บทความวิจัย

การศึกษาเปรียบเทียบคุณสมบัติทางไฟฟ้ากระแสสลับของลูกถ้วยพอร์ซเลนกับอนุภาคฝุ่นซีเมนต์และเกาลินที่เคลือบผิว

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บทคัดย่อ

ในช่วงเวลาหลายปีที่ผ่านมาจนถึงปัจจุบันหลายพื้นที่ในประเทศไทยได้รับผลกระทบจากปริมาณฝุ่นที่มากขึ้น ปริมาณฝุ่นในอากาศที่เพิ่มขึ้นรวมถึงความรุนแรงของสภาพอากาศที่มีอนุภาคแขวนลอยปะปนอยู่เป็นหนึ่งสาเหตุที่ทำให้ฉนวนลูกถ้วยไฟฟ้ามีการนำไฟฟ้าที่สูงขึ้น บทความวิจัยนี้ได้นำเสนอการเปรียบเทียบคุณลักษณะของลูกถ้วยไฟฟ้าที่ถูกเคลือบผิวโดยซีเมนต์และเกาลิน ซึ่งตัวอย่างซีเมนต์ที่นำมาทดสอบกับลูกถ้วยนั้นได้มาจากเขตอุตสาหกรรมผลิตปูนซีเมนต์ จังหวัดสระบุรี ประเทศไทย จากนั้นได้ทำการทดสอบการเปรอะเปื้อนบนผิวโดยใช้ลูกถ้วยพอร์ซเลนเบอร์ 52-1 จากการทดสอบพบว่า แรงดันวาบไฟของฉนวนลูกถ้วยที่อนุภาคฝุ่นซีเมนต์เกาะบนผิวนั้นสูงกว่ากรณีของเกาลิน ในขณะที่กระแสรั่วไหลบนผิวฉนวนลูกถ้วยที่อนุภาคซีเมนต์เกาะบนผิวนั้นมีค่าต่ำกว่ากรณีของเกาลิน ส่วนการเปรียบเทียบหยดน้ำที่ปกคลุมบนผิวลูกถ้วยโดยใช้วิธีการตามมาตรฐานโดยการสเปรย์น้ำสามารถบ่งชี้ได้ว่าลูกถ้วยฉนวนที่ผิวปกคลุมด้วยเกาลินนั้นมีคุณสมบัติของน้ำที่เกาะบนผิวที่ดีกว่ากรณีของซีเมนต์เนื่องจากเกาลินนั้น สามารถละลายน้ำได้ดีและมีขนาดอนุภาคที่เล็กกว่าซีเมนต์

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Research Article

A Comparative Study of AC Porcelain Insulators Characteristics with Cement Dust Particles and Kaolin Surface Coatings

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Abstract

In recent years, the area with high quantity of dust in Thailand has attracted increasing attention in the field of electrical insulator. High dust quantity in air is an extreme weather condition with high concentrations of suspended particulate matter. This can lead to high conductivity on insulator. This paper was to compare the insulator characteristics with cement dust and kaolin coatings. The cement dust was obtained from cement manufacturing industrial area at Saraburi province in Thailand. Simulated contamination tests were then conducted using porcelain insulators class 52-1. The test found that the flashover voltage of the insulators trapped with dust particles was higher than that of insulators trapped with kaolin while the leakage current of the insulator trapped with dust particles was lower. The hydrophobic of the insulators was stated using water droplet on the insulators surface. This indicated that the insulators trapped with kaolin had better hydrophobic characteristic that those trapped with dust particles. This may be due to better solubility of kaolin and smaller sizes in particles.

