Research Article

A New Approach Based on RTV/SiO₂ Nano Coating for Tackling Environmental Pollution on Electrical Energy Transmission and Distributions

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PAPER INFO

ABSTRACT

The crisis of contamination that leads to the accumulation of dust particles on insulation equipment and electrical insulators has disrupted the electricity grid. Electric discharge on infected insulators in wet conditions is a serious threat to the reliability of the grid, which can lead to grid failure and blackout. In this regard, the importance of hydrophobic and dustproof coatings in the electricity industry has increased in recent years. In this paper, silica nanoparticles in the silicon rubber matrix were used to coat ceramic insulators to decrease the environmental impact of dust and moisture on the insulator's coatings. One of the essential properties of these coatings is their hydrophobicity to prevent possible problems in power transmission. With this regard, nanocomposites were applied to 70 kN insulators and the tests were designed according to the available standards. The performance of these nanocoatings was evaluated by the implementation of electrical, salt fog, and hydrophobicity tests. Finally, the nanocomposite sample containing 3 wt % silica was recognized as the best one.

1. INTRODUCTION

The pollution issue is one of the most significant problems in the transmission and distribution of electrical lines. Electric discharge on infected insulators in wet conditions is a serious threat to the reliability of the grid, which can lead to grid failure and blackout [1]. One of the newest solutions is to use nanocoatings on the porcelain insulator surface. Hydrophobic nanocoatings change the surface chemistry and contact angle to protect the substrate against environmental contamination, sunlight damage, temperature changes, and rainfall. Application of these nano coatings can be helpful and effective in removing one of the significant weaknesses of ceramic insulators that perform poorly in the presence of contamination and moisture. If the insulator surface was hydrophobic or superhydrophobic by using nanocomposites, it would prevent the occurrence of dry sparks on the insulator surface due to contamination [2]. The classification of commonly used coatings on ceramic insulators is shown in Figure 1. Nanocoatings are divided into three general categories:

1- Silicone rubber coatings vulcanized at room temperature (RTV) modified by nanoparticles with thicknesses of several hundred microns;

2- Nano ceramic thin film coatings with heat treatment (these coatings are generally nanometer thick);

3- Polymeric-ceramic thin film nanocoatings without heat treatment.

The best performance can be expected from silicone-based coatings vulcanized at room temperature modified by nanoparticles with thicknesses of several hundred microns (Category 1).

One of the most critical components of reliability in power lines is selecting suitable high voltage insulators. Electrical insulators are the essential parts of distribution systems. Insulators must have high voltage breakdown, high resistance to water absorption, and low Dielectric Loss Factor. Therefore, identifying and investigating the destructive factors of insulators and the methods to deal with them can significantly enhance the power distribution.

Ceramic and glass insulators are the most economical insulators widely used throughout the world for power transmission and distribution. There have been many reports of inefficiencies of these types of insulators, such as problems with an electrical discharge in ceramic and glass insulators in humid and polluted areas. As a result of electric discharge, power lines may be cut off for a while, and irreparable damage occurs in hospitals, mechanized factories, and various industrial centers. Because of this phenomenon, a conductive layer is created on the insulators' surface due to the presence of dust and moisture, thereby leaking the flow and reducing

the breakdown voltage [3, 4]. Different methods have been proposed to solve these problems, including cleaning and rinsing with water, changing the chemistry of the using materials in the insulator, such as using polymer-concrete composites and applying self-cleaning coatings on the insulator surface. By altering the surface chemistry and increasing contact angle, the surface is protected against environmental contamination, sunlight damage, temperature changes, and rainfall [2-5]. Hydrophobic nano-coatings are the most cost-effective, environmentally friendly, self-cleaning, UV-resistant, anti-dandruff and dust-proof. Thus, utilization of these nano-coatings to remove one of the significant weaknesses of ceramic insulators, which is the formation of a conductive layer in the presence of contamination and moisture, can be very useful. In addition, coated insulators require less washing, which is also economically and valuable [6].

