Degradation of Hydrophobic Properties of Composite Insulators in Simulated Arid Desert Environment

Yasin Khan

Abstract— Electrical insulators form a very important component of high voltage electric power networks. Along with the traditional insulators i.e. glass and porcelain, etc. presently the polymeric insulators are also used world widely. These polymeric insulators are very sensitive to various environmental parameters such temperature, environmental pollution, UV-radiations, etc. which seriously effect their electrical, chemical and hydrophobic properties. The UV radiation level in the central region of Saudi Arabia is high as compared to the IEC standard for the accelerated aging of the composite insulators. Commonly used suspension type of composite EPDM (Ethylene Propylene Diene Monomer) insulator was subjected to accelerated stress aging as per modified IEC standard simulating the inland arid desert’s atmospheric condition and also as per IEC-61109 standard. The hydrophobic characteristics were studied by measuring the contact angle along the insulator surface before and after the accelerated aging of the samples. It was found that EPDM insulator loses it hydrophobic properties more proportional to the intensity of UV radiations and its rate of recovery is very low as compared to Silicone Rubber insulator. The effect of water salinity and drop size on the contact angle characteristics was also investigated.

Index Term— accelerated aging, contact angle, EPDM composite insulators, hydrophobicity UV-A radiation.

I. INTRODUCTION
Overhead electrical insulators form an important link in an electric power system. Along with the traditional insulators (i.e. glass and porcelain, etc) presently the polymeric insulators are also used world widely. These are used to support the line conductors to separate them electrically from each other. These composite insulators have substantial advantages compared to inorganic insulators. These are light weight, easy installation, comparable or better withstand voltage, improved contamination performance, improved resistance to vandalism, improved handling of shock loads and high hydrophobicity, etc [1]. Together with many advantages, the composite insulators are subjected to chemical changes on the surface due to weathering and from dry band arcing, suffer from erosion and tracking which may lead ultimately to failure of the insulator, faulty insulators are difficult to detect and life expectancy is difficult to evaluate [1, 4].

The property of high hydrophobicity of the composite insulators assures them better performance in contaminated environments. Hydrophobicity of a material is its resistance to flow of water on its surface or resistance to the formation of continuous film of water. It can be described using contact angle (θ) on the material surface that a liquid drop makes on the solid surface when it comes in contact with solid surface. The hydrophobic materials allow less water-surface contact and thus make contact angle greater than 90°. whereas materials which are easily wettable allow water to touch a large surface area and hence make contact angle less than 90° and is known as hydrophilic. Surface is said to be hydrophobic, when contact angle is more than 90°, hydrophilic when contact angle is less than 35° and partially wettable when 35°<θ <90° [2].

The aging mechanism and the flashover processes are different for the ceramic and polymeric insulators due to different characteristics [3-4]. Many investigations are attempted to study the actual hydrophobicity status of the composite insulators specially, the Silicone Rubber (SiR) insulators [5-6].

Polymeric materials are badly affected by environmental stresses like UV-radiations, heat, contaminations, moisture, etc. [4]. The weather conditions in the Middle East including Saudi Arabia are significantly harsh and changing from the daytime to the night. The inland areas of Saudi Arabia are very hot, dry and dusty. The UV radiation level is extremely high in this region [7-8]. The high degree of UV radiation can cause physical as well as chemical changes. The aim of this study is to determine the degree of degradation of the EPDM composite insulators by measuring the contact angle along the insulator surface. Some samples of commonly used suspension type of composite EPDM insulator were subjected to accelerated stress aging as per modified IEC standard simulating the inland arid desert’s atmospheric condition and some other as per IEC-61109 standard [9]. The hydrophobic characteristics were studied by measuring the contact angle along the insulator surface before and after the accelerated aging of the samples.

