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AGING RESEARCH ON SIR AND TPE INSULATORS (AN OVERVIEW)

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Abstract. Silicon Insulating Rubber and Thermoplastic Elastomeric Materials have replaced old ceramic insulators since last three decades and are being used all over the world now-a-days. Moreover they are used very extensively as outdoor electrical Insulation. These materials being partially organic age / degrade due to environmental effects e.g. UVR, Temperature, Humidity and Rain etc, so their performance check is very essential before use in any environment. Accelerated Multistress aging technique is the best one at the moment. This paper describes this technique in detail. The results of many such analysis performed in world has been summarized and useful conclusions drawn along with the future needs of research.

1. INTRODUCTION

To determine the performance of any insulation material, it is necessary to investigate its weather resistance. The weather factors include UV radiation, rain, salt fog and industrial pollutants and biological degradation etc. Polymeric insulators are very successful and have a lot of advantages over ceramic insulators. But, still they have only taken about 50% share of market in many countries. The reason is that polymeric materials due to organic nature age (degrade) biologically. Commercially available polymeric insulators are not older than 30 years. So this time is not enough to guarantee that they can sustain for long times in environments all over the world, especially where biological degradation is worse and/or fast.

Since biological effects are different in each region of earth, so it requires aging of polymeric insulators in each region of earth prior to use in that region. Before they are readily adopted as future insulators, a lot of work on their life estimation is required. A lot of work is in progress all over the world.

The Silicon Rubber (SiR) and Thermo Plastic Elastomeric (TPE) insulators are two 3rd generation materials among the polymers used for making outdoor insulators. They have good leakage current suppression capabilities under intense environment. Long term investigation of these insulators under conditions that simulate the service environment is of practical interest to effectively utilize them. The experience with SiR Insulators is reported in literature. However, a very few authors have reported the experience with TPE insulators. This paper presents literature review of aging of SiR and TPE insulators.

2. AGING OF INSULATORS

Aging is the application of stresses to an insulator, that it is expected to encounter in real life service environment, in order to see what would be its status and/or performance after a certain time. This time can be long or short which define long term or short term aging respectively.

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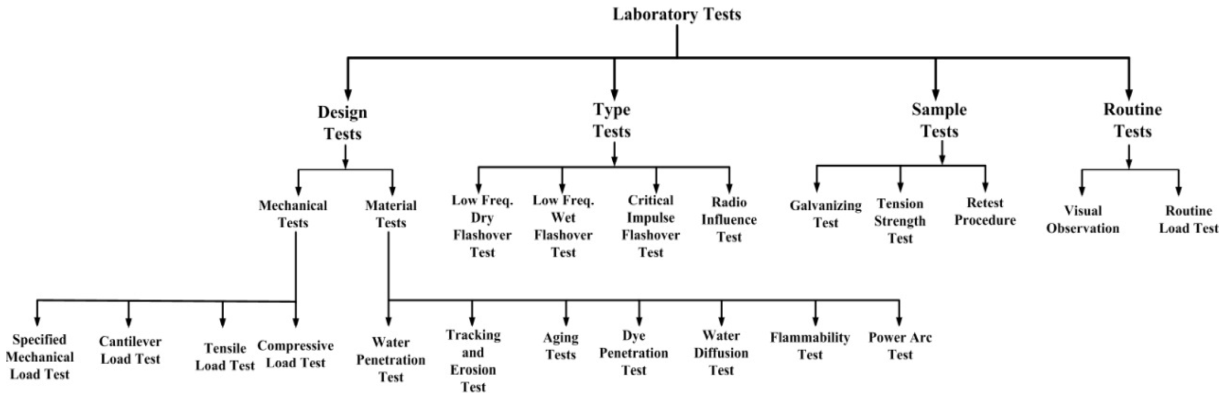

Fig. 1. Types of laboratory tests on polymeric insulators.

2.1. Natural aging

Installation of an insulator in actual outdoor environment for some period of time and to measure / estimate its performance.

2.2. Artificial or Lab aging

In this kind of aging, the insulator is subjected to Simulated Environment inside a room or chamber. It can further be classified into three categories.

1) Tests in laboratory
2) Multi Stress Lab Aging
3) Accelerated Multi Stress Lab Aging.

Tests in laboratory

These tests simulate the effect of any individual environmental parameter(s). A detailed classification of these tests is shown in Fig. 1.

