The Effect of Coating on Leakage Current Characteristic of Coast Field Aged Ceramic Insulator

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***Abstract*—Ceramic insulator is widely used in Indonesian electrical power distribution system. Based on previous research, it is obtained that silicone rubber coating can improve the performance of ceramic insulator due to better hydrophobicity. This paper presents performance of ceramic insulator with and without silicone rubber coating in a coastal area of Pangandaran. 6 silicone rubber coated and 6 uncoated of 20 kV distribution insulators have been installed in the field to get natural aging process for 5 years and 4 months. Along the aging process, their surface properties have been checked periodically. Monitored parameters are magnitude of leakage current, THD, hydrophobicity, and surface temperature of insulator. The result has shown that after 5 years and 4 months aging in coastal area without maintenance, silicone rubber coated ceramic insulator has better performance.**

Keywords—leakage current; ceramic insulator; silicone rubber coating; long term aging

I. INTRODUCTION

Outdoor insulators are exposed to environmental climate such as high temperature and humidity as well as pollution from coast and industries. Particularly in Indonesia, there are a large amount of ceramic outdoor insulators located at coastal areas with high salt pollution. As a result, leakage current may flow on the insulator surface and may degrade the insulator surface leading to the failure of the insulators [1]. Leakage current can be used as a signature of the insulators because it represents the surface condition of insulators and can be an accurate diagnostic tool for flashover warning [2-4].

There are three solutions introduced to solve the environmental problem on the insulator surface which are periodic washing of insulators, improvement of insulator design and coating with water-repellent agents. Previous research has reported that Room Temperature Vulcanization (RTV) silicone rubber coating for ceramic insulator can improve its performance [5-8].

This paper reports a periodical leakage current measurement of long-term field aged ceramic insulator in Pangandaran switchyard coastal area along 5 years and 4 months to show environmental impact to leakage current characteristic of aged insulators and to show how silicone rubber coating can improve performance of ceramic insulators.

II. EXPERIMENTS

Location of the experiment was conducted in Pangandaran substation where located at coastal area which are heavily polluted by sea salt and many flashover were found in that area. Pangandaran Substation is located about 500 m away from Indonesian Sea of Southern West Java Island. The insulators were installed from October 2011 and condition monitoring was conducted along natural aging of insulators at the area. Monitored parameters are leakage current magnitude, THD, hydrophobicity (measured by its contact angle), and surface temperature of insulators.

A. Samples

Samples used in the experiment were 12 pieces of 20 kV class pin-post type ceramic insulators. 6 samples were uncoated and 6 samples were coated with Room Temperature Vulcanized (RTV) silicone rubber by using high pressure nozzle with surface coating thickness of 0,3 ± 0,05 mm. The RTV silicone rubber coating materials were made by Dow Corning.

The insulators were installed in the switchyard area and powered continuously along aging process as shown in Fig. 1. The insulators were produced by PT Twink Bandung, Indonesia with creepage distance of 500 mm. The insulators are widely used in Indonesian State Electricity Corporation (PT. PLN) network.

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a. Front view

b. Side view

Fig 1. Configuration of insulators aging at coastal area

B. *Leakage current measurement*

The leakage current flowed on the insulator surface was measured by measuring the voltage across a series resistance using a Digital Oscilloscope with digitizer of 8 bit, bandwidth of 100 MHz, and the maximum sampling rate of 1 GS/s. LC waveforms including low and high frequency components were obtained. The digital data was transferred to a personal computer through a GPIB for further analysis.

FFT was conducted in order to know harmonic content and calculate Total Harmonic Distortion (THD) of leakage current so the condition of leakage current wave can be diagnosed. The THD is defined as the total ratio of the harmonic components and the fundamental which can be expressed as:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \quad (1)$$

Where I_1 = 1st harmonic (fundamental)

I_n = nth harmonic for n = 2, 3, 4, ….

