International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

The Performance of Polymeric Insulators Which are Being Used in High Transmission and Distribution Lines in the Arid Desert Climate of South Libya

Abdelati M. Taher Jermi

Department of Renewable Energy, Faculty of Natural Resource Engineering, University of Zawia, Libya

Abstract

Libya currently, Polymers have huge production and are therefore enormously used especially in electrical applications. In the overhead transmission and distribution lines polymeric insulators are used in large quantities. The environmentally or naturally induced degradation mechanisms are creating major problems for the electrical properties of these polymeric insulators. The current study was conducted by the author in order to determine the condition of non-ceramic insulators that various power companies in Libya use. This experimental research was done to investigate the suitability of these polymeric insulators. The primary aim was to assess the performance of polymeric insulators which are being used in high transmission and distribution lines in the arid desert climate in the southern Al-Jufra region in Libya. The impacts of enormous heat and ultraviolet radiations on these polymeric insulators were studied. The accelerated aging test chamber was specially designed to achieve the objectives. The aging insulators' electrical strength (withstand) was then compared with the new polymeric insulators. The Dielectric performance indicated that Thermoplastic Elastomers (TPE) insulators overtake the Silicon Rubber (SiR) insulators.

Correspondingly an optical result shows that the surface roughness of the aged sample in the SiR case is more in contrast with the new insulators. However, very minor surface roughness was found in the case of aged TPE insulators over the equivalent aging period. The enhanced surface roughness of aged SiR Insulators might impact the dielectric performance after their exposure for a lengthy period in local environmental conditions.

Keywords: Risk assessment, High voltage polymeric insulators, SiR, TPE, degradation, Libyan climate.

1. Introduction

The line insulators overhead are generally used to support the line conductors at electric towers and poles to isolate them electrically from each other. Conventionally, the line insulators have been produced for a long time by using high-quality glazed porcelain and pre-stressed or toughened glass. Widespread research and the service experience on these materials have indicated that they are highly reliable and cost-effective for an extensive bulk of applications in outdoor However, in the last five decades alternative materials, known as polymers have appeared for use and are nowadays being used largely for different applications in outdoor insulator. Polymeric insulators are progressively being used, both in the distribution of electricity and in transmission voltage ranges. They are steadily taking a broader market share internationally.

Primarily, polymeric insulators (also known as composite insulators or non-ceramic insulators) were thought to be a replacement for porcelain and glass for various special applications including areas having high incidences/occurrences of vandalism, urban locations which are having restrictions on the right of the way and also areas having severe problems of contamination. Nevertheless, many problems were faced with regard to their performance in real service during the initial two decades of its operation. The typical problems in these include: the polymer sheds tracking and erosion, the chalking & crazing of the sheds which can lead to amplified contamination collection, the arcing and flashover, the bonding failures and the electrical breaks alongside rod-shed interface, the corona piercing of the sheds and the water penetration that can bring electrical breakdown [1].

Currently, the polymeric insulators are applied in electric lines which are operating to about 765kv power. Although, they are generally famous for use on transmission levels ranging between 69 kv to 345kv, a fresh global survey indicates that the polymeric insulators that are in service for different voltage levels are thousands in number.

2. Study area

Libya is located in the middle of the northern part of Africa continent is located in the world coordinates from 20^0 N to 34^0 N latitudes and between 10^0 to 25^0 E longitudes [2]. The total area of libyay is approximately 1,759,540 square kilometers.

Al-Jufra is part of Fezzen (former province) geographical division in Libya and it is mostly desert area. Al-Jufra is one of the oldest districts in the country. It lies almost in the centre in Libya. AI-Jufra district have common borders with Site district in the north, Al Wahat district in nonheast, AlKufra district in cast, Murzuq district in the south, Sabha district in the southwest, Wadi al Shati district in the west whle the Jabal al Gharbi district in the northwest Houn is an oasis town and also the capital of Al-Jufra district. Houn is about 240 kilometers south of Sirte Distance between Hoon and Misrata is about 370 kilometers. Houn lies about 272 kilometers north of Sabha Hoon lies in the Sabara Desert and is approximately midway betweon Sabha and the Mediterancan coast.