Multi stress aging

All the environmental stresses are applied on the insulator to be aged in a closed chamber or room. Day, night, summer and winter season are simulated. Although, the time taken to age a sample in case of Multi stress lab aging is same as to that of natural aging, but it has a few advantages over natural aging. These advantages include easy application of many analysis techniques simultaneously to estimate state of aging, which are difficult to apply in outdoor environment such as leakage current measurement, HC classification, Frequent Visual observations etc.

The Natural and multi stress lab aging have the draw backs that they take a long time to age a sample. For example, if we want to see the effect of aging on an insulator after 30 years, no one can wait 30 years. To resolve this problem, H.M. Schneider and his associates first ever put the concept of Accelerated multi stress lab aging of non ceramic (also called organic or polymeric) insulators in 1991.

Accelerated multi stress Lab aging

In the accelerated multi stress lab aging, all the stresses are applied on insulators like they appear in real life, but in a calculated accelerated manner by simulating day and night cycles which are simulated faster than actual. But overall temperature, UV radiation simulating sunlight, rain etc. are also increased. The increase is not straight. Some stresses cancel each other like effect produced by UV is nullified by rain, so while applying acceleration one has to take into account these factors.

Accelerated multi stress aging of polymeric insulators simulates real field conditions and produces result just like natural aging. It also has advantage of causing these changes to occur in less time. Hence, effect of long term natural aging can be achieved in short time. The accelerated multi stress lab aging has now become very popular to test any material and especially polymeric insulators.

Multi stress aging weather cycles

Weather cycle is a term used to represent a sequence of test conditions which repeat themselves just like days and nights and summer and winter season come and go. A very large number of weather cycles can be developed based on weather in all regions of world. A few weather cycles have been developed for testing which correspond to weather of some very intense regions of world. These are listed below [5].

1) EPRI Florida Cycle Test
2) EPRI High Western Desert Cycle Test
3) CIGRE 5000h Cycle Test

4) ENEL 5000h Cycle Test.

2.3. Survey on natural aging

W.L. Vosloo, R. Swinny and J.P. Holtzhausen, [5] indicated Koeberg Insulator Pollution Test Station (KIPTS), which is situated along the Cape West Coast, near Koeberg Nuclear Power Station, South Africa. The test station consists of test bays for 11, 22, 33, 66, and 132 kV. The setup was made to prevent the entry of inferior quality polymeric insulators in South Africa. Many specimens were tested here in natural environment ranging from 8 months to 5 years maximum. The authors of this research state that results of natural aging still not guarantee the exact performance of insulators because of vast variety of materials and environments. The authors also state that IEC 601109 and IEC 1109 standards used for insulator testing have passed the insulators, which were failed lately in outdoor environment only after 8 months, because these standards were built for the only environment of Sweden. So, Polymeric insulators can not be tested according to a fixed standard, instead they should be aged independently according to every environment, where they are intended to be used. Authors also suggest that artificial accelerated aging methods must be used side by side with natural aging.

Wang Shaowu, et al. [6] studied the various kinds of SiR insulators removed after five years of service from 110 kV to 220 kV lines. The authors state that results were satisfactory. But, however, this time is not enough to predict what could be maximum life of these insulators.

Arnaldo G. Kanashiro, Geraldo F. Burani, [7] studied the aging of EPDM insulators for 3 years in environment of Brazil (EPDM is 2nd Generation of Polymeric material used for making insulators). Authors use some algorithm based on leakage current of these insulators, to evaluate the useful life and state that 25 years of life is guaranteed.

Brian Poker, Colin Lee, Don Hawker [8] (IEEE, ICPADM,1994), performed the comparative natural aging of EPDM and SiR long Rod Polymeric insulators in environment of Queensland, Australia for a period of two years. This setup was constructed by Queens Land Electric Company, Australia in 1978 to investigate long and short term outdoor performance of insulators. After several failures, QEC initiated a project to develop leakage current monitoring in late 1980’s. The test site chosen was a highly polluted industrial area with coal burn offs and saltish pollution. The industrial pollution in that area also contains sulphates. Under wet conditions the sulphates are more conductive than chlorides which are found in coastal areas [3]. This was the reason to choose industrial area for this testing. The results indicate best leakage current suppression capability of Silicon Rubber (SiR) insulators. Decreasing length of a certain SiR insulator from 6112 mm to 4801 mm only caused a very slight increase in leakage current. The EPDM was found to come next with 2 to 3 times the leakage current of SiR. However, after every prolonged rain, these current levels decreased. It was seen that rain did not remove pollution from composite insulators sufficiently. Still these insulators preserve good leakage current suppression. The reason for this is LMW transfer to pollution layer making it hydrophobic [13]. The authors state that performance of EPDM insulators was really poor as compared to SiR and even to ceramic insulators. However, they reported that SiR has much better leakage current suppression than ceramic ones even without any cleaning schedule. The authors do not conclude any thing about useful life of these insulators.