C. *Hydrophobicity and surface temperature measurement*

Hydrophobicity of insulator might be a good parameter to know insulator surface condition of water repellency because it can be a cause of dry band. Hydrophobicity is indicated by its contact angle. Hydrophobic surface has contact angle more than 90° while hydrophilic less than 90°. Hydrophobicity was measured by dropping 50 µl water to the insulator surface and then it was captured 2 minutes after the water drop by Sony digital camera with macro lens to see the degree of hydrophobicity. Fig. 2 showed capturing process of the dropped water at insulator surface with distance about 15 cm between camera and insulator surface. The position angle of capturing must be equal with insulator surface to simplify measurement process. After the surface was captured, the contact angle was measured using protractor.

Fig. 2. Hydrophobicity capturing

Besides contact angle, surface temperature measurement can represent insulator surface condition due to the impact of coating to ceramic insulators. The insulator surface temperature was measured using Flir Infrared camera E4 type by capturing desired spot of insulator. The Flir camera has IR resolution 80 × 60 pixels with object temperature range about -20°C to +250°C and accuracy ±2°C. Fig 3 showed capturing process of insulator surface temperature. The distance between Flir camera and the insulator was about 30 cm and spot of the capturing process was depend on which surface temperature spot that we want to measure. Both contact angle and surface temperature capturing process must be done under power off condition for safety measurement.

Fig. 3. Surface temperature capturing

III. EXPERIMENTAL RESULT

The main purpose of the research was to record the leakage current of ceramic insulators at various conditions along 5 years and 4 months aging to explore the advanced information of the leakage currents for contamination flashover pre-warning. The flashover usually takes place easily at higher atmospheric humidity. There were changes on surface condition at before and after aging as shown in Fig. 4.

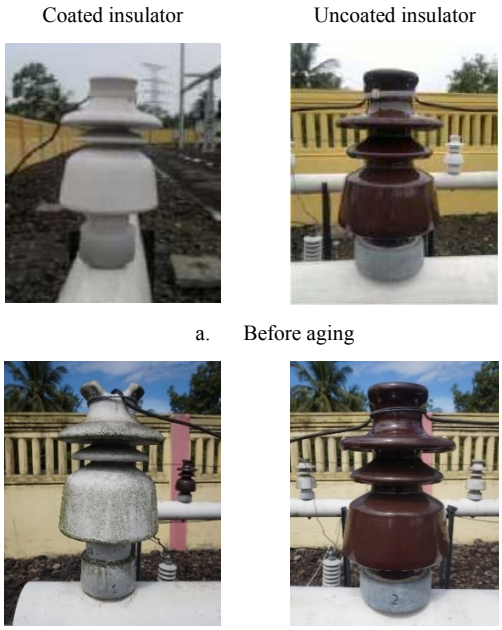


Fig. 4. Insulator condition before and after aging

From visual inspection without measurement, we can see that lichen was found on the coated insulator surface, but interestingly, no biological agent was found on the surface of ceramic insulators in the same environment condition. However, lichen growth has a relatively small impact on the hydrophobicity of the insulators covered with lichen [9].

Leakage current was measured under three different conditions, there were in the morning, afternoon, and evening. These conditions represent different variables of aging factors which are humidity and temperature to know which condition that has higher risk of flashover due to natural environment of coastal area. The characteristic of each condition was shown in Table 1. However, each condition was affected by time of measurement due to dry or rainy season that can caused anomaly measurement result.

TABLE 1. ENVIRONMENTAL CONDITION DURING MEASUREMENTS

Condition	Humidity (%)	Temperature (^{0}C)
Morning	80-90 (high)	25-30 (low)
Afternoon	40-50 (low)	35-40 (high)
Evening	65-75 (mid)	30-35 (mid)

A. Leakage current magnitude and THD insulator

Fig. 5 shows that leakage current magnitude has small increase along time, except for 2nd semester of 2016 measurement. The difference was occurred due to different environmental condition when measurement conducted. Leakage current magnitude will different between rainy and dry season, it was because environment self-restoring. However along measurement conducted, the difference was not significant. The highest leakage current magnitude at first measurement was 62 µA while at last measurement after 5 years and 4 months aging it was 82 µA, so the aging still has small impact to the leakage current magnitude.