This paper investigated the application of RTV hydrophobic nano coatings reinforced with nano-silica particles on 70 KN ceramic insulators. The electrical and hydrophobic properties of these coated insulators were examined through different tests such as dry and wet leakage current, breakdown voltage, salt fog, and the degree of hydrophobicity.
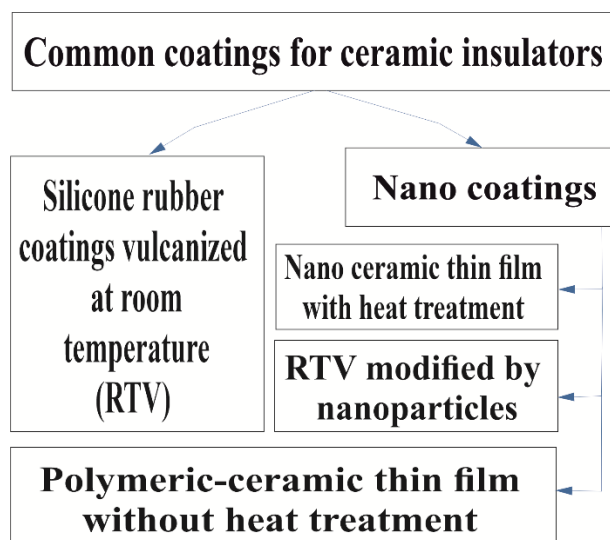

Figure 1. Common coatings used on ceramic insulators

2. EXPERIMENTAL

To investigate the effect of nano-silica on the properties of coated insulators, three samples consisting of different percentages of nano-silica (1, 3, and 5 %) were prepared. A typical coating sample was also prepared with a conventional Canadian RTV CSL product (S0 sample). One non-coated sample was also considered as the control sample (SH sample).

2.1. Ceramic insulator

A 70 kN plate insulator made by the Iran Insulator Company was used to coat and carry out the required tests. These electrical insulators made of clay limit the electric current in a certain direction. The specifications of these insulators are shown in Figure 2 and Table 1.

2.2. Preparing nano coating

Room Temperature Vulcanized Silicone Rubber (RTV1) was obtained from WACKER, USA. (Solid Content = 70 % and

Viscosity 1500 mPa.s at 25 °C by Brookfield method). Nano Silica powder was obtained from FADAK COMPLEX NEW TECHNOLOGIES, Iran. (Grade A1 with Purity of 98 %, particle size: 20 nm, spherical morphology, and Specific Surface Area: 167 m^2/g). Toluene, as a solvent, was obtained from Dr. Mojallali, Iran. (Grade Laboratory- Extra pure with Molecular mass: 98.08 g/mol and Specific density: 1.84 g/cm^3).
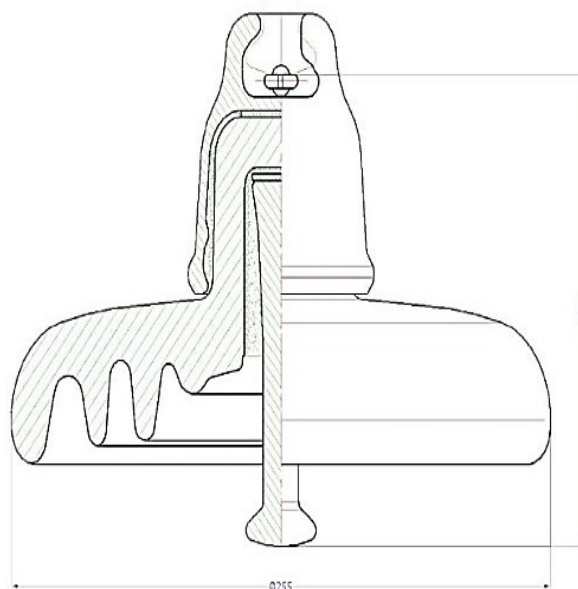

Figure 2. Ceramic insulators used in this research

Table 1. Specifications of used insulators

Properties (unit)	Value
Weight (kg)	4.4
Locking device	R Clip
Ball and socket size (mm)	16
Unit spacing (mm)	146
Porcelain disc diameter (mm)	255
Creepage distance (mm)	295
Electromechanical falling load (kN)	70
Power frequency puncture voltage (kV)	110
Power frequency withstand voltage (kV)	Wet: 40 Dry: 70
50 % Impulse flashover voltage (kV)	Positive: 120 Negative: 125

