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Hydrophobic Characteristics of EPDM Composite Insulators in Simulated Arid Desert Environment

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***Abstract*—**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 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 proportional to the intensity of UV irradiations and its rate of recovery is also very low as compared to Silicone Rubber insulator.

***Keywords*—**EPDM, composite insulators, accelerated aging, hydrophobicity, contact angle**.**

I. Introduction

ELECTRICAL insulators form a very important component of high voltage electric power networks such as sub-stations and transmission & distribution lines. These are used to support the line conductors to separate them electrically from each other. In the early days, insulators were made of ceramic and glass materials. But in 1963, composite insulators were developed and its improvements in design and manufacturing in the recent years have made them attractive to utilities. The primary impetus for their increased acceptance by the electric power utilities is their substantial advantage 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]. 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_c) on the material surface that a liquid drop makes on the solid surface when it comes into contact with it. The hydrophobic materials allow less water surface contact and thus make $\theta_c > 90°$ as shown in Fig. 1(a), whereas materials which are easily wettable allow water to touch a large surface area and hence make $\theta_c < 90°$ as shown in Fig. 1(b) and is known as hydrophilic. Surface is said to be hydrophobic, when $\theta_c > 90°$, hydrophilic when $\theta_c < 35°$ and partially wettable when $35< \theta_c < 90°$ [2].

Two principal mechanisms exist for failure of composite insulators. These are mechanical failure and electrical flashover. The mechanical failure is catastrophic and irreversible. Modern designs have almost overcome this problem and the important challenge in this area is quality control [3]-[4]. Electrical flashover can occur due to transients in the network or the reduction of the insulator withstand capability. An insulator not able to withstand the system working voltage is considered as failed after prolong period of aging. The aging mechanism and the flashover processes are different for the ceramic and polymeric insulators due to different aging characteristics [3],[5]. Many investigations are attempted to study the actual hydrophobicity status of the composite insulators specially, the Silicone Rubber (SiR) insulators [6]-[7].

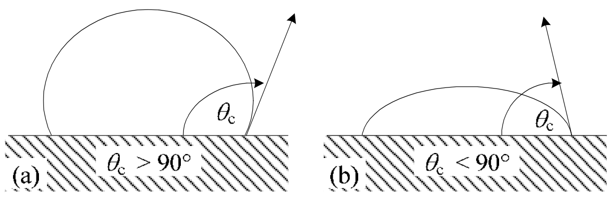

Fig. 1 Schematic diagram of water drop on:
(a) Hydrophobic surface (b) Hydrophilic surface

Polymeric materials are badly affected by environmental

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stresses like UV-radiations, heat, contaminations, moisture, etc. [5]. 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 [8]-[9]. 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 [10]. 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 [9]-[10]. To simulate the ambient conditions of arid desert, a wooden chamber was fabricated for the accelerated aging process for the EPDM test composite insulators. Schematic diagram of the chamber with suspension insulators and other accessories in place is shown in Fig. 2. Based on the above discussion, two types of experimental conditions were created in the accelerated aging test chamber for the tested insulator by applying different stresses mentioned in Table 1, 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.

TABLE I
APPLIED STRESSES

No.	*Stress type*	*Case-1*	*Case-2*
1	Voltage (p.u)	1	1
2	Temperature (°C)	~50	~50
3	UV-A radiation (W m^{-2})	10	40

TABLE II
EPDM TESTED INSULATOR DETAILS

Specifications	*Unit*	
Voltage class	kV	27
Section Length "L"	mm	224
Leakage Distance	mm	609
Power frequency flashover:		
Dry	kV	135.
Wet	kV	105.
Impulse flashover	kV	225.