Satoshi Kobayashi et al. [9] at Furukawa electric institute of Technology, Japan, (Furukawa Review No.1, April, 2002) studied the natural aging effects on HTV SiR for five years in outdoor environment of Okinawa State, Japan. The authors use a statistical technique to extrapolate the results obtained from various techniques over a period of five years, and claim a 34 years of life for these insulators. However, authors also recommend some accelerated scheme which could simulate 34 years in less time, to check the validity of statistical approximation.

Antonios E. Vlastos and Tor Orbeck [10] studied the 7 years natural aged silicon composite insulators. This setup was established by Chalmers University of Technology in Sweden on west coastal area. In this system, a glass insulator is added between the HTV silicon insulator and the tower to allow the measurement of the leakage current. In case of a flashover, the discharge current passes through a lightning arrester flash counter which records the flashover. The results show that HTV silicone rubber insulators with creepage distance of 27.6 mm/kV showed maximum current leakage current of 2mA. The same insulator with creepage distance of 17.3 mm / kV showed currents exceeding 25 mA. The maximum current pulses recorded on the porcelain insulator with 30 mm/kV is also 25 mA. The results showed that composite HTV silicone insulators maintained high surface resistance under severe salt storm conditions of Swedish west coast. Insulators did not develop any continuous dry band arcing, degradation or erosion even after 7 years of exposure in this environment. The authors do not state or calculated expected maximum useful life of these insulators.

Raji Sundararajan et al. [11] studied the EPDM insulators removed after five years of in service from New Hampshire coastal area. These insulators were already reported to be failed. The authors in this paper analyzed these insulators from many material analysis techniques. The authors concluded that EPDM can not be used as it is for making insulators. A very extensive study of fine tuning of fillers in EPDM is required to enhance their quality. Despite this research at this time, all polymeric insulator manufacturers have abandoned the use of EPDM for making insulators.

Salman Amin and Muhammad Amin [12], performed 2 years of aging on SiR Insulators. The results were obtained from various techniques and manipulated to estimate a useful life which came out to be 30 years in environment of Hattar. Many other test setups of natural aging were made and many different kinds of insulators, samples were tested. The results have been reported in many publications.

2.4. Survey on multi stress aging

Raji Sundararajan et. al. [13] performed multi stress accelerated aging of polymer housed (EPSB and SiR) surge arrestors under coastal Florida conditions. The authors simulated 15 lab years. Both the materials preserve excellent surface resistance at the end of 15 years of lab aging compared to virgin. The results of this research for first 5 years indicated a close correlation with natural aging. Authors claim that multi stress aging is quite realistic and desirable.

C. Rattana et al. [14] in IEEE CEIDP 2002, pp.311 performed the 5000 hours multi stress aging of SiR Insulators under the environment of San Francisco. Aging equivalent to six years in service was performed. Aging was estimated using SEM, FTIR, HC Classification, LC measurement. The authors used Weibul's analysis to estimate the life of EPSB and SiR Insulators. The expected life of EPSB was 7-24 years and 8-18 years for SiR in environment of San Francisco.

R. Sundrarajan, et al. [15] performed the multi stress aging of 28 kV thermoplastic Elastomeric insulators simulating the environment of Coastal Florida for 912 hours**.** Degradation was assessed by using electrical impedance spectroscopy (A Technique that gives a plot of resistance vs reactance over a range of frequencies for a sample). Authors state that surface resistance of aged sample was ¼ near energized end and ½ near dead end compared to virgin sample. Authors conclude that surface resistance of every polymeric material depends greatly upon the environment which it is aged/ used, so these materials should be aged in every environment prior to their use. Authors did not state/ conclude anything about expected useful life.

C. Olave et al. [16] performed the 5000 hours multi stress aging of TPE insulators simulating the environment of Arizona State which is mostly a sand terrain. The degradation was observed using FTIR and SEM. The results showed that these insulators perform well under the 5000 hours multi stress conditions. Light arcing, shallow cracking was observed. The authors did not make any statements about the expected useful life.