First, according to the density of composite components, including RTV1 and SiO_2, the density of different composites including 1, 3, and 5 % silica as well as pure RTV1 sample was calculated, according to Eq. 1:

$$\frac{1}{\rho_{com}} = (\frac{\%wt}{\rho})_{SiO2} + (\frac{\%wt}{\rho})_{RTV1} \tag{1}$$

Then, the required mass for coating insulators with specific dimensions was calculated (200 gr) and finally, the precise mass of each component was calculated according to the percentage of each component. Toluene was also used as a solvent in the pure and composite samples (30 wt % of RTV1). Subsequently, coatings were prepared as follows:

2.2.1. Pure RTV1

RTV1 and Toluene were thoroughly mixed with a mechanical stirrer for 5 minutes and poured into a particular container for spraying on the insulator.

2.2.2. Nano composite samples

SiO_2 nanoparticles and Toluene were stirred with the magnetic stirrer for 2 minutes. Then, SiO_2 nanoparticles were utterly dispersed in the solvent by an ultrasonic bath for 2 minutes (1 % and 3 % samples) and 4 minutes (5 % samples). Afterward, RTV1 was added to the above solution and mixed with a mechanical stirrer for 1 to 3 minutes until complete homogenization. The chemical composition of the samples is presented in Table 2.

Table 2. The chemical compositions of the samples

Sample No.	RTV1 (wt %)	SiO_2 (wt %)	Density (g/cm^2)
S0	1	0	1.41
S1	0.99	0.01	1.4166
S3	0.97	0.03	1.4300
S5	0.95	0.05	1.4437

3. METHOD

3.1. Applying nano coating

To apply nanocoating on the ceramic insulators, the gun with a nozzle diameter of 1.8 mm and a windpump were used to spray the coating on the insulator surface. The equipment was used for the coating process, as shown in Figure 3.
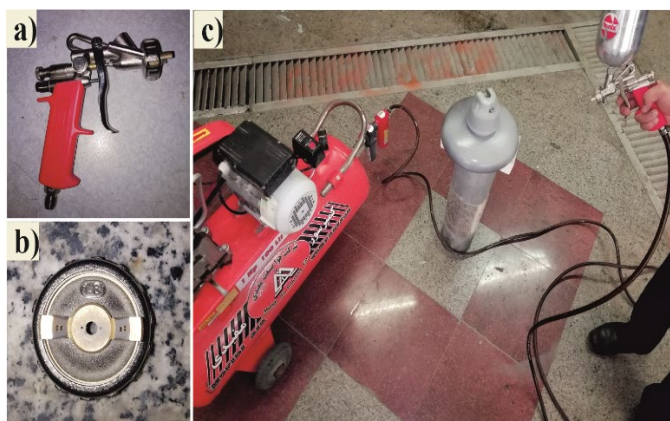

Figure 3. a) Gun used for spraying, b) Nozzles with a diameter of 1.8 mm, and c) Equipment needed for insulator coating operations

The coating was sprayed at a distance of 20 cm from the insulator and after seven days, subsequent tests were carried out. According to the product catalog purchased from Wacker Company, RTV1 resin was utterly cured for seven days. One evidence is that it has a hardness above 30 Shore A. All of our examples passed this hardness level. Figure 4 shows the coated samples.

3.2. Performed tests

Electrical tests including wet and dry leakage current, breakdown voltage, salt fog, and hydrophobic class determination were performed to evaluate and compare the composite samples with the control sample.

Figure 4. Insulation prepared from the exterior and interior views

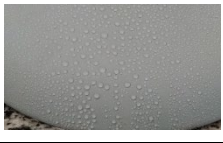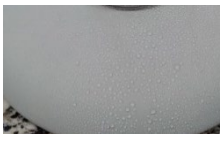## 4. RESULTS AND DISCUSSION

4.1. Hydrophobicity

The hydrophobicity class of coatings was investigated by spray method according to IECTS 62073 standard. Equipment used includes a spray bottle, pure water without chemicals such as detergents and solvents, a magnifying device, and a lamp. The sample area should be between 50 and 100 cm and the spraying process should be performed from 25 ± 10 cm and take 20 to 30 seconds. The hydrophobicity class of samples should be determined 10 seconds after the spraying process has finished. Determination of the hydrophobic class with six different modes HC1 to HC6 was performed. HC1 and HC6 were shown to be wholly hydrophobic and hydrophilic, respectively. Results are presented in Table 3. HC stands for "Hydrophobicity Class".

