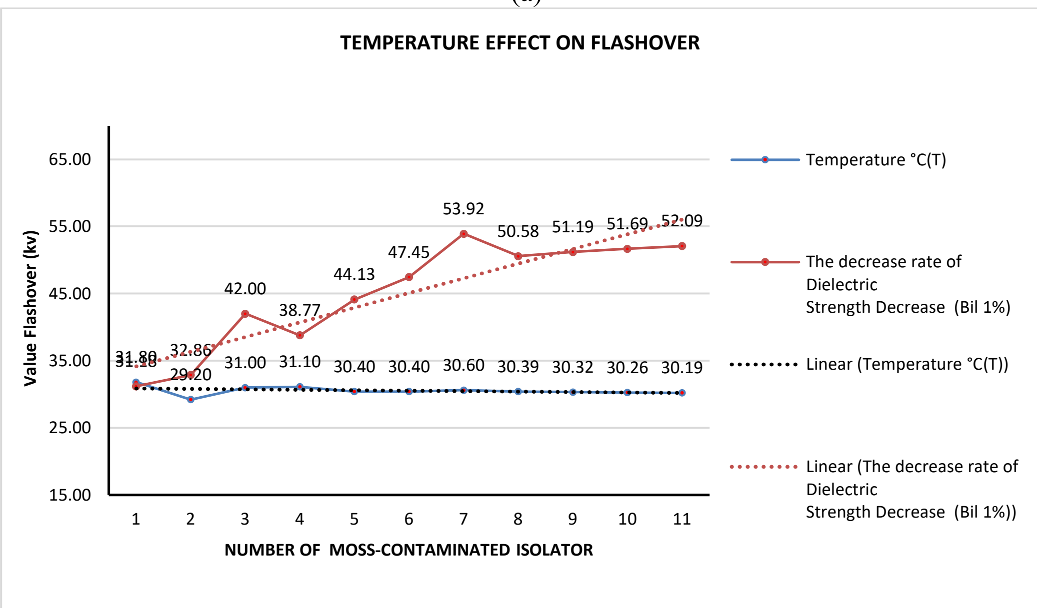
The graph also shows an upward linear trend in the change in temperature of the mossed insulator plates as the voltage increases.

According to the test results, the temperature value tends to increase linearly with increasing voltage for insulators contaminated with dust and moss. Higher ambient temperatures may increase the likelihood of flashover in high-voltage insulators.

3.3. The Measurement of the Effect of Temperature on the Flashover Voltage on Dust and Moss Insulators



(a)



(b)

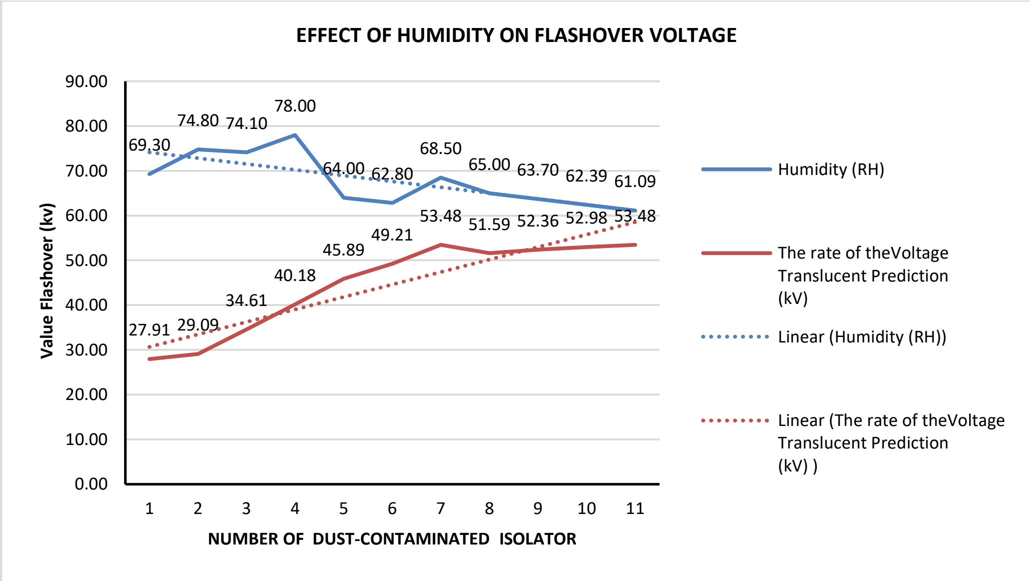
Figure 6. Temperature effect on flashover (a) dust-contaminated (b) moss-contaminated

The results of the two experiments revealed that insulators contaminated with moss significantly decreased dielectric strength compared to those contaminated with dust.

