



The Electrical Characteristics of Medium Voltage Insulators Against Contaminants at Coastal Area

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Abstract: Insulators have an important role in an electrical distribution line. They have a role as a mechanical support and on electrical insulation that isolate the live line and dead part of the electrical poles. Environmental factors will affect the performance of the insulator. Every area where the insulator was installed has a unique characteristics, therefore the electrical characteristics of each insulator will be differ from an area to others area. This study investigated the electrical characteristics of the 20 kV insulator for some feeder that representing all regions in coastal area. Coastal area has four types of areas, namely industrial, household, city, and rural areas. The leakage current of sample of these four area were measured and the Non-Soluble Deposit Density (NSDD) of each sample were also measured. The results show that the industrial area had the highest leakage current value of 1.22 mA while the lowest leakage current was observed in the household area of 0.44 mA. These were also confirmed that the industrial area had the highest NSDD value of 0.2412 mg/cm² and the lowest NSDD in household areas of 0.0228 mg/cm² were observed. Moreover, it was also observed that the highest flashover voltages and insulation resistance were in rural areas of about 53.4 kV and 261.33 GΩ, respectively and the lowest flashovers were in household areas of about 39.34 kV and 118.83 GΩ, respectively.

Keywords: Leakage current, flashover voltage, insulation resistance, NSDD, coastal area

1. Introduction

Every medium voltage network support pole must have an insulator following the standard pole construction. Insulators are one of the electric power system components that functions to isolate the conductors of the voltage network from supporting poles or towers [1]. Insulators located outside the room (outdoor) will be susceptible to various pollutants ranging from industrial dust, salt, motor vehicle fumes and rainwater [2]. Pollutants attached to the insulator surface will affect the performance of the insulator. The low hydrophobic ability of an insulator will make it more susceptible to being attached to pollutants. Over time, the adhering contaminants will form a pollutant layer that can conduct electricity. It will reduce the insulation resistance ability of the insulator, and one day, it will flashover until the worst possibility is that the insulator will break or be damaged [3]. Types of porcelain (ceramic) insulators are widely used in transmission and distribution systems. Recently, polymer insulators are recommended because of their high insulating strength and lightweight compared to porcelain insulators [4].

There are many large industries in the coastal area, so that one of the contaminants attached to the insulators is industrial pollution. With the various existing industries, the types of pollutants attached need further investigation. Some contaminants are low in water-soluble, and some pollutants are high in water-soluble. Examples of contaminants that are low in water-soluble are bassanite (2CaSO₄·H₂O) and those that are high in water-soluble are Salt (NaCl) [5]. Besides, the industry can also cause acid rain, which will negatively impact components exposed to acid rain, one of which is the

insulation. Acid rain will cause the surface of the insulator to become hard and eroded so that the hydrophobic ability of the insulator will decrease. As a result, the insulator will flashover easily, and the leakage current will be higher [6].

With a wide variety of contaminants in the coastal area, it is necessary to study the electrical characteristics of the insulator based on the type of contaminants with samples taken directly from feeders in the coastal area. Therefore, a study was conducted on the electrical characteristics of the 20 kV insulator for each feeder that representing all areas in the coastal area. The insulator will be tested at the high voltage laboratory of the ITS Electrical Engineering Department to determine the characteristics of the insulator. The tests to be carried out include testing the leakage current, flashover voltage, and insulation resistance. The leakage current test will be carried out by stressed voltage at different levels and It will result in a different value of leakage current.

Meanwhile, the flashover voltage test will be carried out by continuously applying voltage and increasing until the insulator flashes over. At that voltage level, data can be used to determine its characteristics [7]. Through the analysis of the insulators, a better attitude can be carried out in terms of insulator maintenance, such as washing the insulators when in industrial areas experiencing rain which is likely to be acid rain. Besides, if the insulator is installed in an area that is hot enough, it can be recommended that silicone insulator because of its high hydrophilic ability [8].

2. Methodology

2.1 Insulator Sample Classification

The first method that needs to be done is to classify the insulator samples that have been collected. Insulator samples collected are the result of an operation or used in the electric power distribution network. The distribution network has rating of 20 kV Voltage. Before testing the insulator, each insulator sample needs to be classified first. The classification is based on a literature study. All samples of insulators collected representing 15 feeders were classified based on the types of areas, including feeders in industrial areas that have FI1 to FI5, feeders in household areas have FR1 to FR3, feeders in city areas have FP1 to FP4, and feeders in rural areas have FD1 to FD3.