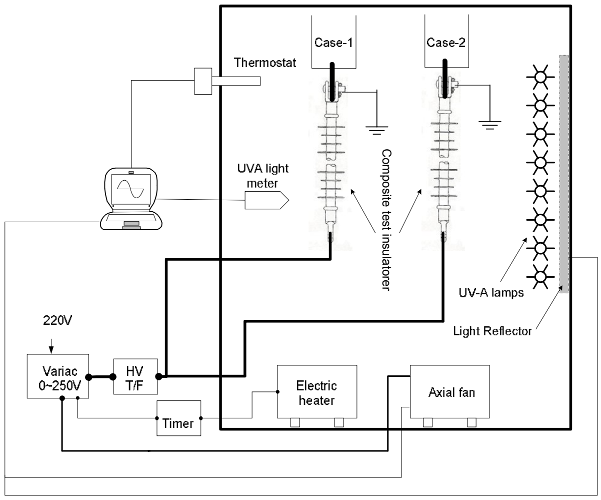

Fig. 2 Schematic diagram of accelerated aging cycle chamber

Three samples of EPDM suspension insulators procured from WT-Henley (UK) were used for accelerated aging for each case-I and case-II. Fig. 3 shows the photograph of the tested insulator. The salient dimensions of the insulators are mentioned in Table 2.

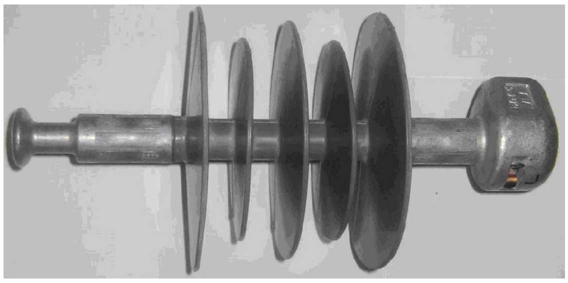

Fig. 3 Suspension EPDM insulator

The stresses mentioned in Table 1 above are applied in cyclic manner for duration of 1000 h is shown in Table 3. Each cycle lasts for 24 hours and a programmed change takes place every 6 hours

TABLE III
ACCELERATED AGING CYCLE

Time (h)	2~8 AM	8 AM ~2 PM	2~8 PM	8 PM ~2AM
Voltage (1 p.u)	On	On	On	On
Heating (~50°C)	On	Off	On	Off
UV-A radiations	On	Off	On	Off

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 aged and newly aged EPDM insulators, such as:

(i) New: These are un-aged (virgin) EPDM insulators

(ii) Already aged insulator: Also called 'old aged' of the same material as mentioned in (i) above. These insulators were

aged about 6 months ago 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

The schematic diagram of the composite insulator aged in the accelerated aging chamber (Fig. 2) is as shown in Fig. (5). One side of the insulator is always facing the UV lamps whereas, the other side is not. The contact angle for both sides i.e. front as well as back side of the insulator was recorded along the length of the insulator for the points A, B, and C (i.e. top, bottom and core), respectively as shown in Fig. 5. 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 and the data was analyzed by computer software "ImageJ". The drop volume was controlled in the range 10~25μL [12]. Deionized water of ~100μS conductivity was used. Methylene blue was added to change the color of the water to get more clear images.

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**.**

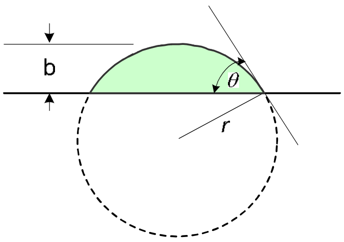

Fig. 4 Contact angle theoretical model.

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

III. Results

The EPDM insulators were placed and aged in the aging chamber as per Case-I (UV-A:1mW/cm^2) and Case-II (UV-A:4mW/cm^2) mentioned in Table 1 above and the contact angles were measured by using "ImageJ" software for the New (virgin), Old aged and Newly aged insulators. The results are graphically shown in Figures(6)-(8), that compares the EPDM insulator's shed-wise contact angle characteristics for the positions A (Top), B (Bottom), C (Core) as shown in Fig. 5 above, for:

(a) "***Old aged -Old aged***" insulator,

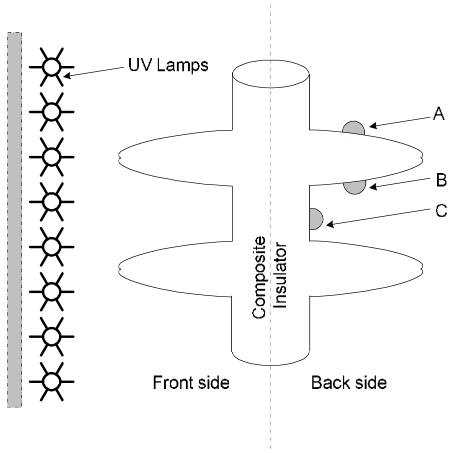

Fig. 5 Schematic diagram of composite insulator showing contact angle measurement positions

