CHAPTER 2

LITERATURE SURVEY

2.1 POLLUTION PERFORMANCE STUDIES OF INSULATORS

Salam et al (2000) have shown that contamination level has strong correlation with the leakage current. Increase of contamination level will increase the value of leakage current. In theoretical, contamination level is directly proportional with leakage current. The equivalent salt deposit density (ESDD) was used to measure the level of contamination of insulators. A study carried out on the effect of ESDD on flashover voltage of contaminated insulator.

Hackam et al (1999) studied the HV composite polymeric insulators that are being accepted increasingly for use in outdoor installations by the traditionally cautious electric power utilities worldwide. In this paper a review is presented about the performance experience of HV composite polymeric insulators in outdoor service, testing methods, aging, the ranking of the materials, the role of fillers, the role of low molecular weight components present in the insulators, the mechanisms responsible for the loss and recovery of hydrophobicity, mechanisms of failure, detection of faults, type and quantity of natural contaminants, effects of exposure to rain, hydrocarbons, stationary air and wind, various methods to optimize the electrical performance and a relatively new method for evaluating the performance status of polymeric insulators in the field.
Homma et al (2005) described a comparison of leakage current properties between polymeric insulator and porcelain insulator subjected to salt polluted conditions. Exposure tests at a sea coast test site were carried out and the leakage current of insulators, climate conditions, and salt deposit density were measured during the tests. Appearance of leakage current for the porcelain insulator was affected by the humidity and the salt deposition on the surface, but that for the polymeric insulator was related to rainfall. The hydrophobic surface of the polymeric insulator must play an important role in suppressing leakage current under the salt polluted conditions compared to the less hydrophobic surface of the porcelain insulator.

Ohno et al (2005) have developed Ethyal vinyl acetate (EVA) polymeric insulators for 22 kV overhead distribution lines. Compared to conventional ceramic insulators, these newly devised insulators are characterized by their smaller size, lighter weight and lower production costs. Results of leakage current measurements and examinations of surface conditions showed no increase in leakage current or problems with use even with the emergence of erosion on the surface. In light of these results, it could be confirmed that the polymeric insulators demonstrate sufficient insulation performance for a long period in actual outdoor environments.

Chandrasekar et al (2007) analyzed the tracking phenomenon in silicone rubber material under AC and DC voltage. The influence of applied voltage magnitude, conductivity, and flow rate of the contaminant on tracking, were analyzed. It is observed that the tracking is more severe under DC voltages. The tracking time is less under negative DC voltage compared to the positive DC voltage. The leakage current during the tracking studies was measured and its trends were analyzed by using the moving average technique. The leakage current magnitude is high with thermally aged specimens when compared to the virgin specimen, irrespective of the type of
applied voltage. It is realized that the tracking time and the leakage current magnitude shows an inverse relationship. In addition, the surface condition of the insulation material was analyzed with the water aged specimen and the diffusion coefficient of the material was calculated. The reduction in contact angle of the specimen has direct impact in the reduction of its tracking time. The tensile test and Dynamic Mechanical Analysis (DMA) test results indicate that thermal aging of the specimen alter the mechanical properties of the material. The activation energy of the material was calculated through DMA studies, indicating that materials with high activation energy show an increase in tracking time of the specimen.

Montoya – Tena et al (2007) have carried out inspection of polymeric insulators used in transmission lines exposed to severe contamination. In-service diagnostic has been periodically carried out to identify high risk insulators, by using the visual corona and electric field measurement techniques. In this paper, the most important results obtained from different inspections performed in-service to polymeric insulators on Mexican transmission lines are presented. These results show that the visual corona and electric field measurement techniques can be used to identify high risk polymeric insulators prior to failure.

Gutman et al (2010) have carried out the modified salt fog and solid layer tests based on procedures described in IEC 60507. Among methods evaluated for polymeric insulators, a modified solid layer test with preconditioning by dry powder is considered as being representative and most promising for future standardization. Further, the proposed procedure allows for testing at different hydrophobic states of the polluted insulators via the introduction of defined time between the application of pollution and voltage test. Finally, if the 50% flashover voltage is determined using the up-and-
down method, results of the tests can be directly applied for insulator selection and dimensioning by means of statistical or deterministic methods.