2.2 Leakage Current Testing

In the leakage current test, the insulator will be given various high-voltage AC variations. Voltage variations include 5 kV, 10 kV, 15 kV, 20 kV, and 25 kV. Before testing, the grounding wire must be connected to the crimped end fitting. Then, the CT 50/5 grounding cable is installed so that the current passing through the cable in the sense that the leakage current can be detected. A multimeter is installed to read currents of milli amperes of the leakage current. The leakage current test circuit model is shown in Figure 1.

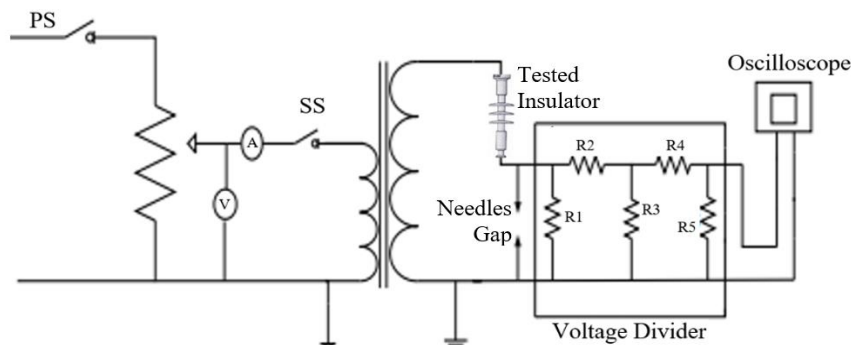


Fig. 1 - Leakage current testing circuit

2.3 Flashover Voltage Testing

The flashover voltage test was carried out using the American Standard Test Method, ASTM-D149, with the most common method, namely the Short Time Test [9]. The working principle of the method is that the insulator is tested for dielectric strength until it reaches the maximum limit of breakdown by increasing the high voltage AC gradually and slowly from 0 kV. A sign that the insulator has broken through is an electric arc that is generally accompanied by a popping sound. Figure 2 shows the flashover voltage test model.

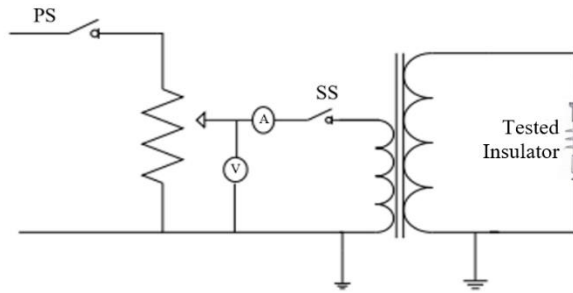


Fig. 2 - Flashover voltage testing circuit

2.4 Insulation Resistance Testing

Insulation resistance testing of the insulator using direct voltage generation (DC) or generally using a tool called Megger (Mega Ohm Meter). The current will flow on the surface and inside of the insulator when a high DC voltage is applied. The current flowing through the insulator surface is called the surface current, while the current flowing through the insulator inside is called the volume current. The working principle of this megger is the same as an ordinary ohmmeter, but the voltage given is much greater with a capacity of tens of kilovolts.

2.5 Non Soluble Deposit Density (NSDD) Value Calculation

NSDD is the amount of non-soluble residue remove from a given surface of the insulator divided by the area of this surface. NSDD is normally used to measure the severity of site pollution severity.

The NSDD (Non-Soluble Deposit Density) method is a method that aims to calculate the level of pollutants that do not contain salt content and are insoluble in water, for example, motor vehicle fumes, factory fumes, cement dust. The surface area of the porcelain insulator is 2197.8 cm². Equation 1 describes the equation for the NSDD method.

$$NSDD = \frac{m_1 - m_2}{A} \text{ (mg/cm}^2\text{)} \quad (1)$$

where:

- m₁ = filter paper mass before filtering (mg)
- m₂ = filter paper mass after filtering (mg)
- A = insulator surface area (cm²)

3. Results and Discussion

3.1 Leakage Current Testing

Table 1 to 5 are the leakage current test results based on the type of area.