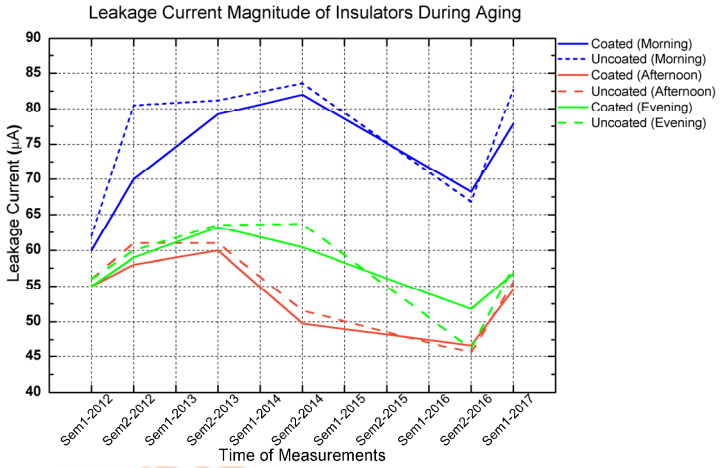


Fig. 5. Leakage current magnitude of insulators during aging

The result showed that highest leakage current magnitude was measured in the morning when humidity was high. It shows that humidity degree has high impact to leakage current magnitude. However with silicone rubber coating, ceramic insulator has better performance to suppress leakage current magnitude. The low leakage current corresponds with high surface resistance which indicates that both coated and uncoated insulators still in healthy condition after 5 years and 4 months aging at coastal area. THD value of leakage current was showed in Fig. 6.

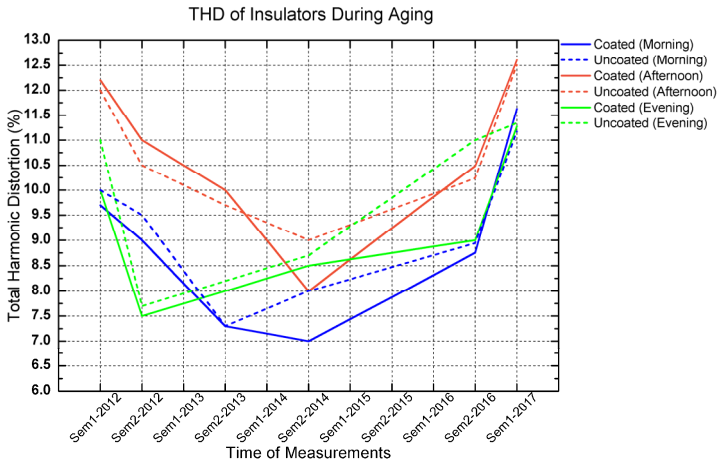
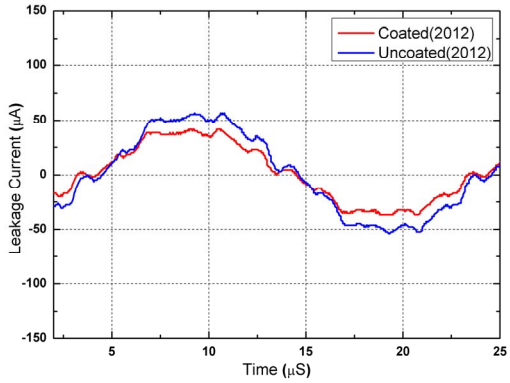


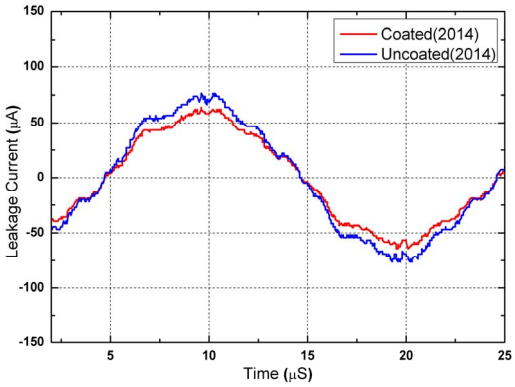
Fig. 6. THD of insulators during aging

Fig. 6 shows that THD value was increase and decrease due to different surface condition. As explained before, the insulator has environment self-restoring. When insulator was exposed by rain, the rain washed insulator surface so THD value was lower while if rain was not occurred, pollutant will collected at the surface and caused THD value higher. The THD value also affected by leakage current magnitude, because the higher leakage current magnitude will rise its fundamental value so total ratio of the harmonic components and the fundamental will decrease. The result showed that the THD value highly affected by pollutant distribution at the insulator's surface and also by magnitude of the leakage current.