Fernando et al (2010) have investigated on the performance of 33 kV silicone rubber insulators characterized by different creepage lengths. The study was performed under natural field and laboratory conditions. The insulators tested included eight types of silicone rubber composite insulators, one type of hybrid silicone-ceramic insulator and one semi-conducting glazed porcelain insulator, while ordinary porcelain and glass insulators were used as reference. During the field investigation, two sets of the insulators were separately installed and energized in coastal and inland region. Their performances were periodically evaluated by visual inspections and measurements of hydrophobicity class. After five years of field exposure, the insulator performances were evaluated in laboratory by measurements of leakage currents under clean fog conditions and of wet flashover voltage. A third set of the insulators was aged in laboratory for 1000 hours inside a salt fog chamber where the insulators were continuously energized and daily sprayed with salt solution for eight hours and left to rest for remaining 16 hours. This treatment represented conditions similar as those in the field i.e. insulators exposed to salt sprays during monsoons. The insulator performances were investigated by measurements of leakage currents and classifying their patterns into different categories, i.e. capacitive, resistive, non-linear, discharge and strong discharge types, by means of fast Fourier transform and short time Fourier transform analyses. It was found that the long-term field exposure yielded weaker insulator deterioration than the salt fog chamber ageing, which indicated for a possibility to increase the electric stress on silicone rubber insulators to levels higher than the ones used today on glass and porcelain counterparts.
2.2 ACCELERATED AGING STUDIES OF POLYMERIC INSULATORS

Lambeth et al (1988) carried out a research work to develop a satisfactory method of assessing the level of performance to be expected from a polymeric insulator over its lifetime in service. They have carried out three different artificial aging procedures, using a set of insulators from four manufacturers as test samples. Insulators of the same design were energized at three sites with quite different characteristics to give naturally aged and polluted test specimens for laboratory measurements. Various diagnostic tests were used to measure the performance of the naturally and artificially aged insulators, and the results of these tests are discussed by the authors.

Que et al (2002) have proposed a methodology based on voltage-current phase angle measurements to understand the surface degradation and aging of polymer insulators. However, further investigations are required to understand the phase angle characteristics of both porcelain and polymeric insulators at different pollution levels and Relative Humidity (RH) conditions.

Sarathi & Chandrasekar (2004) have dealt with the measurement and analysis of leakage current waveform, because it is related directly to arcing phenomena occurring on insulator and it is easy to implement. For a given insulator, LC waveform evolution depends essentially on the changes occurring at the surface pollution layer and surface wetness of the insulator. Leakage current follows different patterns during the various stages involved in the development of flashover.

Kumagai & Yoshimura (2004) have shown that the leakage current affected by the operating voltage, temperature and humidity can provide a more comprehensive description about the state of the contaminated
insulators than the other methods. Therefore, the leakage current is called as one of the most effective dynamic parameters.

Sundrajan et al (2009) have carried out accelerated aging studies of high voltage outdoor polymeric insulators since they are mostly organic materials that contain inorganic fillers. Long term (thousands of hours), multistress, accelerated aging of polymeric insulators in the laboratory under conditions simulating the actual stresses encountered in the field permits a better understanding of the ongoing mechanisms related to aging and life expectancy of these materials. This article presents the multistress aging studies of 28 kV silicone rubber polymeric insulators under east and west coasts of USA.

Venkatesulu et al (2011) studied the multistress aging/weathering of outdoor composite polymeric insulators. This paper deals with the long-term accelerated weathering of full-scale distribution class silicone rubber composite insulators. To evaluate the long-term synergistic effect of electric stress, temperature and UV radiation on insulators, they were subjected to accelerated weathering in a specially designed multistress-aging chamber for 30,000 hrs. All the insulators were subjected to the same level of electrical and thermal stresses but different UV radiation levels. Chemical, physical and electrical changes due to degradation have been assessed using various techniques. It was found that there was a monotonous reduction of the content of low molecular weight (LMW) molecules with the duration of the weathering. Further, due to oxidation and weathering there is an appreciable increase in surface roughness and atomic percentage of oxygen. There is no change in the leakage current of new and aged insulators under both wet and dry conditions at the end of the aging. The results also indicate that there is no influence of UV radiation on the silicone rubber for the durations and conditions under which the studies were made.
Zeinab Farhadinejad et al (2012) investigated the ultraviolet (UV) aging effects of polymeric insulators. The objective of this paper is to study the aging process of silicone rubber insulators exposed to UV radiation. To accomplish this purpose, three different kinds of commercial silicone rubber insulators were aged by UV radiation and contaminated solution. Then their electrical and thermal properties as well as their changes on the surface were investigated by measuring leakage current, thermo-gravimetrical analysis and surface elements. It is observed that, the effect of contaminated solution on leakage current is more than the influence of UV radiation alone. In addition, combination of UV radiation and pollution extremely increase leakage current. Pollution has especially influence on the 3\textsuperscript{th} harmonic component. Aging by UV shifts the thermal decomposition temperature of the insulations to lower temperatures and degrades the surface of the systems especially the polymers surround the filler. Also it was realized that UV is able to decompose the filler and reduce the Al/Si ratio in the sample.

