Condition Monitoring of Outdoor High Voltage Insulators, Online and Offline Techniques: A review

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Abstract

Outdoor insulator plays a vital role in high voltage transmission and distribution system. The performance and properties of outdoor insulator may severely affect due to various types of pollutants. The failure of insulation in high voltage system results in loss of supply and a huge loss of electrical energy to distribution utilities. In order to reduce power losses and provide a reliable power transmission, selection and design of insulators is very important. To monitor the condition and performance of outdoor insulator in contaminated conditions an appropriate diagnostic technique is required. In this paper various online and offline techniques for conditioning monitoring of outdoor insulators are reviewed under different contaminated conditions. To maintain the healthy environment, the condition monitoring of power line insulators is an important requirement. There are number of techniques that have been introduced to fulfil this requirement. Each technique used at different contaminated condition have their own pros and cons. The findings indicate that the most important effect on the surface of the insulators based on the contamination on the surface leakage current and the flashover voltage. This paper will help in the selection and design of condition monitoring techniques for high voltage outdoor insulator.

Index Terms Condition monitoring, outdoor insulators, flashover voltage, surface leakage current, transmission.

Introduction

Transportation of electricity from production sites to places of consumption is one of the important tasks of the energy sector. High Voltage Overhead Power Lines (HVPL) are the most important element in the single technological chain of supplying consumers with electricity. More than half of all interruptions in power supply are caused by the problems of HVPL. The condition of insulation on transmission and distribution power lines is one of the most important conditions for the successful operation of the power system. Insulators that are damaged or do not meet the requirements for their electrical characteristics can lead to power supply interruptions.

Outages in power system can be due to various reasons such as failures of transmission lines, insulators, supports and reinforcement. This is categorized as 52% due to transmission line failures (considering thunderstorm overvoltage's and 37% without taking them into account), 31% due to insulator failures, 13% due to support structures and 4% due to reinforcements [1], [2], [3], [4], [5], [6], [7], [8].

The number of failures is growing due to the increased complexity of power transmission and distribution system. One of the main causes of insulator failure is contamination of its surface during operation. Contamination reduces electrical strength of insulation and in some cases causes a superficial overlap, thereby disrupting normal power supply [1], [2], [3], [4], [5].

The high voltage outdoor insulators experience different environmental condition in different geographical regions. They can be contaminated with different pollutants such as dust, metal particles, agricultural byproducts, and industrial emissions. This contamination results in ageing and deterioration [9]. In polluted insulators, a conductive layer form on the insulator surface when the contaminant is partially dissolved [10]. Pollution and many other factors can affect to minimize their surface resistance. These different types of layers create number of paths for the leakage current. Leakage current is directly proportional to the increment of contamination and perhaps eventually cause flashover [11-12].

In power system, insulators are widely used in transmission and distribution network. The key purpose of an insulator is to setup a non-conductive separation medium between distinct electrical conductors [13]. The condition of insulators has a high impact on the operational efficiency of a power network [14]. Another important aspect is that the insulators at the same time expose to electrical and mechanical stresses. The mechanical strength of an insulator should be high so that it can bear the load and resistance against disruptive discharge should also be high so that an insulator can withstand the electrical tension. The change in atmosphere is causing a deep effect on the properties of outdoor insulators. Pollutants in the form of dust, firing residual and industrial gases in atmosphere lead towards the contamination which causes the deterioration of insulating properties of insulators [15] [16].

When the rate of contamination on an insulator increases a layer is formed on the surface and a conductive path is established between two conductors which results in the rise of frequency due to leakage of current. Furthermore, flash over starts to increase when partial discharge occurs from a small portion of insulator. The repetition of this process causes a complete breakdown or flashover [17].

To examine the effect on hydrophobicity of polymeric insulator when pollution layer is formed, a test was performed by evaluating leakage current and the test insulators used are of Type A- 66Kv and Type B- 33kV and the results are shown in Table 1.1.