Table 1 - Leakage current test result base on industrial area supplier

FI1		FI3		FI5	
Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)
4,99	0,10	5,05	0,10	5,05	0,10
10,11	0,23	10,11	0,28	10,03	0,25
15,02	0,46	15,00	0,51	15,13	0,55
20,17	0,79	20,23	0,86	20,06	0,94
24,96	1,06	25,05	1,21	25,02	1,35

Table 2 - (Continuation). Leakage current test result base on industrial area supplier

FI2		FI4	
Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)
5,09	0,08	5,03	0,13
10,15	0,15	10,17	0,24
15,06	0,31	15,10	0,50

20,04	0,53	20,19	0,87
25	Flashover	25	1,24

Table 3 - Leakage current test result base on household area supplier

FR1		FR2		FR3	
Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)
5,21	0,08	5,04	0,07	5,11	0,10
10,10	0,09	10,07	0,11	10,09	0,13
15,15	0,19	15,02	0,17	15,08	0,23
20,09	0,32	20,05	0,25	20,10	0,36
25,16	0,48	25,08	0,32	25,12	0,53

Table 4 - Leakage current test result base on city supplier

FP1		FP2		FP3		FP4	
Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)
5,03	0,13	5,03	0,09	5,03	0,15	5,08	0,11
10,07	0,19	10,04	0,13	10,16	0,23	10,02	0,16
15,00	0,29	15,08	0,21	15,02	0,34	15,11	0,29
20,05	0,43	20,09	0,30	20,17	0,50	20,12	0,44
25,10	0,57	25,19	0,38	25,17	0,66	25,16	0,57

Table 5 - Leakage current test result base on rural supplier

FD1		FD2		FD3	
Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)	Voltage (kV)	Leakage Current (mA)
5,00	0,13	5,05	0,21	5,09	0,09
10,05	0,17	10,08	0,29	10,12	0,13
15,06	0,27	15,01	0,47	15,08	0,23
20,18	0,39	20,01	0,68	20,10	0,36
25,01	0,47	25,02	0,87	25,14	0,50

After analyzing each area, a conclusion can be drawn regarding the ratio of leakage currents between areas. Based on the average value of the leakage current, the industrial area has the highest leakage current level, while the household area has the lowest leakage current level. Table 6 and Figure 3 shows a table and a graph for ranking the leakage currents from highest to lowest.

Table 6 - Leakage current each area

Rank	Area	Leakage Current Average Value (mA)
1	Industrial	1,22
2	Rural	0,61
3	City	0,55
4	Household	0,44

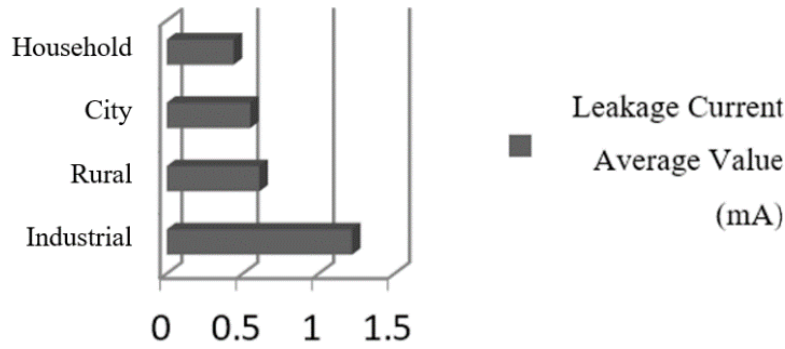


Fig. 3 - Leakage current value graph for all areas

3.2 Flashover Voltage Testing

The AC high-voltage generation circuit at the High Voltage Laboratory of the Electrical Engineering Department of FTE ITS can only be applied at 100 kV. This limitation is in accordance with the rating and capacity of the test transformer to avoid damage to the equipment. Table 7 to 10 show the results of the flashover voltage test based on the type of area:

Table 7 - Flashover voltage test result in industrial supplier

Supplier	Flashover Voltage (kV)
FI1	56,04
FI3	57
FI5	52
FI2	24,42
FI4	25,91

Table 8 - Flashover voltage test result in household supplier

Supplier	Flashover Voltage (kV)
FR1	39
FR2	38
FR3	41,03

Table 9 - Flashover voltage test result in city supplier

Supplier	Flashover Voltage (kV)
FP1	40
FP2	60
FP3	48
FP4	58

Table 10 - Flashover voltage test result in rural supplier

Supplier	Flashover Voltage (kV)
FD1	64
FD2	44
FD3	52,19

Based on the average flashover voltage value, rural area is an area with the highest flashover voltage levels while household areas have the lowest flashover voltage levels. Table 11 and Figure 4 show flashover voltage rating from highest to lowest:

Table 11 - Flashover voltage each area

Rank	Area	Flashover Voltage Average Value (kV)
1	Rural	53,40
2	City	51,50
3	Industrial	43,07
4	Household	39,34