Hernandez et al (2012) have studied the hydrophobicity of polymeric insulators that determine their performance in polluted environments. The hydrophobic property is reduced as the insulator's surface ages due to the electric activity caused by wetting and pollution; however, it is recovered during the resting time in air. The insulators having a high rate of hydrophobicity recovery show better performance. Polymeric insulators of different materials and leakage distances were evaluated in laboratory by using an accelerated ageing method. The hydrophobic property of each insulator was studied by measuring the contact angle on the insulator's surface where the highest electric activity was observed. The measurements were performed before and several times along the ageing test. The performance of the insulators was evaluated by the number and magnitude of the peaks of leakage-current recorded by a home-made system during the entire test. The results show that if the hydrophobic property of the insulator's surface is low,
the performance of the insulator under wet and polluted conditions may be strongly affected by its leakage distance.

Iman Ahmadi-Joneidi et al (2013) studied the effects of ultraviolet (UV) radiation which decreases the hydrophobicity of silicone rubber insulators. Lack of hydrophobicity on the surface of such insulators lowers the flashover voltage and increases the leakage current (LC) of insulators in the moist environment. This paper presents the artificial UV radiation effects on three types of 20 kV silicone rubber insulators in a chamber with nine UV lamps (50 W/m²) for up to 5000 hours. To simulate the moist environment, solid layer method is applied according to IEC 60507 that includes artificial pollution deposition on the insulator surface. Fast Fourier transform of the LC waveforms indicates that the third and the fifth harmonic components are quite sensitive to any incremental discharge on the insulator surface. Thermo gravimetric analysis (TGA) and scanning electron microscope images depict that the polluted insulators include much larger degraded parts under electric stress after aging. Measurements also show that the flashover voltages and the hydrophobicity of aged insulators decrease as the UV exposure time increases for different levels of moisture and pollution.

Mitra Khiabani Moghadam et al (2013) investigated poly dimethyl siloxane (PDMS) as a candidate for high voltage insulation applications and its aging behavior at different temperatures in air. Three models according to ISO 11346 were applied to determine endurance limits in terms of a time-to-failure after aging in hot air. Aging was performed in air from 150 to 170°C. Tensile tests were performed on unaged and aged PDMS specimens at ambient temperature using strain-to-break values as a performance indicator for the degree of aging. For PDMS, the effects of aging were found to depend strongly on the aging conditions. The activation energies and corresponding
lifetime predictions for the chosen temperature range derived from these models are compared and interpreted as to their practical relevance.

2.3 PARTIAL DISCHARGE STUDIES OF INSULATION SYSTEM

Cavallini et al (2003) evaluated the effectiveness of a new inference method for the diagnosis of solid insulation systems, based on partial discharge (PD) measurements. Signal separation, noise recognition, and PD source identification are the main features of the proposed inference method. Techniques for signal separation and automatic noise rejection are reported in this paper, while the problem of the identification of PD phenomena, occurring in defects of insulation systems, is approached. The identification is based on fuzzy logic and enables the recognition of PD generated from different basic sources, such as internal, surface and corona discharges. The different source typologies can be identified by means of fuzzy rules applied to a selection of parameters derived from PD-pulse phase and amplitude distribution analysis, once PD phenomena have been clustered in homogeneous class through a fuzzy algorithm based on PD-pulse shape.