Keywords: Cement Dust Particles, Kaolin, Flashover Voltage, Leakage Current

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1. Introduction

The concentration of particulate matter (PM) is a key air quality indicator since it is the most common air pollutant that affects short-term and long-term health. Two sizes of particulate matter are used to analyze air quality; fine particles with a diameter of less than 2.5 μm or PM2.5 and coarse particles with a diameter of less than 10 μm or PM10. PM2.5 particles are more concerning. The insulator is the main equipment in power systems that do not conduct electricity and responsible for tolerating conductor weight. Pollution introduces contaminant into the environment to cause undesired changes in the insulator. More recently, new problems related to insulators degradation and failure. In many parts of the world, insulator contamination has become a major impediment to the uninterrupted supply of electrical power. On glass and porcelain insulators, which are used throughout the world, wet atmospheric conditions give rise to water filming and in presence of contamination, an uncontrolled leakage current develops and results in flashover. Air pollution in provincial areas is caused by various sources such as the emissions from vehicles, factories, construction sites and open burnings. Different measures were taken for different sources of pollution in urban, industrial and agricultural areas [1], [2].

The most polluted area from Particulate Matters (PM10) of Thailand is at Na Phra Lan Sub-district, Saraburi Province. This area is located in the central region where it is home to the cement manufacturing complex of the country. Due to the problem of very high concentration of PM10, this area had been designated as “the Pollution Control Zone”. Since 2004, Thai government has set up specific action plans as well as budgets to combat with this problem. This cement pollution was contributed from activities related to cement manufacturing processes [3].

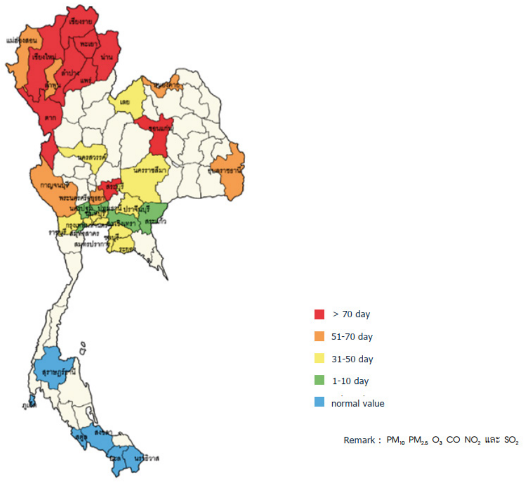

Figure 1: Map of average particulate dust matter (PM10) distribution in Thailand [3].

Figure 1 is the map of average particulate dust matter (PM10) distribution in Thailand. The red dots indicate the quantity of dust particles which exceed 50 μg/cm^3. In this paper, the dust particles is obtained from Saraburi, one of the area with red dot, which has high dust particle level from cement manufacturing. The level of dust particles in Saraburi from 2011 to 2020 is shown in Figure 2. It shows that the average value of dust particles in Saraburi is much higher than that of accepted value (dotted line).

With the above information about dust particles in Saraburi is show in Figure 3, this paper compared the effect of dust particles and kaolin trapped on insulator surface through the value of flashover voltage and leakage current. Also, the hydrophobic characteristics were tested using water

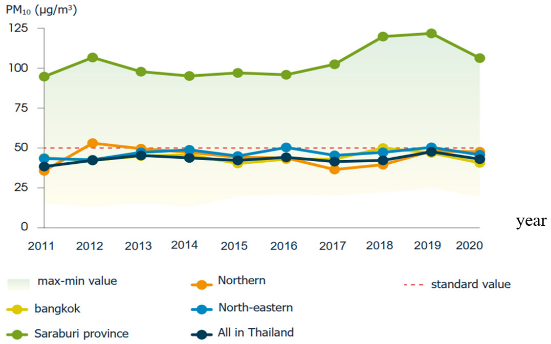

Figure 2: Dust particle (PM10) in Saraburi [4].

Figure 4: Insulator installation in pollution area.

Figure 3: Cement dust particles in factory area.

