Performance Improvement of the Ceramic Outdoor Insulators Located at Highly Polluted Environment Using Room Temperature Vulcanized Silicone Rubber Coating

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Abstract: Ceramic insulators are widely used in transmission as well as in distribution lines. As outdoor insulators, the ceramic insulators are subjected to environmental stresses. In particular case, the insulators may severe high pollution exposure. Under the polluted condition, high leakage current will flow on the insulator surface and dry band arching may take place. The phenomena may initiate the insulator flash over leading to the failure of the lines. Several efforts may be taken to improve the insulator performance under polluted condition. Recently, adding of hidrophobic agent on the insulators was introduced to improve the performance of ceramic insulators under polluted condition. This paper reports the experimental results on the application of room temperature vulcanized (RTV) silicone rubber coating on the medium voltage ceramic insulators under various environmental conditions. The samples were put in a test chamber with controlled humidity and pollution condition. The characteristics of RTV Silicon Rubber coated insulator were analyzed, such as its leakage current (LC), hydrophobicity (indicated by measuring contact angle) and Surface Smoothness (indicated by Scanned Electron Microscopy (SEM)) of the RTV Silicon Rubber insulator surface. The LC's waveform parameters such as magnitude and harmonic content (as indicated by the total harmonics distortion (THD)) were analyzed. It was found that the coating was significantly suppressed the magnitude of leakage current and drastically eliminated the harmonic content. The gradient of cross product value between LC magnitude and THD was proved to be a better indicator to show insulator condition rather than LC or THD alone. The coating also significantly increased the flash over voltage of the insulator. Surface analysis indicated that increasing of the water repellence and enhancement of surface resistance of the insulators played important role in the increase of the insulator performances. These experimental results will be the basis of application of RTV Silicon Rubber coated insulator under polluted conditions, especially in Indonesia.
Keywords: silicone coating, ceramic insulators, highly polluted, flashover voltage

1. Introduction

In a power system, insulator plays an important role to isolate among live parts and between live parts and ground and as mechanical protector. The insulator are widely used at substations, transmission and distribution network as well [1].

Ceramic insulators are widely used in power system since long time ago. At present time the insulators are still widely being used. Ceramic insulator has good mechanical and electrical properties and less expensive. Nevertheless, as outdoor insulator it has some weaknesses especially under certain environmental factors such as humidity, rainy season and pollution which may reduce their surface resistance. The reduction of surface resistance may enhance the leakage current to flow on the surface [2]. Leakage current (LC) with large magnitude flow on the surface for long period may cause degradation of the insulator surface [3]. One of many

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ways for improving its performance is coating with Room Temperature Vulcanized (RTV) Silicone Rubber.
This paper reports the experimental results on the leakage current, hydrophobicity and surface smoothness of RTV Silicone Rubber coated insulator under various artificial conditions.

2. Experiments

A. RTV Silicone Rubber Coated Insulator

Post pin ceramic insulators with 20 kV operating voltage were used as samples. The samples were coated with silicone rubber by using high pressure nozzle with thickness of about 0.3 mm.

(a) (b)

Figure 1. Pictures of non coated (a) and RTV coated (b) samples

The RTV silicone rubber coating materials were made by Dow Corning. The pictures of the samples are shown in Figure 1. A test chamber made from aluminium panel with size of 90 cm x 90 cm x 120 cm was used to simulate pollution exposed to the samples. The front opening of the test chamber was made from acrylic to facilitate the observation of arcing on the sample surface.

For salt layer test, 40 g kaolin was used in every 1 litre water and NaCl was added to the solution to get the desirable conductivity in accordance with IEC Standard No. 507 1991 (salt layer test and salt fog test). For salt fog test, 40 g kaolin was used in every 1 litre of water and NaCl was used as salt fog. The detail of experimental conditions investigated in this experiment are tabulated in Table 1.

Table 1. Experimental Conditions

Test #	Insulator and Environmental Condition	Applied voltage(kV)
1	Clean insulator; clean fog	10-60
2	Insulator polluted with kaolin-salt pollution at 1.3 mS; clean fog	10-60
3	Insulator polluted with kaolin-salt pollution at 2 mS; clean fog	10-60
4	Insulator polluted with kaolin-salt pollution at 3.6 mS; clean fog	10-60
5	Insulator polluted with kaolin pollution; salt fog at 2 mS	10-60
6	Insulator polluted with kaolin pollution; salt fog at 3 mS	10-60
7	Insulator polluted with kaolin pollution; salt fog at 3.6 mS	10-60