Cavallini et al (2003) carried out noise rejection, defect identification and degradation diagnosis in on-field partial discharge measurements. This paper presents tools for automatic noise suppression in measurements performed by ultra wide band digitizers, able to record a large quantity of partial discharge (PD) pulse waveforms. Noise and PD signals are split in different classes on the basis of their shape by means of a fuzzy classifier. Tools used for establishing whether a given class of recorded signals is due to external noise or not are proposed. As an example, two kinds of noise are considered: random noise and rectifier-generated noise and explained how the same classification tools can be employed for the purpose of defect identification.
Suwarno et al (2006) showed that in the case of corona discharges in air, discharge pulses were concentrated around the peak of applied voltage at negative half cycle. For silicone oil positive as well as negative discharges were observed which concentrated around the peak of applied voltage. The positive pulse number was smaller but the magnitude was higher than that of negative discharge. Discharges in void took place at wider range of phase of applied voltage. The unbalance in pulse number and magnitude similar to that of oil discharges were observed. For electrical treeing in LDPE, the discharges were spread before the zero cross of the applied voltage up to the peak at both positive and negative half cycles. The discharge pulse sequence analysis indicated that the PD occurrence in air, oil and void were strongly affected by the magnitude of applied voltage. However, for electrical treeing it was observed that the discharge occurrence was strongly affected by the time derivative of the applied voltage (dv/dt).

Cavallini et al (2007) presented a technique for outdoor ceramic insulator pollution assessment based on partial discharge detection and analysis. Laboratory tests and data coming from a monitoring activity carried out on some insulators of transmission lines are reported. They support the effectiveness of partial discharge detection and analysis as a tool to carry out condition-based maintenance of insulators of overhead lines. In particular, it can be seen that partial discharge analysis highlights the mechanisms bringing insulators to flashover (dry band arc activity) and is, therefore, well suited to predict increasing pollution and imminent flashover. As a consequence, algorithms are proposed to provide a quantitative evaluation of pollution severity.

Chandrasekar et al (2010) analyzed the partial discharge characteristics of silicone rubber insulators, with the aim to develop a better diagnostic tool to identify the pollution severity of outdoor insulators. In this
work, laboratory-based pollution performance tests are carried out on silicone rubber insulators under ac voltage at different pollution levels and relative humidity conditions, using sodium chloride as a contaminant. Partial discharge (PD) is acquired through an innovative PD detection system which is able to collect PD waveforms beside PD patterns. Time domain and frequency domain characteristics of PD pulses at different surface pollution conditions are studied. Statistical parameters of PD patterns are also evaluated in order to achieve a quantitative assessment of pollution severity of polymeric insulators. The results on silicone rubber insulators show that the pollution severity of outdoor polymeric insulators could be identified from the partial discharge pattern analysis.

Mangalvedekar et al. (2013) carried out partial discharge studies which is the major cause for insulation degradation. These discharges occur due to presence of voids or cracks or impurities inside the insulation. There are different types of partial discharges occurring in the insulation system depending on the nature and location of source of discharge. Commonly observed discharge types in rotating machines are delamination, void discharge, end winding discharge, surface discharge etc. Different discharge sources produce different Phase Resolved Partial Discharge (PRPD) patterns. Physical processes taking place at different locations with different intensities during occurrence of partial discharges are responsible for such varying behaviour. The PD detector gives the PRPD data. The values of number of PD pulses (N) and Apparent Charge (Q) from this data is used to calculate effective charge. This effective charge is used to obtain the spectrum plots for delamination type of discharge with increasing applied voltage. Simple Digital Signal Processing (DSP) based tools are used to obtain the frequency spectrum from the PD data. It is observed from these results that the even though the amplitude of the effective charge increases for increase in applied
voltage, the spectrum of the PD remains same. This paper proposes spectrum analysis as one of the method for PD source identification.

Narayanan et al (2014) carried out the partial discharge measurements on polymeric insulators aged under thermal process. Accelerated aging process was carried out in the laboratory and partial discharge signals were measured using advanced ultra wide band PD measuring system. Important features were extracted from the partial discharge phase resolved pattern and neural networks technique was used to develop a condition monitoring system to predict the pollution severity and flashover of polymeric insulators.

2.4 SOFT COMPUTING TECHNIQUES STUDIES OF INSULATORS

Ugur et al (1997) have proposed a methodology to classify the surface condition of the polymeric insulation structure using neural network approach by utilizing the features extracted from the FFT analysis of the leakage current during tracking test.