3. The climate setting and environmental

Weather parameters can have detrimental effects (cracking and chalking) on the aging of non-ceramic materials. The direction and speed of wind, precipitation, relative humidity, and the position of pollution sources all determine the final pollution deposit on an insulator surface [3]. Sunlight can heat up the insulator surface during the day and help prevent wetting. Thus, environmental factors can play an important role in insulator pollution flashover [4].

Generally, almost 95% of Libya lies within the scope of the greater Sahara Desert. The Libyan topographical features encompass two different types of terrain the desert terrain that covers most of the southern regions of Libya and some parts of northern areas and the semi-desert terrain that covers the areas along the Mediterrancan Sea of the country [5].

The study of climate is essential in modern urban planning, construction, and other infrastructure. Climate change may affect the urban environment in different ways. According to Elbendak (2007), who stated that the climate "affects urban life with all respect from Climate in Libya is changing throughout the country”. The northern part of the coast is very Mediterranean with a semi-arid climate. This type of climate is characterized by hot and dry weather in the summer from April to September and cold weather in winter from October to March. This region has an average monthly temperature of 35°C in the summer to 5°C in winter. The Mediterranean climate disappears the other south towards the desert moving. There the temperature can rise to between 40°C and 50°C for a few hours. The southern region is characterized by dry desert climate, characterized by dry summer heat, and dries cold in the winter because it is desert [6, 7]. The rainy season begins in autumn and continues until spring.

The study area of Al-Jufra lies in the desert climate type. It is the same in almost the entire Saharan region in Northern Africa. The Deserts in the study area have characteristics of low rainfall which is highly variable both in seasons and also among seasons. The Desert air in the study area is very dry and has large temperature variations occurring during the day and night. Also, the potential of evapotranspiration is very high. The desert climate type in the study area in Libya is distinguished by high mean annual temperature. The nearby locations of Al-Jufra also have high mean annual temperatures including the areas of Al-Kufra 23.3°C, and Sabha 23.4°C. The annual rainfall is also highly erratic in Al-Kufra rainfall is 2.1 mm, and in Sabha 9.0 mm. In addition to the high range of mean annual temperature like in Al-Kufra temperature is 15°C and Sabah is 14.7°C. Summer temperatures in the study area are exceptionally hot and extremely harsh. The mean summer temperatures are 30.8°C and 30.6°C in Al-Kufra area and Sabha area respectively [8].

4. Effect of Climate on the performance of polymeric insulators

Insulator properties of Silicone rubber (SiR) could be badly affected when it is subjected to climate factors, High temperatures will lead to an increase in the electrical conductivity of the silicone rubber (5iR). Ultraviolet radiation exposure causes a significant change in the chemical bonds of the polymer by cross-linking reactions, and the resistance of SiR Insulator surfaces is decreased when subjected to fog. Mist or rain Environmental impact on outdoor polymer insulators constitutes a substantial research area [9, 10, 11, and 12]. An extensive list of publications describing detailed studies and developments on insulator contamination has been prepared by the working groups on insulator contamination, with increasing pollution from industrial sources and agricultural sources and shifting to ever-increasing transmission voltages, nsulator flashover shall have more serious and more costly repercussions. Modem service quality requirements demand good insulator performance As a result studies have been conducted with a view to improving insulator performance by increasing leakage path length, modifying the insulator design (e.g. texturing), and using surface coatings.

For the successful application of polymeric insulators, it is very important to know that polymeric materials degrade with exposure to natural environmental factors. The main environmental processes giving rise to insulator degradation are Ultraviolet radiations, temperature variations, moisture (humidity), winds, and pollutants [13, 14]. The severity of degradation due to the above-mentioned factors is mostly dependent on their intensity, duration, and sequence. Additionally, electrical factors, such as discharges, corona, and leakage current, play significant roles in the process of aging [15, 16].

5. Literature review and data collection

Designed for use in outdoor installations the polymer insulators are being accepted more by the conventionally careful electric power functions globally.