(b) "***New aged -New aged***" insulator,
(c) "***Old aged -New aged*** " insulator,

These results are explained as under:

*(a) "**Old aged -Old aged**" insulator,*

Fig. 6 compare the shed-wise top, bottom and core contact angle measurement results of front to back side for the old-old aged under UV radiations intensity of 1mW/cm^2 and 4mW/cm^2. Comparison of these figures clearly shows that contact angle for new (virgin) insulator is highest as compared to old aged insulators. Furthermore, it is also observed that the contact angle of aged insulator under UV radiation intensity of 1 mW/cm^2 is higher as compared to aged insulator under UV radiation intensity of 4mW/cm^2. It is also found that the part of the insulator facing the UV radiations have lower contact angle as compared to the back side of the tested insulator. Similarly, higher UV radiation intensity deteriorated the insulator surface more [9] and causes less contact angle as compared to lower UV radiation intensity thus the insulator shows a more hydrophilic behavior under higher UV radiation intensity.

*(b) "**Newly aged -Newly aged**" insulator,*

Fig. 7 compares the shedwise contact angle measurement results of front to back side for the new-new aged under UV radiations intensity of 1mW/cm^2 and 4 mW/cm^2. Comparison of these figures clearly shows that contact angle for new (virgin) insulator is highest as compared to newly aged insulators. Furthermore, it is also observed that the contact angle of aged insulator under UV radiation intensity of 1mW/cm^2 is higher as compared to aged insulator under UV radiation intensity of 4mW/cm^2. It is also found that the part of the insulator facing the UV radiations have lower contact angle as compared to the back. Similarly, higher UV radiation intensity that deteriorates the insulator surface has less contact angle as compared to lower UV radiation intensity thus the insulator shows a more hydrophilic behavior under higher radiation intensity. The variation in the contact angle for the newly aged and virgin insulator is more as compared to the variations depicted in Fig. 6, before.

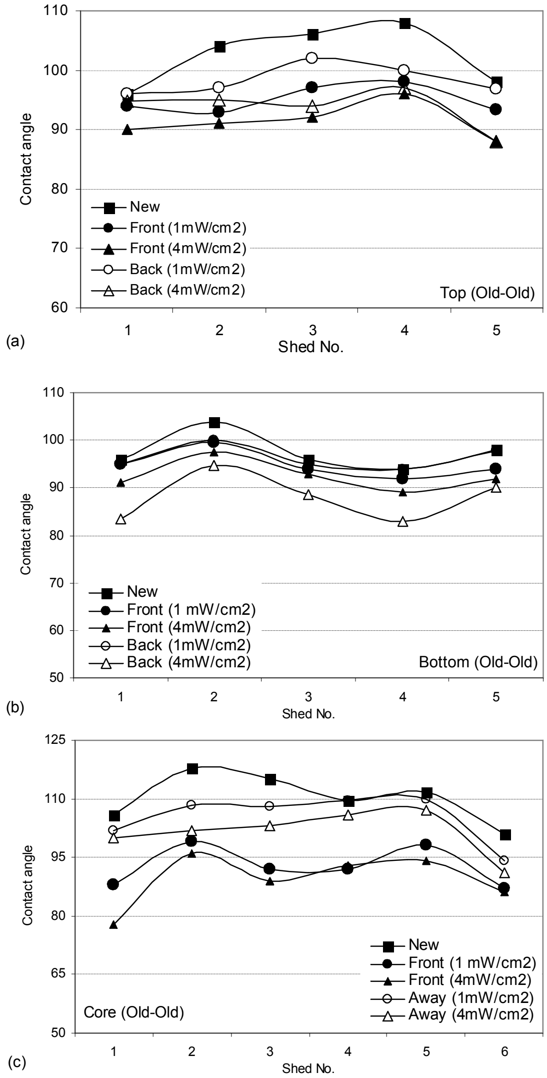

Fig. 6 Contact angle characteristics along the insulator sheds for old-old aged (a) Top (Position A, Fig. 5) (b) Bottom (Position B, Fig. 5) (c) Core (Position C, Fig. 5)

*(c) "**Old aged -Newly aged**" insulator,*

The contact angles data for the old aged insulators was compared with the newly aged insulator, and the result is shown in Fig. 8. Comparison of these figures clearly shows that contact angle for newly aged insulator is lower as compared to old aged insulator under. This result shows that the EPDM insulator also 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 [5], [13].