Figure 5: Test insulator [5].

droplet on the insulator surface. The Kaolin appears as odorless white to yellowish or grayish powder and contains mainly the clay mineral kaolinite. In its natural state kaolin is a white, soft powder consisting principally of the mineral kaolinite, and varying amounts of other minerals such as muscovite, quartz, feldspar, and anatase. The insulators used in this work are widely used for Provincial Electricity Authority (PEA) as show in Figures 4 and 5.

2. Materials and Methods

2.1 Samples

The test samples were porcelain suspension insulators type 52-1. The dimension is shown in Table 1 and Figure 6, in which H is the configuration height,

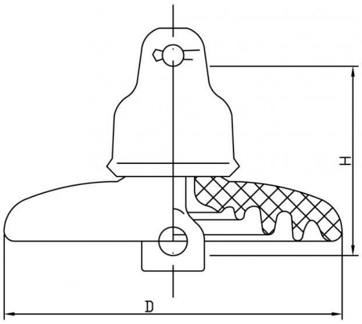

Figure 6: Structure of the test sample.

L is the leakage distance and D is the diameter of insulators.

Table 1: Parameter of the insulator

Suspension Types	Material	Parameters (mm)		
		H	D	L
52-1	Porcelain	140	160	178

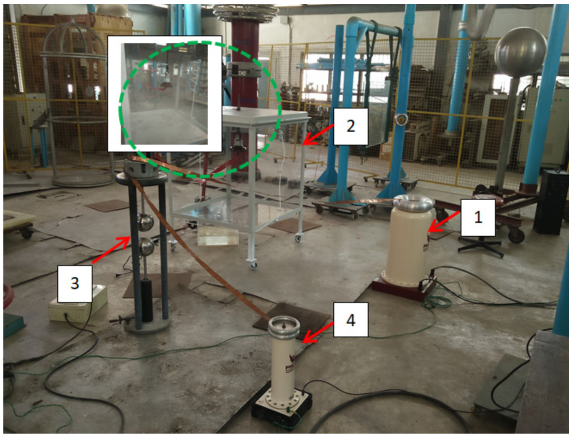

Figure 7: AC Pollution test circuit: 1. Test transformer 2. Chamber test 3. Protection gap 4. Voltage divider.

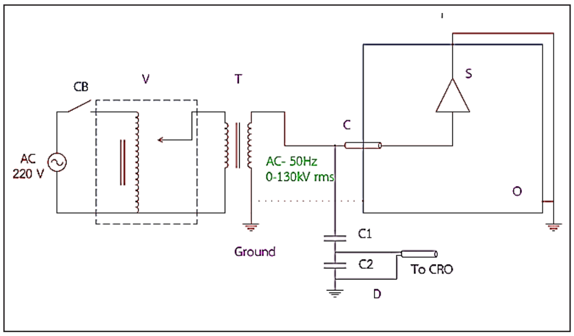

Figure 8: Equivalent test circuit.

2.2 Test set up

From Figure 7 the tests were carried out in the multi-function artificial climate chamber (No.2). The artificial climate chamber, with a size of 1.5 m^3, can simulate fog conditions. The power was supplied by a 130 kV/50 kVA pollution test transformer, of which the maximum frequency is 50 Hz was built in the High Voltage Laboratory, it can meet the requirement of pollution flashover test.

The actual circuit were tested by simulating the contamination conditions to be close to the actual weather conditions of the insulators installed in the closed system test room with a size of 1.5 m^3 as shown in number 2. The electricity supply from alternating current transformers shown as number 1, high-voltage protective cap shown as number 3 and the number 4 is a voltage divider are shown in Figure 7.

The test circuit was shown in Figure 8, where V is the voltage regulator, T is the test transformer (input voltage 0–220 V, output voltage 0–130 kV, rated capacity 50 kVA), C is the wall high voltage connector, D is the capacitive voltage divider (ratio 10000:1), O is the chamber and S is the insulator.

2.3 Experiment Process

Before the tests, all the samples were carefully cleaned by deionized water solution so that all traces of dirt was removed. The samples were let to dry naturally indoor to avoid dust or other pollution, and the relative humidity surround was 60–70%, temperature 32–35 °C and atmospheric pressure 750–760 mmHg.