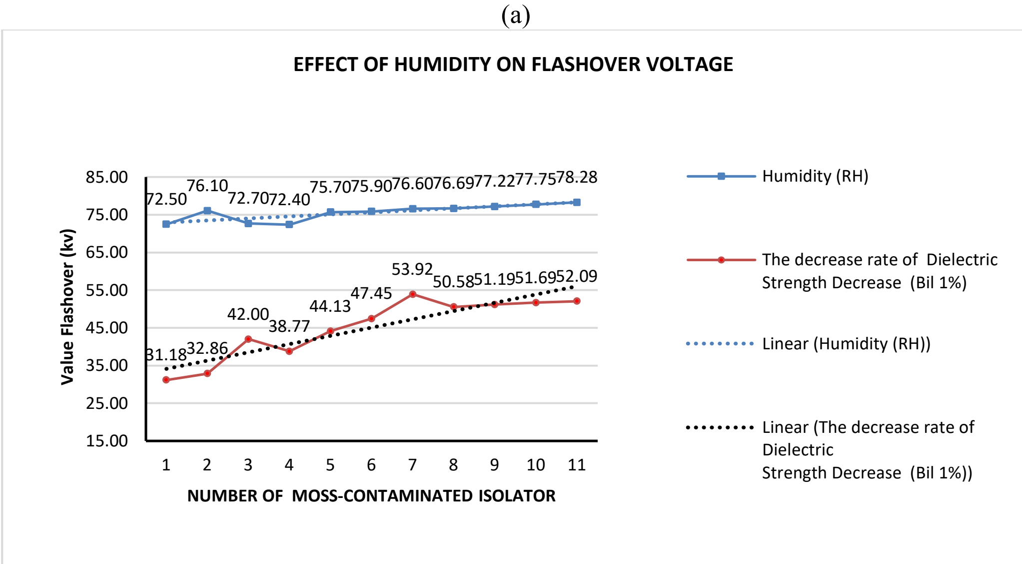
The possibility of a flashover can be observed in the experimental results, which show that flashover occurs on the seventh insulator plate at 53.48% and 53.92%, respectively, for the dust insulator and moss insulator.

The graphs (a) and (b) in Figure 6 show that the flashover voltage increases with increasing temperature. According to Equations (1) and (2), increasing the ambient temperature can make the air around the insulator more conductive, lowering the dielectric resistance and increasing the chance of flashover.

3.4. The Measurement of the Effect of Humidity on the Flashover Voltage of Dust and Moss Insulators



(a)



(b)

Figure 7. Effect of humidity on flashover voltage (a) dust-contaminated, (b) moss-contaminated

Compared to insulators contaminated with dust, insulators with moss demonstrated the most significant decrease in dielectric strength. The increased risk of flashover due to contamination conditions can be observed in the experimental results. Flashover occurred on the seventh insulator plate at 53.48 kV and 53.92 kV for the dusty and mossy insulators, respectively. However, not all experimental results adhere to the expected linear pattern. For instance, in the fourth plate insulator, contaminated with dust, the humidity value is 78.0, but the number of flashover events is only 40.18.

Some conditions defy current theory in the third and seventh-order dust contaminant isolators. This can be caused by environmental factors that cannot always be regulated or controlled during testing. Overall, the experimental results indicate that the higher the humidity value, the flashover value tends to increase. This is caused by excessive humidity on the insulator's surface, which can reduce the insulator's dielectric strength.

This factor has the potential to reduce the dependability of high-voltage insulators.

Figure 7 demonstrates that the higher the voltage, the lower the relative humidity value. According to Equation (3), humidity and tension have an inverse relationship.

In addition, as shown by Equation (4), the insulator flashover voltage during testing has an inverse relationship with humidity. Consequently, as humidity increases, the flashover voltage tends to decrease, indicating that high humidity can increase the risk of flashover in high-voltage insulators.

3.5. Experiment Breakdown Voltage Test on Dust and Mossy Insulator Base on Temperature and Humidity

The breakdown voltage test for dust and moss insulators was conducted to measure the ability of the insulator to maintain the stability of its electrical insulation in various environmental conditions, particularly temperature, and humidity, with the results shown in Tables 2 and 3 for dusty and mossy insulators, respectively.