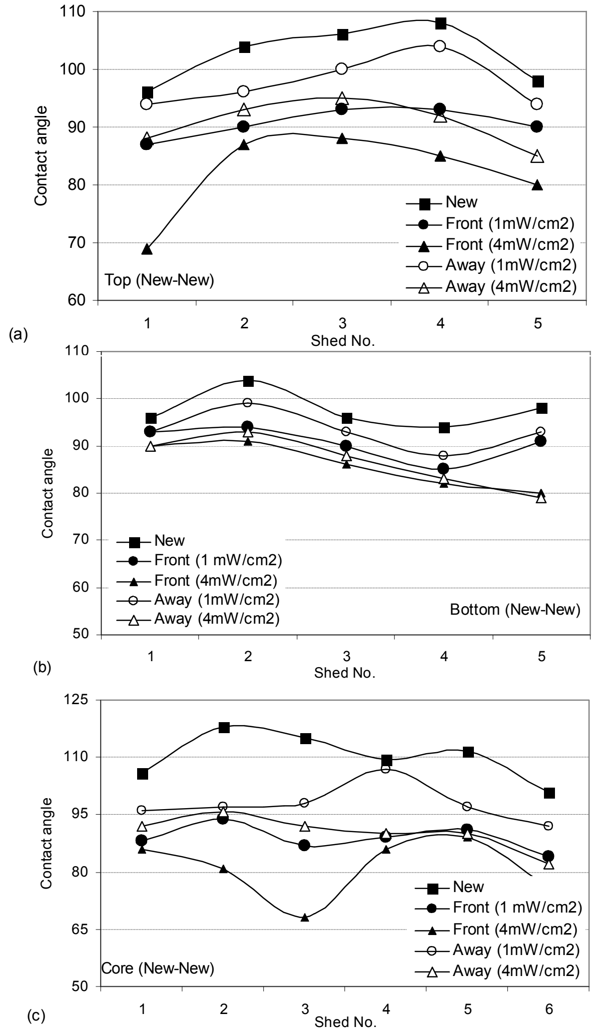

Fig. 7 Contact angle characteristics along the insulator sheds for New-New aged (a) Top (Position A, Fig. 5) (b) Bottom (Position B, Fig. 5) (c) Core (Position C, Fig. 5)

IV. Discussion

The contact angle measurements results depicted in figures (6)-(8) 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 [9] of the insulator material results in lowering the contact angles as indicated in figures (6)-(8). This result is in agreement with [6] although such dependency is not always observed [11].

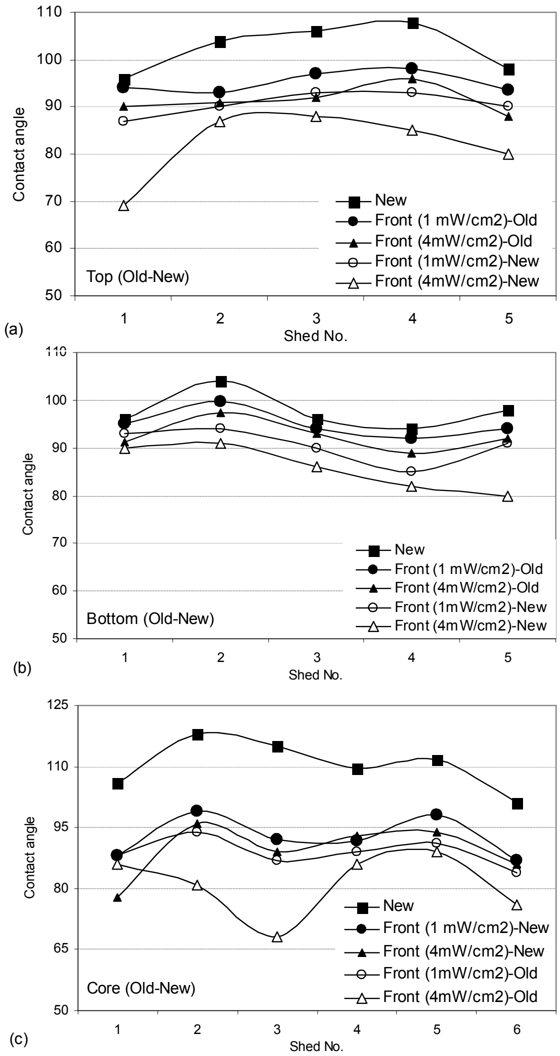

Fig. 8 Contact angle characteristics along the insulator sheds for Old-Newly aged (a) Top (Position A, Fig. 5) (b) Bottom (Position B, Fig. 5) (c) Core (Position C, Fig. 5)

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. $4mW/cm^2$) as shown in Fig. 7(a) & 8(a).