There are 3 main experiments: leakage current, flashover voltage and hydrophobicity tests. The test condition is concluded in Tables 2-4. In all tests, the clean insulator is defined as the insulator cleaned with water and then leaves it in air for at least 8 hours. The pollutions used in this paper are Kaolin and cement dust. The insulators were tested in 4 scenarios as shown in Tables 2–4. The leakage current and flashover voltage were measured according to IEC 61815-1 [6] IEC 61815-2 [7] and IEC 60507 [8] respectively. The atmospheric condition in this present work is 60–70 % of the relative humidity and the temperature range is 32–35 °C.

Table 2: ESSD value of kaolin

Position	ESDD (mg/cm^2)
Total	0.0000196
Bottom	0.0000230
Top	0.0000140

Table 3: ESDD value of cement dust

Position	ESDD (mg/cm^2)
Total	0.0000088
Bottom	0.0000130
Top	0.0000060

Table 4: Comparison of experimental method for cement dust and kaolin

Scenario	Replicated Environment	Kaolin Position	
		Top	Bottom
1	Clean insulator	-	-
2	Unclean insulator	✓	✓
3	Unclean insulator	✓	-
4	Unclean insulator	-	✓

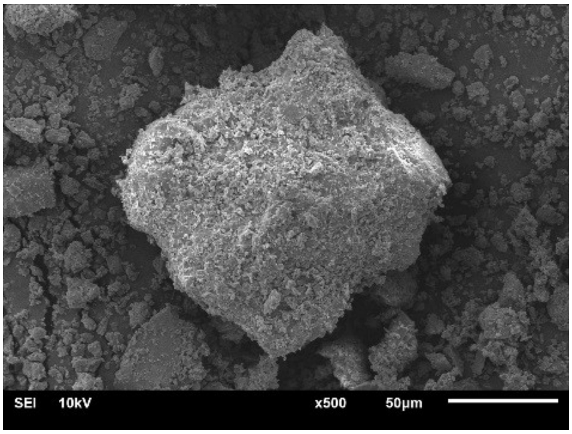

Figure 9: Cement dust physical structure.

2.4 Preparation of fragment pollution

From Figure 9 cement dust is a sedimentary cement, composed mainly of skeletal fragments of marine organisms such as coral, forms and molluscs. Its major materials are the minerals calcite and aragonite, which are different crystal forms of calcium carbonate ($CaCO_3$).

Cement dust has numerous uses as a building material, an essential component of concrete (Portland cement), as aggregate for the base of roads, as white pigment or filler in products such as toothpaste or paints, as a chemical feedstock for the production of lime, as a soil conditioner, or as a popular decorative addition to cement gardens.

The origin of cement dust is the accumulation of core-shell of lives. This cement dust is the main components for cement manufacturing in Saraburi province. The cement dust consists of 3 main elements: Carbon, Oxygen and Calcium while the main constituents in kaolin are Carbon, Oxygen, Aluminium and Silicon.

Kaolin is the most common mineral of a group of hydrated aluminum silicates, approximately $H_2Al_2Si_2O_8$- H_2O. It is prepared for pharmaceutical and medicinal purposes by levigating with water to remove sand, etc.

The contaminated particle size was measured by SEM as shown in Figure 10. SEM is suitable for measuring particles haves that irregular sizes compared to other methods. The measured particle size was the average of the shortest and longest sides of the measured particle obtained by random sampling. The average size of particles are in the range of 25–100 μm.