Currently, they represent about 60 to 70% of the newly installed High Voltage insulators in North America [17]. This tremendous increase in the use of non-ceramic composite insulators with the reason of their advantages as compared to conventional ceramic insulators and glass insulators, The advantages include their lightweight, enhanced mechanical strength-to-weight ratio, resistance to vandalism, better performance in areas of heavy pollution, and in humid conditions, als Comparable or excellent withstand voltage by comparison porcelain insulators or glass insulators. Nevertheless, the polymeric insulators comparatively are new and their predictable lifetimes, as well as their long-term consistency, are not understood well so, therefore, it is of concern to the uses. In addition to these, they could be damaged by erosion and tracking due to the reason of severe contamination and sustained moisture in the area. This might lead to the development of dry band arcing which due to certain conditions would result in the failure of the polymeric insulators.

6. Experimental setup and the procedure

- **Polymeric insulator's significance in accelerated aging**

The weather features that can degrade the polymers especially if energized are heat, light, and moisture. Chemical pollutants including sulfur dioxide and the ozone can also degrade materials. An additional significant factor is Oxygen which can maintain constant concentration in the atmosphere. Supplementary factors like wind, dust, microbiological organisms, ozone, and additional chemical pollutants. In the coastal areas, significant is the salt. Besides chemical effects, moisture and precipitation can have a pronounced impact on the physical nature.

In the south of Libya, the weather conditions are considerably severe and the changes occur from daytime to nighttime. The areas lying inland are extremely hot, dry, and dusty. The Ultraviolet rays that can cause chemical changes in composite insulators are enormously high in this area. For selecting a proper material having significant resistance against weathering, it is of utmost importance to have an understanding of the weather factors and how they are affecting the different materials. These situations demand more precise and systematic research for optimizing design criteria in the deserts and dry regions such that prevail in the south of Libya.

In this respect, experimental investigations were done to study the impacts of the ultraviolet rays in addition to heat on the composite insulators' performance. To achieve this objective, the accelerated aging test was first designed and then implemented.

- **Acceleration of the aging cycle**

According to the IEC standard 1109, for the process of accelerated aging [70] (for the non-ceramic (polymeric) and composite insulators) the tests were conducted on the polymeric insulators that were produced by SiR and TPE, different stresses to be used in cyclic manner, as according to the standard IEC 1000 hours test are:

- Simulation by Solar radiation.
- Dry heat.

Moreover, the temperature difference can cause nearly some degree of mechanical stress, especially at insulator interfaces, and also can give rise to condensation phenomena that are repeated a few times in the course of the cycle.

The aging cycle involves electrical, temperature, and Ultraviolet ray stresses applied as shown in Table 1. Here, every cycle lasts for 24 hours and the programmed change takes place after every 6 hours interval. Through the time when heating is not in operation, the insulators will be cooled down to the ambient temperature. As per the standard, a rise from the ambient temperature to the desired level would take less than 15 minutes. Ultraviolet rays around 1m W/cm² were sustained on the surface of the insulator for a period of about 6 hours.

Table 1: Accelerated Aging Cycle

Measuring time (hours)	**2 to 8AM**	**8 AM to 2 PM**	**2 to 8 PM**	**8 PM to 2 AM**
Heating temperature (~57°C)	in Process	out Process	in Process	out Process
Radiation degree (1mW/cm)	in Process	out Process	in Process	out Process
AC voltage (28 kV) line	in Process	in Process	in Process	in Process

- **Accelerated aging test chamber design**

For the non-ceramic insulators having accelerated aging as in accordance with the IEC standard [18] the wooden chamber was made in the faculty of electrical engineering laboratory, Hoon, Libya. Dimensions are 120cm wide Hig x 180cm long approximately of the test chamber. About 12 post insulators having 28kVL-L, an equivalent number of suspension insulators with dead ends, could be subjected to an accelerated aging cycle in the chamber. The higher voltages are possibly having very little alterations in the chamber. The schematic diagram of this chamber is presented in the Fig1 while the picture of the front view of the chamber has a 28 kV suspension ínsulator on a plate as shown in the Fig 2. The data was then transferred from the sensors to the PC wíth help of CASSY® laboratory software having version 1.53 (1eybolds LD Didactic, GMBH).