The graph of the respective results in Table 1.1. and 1.2. Are also shown below:

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Table 1.1. Leakage current for different coating in Trial 1

S. No.	Insulator	Coating Type	Max Leakage current (µA)
1	Type A	Without Coating	44
		Thin	55.3
		Medium	182.3
		Thick	214
2	Type B	Without Coating	16.9
		Thin	116.9
		Medium	152.3
		Thick	193.6

Table 1.2. Leakage current for different coating in Trial 2

S. No.	Insulator	Coating Type	Max Leakage current (µA)
1	Type A	Without Coating	10.7
		Thin	122.4
		Medium	112.3
		Thick	158.4
2	Type B	Without Coating	43.9
		Thin	138.2
		Medium	199
		Thick	189

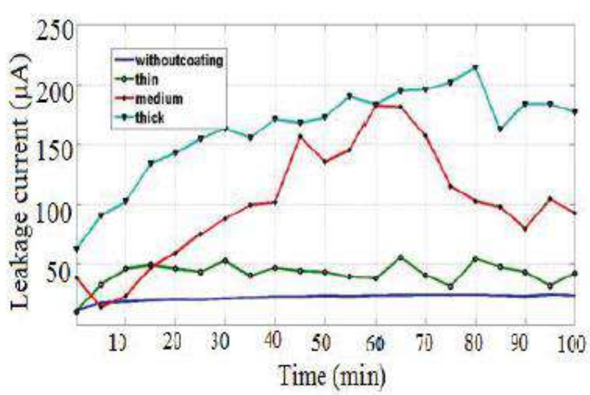

Fig. 1. Leakage current variation for Type A in Trial 1.

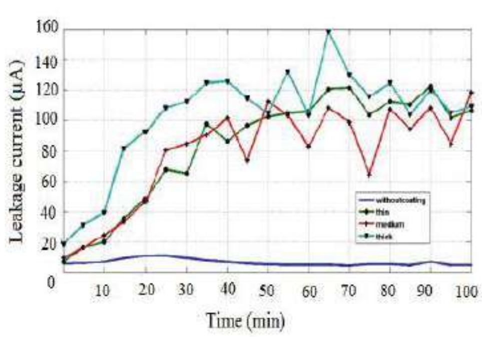

Fig. 2. Leakage current variation for Type A in Trial 2.

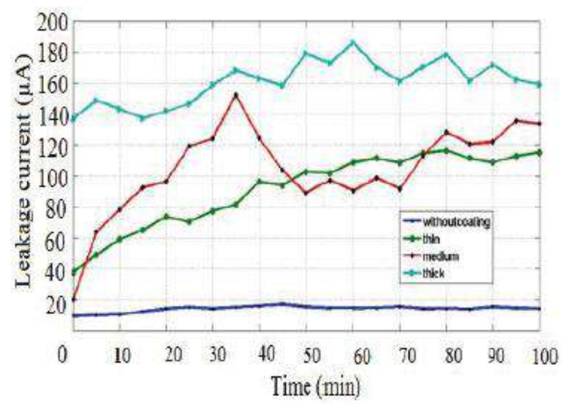

Fig. 3. Leakage current variation for Type B in Trial 1.

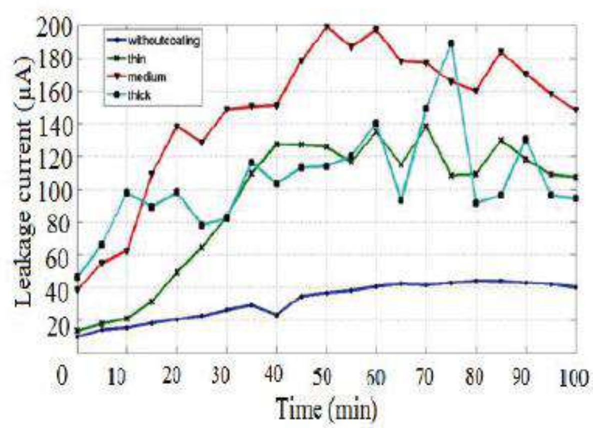

Fig.4. Leakage current variation for type B in Trial 2.