From the physical characteristics of the sampling cement dust from the real insulator installation area, the chemical analysis of the sampling determined by

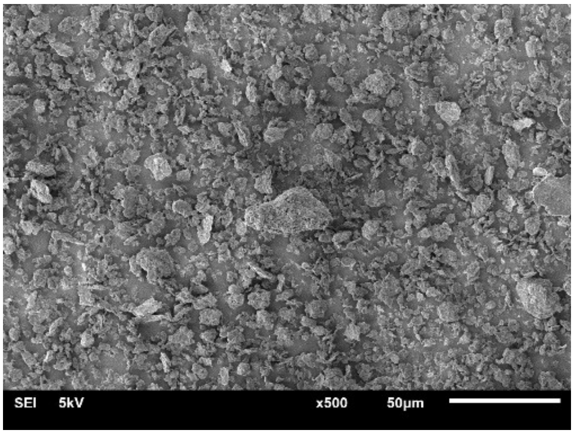

Figure 10: Kaolin physical structure via SEM.

X-ray energy dispersive spectroscopy (EDS) found that the dominant element of cement dust is calcium, which contains 36.73 by weight and this element has a specific electrical resistance of 33.6 nΩ.m. When considering kaolin samples compared with cement dust, it is found that the chemical analysis containing of Al 17.84% by weight which has an electrical resistance has 28.3 nΩ.m and Si has 21.04% by weight. The unique characteristic weight of Si is that it is a semi-metallic element [9], [10] and has very little electrical resistance compared to Calcium and Al.This result shows that kaolin has better conductivity than cement dust.

2.5 Flashover test

The prepared insulator samples were tested after 8 hours of natural drying. The 50% AC flashover voltage stresses were obtained following IEC 60507.

2.6 Hydrophobicity test

For practical purposes, the degree of the water repellency of an insulator surface may be divided into seven hydrophobicity classes (HCs) according to the IEC TS 62073 classification guide. HC1 is the most water repellent class, whereas HC7 refers to completely hydrophilic surfaces. One of the manual methods to detect the hydrophobicity class in outdoor environment can be described as follows: Firstly, the surface to be studied (50–100 cm^2) is sprayed with water. The obtained drop pattern is observed and attributed to one of the seven hydrophobicity classes. For Hydrophobicity investigation on the insulator surface, the photo will be used as a tool to investigate Hydrophobicity format. The Hydrophobicity used as indicator for HC1 to HC7 according to IEC TS 62073 [11].

3. Results

3.1. Leakage current

The pollution suspension of ceramic insulators was prepared according to a modified version of IEC 60507 solid layer methods. The contaminating suspension consisted of cement dust, a volume conductivity range from 103 to 113 μmhos/cm: 103.3 μmhos/cm (bottom), 104.5 μmhos/cm (top) and 113.4 μmhos/cm (both top and bottom). Also, Equivalent Salt Deposit Density (ESDD) is shown in Table 2 and 3. The ESDD value in case of top coating only is always higher than that of the case for bottom coating only.

The leakage current in this experiment was measured by applying voltage at 80% (blue graph), 100% (orange graph) and 120% (green graph) as conditions shown in Tables 4 while the related graphs are shown in Figures 11 and 12. The results found that Scenario 2 has the highest value followed by Scenario 4, Scenario 3 and Scenario 1 respectively. The maximum difference between the maximum

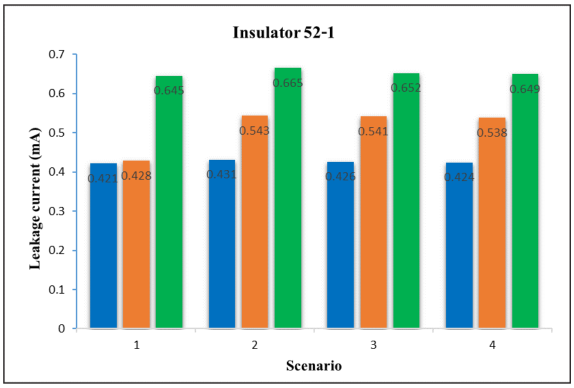

Figure 11: Average leakage current as a function of applied voltage for cement dust pollution.