Raji Sundarajan, et al. [17] performed the multi stress aging of 28 kV SiR under the simulated conditions of Phoenix and Boston for 60 days simulating the one year of actual service. The results were quite satisfactory as stated by authors, the weather of these two regions is not very intense but pollution levels are very high. Authors conclude that these insulators can perform well in the environment of Boston and Phoenix for at least 20 years.

Raji Sundarajan, et al. [18], performed the 5000 hours aging of TPE insulators according to IEC 61109 standard. This standard does not represent any service environment. However, authors state that slight modifications were made to this standard to make it simulate the environment of Florida state coastal area. Results of this study showed that TPE insulators performed well and there were no major degradation. However, there was a severe loss of hydrophobicity in very early stages, which persisted till the end. In spite of that leakage current suppression was good. This behavior is opposite to that of SiR Insulators, where leakage current is severely dependant upon hydrophobicity of surface.

N. Chaipanit et al. [19] “online article” presented results of accelerated multi stress aging of polymeric insulators under San Francisco Coastal Environment. A lab aging equivalent to 4 years of service aging was performed. Results of aging were observed using FTIR, SEM, Leakage current measurement and hydrophobicity classification. No major degradation was observed. The samples at the end of three years have the highest porosity and roughness and loss of hydrophobicity. The samples were in recovery phase in 4th year. The authors at the end recommend a longer study to see the insight into this behavior of degradation and recovery. Another study of same kind and duration was made by these authors but simulating the environment of Detroit, which is a highly polluted industrial city of America.

In S. Kumagai, N. Yoshimura, and R. Matsouka [20], authors performed the multi stress aging of SiR and EVA (ethylene vinyl acetate) samples and blends of SiR and EVA in various ratios. Degradation was measured using FTIR, SEM, LC, HC (contact angle) and visual inspection. The authors claim that hydrophobic satiability of blends of SiR and EVA was more than the two individual materials. Also blend was more stable when silicone to EVA ratio was higher. The authors conclude that more hydrophobic stability of silicone as compared to EVA is due to LMW, which are able to migrate and finally recover the aged surface.

S. Kumagai and N. Yoshimura [21], studied the hydrophobic transfer mechanisms of RTV SiR Insulators under 1000 hours IEC 1109 multi stress conditions. SEM. FTIR, HC (contact angle) and fractional distillation method was used to identify the % age of LMW silicone fluid (main competent responsible for Hydrophobicity of these insulators) in the bulk of samples. One of the most important out come of this study was that corona discharges of long duration can regain the recovery ability decreased by previous environmental stresses. Therefore, the hydrophobicity of RTV previously aged by corona stress becomes stable against overlapping stresses. This study was not based on any practical environment, so authors did not conclude any thing about the expected useful life of these insulators.

M. Ugur, A. Kuntman, and A. Merev [22], performed the multi stress aging of SiR Insulators according to ASTM D 2303 standard. The authors state that initially insulators resisted the deposition of contaminants on their surface, but after some time which was named as tracking initiation time, the pollutants start accumulating on the surface. More focus was made to investigate the effect of excessive stresses on tracking initiation time. The authors conclude that breakdown times of these insulators are greatly affected (up to 50%) by the environmental stresses.

B Venkatesulu and M.Joy Thomas [23] performed the 3800 hours aging of full scale 11 kV distribution class SiR Insulators. EDX (Energy Dispersive X-Ray, A technique which gives % element weight of C and O in material), FTIR, SEM, Hydrophobicity & Leakage current monitoring was done to estimate aging. Authors conclude the multi stress aging even in dry condition can age material in the long run. Monitoring of leakage current under dry conditions does not give any indication of chemical degradations occurring inside the substance. Authors did not state any thing about expected useful life.

J. M Fourmigue, M. Noel and G. Riquel [24] in online technical article presented the results of 5000 hours comparative aging of SiR and EPDM under IEC 61109 Standard. Authors also gave a comparison of artificial and natural aging techniques used for aging these insulators. The authors prove that artificial aging techniques are in quite correlation with natural aging and best to get the real service aging effect in short time. The authors also reported that changes in roughness, hardness, and oxidation for SiR is greater than EPDM, but still performance of EPDM was bad because its hydrophobicity is severely effected and recovery process in this material are very slow. Based on above argument authors claim that EPDM will not prove to be a good material for making outdoor insulators.