Fig 1: a& b shows the picture of the tested insulatorrs and c shows photograph

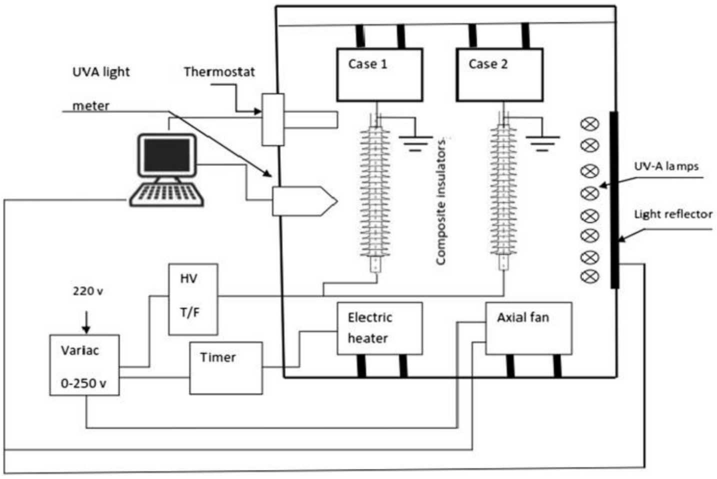

Fig 2: Schematic diagram of experimental setup

- **Details.of Polymeric Insulators**

Three SiR insulators as well as three TPE distribution or dead-end type of insulators having a rating of 28Kv $_{L\text{-}L}$, obtained from the GLP Power Canada were applied for the laboratory accelerated aging study.

Table 2: The Salient Dimension of theTested Insulators

Specifications		Unit	Thermoplastic	Silicon Rubber
Voltage stress line		kV$_{L.L}$	28	28
Section Length "L"		mm	438	433
Dry arcing Distance		mm	285	290
Leakage Distance		mm	675	590
Flashover Power Frequency	**Dry**	kV	136	129
	Wet	kV	106	116
Flashover Impulse		kV	230	213

- **Arrangement of heating**

According to the IEC standard of 1109[18, 19] for an accelerated aging cycle, the increase in temperature and fall in the chamber must occur in only 15 minutes.To achieve this objective, the increase or decrease in temperature data is calculated in the chamber in addition to the surface of polymeric insulators, using the K-type

- **Timers**

For controlling the time-dependent aging cycles, heat and Ultraviolet radiations are applied to tested insulators in a cyclic manner. Every heater and the Ultraviolet lamps are put in the control system of ON & OFF after a period of approximately hours. The control system of the heater and the Ultraviolet lamp is achieved automatically by electric timer's type of TH-30A (Kawamura, Japan).

7. Experimental aging testing conditions

Two types of experimental conditions were generally created in the accelerated aging test Chamber for every type of tested insulator due to applying various stresses described in the Table 3.

- Case 1: Based on the IEC standard of 61109 [21].
- Case 2: Modified aging cycle which is based on actual Ultraviolet -A radiations level(40W m^{-2}).

Table 3: Applied Stresses

Stress type	Case 1	Case 2
Voltage (28 kV)	1	1
Temperature (57^{O}C)	57	57
Radiaition (1 mw/cm^{2})	1	4

In order to simulate solar irradiations, eight UV lamps having the same law, end cutoff wavelength as sunlight were utilized. The UV-radiation intensity for the two cases was controlled by adjusting the distance between the lamps and insulators.

The stresses mentioned in Table 3 above are applied in a cyclic manner for duration of 1000 h as shown in Table 4. Each cycle lasts for 24 h and a programmed change takes place every 6 h.