From the above figures it can be conclude that less current will be drawn from the insulator surface when pollutant coating is thin while thickly contamination coated insulator draws the high current.

In designing the insulators ambient temperatures, moisture, dew drops, fog and rain also taken into consideration. Insulators are one of the key components in High Voltage Applications. Due to contaminants on insulators the blackout power losses are a key issue facing internationally [18] [16]. Reliability is an important factor in selecting the insulator for example ceramic, glass and polymeric. Due to latest mechanical modelling techniques the mechanical strength of an insulator is quite good but in case of judging the electrical strength of an insulator then it is hard to say how reliable electrically an insulator is. The most commonly used insulator are ceramic insulators there electrical and mechanical strength is quite good having a resistive quality against corrosion and self-cleaning attribute when rain fall on ceramic insulators but due to hydrophilic characteristics of ceramic, it was noted that these insulators are subjected to flow of leakage current on the surface of insulator when passed through high voltage which lead towards the degradation and failure of an insulator. Generally the circuit used for measuring leakage current is as shown in Fig. 1.5.

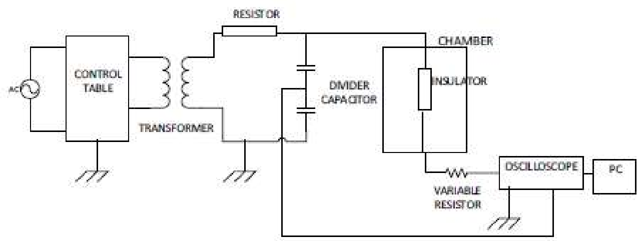

Fig. 5. Schematic diagram of leakage current measurement [19].

Room temperature Vulcanized silicone rubber is coated over ceramic insulator to enhance the performance of a ceramic insulator [19] [13]. The glass insulators are mostly used in transmission lines [20]. Comparing glass insulators with porcelain, the dielectric properties of glass do not show much variation. Dielectric properties define the electric strength of a material that how much electric stress an insulator can withstand [21].

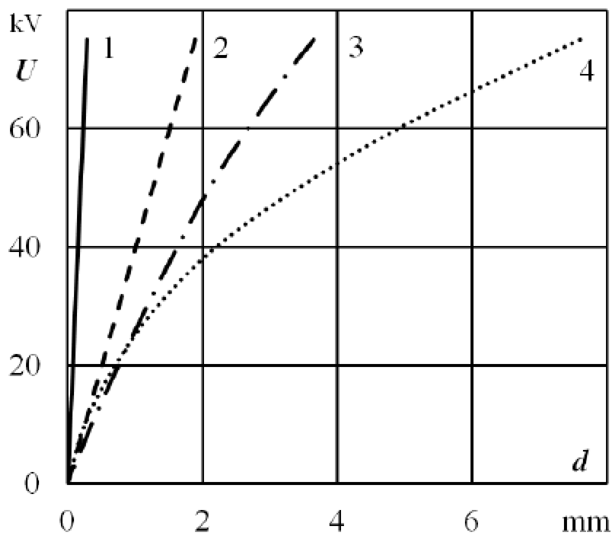

Fig. 6. Breakdown Voltages of glass and porcelain relative to the thickness [21].

Advancement in the field of high voltage brings a new type of insulator named as polymeric insulator. The features of polymeric over ceramic and glass is that polymeric insulators are less in weight, low cost and effect of pollution on performance of polymeric insulator is low [22].

Polymeric insulators are used as a second choice instead of using glass and porcelain insulators. The aging process which effects the performance of polymeric insulators leads to the decrease in electrical and mechanical strength. In a typical polymeric insulator, the areas where problems arise are in FRP rod and sheds material etc. leads toward the electrical failure of a polymeric insulator. The problems on these areas are due to weak bonding in FRP rod material, erosion and tracking issues on weather sheds. Improper connection between FRP and end fitting causes decrease in mechanical strength. It is noted that before deploying the polymeric insulators the insulator should be passed through various material and aging tests as aging is an important issue and concern for insulators manufacturers and power utility companies.