S.M. Oliveria and C.H. Tourreil [25] studied the composite EPR (Ethylene Propylene Rubber) under IEEE/IEC 1000 h test procedures. The authors state that EPR formulations perform better than the first generation of epoxy resin insulators. The authors claim that aging test methods and the acceptance criteria proposed by IEC and the IEE are not suitable to describe the performance of several polymeric insulator materials under different environments of the world. So test procedures for every environment should be developed individually.

Salman Amin and Muhammad Amin [26] performed accelerated multi stress aging on four samples of full scale insulators (2 SiR and 2 TPE) were aged for 3600 hours**.** The results were obtained using HC classification, Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM), leakage current measurement. No arcing or chalking was observed in any sample until five years of lab aging. All samples had low leakage current values until the end of fifth year. However, TPE insulators have shown more loss of hydrophobicity especially in vertical direction, but still had acceptable values of leakage currents. The results of all techniques of analysis have found a close correlation with each other. All of them present a degradation /recovery cycle of about 4-4.5 years.

M. Amin, M. Akbar, and R. Matsouka [27] performed 670 hours of multi stress aging of HTV SiR without ATH. The authors approximated the life of these insulators using a statistical technique that came out to be 13 years. This low life is due to no filler inside that material. The authors comment that fillers play an important role in life of polymeric insulators. However, insulators on the overall preserved good weather resistance and recovery properties. A lot of work has been done on polymeric insulators in Pakistan at UET, Taxila.

M. Amin and M. Akbar [28] studied the properties of polymeric insulators under different individual environmental parameters of Pakistan. The authors state the individual parameters working alone one by one cause no significant degradation.

Muhammad Amin and Muhammad Akbar [29] studied the effect of UV Radiations on Heavily Polluted Polymeric Insulators. Up to pollution level of 0. 45 mg/cm^2, a UV radiation has caused degradation. At 0.68 mg/ cm^2 and above no degradation occurred. So, authors conclude that a thick layer of 0.65 mg/cm^2 acts as protection cover against the effects of UV Radiations. The ages of un-energized and energized samples were estimated to 15.57 years and 16.83 years respectively.

J. L Fierro Chavez, I. Ramirez Vazquez, and G. Montoya Tena [30] developed a system for measurement of leakage current and surface resistance of insulators in Monterrey, Mexico. This system was installed on several towers along the 400 kV line as a diagnostic tool to monitor the surface condition of polluted insulators. The results showed values from 50-150 mA in first two months of installation. But such high values never appear again when some of faulty insulators were replaced once. The authors suggest that cleaning or replacement of insulators is necessary when peaks of 250 mA or more are observed in rainy season.

Tomohiro Nakanishi et al. [31,32] establish a setup. This setup was developed in Japan by Chubu University. The setup was actually developed for many other purposes including leakage current monitoring of Composite insulators [31]. Salt fog ageing tests were conducted in this setup according to the specifications given by CIGRE WG 15-06 [23].

The research by one of the authors described in [10] was done to investigate what kind of leakage current is most influential on aging deterioration of polymeric insulators. How different leakage current measuring methods give results and what is the effect of UV radiation on leakage current. Insulators were subjected to salt fog test in chamber. The leakage current was measured by measuring voltage across a 100 ohm resistor placed in series between the insulator sample and ground. All specimens were of 250 mm length and 30mm diameter. Leakage current was measured by two different methods [33].

<u>Method 1:</u> This method was adopted to see the effect of UV on leakage current. In this method, the wavelet transformation of leakage current measured by sampling rate of 10000 per second was determined. Leakage current was divided into three components: Conductive, Dry band, and Pulsive. Among theses components, most of degradation is caused by dry band arcing [33].Conductive Components is the one which has the shape like supply voltage with minimum distortion. Pulsive component appears like surges on conductive current shape. And the dry band arc a component is that lags more than $\pi/10$ from supply voltage. The results show that samples exposed to UV radiation have smaller values of leakage currents than those which were not exposed to UV. The reason could be drying of surface due to heating caused by UV. The dried surface also has more hydrophobicity. Accumulative charge was also less on samples exposed to UV as compared to others [10].

<u>Method 2:</u> This method was adopted to see the effect of UV radiation on aging deterioration. In this method the instantaneous magnitude of leakage current was measured by sampling rate of 1000 per second and accumulated charge was calculated. Minimum measurable value of leakage current is 1 mA. The occurrences of 10, 50, and 100 mA surges were also counted every minute. The results from this method did not show any count of leakage current pulses of 10, 50, or 100 mA for silicon rubber samples. Only surges of 10 mA were observed on porcelain insulators. But even porcelain did not have any surge count of 50 or 100 mA. Based on these, authors claim that surge counting levels of 10, 50, and 100 mA are too high and meaningless, when trying to investigate aging deterioration of composite insulators.