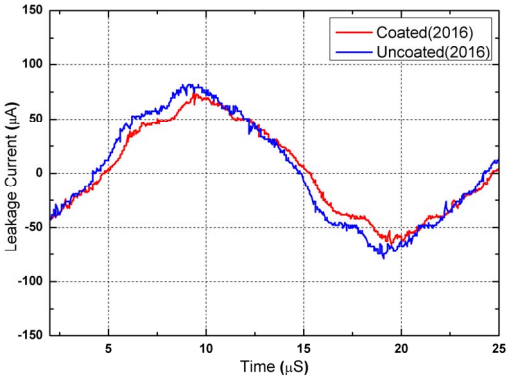
The THD value was represent how distorted leakage current waveform by harmonic content which caused by pollutant. Along aging time, leakage current waveform has changes. Fig. 7 shows typical waveforms taken from both coated and uncoated insulators at morning time to show the changes.



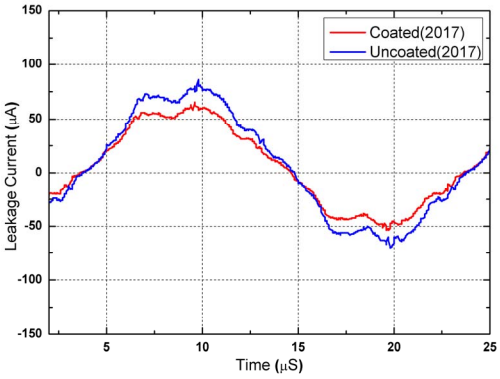
a. 2012 measurement



b. 2014 measurement



c. 2016 measurement



d. 2017 measurement

Fig. 7. Comparison of leakage current waveform at different measurement time

As shown in Fig. 7, there were comparison of leakage current waveform at different measurement time with coated insulator was red and uncoated insulator was blue sign. Harmonic content of leakage current waveform has changes along the years, but still in small turn with 5th dominant harmonic appear. Besides it, along long-term aging small arc arise and caused peak form of the wave was changed.

The results showed that in general the magnitude of leakage current was good enough to show the condition of the insulators. However, the leakage current magnitude should be combined by the THD to show a better correlation with the insulator condition because natural environment was very dynamic so it can changed every time with different effect to the insulator condition. Further analysis indicated that the product of leakage current magnitude and THD is the best in indicating insulator conditions than that of leakage current magnitude and THD. Therefore, it is proposed as candidate for indicator to assess the condition of insulators [10]. Product of leakage current and THD shown in Fig. 8.