II. EXPERIMENTAL SET-UP AND METHOD

A. Accelerated aging of the sample
The actual UV-A radiations level and temperature variations in central region of Saudi Arabia is quite higher as compared to the values recommended in the IEC std. 61109 [8,9]. To simulate the ambient conditions of arid desert, a wooden
chamber was fabricated for the accelerated aging process for the test insulators. Schematic diagram of the chamber is shown in [8]. Based on the actual UV-A radiation intensity in the central region of Saudi Arabia and the IEC std. recommended value, two types of experimental conditions were created in the accelerated aging test chamber for testing the insulators by applying different stresses mentioned in Table I, i.e.:

**Case 1:** Based on the IEC std. 61109 [10]

**Case 2:** Modified aging cycle based on the actual UV-A radiations level (40 W m⁻²) as shown in Fig. 2.

![Schematic diagram of the chamber](image1.png)

**Fig. 1** shows the photograph of the tested insulator. These insulators were procured from WT-Henley (UK). Three samples were used for accelerated aging for each case-I and case-II. The salient dimensions of the tested insulators are mentioned in Table II.

![Photograph of composite EPDM insulator](image2.png)

**Table I**

<table>
<thead>
<tr>
<th>No</th>
<th>Stress type</th>
<th>Case-1</th>
<th>Case-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Voltage (p.u)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Temperature (°C)</td>
<td>~50</td>
<td>~50</td>
</tr>
<tr>
<td>3</td>
<td>UV-A radiation (w m⁻²)</td>
<td>10</td>
<td>40</td>
</tr>
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</table>

**Table II**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Voltage class</td>
<td>kV</td>
</tr>
<tr>
<td>2 Section Length &quot;L&quot;</td>
<td>mm</td>
</tr>
<tr>
<td>3 Leakage Distance</td>
<td>mm</td>
</tr>
<tr>
<td>Power frequency flashover:</td>
<td></td>
</tr>
<tr>
<td>4 Dry</td>
<td>kV</td>
</tr>
<tr>
<td>5 Wet</td>
<td>kV</td>
</tr>
<tr>
<td>6 Impulse flashover</td>
<td>kV</td>
</tr>
</tbody>
</table>

![Schematic diagram of composite insulator](image3.png)

**TABLE II**

**EPDM TESTED INSULATOR DETAILS**

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Voltage class</td>
<td>kV</td>
</tr>
<tr>
<td>2 Section Length &quot;L&quot;</td>
<td>mm</td>
</tr>
<tr>
<td>3 Leakage Distance</td>
<td>mm</td>
</tr>
<tr>
<td>Power frequency flashover:</td>
<td></td>
</tr>
<tr>
<td>4 Dry</td>
<td>kV</td>
</tr>
<tr>
<td>5 Wet</td>
<td>kV</td>
</tr>
<tr>
<td>6 Impulse flashover</td>
<td>kV</td>
</tr>
</tbody>
</table>

The stresses mentioned in Table I above are applied in cyclic manner for duration of 1000 h is shown in Table III. Each cycle lasts for 24 hours and a programmed change takes place every 6 hours

![Schematic diagram of composite insulator showing contact angle measurement positions](image4.png)

**Table III**

<table>
<thead>
<tr>
<th>ACCELERATED AGING CYCLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (h)</td>
</tr>
<tr>
<td>Voltage (1 p.u)</td>
</tr>
<tr>
<td>Heating (~50°C)</td>
</tr>
<tr>
<td>UV-A radiations</td>
</tr>
</tbody>
</table>

**B. Contact angle measurement**

The hydrophobic characteristics of the EPDM insulator were studied by measuring the contact angles along the surface of the insulator for new, old and newly aged EPDM insulators, such as:

(i) New: These are virgin EPDM insulators

(ii) Already aged insulator: Also called 'old aged' of the same material as mentioned in (i) above. The contact angle measurements were made after about 6 months of aging in similar environmental conditions as discussed earlier.

(iii) Newly aged insulator: These insulators are newly aged and the contact angle is measured within 24-hours after the accelerated aging cycle is completed

One side of the insulator is always facing the UV lamps whereas; the other side is not as shown in Fig. 2. The contact angle was measured on the points A, B, and C (i.e. top, bottom and core), respectively on the side facing the UV lamps.

![Photograph of composite insulator showing contact angle measurement positions](image5.png)

Fig. 2. Schematic diagram of composite insulator showing contact angle measurement positions

For measurements of the contact angle at desired positions (A, B or C), the insulator was oriented so the surface under consideration was approximately horizontal. The drop is carefully placed on the horizontal surface of the insulator with the help of a hypodermic syringe needle. The photographs of drops are taken quickly with the help of high resolution digital camera just after putting the drop of water on insulator (Fig.3) and the data was analyzed by computer software “ImageJ”. The drop volume was controlled in the range 10~25µL [12]. De-ionized water of ~100µS conductivity was used. Methylene blue was added to change the color of the water to get more clear images.