Table 4: The Accelerated Aging Cycle

Time(h)	**2 to 8AM**	**8 AM to 2 PM**	**2 to 8 PM**	**8 PM to 2 AM**
Voltage (28kv)	On	On	On	On
Heating (~57 °C)	On	Off	On	Off
Radiation (1 mw/cm²)	On	Off	On	Off

8. Results and discussion

1. The lighting impulse withstands the test

For comparing the effect of the accelerated aging with all laboratory aged in addition to the control (or new) insulator samples of every type (both the SiR Insulator and TPE insulator) then was subjected to the applications of impulse voltage. An impulse generator is then adjusted for producing the standard Lightning Impulse (LI) waveforms (1.2/50us) having both positive & negative polarities. An increase in voltage was done in smaller steps with 1.0 kV until a flashover occurred at the critical level. This method of the test was repeated 3 to 5 times as well and the average value of the tests on 3 units in the case of the aged sample and 1 unit in the case of the un-aged sample were registered for comparison purposes.

The results being described here were corrected with standard atmospheric conditions according to the IEC publication of 60-1 [21] Table 5shows a comparison of flashover voltages of all insulators aged by the laboratory in addition to un-aged insulators or the new insulator of both materials (SiR insulators and TPE insulators) under the +LI and also the -LI.

Comparison between TPE and Sir of flashover voltages under the +LI and –LI It is clear from this fig that TPE insulator outperforms SiR Insulator as the effect of aging on TPE is minimal. For SiR Insulators about 9% and 14% reduction has been observed under +LI and -LI respectively, whereas only about 4% reduction is observed in the case of type TPE insulators.

Table 5: Percntage of VBD Reduction withRespict to (w.r.t) Virgin Insulator

Test Type		**Percentage of VBD reduction w.r.t new insulator**			
		SiR		**TPE**	
		1 mW cm^2 (%)	4 mW cm^2 (%)	1 mW cm^2 (%)	4 mW cm^2 (%)
Lighting Impulse	**Positive**	9	10	4	11
	Negative	14	14	4	7.5

Table 6 shows comparisons of flashover voltages (kVp) of all aged insulators in addition to the new insulators for both positive and negative polarities. It is clear that SiR Insulators are comparatively better than TPE insulators as the effect of aging on SiR is slightly less as compared to TPE. For TPE insulators about 7 and 11.5% reduction as compared to virgin insulators being measured in the +LI and -LI, respectively. While a mere around 7% to 9% decrease was found in the case of SiR Insulators.

Table 6: Flashover Voltages underNegative Lightning Impulse

Test Type	**Flashover Voltages (kV)**					
	SiR			**TPE**		
Lighting	**New**	**1 mW cm^2**	**4 mW cm^2**	**New**	**1 mW cm^2**	**4 mW cm^2**

Impulse	**Positive**	235	227	212	240	232	228
	Negative	275	258	255	244	230	220

2. The dry power-frequency withstand test

A 200 kV power transformer was used for performing the Dry power according to the IEC-38311881 and adjusted for meeting the IEC-60-1 [22] an artificial rain employed as the requirements for resistivity and the rain intensity (or precipitation) for the horizontal as well as the vertical insulators components. The resistivity of water was tuned to 10552-m whereas the rate of rainfall was kept at 1.5 mm/min.

The samples then were wetted for 15 minutes duration before applying the test voltage. The voltage at around 75% of withstand test voltage then was used in the ramp and so gradually enhanced having a rate rise of around 2% / second until the occurrence of flashover.

The withstand voltage of every test is the highest reading which is maintained for 1 minute prior to the flashover taking place. A Flashover voltage is usually the average mean value of the three successive flashovers having a one-minute interruption among the two succeeding flashovers. After correction to the standard conditions of the atmospheres, the voltage values shown in the Table 7

Table 7: Percntage of VBD Reduction withRespict to (w.r.t) Virgin Insulator

Test Type	**Percentage of VBD reduction w.r.t new insulator**			
	SiR		**TPE**	
	1 mW cm^2 (%)	4 mW cm^2 (%)	1 mW cm^2 (%)	4 mW cm^2 (%)
Power Frequency Dry	6.5	13.8	Negligible	4.7

Table 8: Flashover Voltage under 60 Hz. AC (Dry)