Figure 2 shows the dependencies of leakage current for clean sample and kaolin-salt polluted samples on the applied voltage for both RTV Silicone Rubber coated and non-coated insulator. It is clearly seen that LC magnitude increase almost linearly with the applied voltage. Figure 2 also shows that the LC magnitude greatly affected by the different pollution levels applied on the samples. On applied voltage 10 kV, it can be seen that the LC magnitude almost the same for clean sample and kaolin-salt samples. Along with the increasing of applied voltage, the LC magnitude of kaolin sample is higher than the clean sample. The amounts of salt applied also affected the LC. The greater amount of kaolin-salt pollution caused higher LC magnitude. At 60 kV, the highest LC magnitude flowed on insulator polluted with kaolin-salt pollution at 3.6 mS and the lowest LC magnitude flowed on clean sample. The greater amounts of kaolin-salt pollution increase the surface conductivity. Conductive surface caused the LC flowed on insulator surface increased. It can also be concluded from Figure 2 that LC magnitude of insulator with greater amount of pollution has greater gradient as a function of applied voltage. We can also see form Figure 2 that LC magnitude of non-coated ceramic insulator much higher than LC of RTV Silicone Rubber in the same experimental condition (kaolin-salt 3.6 mS). It means that the RTV Silicone Rubber coated suppressed the magnitude of leakage current flowed. It also means that RTV Silicone Rubber coated can maintain surface resistance since the LC magnitude for various polluted conditions almost the same. This phenomenon does not happen for the non-coated ceramic insulators which cannot maintain its surface resistance under polluted conditions.

Figure 3 shows the dependencies of total harmonic distortion (THD) of LC waveform on the applied voltage and the amounts of kaolin-salt pollution. It is clearly seen that THD increase with the applied voltage. However, Figure 6 also indicates that THD value for kaolin-salt polluted insulator under clean fog was decreased together with the increasing amounts of pollution applied. This is due to the increase of surface conductivity and reduction of electric field. This phenomenon also applied for the non-coated ceramic insulators.

There was not any flashover or spark observed from clean and kaolin-salt polluted insulator with RTV silicone rubber coated. Whereas it was reported [4] that spark observed at 40-60 kV for ceramic outdoor insulator under similar experiment.

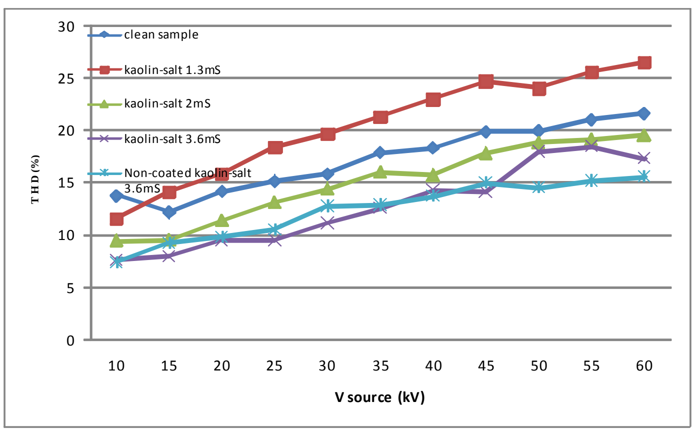


Figure 3. THD as function of applied voltage for insulator polluted with various kaolin-salt pollution under clean fog

These results indicate that RTV silicone rubber coating improves the performance of ceramic outdoor insulator. RTV silicone rubber coating suppressed the magnitude of leakage current, the harmonic content of leakage current and increased the flashover voltage. The low LC corresponds with high surface resistance which indicates high quality of insulator.

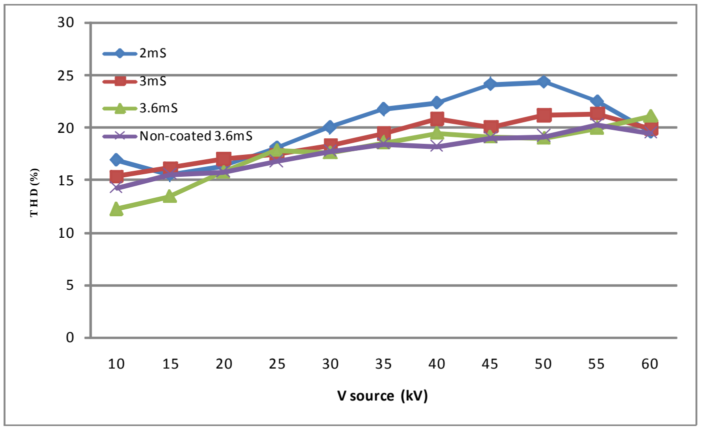


Figure 5. THD as function of applied voltage for insulator polluted with kaolin- pollution under salt fog with various conductivity