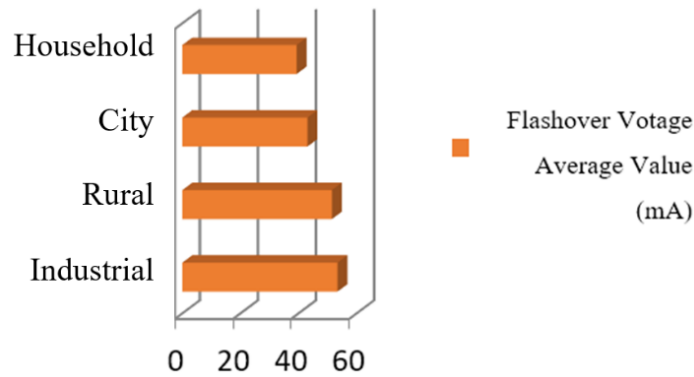


Fig. 4 - Flashover voltage value graph for all areas

3.3 Isolation Resistance Testing

In the insulation resistance test, the applied voltage is 5000 VDC and waited for 1 minute. This procedure is in accordance with the IEEE 43 year 2000 standard, where for equipment with an operating voltage of more than 12000 volts, a DC voltage of 5000 volts is applied [10]. Table 12 to 15 are the results of the insulation resistance test based on the type of area:

Table 12 - Industrial supplier insulation resistance test result

Supplier	Insulation Resistance (GΩ)		
	15 s	30 s	60 s
FD1	201	254	266
FD3	30,5	36,7	36,9
FD5	37,7	48,1	52,5
FD2	168	176	199
FD4	367	456	468

Table 13 - Household supplier insulation resistance test result

Supplier	Insulation Resistance (GΩ)		
	15 s	30 s	60 s
FR1	20,8	22,4	23,4
FR2	141	200	285
FR3	33	47,2	48,1

Table 14 - City supplier insulation resistance test result

Supplier	Insulation Resistance (GΩ)		
	15 s	30 s	60 s
FP1	120	170	217
FP2	64	70,9	82,7
FP3	67,4	71,6	85,4
FP3	84,1	87	106

Table 15 - Rural supplier insulation resistance test result

Supplier	Insulation Resistance (GΩ)		
	15 s	30 s	60 s
FD1	113	128	131
FD2	192	300	448
FD3	183	191	205

Based on the average value of isolation resistance, rural areas have the highest level of the isolation resistance, while household areas have the lowest level of isolation resistance. Table 16 and Figure 5 show the flashover voltage rating from highest to lowest.

Table 16 - Insulation resistance each area

Rank	Area	Insulation Resistance Average Value (GΩ)
ss1	Rural	261,33
2	Industrial	204,48
3	City	122,78
4	Household	118,83

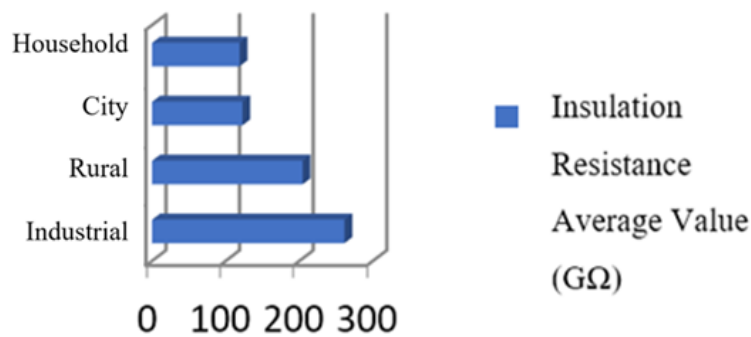


Fig. 5 - Insulation resistance value graph for all areas

3.4 NSDD Value Calculation

NSDD calculations were carried out using a plain white cotton cloth used as a filter media for insulating pollutants. Before filtering out pollutants, cotton cloth is weighed using digital scales. Each area is sampled from an insulator, and then the NSDD value is calculated using equation 1. Table 17 is the result of the NSDD calculation for the entire coastal area.