A drop of water tends to wet a surface that is chemically high in surface energy. If the water droplet's adherence to itself is more significant than an outer surface, it is called a hydrophobic surface and in this case, the angle of contact is greater than 90°. If the chemistry of a surface is hydrophobic, the contact angle increases with the surface roughness [6, 7]. In order to determine the class of hydrophobicity by spray to prove to the surface hydrophobicity, the shape of the water droplets from the top view should be circular and the amount of hydrophobicity decreases, as the droplets come out of the circle shape. As shown in Table 3, some droplets on the surface of the control sample SH and the pure sample S0 are oval; however, the number of these oval droplets decreased with increasing silica content in the S1, S3, and S5 samples. By comparing the test results based on existing criteria, the hydrophobicity class of samples SH and S0 was determined to be HC2 equivalent (high and favorable hydrophobicity), whereas for samples containing silica nanoparticles (samples S1, S3, and S5), a hydrophobic class equivalent to HC1 was determined, which is completely hydrophobic. The accepted standard hydrophobicity for this report is HC2 and HC1; thus, these samples are approved.

The result of this test shows hydrophobicity improvement due to the addition of silica nanoparticles to the RTV-SIR. The reason for the hydrophobicity difference between pure RTV and composite with silica is the low gravity between surface and water, as a consequence of low surface energy, which is a property of the hydrophobic surfaces. In addition, on the hydrophobic surfaces, the droplet/coating intersection can be replaced with the droplet/air intersection and it significantly reduces tensile strength. Since the hydrophobic surfaces create an air layer between the drop surface and the solid layer, it is expected that the wet surface area be reduced, which also reduces the tensile force between the drop surface and the hydrophobic surface. In this case, the water droplet automatically moves on the surface of the hydrophobic

surface, while the spontaneous behavior of the water droplet motion on the pure RTV coating is limited [7, 8].

Table 3. Results of hydrophobicity class test

Sample No.	Sample picture	Hydrophobicity class
SH		HC2
S0		HC2
S1		HC1
S3		HC1
S5		HC1

4.2. Electrical test

4.2.1. Dry leakage current

Dry leakage current was measured according to IEC 60060 standard. According to the standard, the laboratory environment was standardized at a temperature of 12.5 °C, 846.1 hPa, and 54.5 % humidity. The sample was installed in an appropriate location for applying voltage. The voltage of 20 kV was applied to the insulator, and the ammeter noted the leakage current after being fixed. As shown in Figure 5, the insulator is observed under test conditions. The rods hung at the bottom of the insulator are the conductor for the power line simulator.

The results of the samples dry leakage current test are listed in Table 4. Figure 6 also shows changes of dry leakage current with an increasing percentage of nano-silica in the coating. According to Table 4, the dry leakage current increased more than the uncoated sample by applying pure RTV to Sample S0 (control sample SH). However, it was expected that dry leakage would not be reduced by applying coatings because the performance of nanocoating on insulators was more significant in salt fog or contaminated tests [8-10].

Table 4. Dry leakage current test results

Sample No.	Dry leakage current (µA)	Improvement (%)
SH	356	-
S0	364	2.25
S1	364	2.25
S3	367	3.09
S5	354	-0.56

Figure 5. Insulator mounted for electrical testing
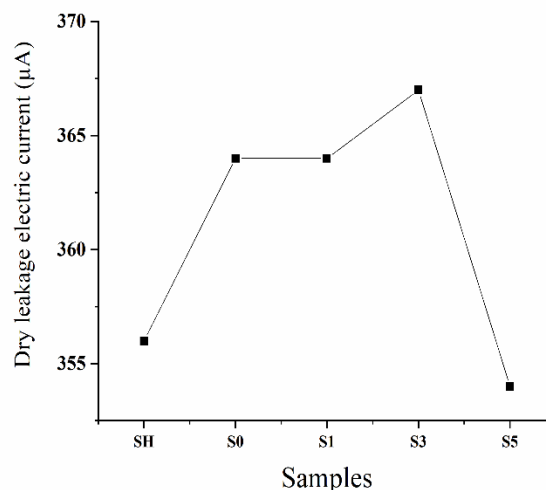