B. Gradient of Cross Product Between LC Magnitude and THD as an Indicator of Insulator Condition

Some papers reports that high THD value of leakage current waveforms correlated with the appearance of dry band arcing on sample surface prior to flashover. However, for RTV Silicone Rubber coated insulator this assumption does not apply. Experimental results, as shown in Figure 3 and Figure 5, shows that THD value of RTV coated insulator are pretty high compared to non coated, but this condition does not exactly point out that the severity of insulator surface condition especially RTV coated insulator. From experiment, we found out that there is no flashover observed for RTV coated even though at highly polluted condition it has higher THD value compared to the non-coated insulator. THD value for RTV Silicone rubber is higher or at least equal with THD for non-coated for the same applied voltage and under the same experimental condition.

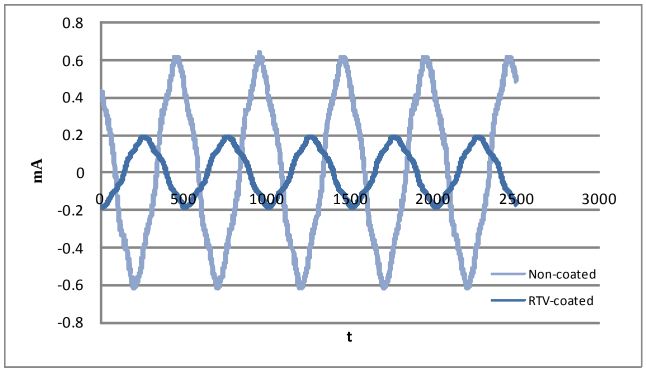
However, experiment for insulator polluted with extreme pollution kaolin-salt 20ms/cm, under clean fog show that the non-coated insulator flashover at 50 kV, meanwhile at 60 kV the RTV coated insulator does not flashover and there are no arc observed.

From this experiment, it is concluded that we cannot apply the assumption that high THD value revealed the severity of insulator surface condition for every condition and every insulator. We might add, this assumption is correct for certain extreme polluted condition and certain type of insulator. High value of fundamental harmonic order might reduce the THD of insulator. For example, the THD for RTV coated at under kaolin-salt 1.3 mS are higher than the THD for non-coated at kaolin-salt 3.6 mS, but that does not mean that the RTV coated surface condition is more severe. It is mainly because the THD for RTV coated has lower value of fundamental harmonic order compared to the non-coated insulator. That condition causes high THD value. In reality, the non-coated insulator has more severe surface condition due to its high value of fundamental harmonic order and high polluted.

LC magnitude also cannot reveal the insulator surface condition. High LC corresponds with low surface resistance which indicates low quality of insulator. The high magnitude of LC in turn will heat the insulator surface and may promote the degradation of the insulator. High LC magnitude revealed the severity of insulator surface condition. But at certain condition, we may find the oscillation effect where the LC magnitude is change with time. The occurrence of dry band may cause oscillation of LC magnitude. That is why LC magnitude alone is not a reliable indicator of insulator condition.

C. Analysis of Leakage Current Waveform

Leakage current for samples at clean fog condition: Figure 6 compared typical leakage current waveforms for RTV Silicone Rubber coated insulator and non-coated ceramic insulator for kaolin-salt polluted under clean fog at applied voltage (a) 10 kV, (b) 40 kV and (c) 60 kV. The waveforms slightly distorted from their sinusoidal due to presence of harmonic components especially 5th component.

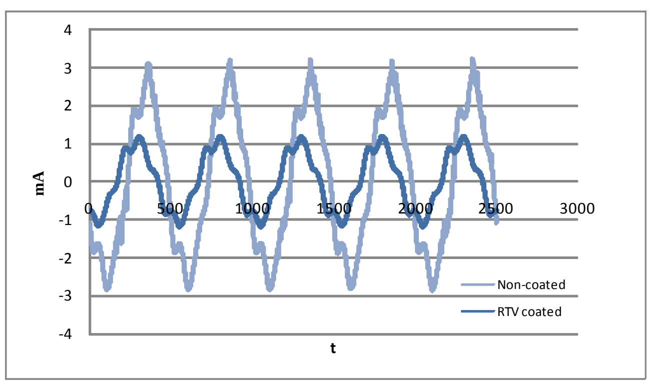


(a)

For RTV Silicone Rubber coated insulator, at applied voltage from 10 – 60 kV, the leakage current waveform distortion was symmetrical at both polarity (positive and negative half cycles) and the 5th harmonics greatly contributed to the THD. On the contrary, the 3rd harmonic component was not significant for polluted insulator with kaolin-salt pollution at 3.6 mS. The greater amounts of kaolin-salt pollution applied may increase the surface conductivity. Therefore at kaolin salt pollution at 1.3 mS and 2 mS the insulator surface were not very conductive caused the THD value larger than for kaolin salt pollution at 3.6 mS. Those are because at small amounts of kaolin-salt polluted, the 3rd harmonic more significant.