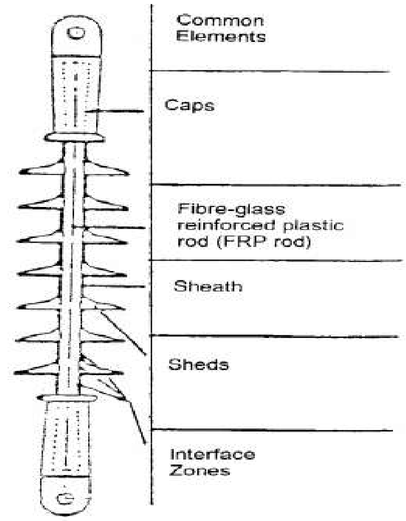

Fig. 7. Parts of Polymeric Insulator

Electric field stress and water conductivity experiments on polymeric insulators are effective in finding out the significant results in short time duration. As polymeric aging test are different from the tests used for evaluating the aging of porcelain and glass [23].

Composite insulators have many advantages if compare with porcelain and glass insulators composite insulators are less in weight and easy to install. The use of composite insulators for 60kV and 220kV transmission lines are common but it can also be used in 400kV transmission systems. Algerian Electric Power and Gas Company started deploying composite insulators and presented that composite insulators gives better insulation performance under different polluted environment and distributed electric fields in comparison with glass insulators. The performance of composite insulators is affected by various factors for example Shed architecture and framework, point of corona, creepage distance and pollution layer. Electric field distribution is affected by the layer of contaminants formed over the weather shed surface on composite insulators. This electric field is maximum at the triple junction of high voltage lines ending point. Electric field over the surface of composite insulators is perverted by the water drops as shown in Fig.1.8.

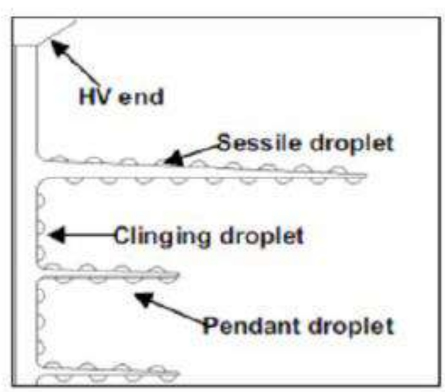

Fig. 8. Water droplets formation on composite insulators.

In comparing the composite and glass insulator for determining the Maximum Electric field, a 1mm thickness of pollution layer is deployed on an insulators having an electric conductivity of $\sigma = 0.071\, S/m$. It was observed that composite insulators showed lower magnitudes of maximum electric field as compared to glass insulators in case of both clean (normal) and polluted condition As shown in Table 1.3. [24]

Table 3. Maximum Electric field between Composite and Glass Insulator.

	Maximum Electric Field E_{max} (10^5V/m)			
	HV End		Ground End	
	Composite Insulator	Glass Insulator	Composite Insulator	Glass Insulator
Dry and clean conditions	1.92	2.84	1.57	2.02
Polluted thickness	2.52	3.02	1.74	2.26

For finding out the contamination level of the insulator optimal prediction characteristic technique is important. There are three types of characteristics for leakage current, which are: mean value, maximum value and standard deviation on the basis of these values' contamination level is defined. The values of these three parameters decrease with increase in leakage current distance. Evaluating the three parameters for the leakage current and other factors which are relative humidity and operative voltage the resultant values become the input of a Neural Network (NN) model. The Neural Network model optimally predict the pre-warming of contaminated insulator before flash over can occur. For the design of outdoor insulators this type of prediction is very helpful in high voltage system [25]. The flow chart of whole process followed by NN as shown in Fig. 1.9. Represents the prediction process which helpful in determining the method of the conditions of the field.