On the core the variation in contact angle is about 15°-20° from HV to grounded electrode end. The lowest values were observed in the center as evident from Fig. 7(c) & 8(c). 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 [7], [14]. 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. Fig. 8, shows the hydrophobicity recovery of the tested insulators as the contact angle of the old aged insulator is more as compared to the newly ages 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 co-related 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.

- Due to high temperature, high UV radiation intensity in arid desert conditions and high current densities in the core, more hydrophilic properties were observed on the front side as compared to the back side of the aged insulator.
- 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.

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REFERENCES

[1] EPRI Technical Brief, "*Polymer Insulator Survey-1007769*", April 2003
[2] M. Amin, M.Akbar, and S. Amin, "*Hydrophobicity of SiR used for outdoor insulation*, Rev. of Advanced Material Science, Vol.16, pp.10-26. 2007.
[3] G.G. Karady, "Flashover Mechanisms of Non-ceramic insulators", IEEE Trans. on DEI, Vol. EI-6, No.1, pp. 557-585, 1999.
[4] L. Kumosa, K. Kumosa, & D.Armentrout, "*Failure Analysis of non-ceramic insulators, Brittle fracture Characteristics*", IEEE Electrical Insulation Magazine, Vol. EI -21, No.3, pp. 14-27, 2005.
[5] R. Hackim, *Outdoor HV Composite Polymeric Insulators*", IEEE Trans. on DEI, Vol. EI-6, No.5, pp. 557-585, 1999.
[6] R. Sundarajan, A. N. Mohammad, T,Chaipanit, Z.Karcher, and Z. Liu, "*In Service aging and degradation of 345 kV EPDM transmission line insulators in a coastal environment*", IEEE Trans. on DEI, Vol. EI -11, No.1, pp.248-261, 2004.
[7] S.M. Rowland, Y.Xiong, J.Robertson, & S. Hoffman, "*Aging of Silicon Rubber Composite Insulators on 400 kV Transmission Lines*", IEEE Trans. on Dielectrics and Electrical Insulation, Vol. EI -14, No.1, pp.130-136, 2007.
[8] Y.Khan, M.I. Qureshi, N. H. Malik, & A. A Al-Arainy, "*Performance of composite insulators in simulated environmental conditions related to central region of Saudi Arabia*", IEEE, International Conf. on Emerging Technologies (ICET), pp. 303 – 307, 2006.
[9] Y. Khan, "*Degradation of High Voltage Polymeric Insulators in Arid Desert's Simulated Environmental conditions*", American J. of Engg. and Applied Sci., Vol. AJEAS-2, No.2, pp. 438– 445, 2009.
[10] IEC Standard-61109: *Composite Insulators for A.C. Overhead Lines with a Nominal Voltage Greater Than 1000 V - Definitions*, Test Methods and Acceptance Criteria", 1995.
[11] A.E. Vlastos, & E:Sherif, "*Natural aging of EPDM composite insulators*", IEEE Trans. on PWRD, Vol. 5, No.1, pp. 406-410, 1990.
[12] Swedish National Testing and Research Institute (STRI): *Hydrophobicity Classification Guide*", Guide 92/1, 1992.
[13] R.Sundarajan, E.Sundarajan, A.Mohammad & J. Grames,"*Multi-stress Accelerated Aging of Polymer Housed Surge Arresters Under Simulated Coastal Florida Conditions*", IEEE Trans. on DEI, Vol. EI -13, No.1, pp.211-228, 2006.
[14] J.Mackerich, & M.Shah, "*Polymers Outdoor Insulation Material, Part I: Comparison of Porcelain and Polymer Electrical Insulation*", IEEE Electrical Insulation Magazine, Vol. EI -13, No.3, pp.5-11, 1997.

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