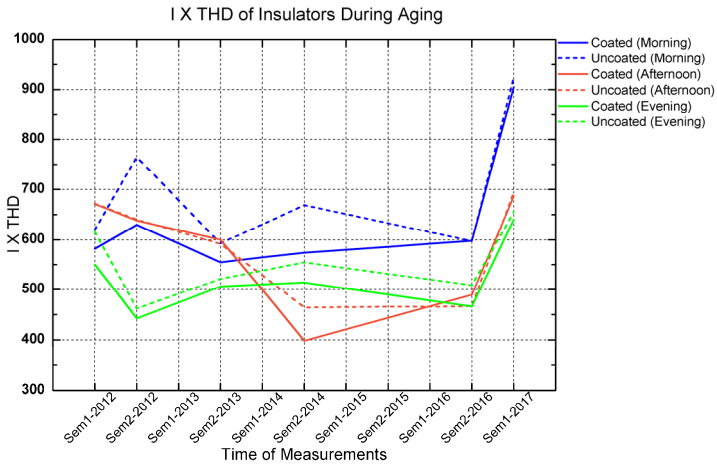


Fig. 8. I*THD of insulators during aging

From leakage current magnitude and THD we can diagnose both cause of leakage current changes which were humidity and pollutant severity that can be a flashover warning, so the leakage current magnitude and THD can be used as a key of leakage current parameters for insulators diagnosis as long as it monitored continuously. The result showed that after 5 years and 4 months aging without maintenance, both coated and uncoated ceramic insulators still in healthy condition. Besides caused by aging, the leakage current of the insulator has changed most depend on the weather in Pangandaran coastal area, however with continued monitoring, the worst case of insulators can be detected earlier.

B. Hydrophobicity and surface temperature

After capturing dropping water at insulator surface, then degree of hydrophobicity was defined by measuring contact angle using protractor as shown in Fig. 9.

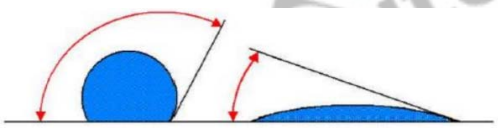


Fig. 9. Measurement of contact angle

Contact angle shows the degree of hydrophobicity. Hydrophobic surface has contact angle more than 90° while hydrophilic less than 90°. As shown in Fig. 10 and Table 2, Hydrophobicity of aged insulator have dropped along the years. As explained before, leakage current magnitude of coated insulator was lower than uncoated insulator. It was because hydrophobicity of the coating that caused insulator surface has water repellency so surface water content of coated insulator was lower and surface resistance higher that make leakage current magnitude was lower.

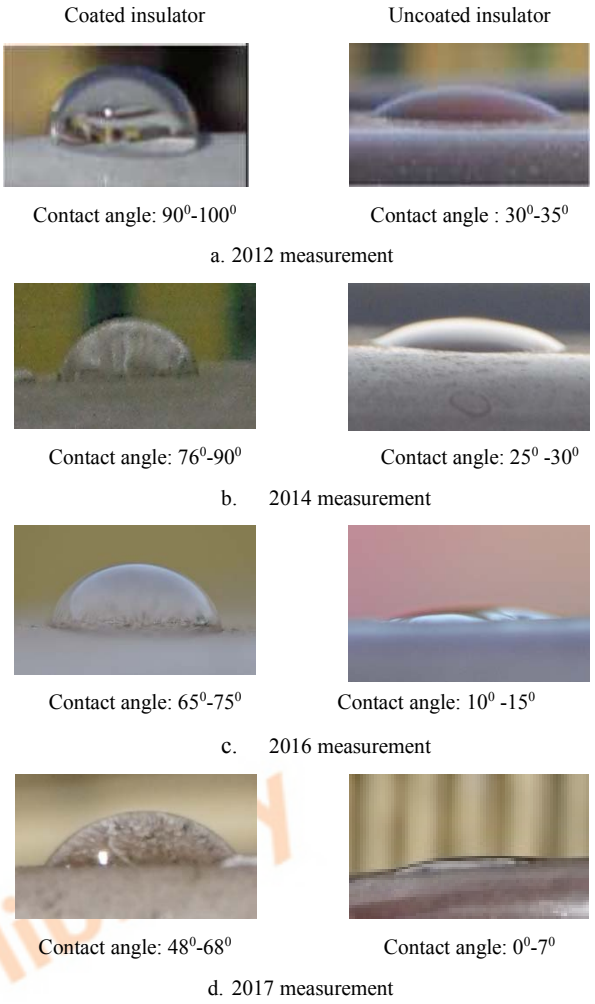
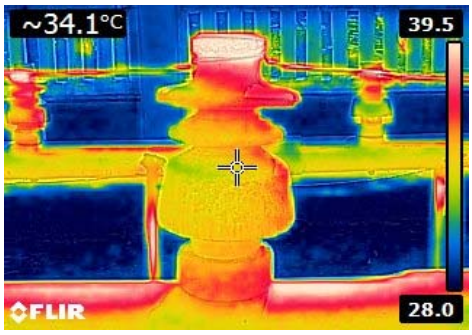