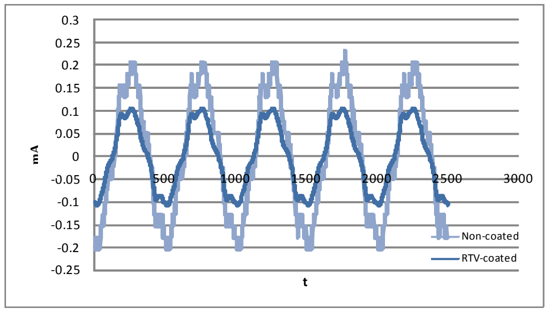
On the contrary, for non-coated insulator, at applied voltage from 40 – 60 kV, the leakage current waveform distortion was asymmetrical. Spark was observed in positive half cycles. The 5th harmonics greatly contributed to the THD. Meanwhile the 3rd harmonic component is still insignificant.

It is reported that the appearance of arcing of 3rd harmonic is always insignificant until an arc present on the surface of insulator [7]. Since the arcing was not observed in the experiment, and the 3rd harmonic component is insignificant, we can fully agree with the statement.

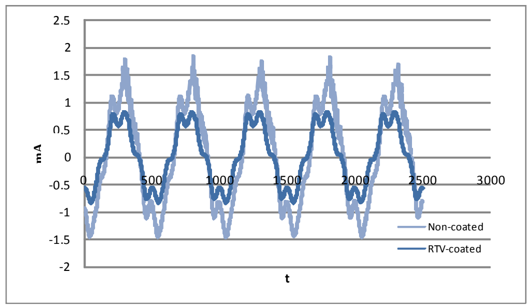


(b)

Figure 6. Typical LC waveforms for insulator polluted with kaolin-salt pollution under clean fog at applied voltage (a) 10 kV and (b) 60 kV



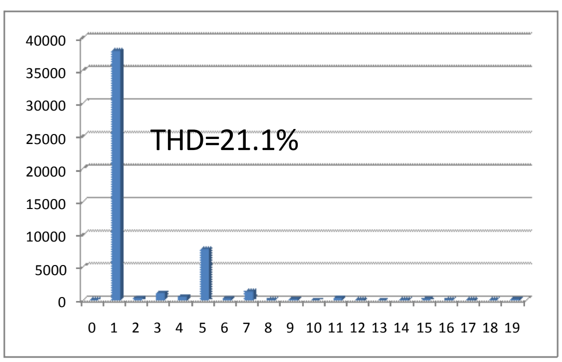
(a)



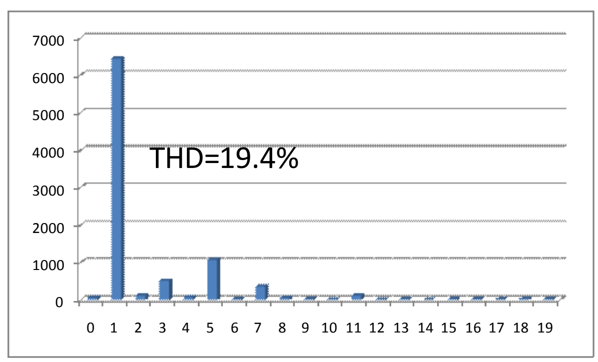
(b)

Figure 8. Typical LC waveforms for insulator polluted with kaolin pollution under salt fog at applied voltage (a) 10 kV and (b) 60 kV

From Figure 9, it is clearly seen that the 3rd harmonic is very small compared to 5th harmonic. Figure 9 also shows that for the non-coated ceramic insulator at applied voltage 60kV, the 3rd harmonic is observed, though it is still small compared to 5th harmonic. The main difference between non-coated and RTV coated insulator are the fact that the 3th harmonic more significant than the 7th harmonic. These results are typical for polluted insulator with kaolin pollution under salt fog.