Felix Amarh (2002) have developed theory that links the flashover mechanism to measurable quantities which are suitable for flashover prediction, Experimental validation of the theory of flashover prediction using signature analysis and also developed electronic sensor system for flashover prediction and validation of system operation. This dissertation has described the signature analysis of the easily measurable insulator leakage current, as a means of predicting flashover. Also, this concept of signature analysis of the leakage current has been evolved to create an online computer-based diagnostic system.
Chandrasekar et al (2005) have studied the analysis of leakage current characteristics of power transmission line insulator in order to develop a better diagnostic tool to identify the surface condition of insulators. In this work, laboratory based pollution performance experiments are carried out on porcelain insulator under AC voltage at different pollution levels and relative humidity conditions with sodium chloride as contaminant. The leakage current signals are analyzed using Discrete Wavelet Transform (DWT) technique and the important features are extracted from the Multi Resolution Signal Decomposition (MRSD) Analysis. The process of identification of surface condition of the insulation structure was automated using Artificial Neural Network (ANN) with Back Propagation Training Algorithm. Reported results shows that the surface condition of outdoor insulators could be identified using this proposed approach.

Sarathi et al (2006) have shown that the Fourier Transform should not be applied to non-stationary signals and this limitation could affect proper understanding of the various LC pattern. Multi resolution signal decomposition using Discrete Wavelet Transform (DWT) technique has been, therefore, proposed as an effective tool to understand time-frequency characteristics of leakage current signals and provide important features to identify the surface condition of the insulation structure.

Chandrasekar et al (2009) have shown that Discrete Wavelet Transform understands the time frequency characteristics of the leakage current signal. The pollution severity of outdoor insulators could be identified from the DWT STD-MRA (Standard Deviation Multi Resolution Analysis) Distortion Ratio pattern analysis of leakage current signals.

Jingyan Li et al (2010) studied nearly 30 insulator strings at five pollution levels in an artificial fog chamber, where their leakage currents were continuously recorded at the same operation conditions. The three
characteristics of the leakage current, namely the mean value, maximum value, and the standard deviation of the root-mean-square (RMS) value of the leakage current, have been extracted. They describe jointly the current contamination levels of an insulator surface. In addition, regression equations between the three characteristics and various contamination levels have been established. The same three characteristics have been selected and used as the inputs of a neural network model together with two more parameters, the relative humidity and operating voltage. Also, the influence of each characteristic on the contamination prediction results has been investigated. The model is appropriate to predict the equivalent salt deposit densities (ESDD) with a difference of less than 0.035 mg/cm² if the training data and the testing data are selected at the security stage. This research results in the optimal prediction input parameters and sufficient pre-warning time before a contamination flashover.

Hadi Hosseini Kordkheili et al (2010) analyzed a new method and criteria to predict the flashover occurrence of SIR composite insulators and its probability by using leakage current harmonic component. The tests were performed on various profiles of artificially polluted SIR insulators under clean fog condition. It is proposed that an important index is the ratio of 5th harmonic component to the 3rd for which the operational and critical limits have been determined. The probability of flashover occurrence has also been calculated by geometric distribution. The presented criteria can be used to optimally schedule overhead lines maintenance teams and to develop proper Condition-Based Monitoring Systems (CBMS).

Chandrasekar (2010) carried out the analysis of leakage current characteristics of power transmission line insulator in order to develop a better diagnostic tool to identify the surface condition of insulators. In this work, laboratory based pollution performance experiments are carried out on
porcelain insulator under AC voltage at different pollution levels and relative humidity conditions with sodium chloride as a contaminant. The leakage current signals are analyzed using Discrete Wavelet Transform (DWT) technique and the important features are extracted from the Multi Resolution Signal Decomposition (MRSD) Analysis. The process of identification of surface condition of the insulation structure was automated using Artificial Neural Network (ANN) with Back Propagation Training Algorithm. Reported results shows that the surface condition of outdoor insulators could be identified using this proposed approach.

Narayan et al (2014) investigated the development of a better diagnostic tool to predict the flashover and pollution severity of power transmission line insulators based on the wavelet transform and fuzzy c-means clustering approach. In this work, laboratory experiments were carried out on power transmission line porcelain insulators under AC voltages at different pollution conditions and corresponding leakage current patterns were measured. Discrete wavelet transform technique is employed to extract important features of leakage current signals. Variation of leakage current magnitude and distortion ratio at different pollution levels were analyzed. Fuzzy c-means algorithm is used to cluster the extracted features of the leakage current data. Test results clearly show that the flashover and pollution severity of power transmission line insulators can be effectively realized through fuzzy clustering technique and it will be useful to carry out preventive maintenance work.