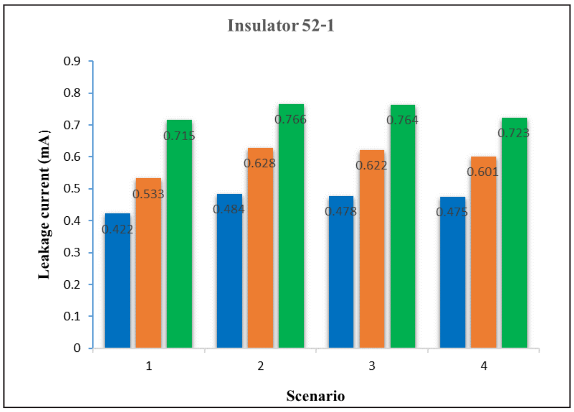

Figure 12: Average leakage current for voltage energized case kaolin pollution.

and the minimum of leakage current is 18.16% for cement dust and 15.13% for Kaolin.

The leakage current of a conventional insulator was recorded during the application of a high voltage AC source and spray pollution simultaneously. Figures 11 and 12 show the variation of the leakage current flowing in the wet pollution layer. The maximum conductance value was about 0.766 mA in Figure 12 at scenario 2 case pollution full surface. From results of leakage current and ESDD, it shows that the leakage current and ESDD have direct

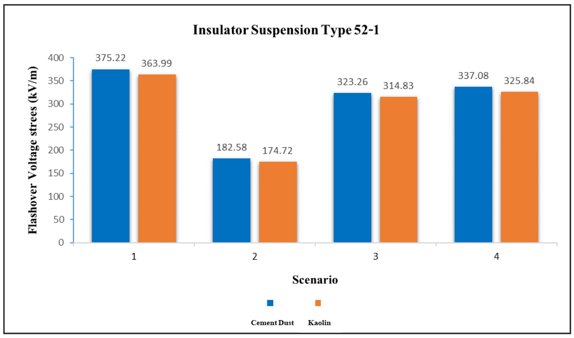

Figure 13: Average flashover voltage stress for all scenario.

relationship.

The main components of cement dust, Ca and Si, have less electrical conductance compared to those of Kaolin as shown in Figures 11–13. With the applied voltage of 22 kV, the insulator contaminated with Kaolin only on top or bottom has 10–13% higher leakage current than that contaminated with cement dust. While the insulator fully contaminated with Kaolin has 37.2% higher leakage current as shown in Figures 14 and 15. The relationship between leakage current and ESDD of cement dust and kaolin as shown in Equation (1) and (2) respectively.

$$I_{cement} = [0.9945 \times ESDD] - [2 \times 10^{-5}] \quad (1)$$

$$I_{kaolin} = [0.9663 \times ESDD] - [8 \times 10^{-6}] \quad (2)$$

Where I is leakage current on insulator (mA). EDDD is Equivalent Salt Deposit Density (mg/cm^2).

The effect of AC voltage on the surface cement dust pollution of the insulators was studied in the simulated environment, as shown in Figures 13 and 14. Under 50 Hz power frequency and AC voltage conditions.

The contamination degree is significantly higher when the system is under power and the lower

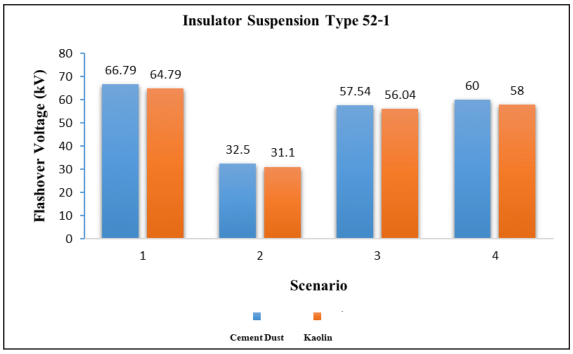

Figure 14: Average flashover voltage for all scenario.

Figure 15: Test clean insulator, HC=2.