Table 2. The breakdown voltage test on dust insulators based on temperature and humidity

Isolator plate	**BIL (kV)**	**The rate of voltage Translucent Prediction (kV)**	**The decreased rate of Dielectric Strength Decrease**	**BIL 1%**	**The decreased rate of Dielectric Strength Decrease (Bil 1%)**	**The decreased rate of Dielectric Strength Decrease (Bil 1%)**
1	110	79,30	30,70	1,1	72,09	27,91
2	220	156,00	64,00	2,2	70,91	29,09
3	330	215,80	114,20	3,3	65,39	34,61
4	440	263,20	176,80	4,4	59,82	40,18
5	550	297,60	252,40	5,5	54,11	45,89
6	660	335,20	324,80	6,6	50,79	49,21
7	770	358,20	411,80	7,7	46,52	53,48
8	880	426,03	453,97	8,8	48,41	51,59
9	990	471,63	518,37	9,9	47,64	52,36
10	1100	517,24	582,76	11	47,02	52,98
11	1210	562,84	647,16	12,1	46,52	53,48

Table 3. The breakdown voltage test on mossy insulators based on temperature and humidity

Isolator plate	BIL (kV)	The rate of voltage Translucent Prediction (kV)	The decreased rate of Dielectric Strength Decrease	BIL 1%	The decreased rate of Dielectric Strength Decrease (Bil 1%)	The decreased rate of Dielectric Strength Decrease (Bil 1%)
1	110	75,70	34,30	1,1	69	31,18
2	220	147,70	72,30	2,2	67	32,86
3	330	191,40	138,60	3,3	58	42,00
4	440	269,40	170,60	4,4	61	38,77
5	550	307,30	242,70	5,5	56	44,13
6	660	346,80	313,20	6,6	53	47,45
7	770	354,80	415,20	7,7	46	53,92
8	880	434,93	445,07	8,8	49	50,58
9	990	483,19	506,81	9,9	49	51,19
10	1100	531,46	568,54	11	48	51,69
11	1210	579,72	630,28	12,1	48	52,09

Figures 8 and 9 depict a comparison between the measurement of the breakdown voltage and the decrease in the dielectric strength of the insulator based on data provided in Tables 2 and 3.

The breakdown voltage test can only be conducted with seven insulator plates. In contrast, the subsequent insulator plate test employs trend analysis, the outcomes of which are depicted in Figures 8 and 9 below.

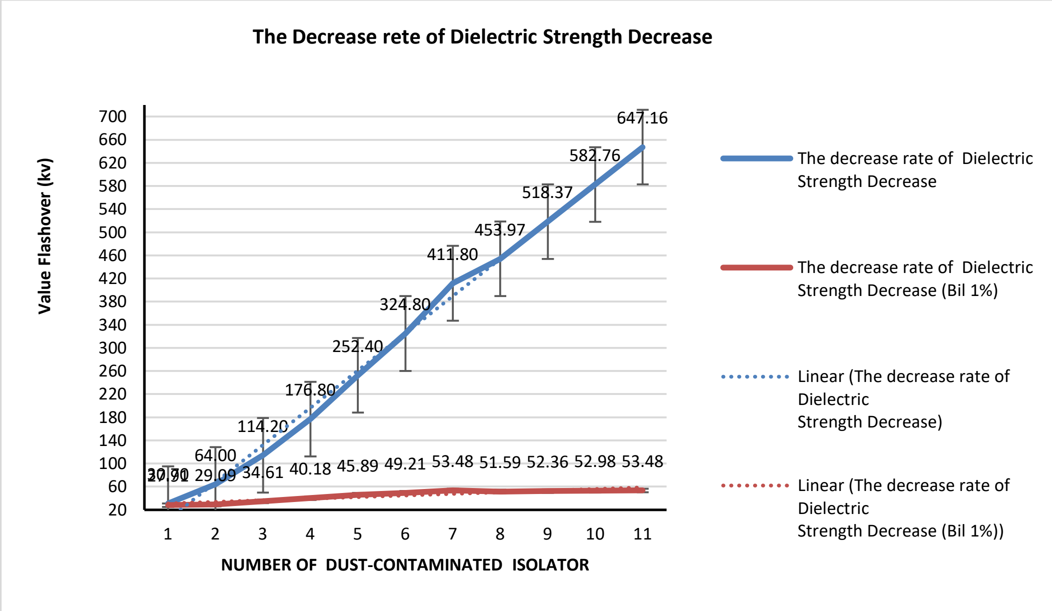


Figure 8. The decreased rate of dust-contaminated insulators' dielectric strength