Tomas G. Gustavassen wrote a PhD Thesis Chalmers University, Sweden [34]. The author of this thesis studied the impact of different material formulations of polymeric insulators on the life and performance of these insulators. It was found that the high contents of material additives. i.e., silicone oil and ATH filler initially caused an earlier onset of surface discharge activity. However, after prolonged exposure both extra oil and high filler content decreased the rate of surface degradation. Concerning the silicone oil parameter, no significant consumption of LMW fractions could be measured after the test. Furthermore, it was verified that low molar mass siloxanes had been regenerated during aging. Therefore, it was judged as unnecessary to fill the material with extra silicone oil. The intrinsic effect of higher filler content was documented both under natural and laboratory conditions. The laboratory tests showed this effect for both wet (rotating wheel dip test) and dry (streamer propagation) conditions. However, in the long run the least filled materials (50 p1w ATH) were found to have an insufficient thermal protection, which explain its higher degradation pace under dc voltage. The found erosion was not deep but once the damaged surface began to brake-up into cluster-like formations of particles the process became auto accelerating. Therefore, it must be avoided. The latter process occurred only on materials with 50 phr ATH, which means that sufficient erosion resistance was provided hr ATH contents of 75 phr or higher.

P. Cygan and J.R. Laghari [35] presented an overview of multi stress aging techniques. The authors have presented several methods used by researchers all over the world to accelerate the aging process, but suggest that most popular are the experiments performed at voltages and temperatures. There are further two methods, one is to keep all stresses constant and not the time to failure or satisfactory period. Other is to increase the stresses in steps, and note the values of stresses at which failure occurs. The results from both of them are then correlated to get an empirical formula or model of aging. The authors have also discussed feasibility of setting many mathematical models, to get equation of aging from experimental data. At the end, authors predict that multi stress aging will be the most suitable option in a few years to demonstrate the performance of insulating materials.

N. Yoshimura, S. Kuamgai, and R. Matsouka [36] presented a detailed over view of electrical and environmental factors causing the aging of SiR used for outdoor insulation. The authors concluded that all the degradation/ phenomena occurring in these insulators are due to the LMW in their bulk, which are responsible for the hydrophobic x-tics, and hence very good leakage current suppression.

R. Matsuoka K. Naito, T. Irie, and K. Kondo [37], “Evaluation methods of Polymer Insulators under contaminated conditions” IEEE/PES Yokohama, Japan October 2002 presented and compared the different techniques use to study the aging of polymeric insulators. Authors suggest a most suitable set of following five techniques namely Visual inspection, FTIR, SEM, Hydrophobicity and leakage current measurements.

Ali Naderian, Majid Sanaye, and Hosein Mohseni [38] presented a review of artificial contamination with stand test methods used for polymeric insulators. The authors give details of Eq. Fog Test, pollution rain test, Variable voltage test, B-Rapid flashover test, Dust Cycle test, salt fog test, clean fog, accelerated multi stress tests etc. Authors state that although several recommendations and standards have been published by recognized organizations for aging of composite insulators, there still remains some uncertainty about the contamination behavior of these insulators. Because of this, there are several non-standard test recommendations formulated to evaluate the behavior of insulators under different conditions, which are proving to be better than standard methods. At the end, authors stress that it is necessary to determine age polymeric insulators for field application of different environments, so that users and customers will able to select proper composite insulator according to the characteristics of their environment.

J. W. Chang and R. S. Gorur [39] presented results of a study performed to obtain a better understanding of the material characteristics responsible for hydrophobicity recovery leading to a high wet surface resistance in silicone rubbers used for outdoor HV insulation. The samples were obtained from new and artificially aged HV insulators using HTV silicone rubbers (3 different formulations) as weather shed and RTV silicone rubbers (2 different formulations) as a protective coating. The main experimental facilities employed consist of a salt fog chamber for artificially aging the insulators, and a scanning electron microscope (SEM) for material studies. New results of practical significance that have emerged from this study are: (1) hydrophobicity recovery, pre- dominantly due to diffusion of low molecular weight (LMW) silicone polymer chains, occurs with only a fraction ($< 20\%$) of the total LMW polymer content initially available in an un- aged material surface, (2) LMW chain regeneration and hence surface hydrophobicity recovery occurs even after the initial supply of LMW polymer is depleted, and (3) hydrophobicity recovery is significantly affected by ambient temperature. The results show the same pattern for different formulations of HTV and RTV rubber materials studied. The X-ray Mapping feature in the SEM provides a visual indication of the diffusion process which is a noteworthy contribution. The pattern of the results was consistent for the different formulations of HTV and RTV silicone rubbers evaluated. The use of the XRM feature in the SEM as a visual indicator of the diffusion process has been demonstrated. This method could be employed for surface studies of insulating materials.