(a)

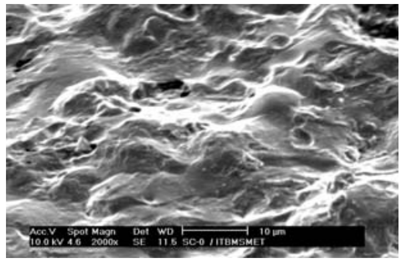


(b)

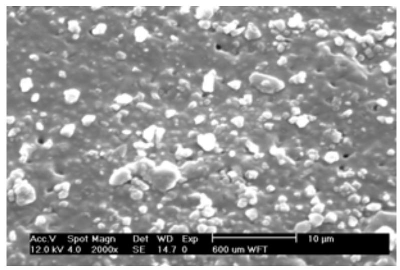
Figure 9. Typical harmonic components for (a) RTV coated insulators and (b) non-coated insulators polluted with kaolin pollution under salt fog at applied voltage 60 kV

E. Surface Smoothness

Surface smoothness of RTV silicone rubber coated insulator surface is indicated by Scanning Electron Microscopy (SEM) of the insulator surface. Figure 10 (a) shows SEM of non-coated clean ceramic insulator surface and (b) shows SEM of clean RTV silicone rubber coated insulator.



(a)



(b)

Figure 10. (a) SEM of non-coated clean ceramic insulator surface and (b) SEM of clean RTV silicone rubber coated insulator

From Figure 10, it is clearly seen that RTV silicone rubber coating increased the smoothness of insulator surface. Similar results had been found for silicone grease coated insulator. Both silicone based coated insulator has smoother surface and better hydrophobicity than the non-coated.

These results indicated RTV silicone rubber coatings improve surface smoothness. These results also indicated that smooth insulator surface tend to have good hydrophobicity. It is directly caused the leakage current flowed on insulator surface decreased. Insulator with good hydrophobicity could increase the flashover voltages, so there was not any flashover observed during experiments for applied voltage 60 kV. If insulator surface has smoother surface then it can be concluded that it has good hydrophobicity and higher surface resistance than the non-coated insulator.

F. Flashover Voltage

Under extreme polluted condition kaolin-salt 20mS/cm, under clean fog, non coated insulators, spark observed at 35 kV and flashover at applied voltage of about 50 kV. However, silicone-coated insulator did not show any flashover and spark until 60 kV for an hour test. Figure 11 shows typical insulator flashover. These experiments indicate that RTV silicone rubber coating increases flashover voltage of ceramic insulator under polluted condition. RTV Silicone Rubber coating successfully overcome some ceramic insulator weaknesses especially under certain environmental factors such as humidity, rainy season and pollution which may reduce their surface resistance. These results also indicate that the coating reduces leakage current and furthermore reduce dry band arcing that might occur on the ceramic insulator surface so there are no flashover observed of RTV Silicone Rubber coating insulator.

[6] Suwarno, "Leakage Current Waveforms of Outdoor Polymeruc Insulators and Possibility of Application for Diagnosis of Insulator Conditions". *The Korean Institute of Electrical Engineers Journal pf Electrical Engineering and Technologies, Vol.1, No.1,* pp. 114-119, 2006.
[7] Suwarno, and Parhusip, Juniko Parlinggoman. "Investigation on Leakage Current Waveforms and Flashover Characteristics of Ceramics for Outdoor Insulators under Clean and Salt Fogs". *WSEAS Trans. Power System, Vol. 3, Issue 6, 2008,* pp. 456-465.
[8] Cherney, E A, and R S Gorur. "RTV Silicone Rubber Coatings for Outdoor Insulator." *IEEE Transactions on Dielectrics and Electrical Insulation*, 2006.
[9] Kim, Jeong Ho, et al. "Leakage Current Monitoring and Outdoor Degradation of SIR." *IEEE transaction on Dielectrics and Electrical Insulation*, 2001: 1108-115.
[10] Devendranath, D, Channakeshava, and A D Rajkumar. "Leakage Current and Charge in RTV Coated Insulators under Pollution Conditions." *IEEE Transactions on Dielectrics and Electrical Inslations*, 2002.
[11] Kim, Seog-Hyeon, Edward A Cherney, and Ruben Hackam. "Hydrophobic Behaviour of Insulators Coated With RTV Silicone Rubber." *IEEE Transactions on Electrical Insulation*, 1992.
[12] Suwarno, & Pratomosiwi, F. "Application of RTV Silicone Rubber Coating for Improving Performance of Ceramic Outdoor Insulator under Polluted Condition." *International Conference on Electrical Engineering and Informatics 2009,*

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