Fig. 10. Comparison of hydrophobicity at different aging time

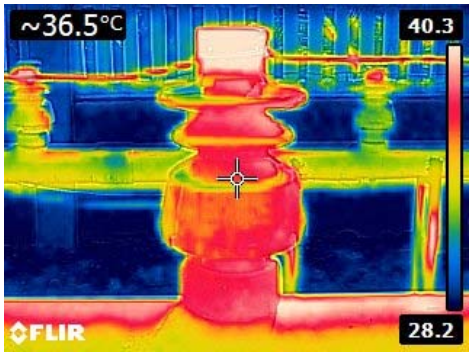
TABLE 2. CONTACT ANGLE OF THE INSULATOR

Contact Angle/year	Coated	Uncoated
2012	90⁰-100⁰	30⁰-35⁰
2014	76⁰-90⁰	25⁰ -30⁰
2016	65⁰-75⁰	10⁰ -15⁰
2017	48⁰-68⁰	0⁰-7⁰

Surface water content of insulator also influenced to ability of pollutant repellency. With hydrophobicity of coated insulator, the water can be one way of self-cleaning of the insulator. When the humidity was high, a lot of water appear on the surface and make leakage current higher because of the rise of surface conductivity. However, because aged ceramic insulator has hydrophilic characteristic, so the water on the surface can be absorbed easily. When source voltage was applied, current flow caused the water dried and dry band to occur. But for coated insulator, it has better hydrophobicity so the water just stay on the surface and bring the pollutants down. After the humidity reached lower level (due to the weather), surface of the insulator become clean and dry again making the leakage current lower than before.



a. Coated insulator



b. Uncoated insulator

Fig. 11. Surface temperature of the insulator

Fig 11 showed surface temperature measurement result from Flir camera. The figure shows thermal distribution of insulator surface from the lowest to the highest value. As we can see that in the same spot of coated and uncoated insulator surface, coated insulator has lower temperature with surface temperature was 34,1 ^{0}C while uncoated insulator 36,5 ^{0}C. Difference surface temperature was influenced by leakage current flowed at insulator. The higher leakage current magnitude, there was higher temperature at leakage path. As shown in Fig. 5, uncoated insulator always has higher leakage current magnitude so it has higher surface temperature.

TABLE 3. SURFACE TEMPERATURE OF INSULATOR AT EVERY CONDITION

Surface Temperature (^{0}C)		Morning	Afternoon	Evening
2012	Coated	33	39	31
	Uncoated	36	41,5	31,5
2014	Coated	35,15	40	32
	Uncoated	36,7	41,5	33
2016	Coated	37,37	40	37,8
	Uncoated	40,03	41,4	39,5
2017	Coated	36,3	41,2	37,1
	Uncoated	38	42,2	38,5

Besides leakage current, environment temperature was influenced surface temperature of insulator. In the morning the highest leakage current was flowed at the surface, but it has low temperature that influenced surface temperature. As shown in Table 3, surface temperature at every measurement tend to rise because affected by aging. Both of insulator has highest temperature at afternoon time with uncoated insulator always has higher temperature. It shows that coated ceramic insulator has better thermal degradation resistance.

IV. CONCLUSION

Along monitoring, leakage current of both coated and uncoated insulators increase and decrease that were caused by environmental condition. Leakage current magnitude was affected by humidity degree while THD was affected by the distribution of pollutant at insulator's surface. The most affected parameter by long-term aging of both coated and uncoated ceramic insulators were the hydrophobicity and surface temperature while leakage current condition still in healthy stage because of self-cleaning.

Morning time was susceptible condition to flashover occur because it has average highest humidity, so it was important to has monitoring condition of insulator to avoid unexpected flashover. Silicone rubber coating can increase hydrophobicity and surface thermal capacity of ceramic insulator so it can be a solution to improve its performance especially for heavily polluted area with high humidity. After 5 years and 4 months aging in coastal area without maintenance, silicone rubber coated ceramic insulator has better performance.

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