![Drop photograph](image6.png)

Fig. 3. Drop photograph

The Contact angle analysis software “ImageJ” in general assume the drop is part of a sphere as shown in Fig. 4.
However, due to gravitation and molecular dispersion, the shape of a drop is close but not exactly a part of a sphere. The hidden assumption is when the drop volume is small; the gravitational effect can be ignored.

![Image](image-url)

**Fig. 4.** Contact angle calculation theoretical model.

The contact angle (θ) shown in Fig. 4 above is calculated as:

\[
\theta = 90 - \tan^{-1} \left[ \frac{r - b}{\sqrt{2rb - b^2}} \right]
\]

**III. RESULTS**

The EPDM insulators were aged in the accelerated aging chamber as per Case-I (UV-A: 1 mW/cm²) and Case-II (UV-A: 4 mW/cm²) mentioned in Table I above and the contact angles were measured by using “ImageJ” software for the new, old aged and newly aged insulators. The results are graphically shown in Fig. (5)-(7), that compares the shed-wise contact angle characteristics for the position A, B, C shown in Fig. 2. The contact angles data for the old aged insulators was compared with the newly aged insulator, and the result is shown in Figs. 5-7 below.

Comparison of these fig. clearly shows that contact angle for newly aged insulator is lower as compared to old aged insulator. This result shows that the EPDM insulator recover some of its hydrophobic properties with the passage of time but this rate of recovery is very slow as compared to SiR which usually recovers very quickly [4], [12].

![Graph](graph-url)

**Fig. 5.** Contact angle characteristics along the insulator sheds for Old-New aged samples for Position A of Fig. 2

![Graph](graph-url)

**Fig. 6.** Contact angle characteristics along the insulator sheds for Old-New aged samples for Position B of Fig. 2

The effect of water salinity on contact angle for the new, old and newly aged EPDM insulators was also studied by measuring the contact angle for the de-ionized water, tap water, 5% natural salt added to de-ionized water and 5% salt added to tap water. The contact angle measurement results are as shown in Fig. 8, below.

![Graph](graph-url)

**Fig. 7.** Contact angle characteristics along the insulator sheds for Old-New aged samples for Position C of Fig. 2

The effect of water salinity on contact angle for the new, old and newly aged EPDM insulators was also studied by measuring the contact angle for the de-ionized water, tap water, 5% natural salt added to de-ionized water and 5% salt added to tap water. The contact angle measurement results are as shown in Fig. 8, below.

![Graph](graph-url)

**Fig. 8.** Effect of water salinity on the contact angle for old-new aged samples

This fig. clearly indicates that there is visible effect of the water salinity on the contact angle. The hydrophobicity of the EPDM insulator decreases with the increase in water salinity. Further, accelerated aging under the increased UV-irradiation the contact angle measure was decreased [14]. The recovery hydrophobicity of the old aged insulator is evident from Fig. 8.

**IV. DISCUSSION**

The contact angle measurements results depicted in fig. (5)-(7)
show considerable variations along the insulator surface. Each is considered below before general observations are made.

(i) Hydrophobicity variation along the insulator length
The hydrophobicity tends to be less near the two ends of the insulator as compared to the remaining sheds of the insulator. This is especially true for the high voltage electrode end of the insulator where the electric filed strength at the triple junction (conductor-insulator-air) is high as compared to the rest of the insulator string. This high electric field at the triple junction together with high dry desert temperature and UV radiations that causes heavy surface deterioration [8] of the insulator material results in lowering the contact angles as indicated in fig. (5)-(7). This result is in agreement with [5] although such dependency is not always observed [10].

The contact angle variation between the top and bottom surfaces of the insulator was also marked. The average variation in the contact angles from HV to ground electrode for top (position A) as well bottom (position B) is more consistent, however, the wide variation in contact angle was observed especially under the newly aged insulators when the insulator was aged under high UV radiation intensity (i.e. 4mW/cm2) as shown in Fig. 5 & 7.