Test Type	**Flashover voltages (kV)**					
	SiR			**TPE**		
Lighting Impulse	**New**	**1 mW cm^2**	**4 mW cm^2**	**New**	**1 mW cm^2**	**4 mW cm^2**
	137	130	122	128	125	121

Table 8 results indicate that UVA radiations and heat are important factors in the degradation of polymers. The results of the breakdown of various molecular bonds with Ultraviolet rays indicate to as they are much more vulnerable to oxidation [23, 24, and 25]. The roughness of the surface can be the dust source and also the pollution accumulation thereby causing a decrease in the dielectric performance in composite insulators for the longer-term application in the system of polymers' actual power.

9. Conclusion

In the southern region of Libya which is mostly the arid desert addition to weather conditions in this region being very severe the level of ultraviolet radiation is well exceeding 4 mW/cm^2 whereas the current study shows that the surface temperature of the insulators will rise from 5 °C to 11 °C over which ambient predominant atmosphere temperatures range from 42°C to 57°C.

All users appear to agree that the key advantages of composite insulators over ceramic or glass insulators are superior. The use of thermoplastic elastomeric (TPE) materials is continuously increasing for huge applications in daily life. Over-molding and encapsulation are the most widely used applications of TPE materials. About 85% of plastic products in the modern world are made up of TPE thermoplastic elastomeric materials because they provide competitive price performance as compared to other natural rubbers.

And thermoplastic elastomeric TPE material for any particular application requires a special focus, on chemical, mechanical, and electrical properties. The glass transition temperature of a TPE material is the temperature at which many of its properties start changing. Above the temperature, the polymer is most susceptible to degradation. All TPE materials are based on two major components a hard thermoplastic and a soft elastomeric. The physical properties show the advantages of both rubber and plastics. TPE materials are environmentally friendly and very easy to recycle. In addition to that their major disadvantages are low thermal and chemical resistance and a bit high cost. But the advantages offered by them dominate the disadvantages that is why their use increasing by day.

Results of the study also revealed that TPE types of insulators outperform the SiR Type insulators by subjecting them to accelerated aging laboratory tests which were adopted by the tests.

The Research showed that multi-stress tests aging are being compared to the actual field aging. A long-term multi-stress accelerated aging for the thermoplastic insulators in a changing environment is required. The aging or biological deterioration nowadays is a major problem for composite insulators.

Also, the Research showed that multi-stress tests aging are being compared to the actual field aging. A long-term multi-stress accelerated aging for the thermoplastic insulators in a changing environment is required. The aging or biological deterioration nowadays is a major problem for composite insulators. The key thing for aging is predicting how, when, and with how much speed it is occurring and in which conditions it will be leading to failure & what is average expected life of the composite insulator as a whole is. To search out this various research works have been completed.

10. References

1. J.R. Hall, "History and Bibliography of Polymeric Insulator's", IEEE Trans. on PWRD, Vol. 8, pp. 376-385, 1993.
2. E.A. Cherney, "RTV Silicon- A High Tech. Solution for a Dirty Insulator Problem", Electrical Insulation Magazine, Vol. 11, No. 6, pp. 8-14, 1995.
3. A.E. Vlastos and E. Sherif, "Experience from Insulators with RTV Silicone Rubber Sheds and Shed Coating", IEEE Trans. on PWRD, Vol. 5, pp. 2030-2038, 1990.
4. E.A. Chemney, G. Karady, R.L. Brown, J.L. Nicholls, T. Orbeck and L. Paragamin, "Application of Composite Insulators to Transmission Lines", IEEE Trans. on PAS, Vol. 102, pp. 1226-1234, 1983.
5. IEEE Std. 1133-1988, "IEEE Application Guide for Evaluation Non-Ceramic Materials for HV Outdoor Applications", 1988.
6. IEC 1109-03, 1992, "Composite Insulators for AC Overhead Lines with a Nominal Voltage Greater than 1000 V-Definitions, Test Methods and Acceptance Criterion".
7. "American National Standard for Composite Suspension Insulators for Overhead Transmission Lines Tests", ANSI-C29, 11, 1989.
8. L. Gutman, R. Hartings, R. Matsouka and K. Kondo, "The IEC 1109, 1000 h Salt-Fog Test: Experience and Suggestions for Improvements", Nordic Insulation Symps, Bergen, June 10-12, pp. 389-398, 1996.