Figure 6. Changes of dry leakage current with an increasing percentage of nano silica in the coating
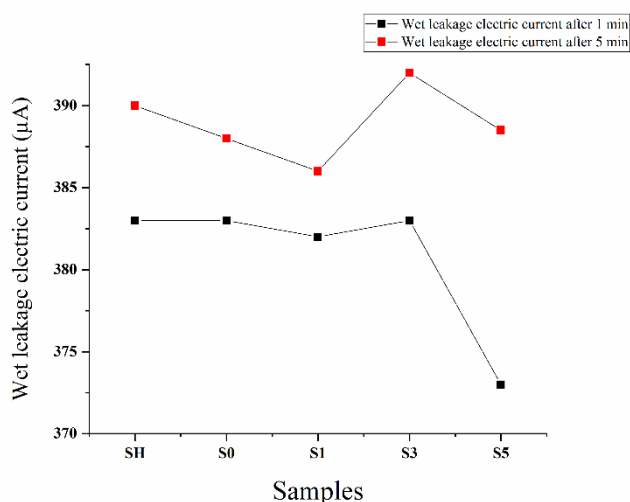
4.2.2. Wet leakage current

This test was performed according to IEC 60071 standard. The wet leakage current test had the exactly dry leakage current test conditions. In this test, water (a combination of distilled water and municipal water) was sprayed with a specific resistance rate of 100 ± 15 µS/sec and an injection rate of about 1 to 2 mm/min at an oblique angle of 45°. Therefore, water is sprayed to the insulator at an angle of 45° and the voltage of 20 kV is applied for two different durations, 1 and 5 minutes.

The results of the wet leakage current test of the samples are listed in Table 5. Figure 7 also shows changes of wet leakage current with an increasing percentage of nano-silica in the coating. According to the table, the worst case is the S3, with its leakage rate even higher than the control sample (SH) after 5 minutes. S1 sample, which has the lowest wet leakage current and is considered the best, reduced the current leakage rate by 1.02 %. However, the results of all the samples are very close together and precise analysis and comparison are not possible [10-12].

Table 5. Wet leakage current test results

Sample No.	Wet leakage current after 1 min (µA)	Wet leakage current after 5 min (µA)	Improvement after 5 min (%)
SH	383	390	-
S0	383	388	-0.51
S1	382	386	-1.02
S3	383	392	-0.51
S5	373	388.5	0.38

Figure 7. Changes of wet leakage current with an increasing percentage of nano silica in the coating
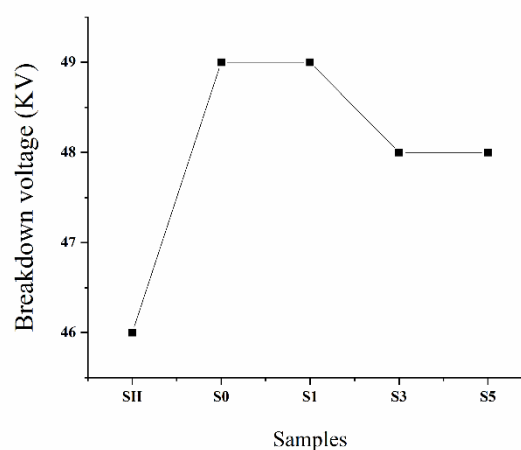
4.2.3. Breakdown voltage

This test was performed according to the IEC60383 standard and evaluated the insulator's performance under contamination conditions. The test conditions were the same as the leakage current tests. However, in this test, the applied voltage to the samples increased after exposure to water until the spark on the insulator surface was observed and its value was recorded at the moment of electrical failure. The breakdown voltage was reported by dividing the recorded voltage by the correction factor according to the ambient conditions. The correction factor for this test was 0.98 % according to environmental conditions. The breakdown voltage test results of the samples are listed in Table 6. Figure 8 also shows the breakdown voltage changes with an increasing percentage of nano-silica in the coating [13-15].