Table 17 - NSDD value calculation

Area	Leakage Current (mA)	NSDD (mg/cm ²)	pollutant category
Industrial	1,35	0,2412	Mid
City	0,66	0,0810	Slight
Rural	0,47	0,0648	Slight
Household	0,32	0,0228	Slight

3.5 Overall Scale Comparison

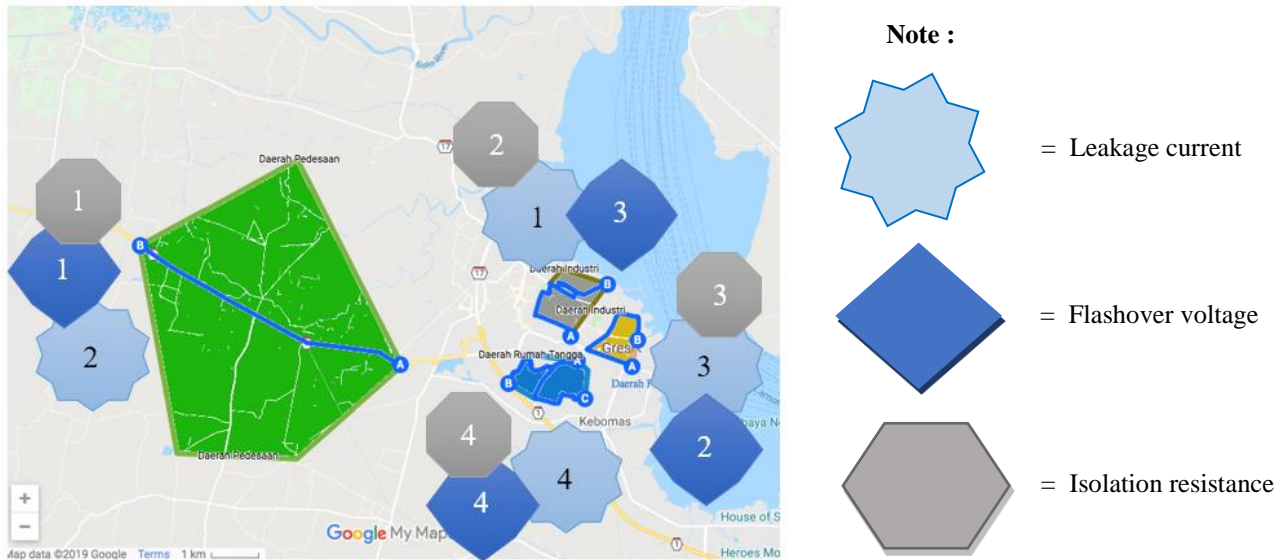


Fig. 6 - Coastal area map with area rank number

In Figure 6, the industrial area is ranked first in the leakage current test. This is due to its geographical location which is close to the coast, so it is possible to be exposed to sea breezes. Besides, industrial pollutants also significantly affect the leakage current. For the flashover voltage, the industrial area is ranked 3rd where the average value of the flashover voltage is small. This is because the pollutants that stick to it come from the industry itself and the sea breeze. The insulation resistance of industrial areas is in the 2nd place of 204.48 GΩ. This means that the dielectric strength of the industrial area insulator is good and the porcelain material is strong. The city area is ranked 3rd in the leakage current test with a value of 0.55 mA. For flashover voltage city area is ranked 2nd where the average value of the flashover voltage is quite large, with a value of 51.5 kV. The insulation resistance of the industrial area is in the 3rd place of 122.78 GΩ. Rural area is ranked 2nd in the leakage current test with a value of 0.61 mA. For flashover voltage, rural area is ranked 1st where the average value of the flashover voltage is large, with a value of 53.4 kV. This is because of the pollutants that stick only from dust, not from industry or sea breezes. The isolation resistance of rural area is ranked 1st at 261.33 GΩ. This means that the dielectric strength of the rural insulator is good and the porcelain material is strong. The household area is ranked 4th in the test for leakage current, flashover voltage and insulation resistance with values of 0.44 mA, 39.34 kV, and 118.83 GΩ, respectively.

5. Conclusion

Based on the experiments and tests result carried out, the conclusions that can be taken are as follows. Firstly, the higher the voltage applied to the insulator, the leakage current value will increase. This means that the conductivity in industrial area is greater than in other areas. In NSDD, the higher the NSDD value in the insulator, the more the leakage current value will increase, which in industrial areas has a higher level of conductivity than in other areas. The order of the highest to lowest NSDD values is the same as the order of the leakage current values. In addition, industrial areas have the highest NSDD value, so they are categorized as moderate pollutants, while other areas are classified as low pollutants.

The highest flashover voltage and insulation resistance are in the rural area insulator, while the lowest flashover voltage is in the household area. However, after the experiments, the sequence is different from the leakage current. Apart from being influenced by the leakage current, the flashover voltage is also influenced by other things such as the dielectric strength of the insulator, the porcelain material used by each manufacturer is different.

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