Figure 16: Test kaolin pollution, HC=5.

Figure 17: Test cement dust pollution, HC=4.

surface exhibits a greater difference than the upper surface. The reason for the more evident influence is that both gravity and electric field force have effect on the accumulation of particles around the upper surface.

Thus, the electric field force plays a major role. As a result, the increase in crushed stone is mainly due to adsorption. The results for the charged systems are obviously more relevant when considering real-world effects on the power grid.

The flashover voltage decreases with ESDD increase. But ESDD is directly proportional to leakage current, so we can conclude that as the leakage current increases, the voltage at which flashover will occur decreases. In other words, leakage current is inversely proportional to flashover voltage.

3.2 Hydrophobicity

Hydrophobicity of any material is its resistance to flow of water on its surface. A material is highly hydrophobic if it resists to flowing water dropped on it and is least hydrophobic if dropped water flows in form of tracks on its surface. The hydrophobic surface is water repellent, in contrast with a hydrophilic surface that is easily wetted [12].

Hydrophobicity classification is the criterion used to classify the actual wetting appearance on the surface of the insulator as mentioned Hydrophobicity classification ranges were defined from HC1 to HC7 [11].

The hydrophobic test is shown in Figures 15–17. These show that the clean insulator has the best

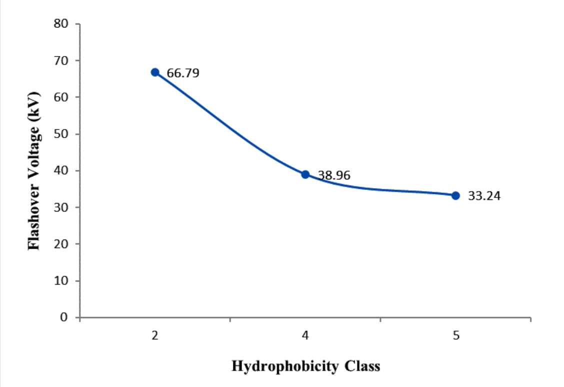

Figure 18: Average flashover voltage of a function of the Hydrophobicity.

hydrophobicity on surface insulator, HC = 2 followed by the insulator trapped with cement dust (HC = 4) and the insulator trapped with Kaolin (HC = 5). This may be explained by non-polar characteristics of cement dust. Also, the physical structure of the cement dust is bigger than that of Kaolin. The flashover voltage of each value of HC is shown in Figure 18.

This Figure 18 shows that the flashover voltage indirectly depends on Hydrophobicity. Leakage current is directly proportional to hydrophobicity loss, especially for insulators. The more is the loss of Hydrophobicity, the more the leakage current become.

From the experiments consisted of leakage current test, flashover voltage test and hydrophobicity test. It was found that, the test result of leakage current is direct variation to the flashover voltage and inverse variation to the hydrophobicity in all scenario tested in this study.

4. Discussion and Conclusions

Pollution testing of suspension type 52-1 insulators have been carried out, employing a piece from the field, with original contamination, another similar one, but cleaned before testing. The procedures of testing employed a pollution and hydrophobicity test, it can be concluded that the contamination of the place where the actual line runs is very light, still it has contributed to determine the worst performance of the tested insulators.

The results show that, dust and kaolin on insulator surface in the simulation condition are different ESDD approximately 43–57%, causing the leakage current and flashover voltage to be different 10–12% % (scenario 3 estimates 0.541–0.66 mA) and 2–4 (scenario 3 estimates 31.5–32.5 kV) respectively. The effect of hydrophobicity will increase in both cases when compared with normal conditions or clean insulators with hydrophobicity has 2–5.

The artificial experimental results were only affected by single factor, whereas the results of the real-world pollution test were influenced by many factors, such as wind, frost, rain and so on. The study of the equivalence between them will be one of the main research directions in the future. The result of this work can be used as information to help decision on maintenance or cleaning of insulators in polluted areas in Saraburi province.

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