On the core the variation in contact angle is about 15°-20°. The lowest values were observed in the center as evident from Fig. 7. This shows that, this part of the core is more heavily damaged than the sheds. One explanation to this is that this part of the insulator presents a smaller cross-section to the leakage currents, which results in higher current densities and so more likelihood of the discharges and dry band arcing on the sheds [6], [13]. The other possible explanation to this reduction is that the core is more exposed to UV radiations as compared to sheds of the insulator. Due to this high temperature, high UV radiation intensity, and high current densities in the core, some visible damages were also observed on the core. It may be noted that these damages were observed on the side of the tested insulator that directly face the UV radiation lamps. It is therefore suggested that the aging of the insulator core is primarily due to surface discharge activities and high UV-radiations.

(ii) Hydrophobicity variation on the front-back side
The contact angle measured on both the front as well as back sides of the insulator were also measured and shown in Fig. (6) & (7). The contact angle measured was smaller on the front side as compared to the back side of the aged insulator. This shows that the front side of aged insulator was more hydrophilic as compared to the back side which suggests that natural environment plays an important role in the aging process. The variation in contact angle between the front and back face is several degrees. The greatest difference between the front and back is seen on the core in the center of the insulator length, may be due to enhanced electrical activity in this region.

(iii) Hydrophobicity Recovery
Scanning Electron Microscopic (SEM) photographs of the EPDM insulators surface were tried to obtain but due to static charges in the samples, the author was unable to get these images, however, some visible discoloration was observed on the core as well as on the sheds of the insulator. Fig. 5-7, shows the hydrophobicity recovery of the tested insulators as the contact angle of the old aged insulator is more as compared to the newly aged insulator. It can also be seen that higher the UV-radiation intensity, the EPDM insulator shows more hydrophilic characteristics for the newly aged as well as old aged insulators. This property of EPDM material can be correlated with the static charge on the sample. Hydrophobicity recovery takes place after decaying these static surface charges. Therefore, charge accumulation on EPDM insulator should be considered in hydrophobicity recovery process.

V. CONCLUSIONS
In this study, the hydrophobic characteristics of a commonly used suspension type of composite EPDM insulator were studied by measuring the contact angle along the insulator surface before and after the accelerated aging as per modified IEC standard simulating the inland arid desert’s atmospheric condition and as per IEC-61109 standard. The following conclusions were drawn:

- The average variation in the contact angles from HV to ground electrode for top as well bottom of insulator shed is more consistent, however, the wide variation in contact angle was observed when the insulator was aged under high UV radiation intensity.
- The hydrophobicity of the EPDM insulator decreases with the increase in water salinity.
- The contact angle of the old aged insulator is more as compared to the newly aged insulator. This shows that the EPDM insulators recover its hydrophobic characteristics with the passage of time.

ACKNOWLEDGMENT
The author is highly indebted to the Research Center, College of Engineering, King Saud University, Riyadh for technical support and Saudi Arabian Basic Industries Corporation (SABIC) for financial support of this project (No. 18/428).

REFERENCES

Yasin Khan obtained PhD degree in Electrical Engineering from Kyushu University, Fukuoka, Japan in 2004. He also holds the MSc. and BSc degrees in Electrical Engineering (Power) from NWFP University of Engineering and Technology, Peshawar, Pakistan in 1997 and 1993, respectively. He was working in the Planning Commission, Government of Pakistan initially as Research Officer (1995-1997) and then promoted as Assistant Chief (1997-2000) in 1997. His main responsibilities in the Planning Commission included, preparations of energy plans, analysis of energy policy issues, load forecasting, appraisal and monitoring of energy projects, etc.

Dr. Khan has published more than 20 research papers in the international journals/conferences whereas he presented a number of papers in the national seminars of international repute. For excellent research work in the field of Electrical engineering, the Institute of Electrical Engineers of Japan (INEEJ) awarded him the "100th Anniversary Gold Medal" in the National Convention – 2002, held at Tokyo. Furthermore, he also won the "Best Paper Presentation Award for Young Researcher" in the Japan-Korea Joint Symposium on Electrical Discharges and High Voltage Engineering held at Miyazaki, Japan, in 2001. In 2009, he got the "Best Research Report" from the King Saud University, Saudi Arabia.

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