Table 6. Breakdown voltage test results

Sample No.	Breakdown voltage (kV)	Improvement (%)
SH	46	-
S0	49	6.52
S1	49	6.52
S3	48	4.35
S5	48	4.35

According to the standard of acceptance, since the minimum breakdown voltage of 50 kV is accepted, based on the results, none of the coated insulators were accepted. However, the results presented in Table 5 are too close and can be considered as a fall within the error range of the test. Results

also show that application of RTV coating and increase of nanoparticles percentage improved the breakdown voltage. The presence of silica nanoparticles in the composite composition increased the number of crosslinks, reduced the gap between the polymer chains, ultimately improved the hardness of the coatings, and resulted in the presence of samples in power lines under environmental conditions, such as rainfall and lightning. In addition, electrical properties maintain coverage. In the samples with higher nanoparticles percentages, such as S5 (samples with 5 % nanoparticles), there was a probability of optimum dispersion of the filler in the polymeric field [10, 11].

Figure 8. Changes of breakdown voltage with an increasing percentage of nano silica in the coating

4.2.4. Salt fog test

A salt fog test was performed on coated insulators according to IEC 62217 standard. In this test, insulators coated with pure RTV resin and composite containing 3 % silica nanoparticles (S0 and S3 samples) were compared with the control sample (SH). Insulators were immersed in a test chamber containing 800 g of salt in 100 ml of distilled water for 5 h. Then, the leakage current was measured at three voltage levels of 12, 20, and 24 kV. Figure 9 shows the samples in the salt fog chamber.

The results of the salt fog test after five hours are shown in Table 7. Figure 10 also shows the leakage current changes at three voltage levels of 12, 20, and 24 kV. Results show that utilizing silica nanoparticles in the coatings of insulators reduced the leakage current at different voltages [15-17].

Figure 9. Samples in the salt fog chamber

Table 7. Results of the salt fog test for five hours

Sample No.	Leakage current (μA)		
	12 kV	20 kV	24 kV
SH	157	258	337
S0	135	224	275
S3	135	223	273
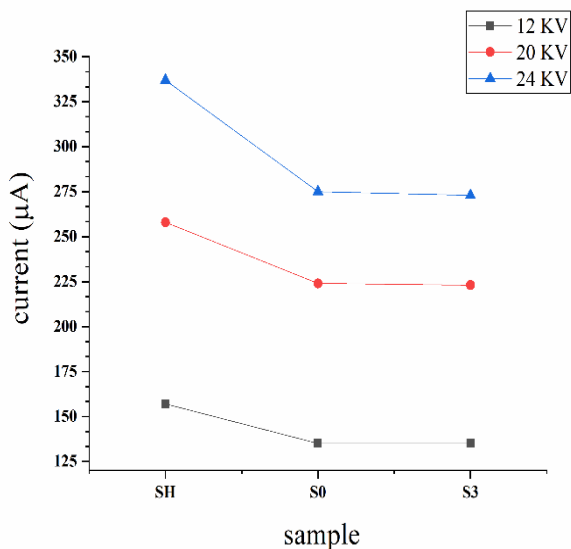
Figure 10. Changes of leakage current at 3 voltage levels of 12, 20 and 24 kV

5. CONCLUSIONS

Since the crisis of micro grids in humid areas has caused problems in electricity transmission, the use of these hydrophobic coatings can prevent the contamination of electrical equipment and their disruption.

In the test of hydrophobic class determination of spray-coated insulators, control samples (SH) and pure RTV (S0) of HC2 class and optimum hydrophobicity were evaluated. The samples containing silica nanoparticles were all evaluated with HC1 class and completely hydrophobic.

In electrical tests including dry leakage current, wet leakage current and breakdown voltage, the presence of silica nanoparticles had a normal effect on the electrical properties of the coatings and the reported numbers were very close. However, the improvement of the electrical properties resulted from an increment in the number of crosslinks and the decrement in the gap between the polymer chains by the addition of nanoparticles. It was also shown that these nanocomposite polymer coatings could be used to eliminate the adverse effects of dust and other environmental contaminants instead of removing ceramic insulators.

6. ACKNOWLEDGEMENT

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