9. L. Gutman, R. Hartings, R. Matsuoka and K. Kondo, "Experience with IEC 1109 1000 h Salt-Fog Aging Test for Composite Insulators", IEEE Electrical Insulation Magazine, Vol. 13, No. 3, pp. 36-39, 1997
10. I.Y. Al-Hamoudi, "Performance of SiR Insulators in Easter Coastal Industrial Area of Saudi Arabia" CIGRE 2000, Paper No. 15-101, 2000.
11. R. Sundarajan, Esaki, Sundarajan, A. Mohammed, J. Graves, "Multistress Accelerated Aging of Polymeric Housed Surge Arrestors under Simulated Coastal Florida Conditions", IEEE Trans. on DEI, Vol. 13. No. 1, pp. 211-225, 2206.
12. R.S. Gorur, E.A. Cherney and R. Hackam, "A Comparative Study of Polymer Insulating Materials Under Salt-Fog Conditions", IEEE Trans. El. Vol. 21, pp. 175-182, 1986.
13. F. Shmuck and B. Barsch, "Electrochemical and Microbiological Phenomena During Accelerating Aging Tests of Polymeric Insulators", Proc. of 8th ISH, Yokohama, Japan, Paper 41.02, 1993.
14. P.J. Lambeth and H.M. Schneider, "Clean Fog Test for HVAC Insulators", IEEE Trams on PWRD, Vol. 2, pp. 1317-1326, 1987.
15. R.E. Carberry and H.M. Schneider, "Evaluation of RTV Coating for Station Insulators Subjected to Coastal Contamination", IEEE Trans, on PWRD, Vol. 4, pp. 577-585, 1989.
16. EEE Dielectrics and Electrical Insulation Society in Outdoor Service Environment Committer S-32-3. “Round Robin Testing of RTV Silicone Rubber Coating for Outdoor Insulations”, IEEE Trans On PWRD, Vol. 11, pp. 1881-1887, 1996.
17. S.M. de Oliverica and C.H. Toureill, "Aging of Distribution Composite
18. Noble, and H. Gitay. "Deserts in a changing climate: impacts", Climate change, IPCC, Cambridge University Press. 1995.
19. X. Lin, Z. Chen, X. Liu, K, Chu, K. Morita, R. Matsouka and S. Ito, "Natural Insulator Contamination Test Results on Various Sheds Shapes in Heavy Industrial Contamination Areas", IEEE Trans, on El, Vol. 27, pp. 593-600, 1992.
20. R. Matsuoka, H. Shinokubo, K. Kondo, Y. Mizuno, K. Naito, T.Fujimura and T. Terada, "Assessment of Basic Contamination Withstand Voltage Characteristics of Polymer Insulators", IEEE Trans on PWRD, Vol. 11, pp. 1895-1900, 1996.
21. H.E. Schroeder (Carl Hanser Verlag, Munich, vol.80, 1987), p. 574.
22. R. S. Gorur, and T. Orbeck. "Surface dielectric behavior of polymeric insulation under HV outdoor conditions." IEEE Transactions on Electrical Insulation, vol. 26. no. 5, pp. 10641072. 1991.
23. S. M. Gubanski. "Properties of silicone rubber housings and coatings," Electrical Insulation, IEEE Transactions on, 27, 374-382.1992.
24. P. Toensmeier. "TPE formulations show new versatility," Modern Plastics. Vol. 72. 70. May 1995.
25. B. M.Walker, C. P. Rader, Eds. "Handbook of Thermoplastic Elastomers", Van Nostrand Reinhold Company, New York, 4-5.1988.
26. Elbendak, Omar Emhamed. Urban transformation and social change in a Libyan city: An anthropological study of Tripoli. Diss. National University of Ireland Maynooth, 2008.