H. M. Schneider et al.[40] presented the behavior of 138 kV non ceramic line post insulators is investigated by means of clean fog tests conducted before and after aging in a specially designed accelerated aging chamber. The laboratory aging cycles are justified on the basis of actual weather in the coastal regions of Florida. Analytical measurements quantifying the degree of artificial aging are discussed and comparisons of artificial aging with service experience are presented. Observations of audible noise and radio influence voltage during the clean fog tests are reported. An artificial aging chamber was developed at HVTRC with environmental cycle's representative of the specific conditions in the most severe locations of the Florida Power Light Co. transmission system. The environmental cycles developed to age non-ceramic insulators for the Florida coastal climate reduced the clean fog flashover voltage for the four types of non ceramic insulators tested. The clean fog flashover voltage of all non- ceramic insulators tested in this program, both un-aged and aged in the HVTRC accelerated aging chamber, exceeded that of the high strength porcelain line, post insulators. ESDD is not an adequate index of contamination severity on non ceramic insulators exhibiting high hydrophobicity. Non ceramic insulators produce increased audible noise but decreased radio interference as a result of aging in the HVTRC accelerated aging chamber. Silicone rubber insulators generally had less reduction in contamination flashover voltage than EPR insulators after artificial aging, and had higher absolute flashover voltages.

R. Sundararajan [41] presented the results of a 2544 hours multi stress aging of TPE and SiR polymeric insulators under simulated conditions of Mexico City. The results indicate that the silicone rubber insulators perform better than TPE and there is discoloration, light arcing loss of hydrophobicity and bond breaking in both type of insulators, but still they have preserved good electrical and mechanical x-tics and are estimated to serve several years in the field.

Salman Amin et al. [42] performed a 10000 hours comparative multi stress accelerated aging of TPE and SiR insulators in the environment of HATTAR, Pakistan under the effect of UVA, heat, salt fog, acid rain and electric stress. The analyses were made using electrical (leakage current), physical (discoloration, hydrophobicity classification) variables, and sophisticated material analysis techniques, such as Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscopy (SEM). It was seen that all insulators showed excellent performance till 13th year. But in 14th and 15th year all of them showed a drastic change, however still preserving good electrical properties. There was a drastic change in results of all techniques of analysis at the 9000 hours point which is equivalent to 15 lab years. So an aging exceeding this point must be carried. To investigate this more, a 30 years simulated aging is under way by same authors.

B. Marungsri, H. Shinokubo, R. Matsuoka and S. Kumagai [43] investigated the effects of specimen configuration on the deterioration of silicone rubber insulators in a salt fog ageing test. A cyclic salt fog ageing test was conducted on three types of high-temperature vulcanized silicone rubber (HTV SiR) specimens. One was having sheds and other without sheds. The test was based fundamentally on the CIGRE WG 15-04 specifications. After 50 test cycles, the three types of specimens showed different degrees of surface deterioration. Erosion on the straight shed insulator was more severe than that on the alternate shed insulator even though the two had the same leakage distance. No erosion was observed on the rod-type specimens, which had shorter leakage distances than the insulator-type specimens. In general, SiR Insulators performed well throughout the tests.

B. Marungsri, H. Shinokubo, R. Matsuoka, and S. Kumagai [44] investigated anti-tracking/anti-erosion performance of housing materials for outdoor polymer insulators under salt fog ageing tests. . The effect of fog conditions on the deterioration of silicone rubber under two different salt fog conditions generated by an ultrasonic humidifier and an IEC nozzle was monitored. Authors state that in spite of the same injection rate and the same salinity, the results obtained from two salt fog conditions generated by the ultrasonic humidifier and the IEC nozzle were not comparable. However, they become a bit comparable after controlling the salt fog particle size distribution. Authors conclude standard testing procedures are not well suited for all kinds of salt fog conditions, so in spite of adopting standardized procedure , more realistic aging can be achieved by simulating each an every environment independently.