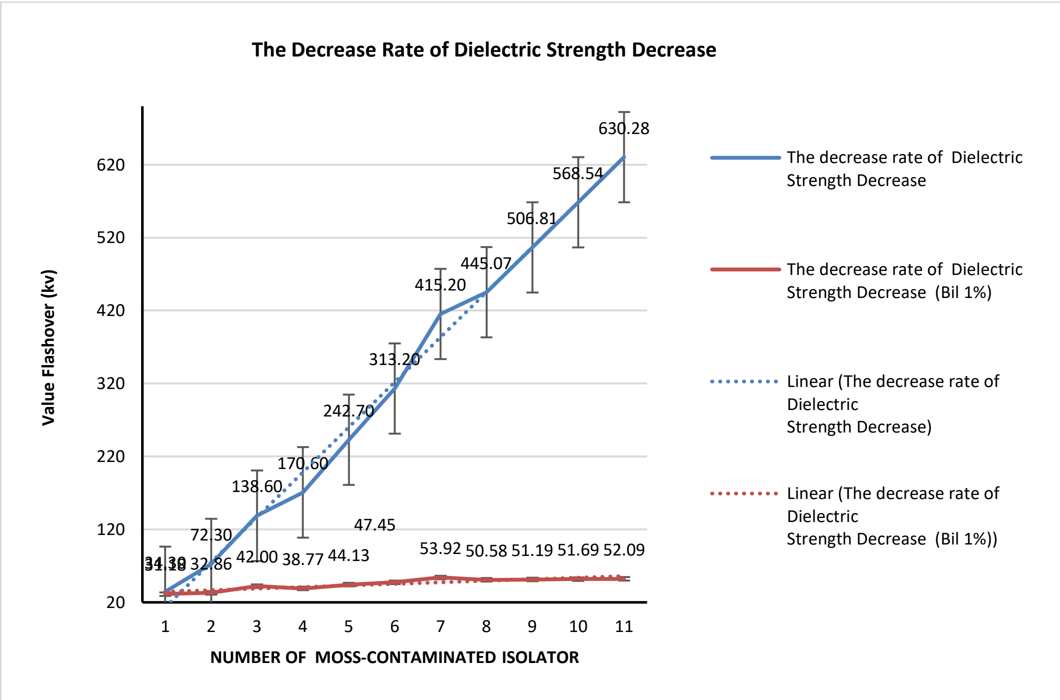


Figure 9. The decreased rate of moss-contaminated insulators' dielectric strength

Figures 8 and 9 indicate that the number of insulator plates tested influences the insulator's breakdown voltage and dielectric strength. The breakdown voltage value increases as the number of insulator plates tested increases. Similarly, the low dielectric strength is caused by the insulator circuit's 1210 kV BIL value. The average decrease in dielectric strength values for dusty insulators was 44.62 percent per insulator plate and 45.08 percent for mossy insulators.

4. Conclusion

Test results indicate that insulators contaminated with dust tend to have lower humidity than pure insulators, which can reduce insulator humidity. In contrast, moss-contaminated insulators tend to be more humid than spotless insulators, as moss contamination makes the insulator more humid.

Dusty and mossy insulators exhibit a linear trend in their variations of moisture content.

Dusty insulators typically experience a decrease in humidity, whereas mossy insulators typically experience an increase. The most significant decrease in dielectric strength occurred in insulators contaminated with moss, compared to insulators contaminated with dust. Moss contamination has a more significant impact on reducing dielectric strength.

An increased risk of flashover due to contamination conditions can be observed in the experimental results. Flashover occurs at lower voltages in insulators contaminated with dust and moss. Early flashover can be triggered by contamination during isolator operation. However, there is a general trend that the higher the relative humidity, the lower the flashover value; not all experimental results adhere to the expected linear pattern. Field-specific environmental factors can influence test results.

Meanwhile, the temperature value increases linearly for both insulators contaminated with dust and moss, along with increasing voltage. Compared to insulators with dust, those contaminated with moss experienced the most considerable decrease in dielectric strength. This suggests that a rise in ambient temperature can make the air surrounding an insulator more conductive, decreasing dielectric resistance and increasing the risk of flashover. The average decrease in dielectric strength values for dusty insulators is 44.62 percent per insulator plate and 45.08 percent for mossy insulators.

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