A. Ito et al. [45] investigated about use of possible techniques to detect failures in polymeric insulators removed from actual lines after a service of about 10 years in Shanghai area. Authors state that serious ageing deterioration, such as puncture, brittle fracture, tracking, erosion of polymeric insulators has been observed in fields. Therefore, the diagnostic techniques to detect deteriorated polymer insulators before serious accidents are essential for wide application of these insulators in future. Authors suggest that both qualitative and quantitative analysis techniques should be used to detect problems and failures in insulators. The leakage current and hydrophobicity measurement are good indications of electrical health, whereas authors also investigated detection of punctured insulators by image intensifier. Authors state that under normal operating voltage image intensifier can be used to detect the micro punctures.

N. Okada et al. [46] investigated the contamination withstand voltage performance of hydrophobic polymer insulators. SiR insulators were installed in under different precipitation and water droplet conditions. Authors state that hydrophobicity is influenced largely by wetting conditions. Heavier wetting, such as heavy fog and rain could give lower contamination withstand voltages compared with the light fog conditions specified for conventional ceramic insulators. Simulated acid rain test is proposed to be included for evaluation of insulation performance of polymeric insulators. SEM is useful tool to study the morphological properties of contaminated insulator specimens. Based on study, the authors predict that polymer insulators can perform well without maintenance for about 24 years.

June-Ho Lee et al. [47] studied the influences of changes in amount of low molecular weight materials (the vinyl content of polydimethylsiloxane and reinforcing silica) on the electrical and mechanical properties of silicone rubber for high voltage insulation. It was observed in this study that when the content of vinyl group was increased, hardness and cross-linking density were increased, where as volume resistivity, tracking resistance and tensile strength were improved. It was also observed that performance of silicon rubber reinforced with fumed silica is much better than those reinforced with precipitated silica. This is due to the reason that precipitated silica contains the more water contents as compared to fumed silica. However, in both compositions SiR rubber have very good hydrophobicity and preferred over the thermoplastic insulators which have low hydrophobic stability. Authors suggest that a long term multi stress aging of SiR Insulators is required in order to predict their performance to varying extents in varying environments.

Tumiran et al. [48] performed the natural aging of epoxy resin based SiR Insulators. The specimens where prepared by authors themselves using RTV silicon rubber and 325-mesh silica filler. The dimension of a sample was 70 x 70 mm with the thickness of 5 mm. The samples were laid upon an iron construction supporter about 8 m from the ground on Parangtritis beach, which is about 30 km away to the south of Yogyakarta city, for obtaining sea pollution in order to estimate their ageing performances. The investigation was carried out for 60 weeks. Analysis was done using SEM, FTIR, and STRI hydrophobicity classification. Results of SEM show that silane epoxy resins polymeric insulation materials after 60 weeks aging have no significant surface erosion as compared with new virgin samples. FTIR results Analysis of the chemical structure with FTIR also indicate that the silane epoxy resins polymeric materials after 60 weeks aging, compared with new materials and the chemical structure are not change.

3. CONCLUSIONS

A number of utilities all over the world have experienced failures with silicone rubber insulator in heavily contaminated and moist environment. For a complete comprehension of aging and performance degradation, accelerated aging that closely simulates realistic conditions is desirable.

- IEEE/IEC standards have been reported by authors to be inappropriate as they reflect only specific regional impact, and authors suggest using the individual environmental stress values instead of these standards.
- SEM, FTIR, HC, LC, and Visual Observation are the most commonly used techniques for aging estimation of these insulators all over the world.
- Maximum Multi stress aging done by any author is of 5000 hours.
- Maximum natural aging done is of 7 years; however various insulators tested after removing from service environments have ages of up to 20 years.
- The life estimation is done by very few authors and ranges between 16 to 30 years with most typical value of 24 years.
- A lot of authors worked on SiR but a very little work has been reported on TPE.
- Research has shown that these multi stress tests simulate aging comparable to actual field aging.
- A very long term multi stress accelerated aging of thermoplastic insulators under varying environments is needed.

3.1. Potential avenues found from survey

Keeping in view the above findings following is needed

1) A Multi stress accelerated aging of Silicon Rubber and thermoplastic insulator side by side in the same environment and under varying environments
2) The accelerated aging should at least reflect more than 24 simulated years because it is the most typical value estimated by some authors.
3) Based on the results of simulated 24 years or more some statistical technique should be used to estimate the life of both of these insulators
4) Results of TPE and SiR insulators will be compared with each other to find which of them is better for a specific environment and in general
5) A special contribution to literature on TPE insulators is needed.

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