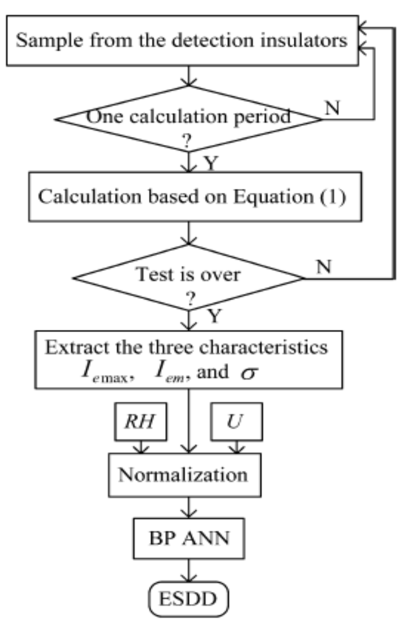

Fig. 9. Prediction process by Neural Network

The most common methods used for measuring the contamination on an insulator are equivalent salt deposit density, leakage current, insulator shell conductance and measurement of air pollution [26]. ESDD is used for denoting the soluble part of surface contamination. For testing the contamination on ceramic and glass ESDD is used but there are locations where contamination and pollution severity is very high which contains non soluble particles harder to dissolve in water. The severity level of these particles is denoted by NSDD. It is noted during experimentations that with the increase in Non-Soluble Deposit Density at constant ESDD the flash over voltage decreases. This is due to the thick water layer in assistance of inoperative material for example kaolin and binder [27]. For determining the effect of Kaolin, a standard IEEE insulator tested under AC voltage it has been observed that at Flash over Voltage the insulator shows both the effect of content and kaolin at ESDD and Flash over voltage (FOV) graph as shown in Fig. 1. 10.

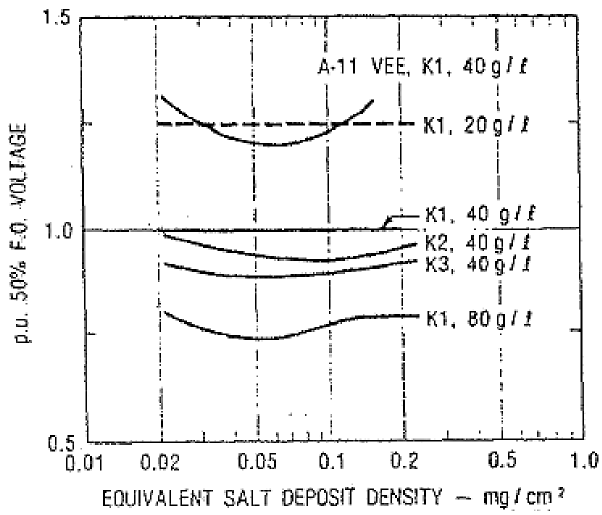

Fig. 10. Showing effect of content and kaolin on AC FOV on a standard A-11 IEEE Insulator. K1, K2, K3 are representing kaolin types.

From the graph it has been seen that FOV increase for K1 at 20 g/l while on 80 g/l the FOV decreases.

The widely used technique for condition monitoring of an insulator is the measurement of leakage current. As contamination on an insulator effects the leakage current and hydrophobicity. Measuring leakage current is more suitable and effective as compared to measuring hydrophobicity. One of the reasons of measuring leakage current on an insulator is that leakage current has a direct relation with pollution deposit on surface of an insulator. For monitoring the leakage current transducer are connected in series with an insulator and then voltage is measured across it. This measured voltage is transcribed with actual value via software or microcontroller [28].

Condition Monitoring of Insulators

Flashover in outdoor insulators occurred due to leakage current when become strengthened due to environmental contamination such as humidity, fog, water droplet, moisture and snow. This leakage current is a combination of surface leakage current and volume leakage current. Contamination and humidity affect the surface leakage current only, it is therefore important to consider surface leakage current is an indicator for outdoor insulator conditioning monitoring. Surface leakage current is extracted using the method of harmonic analysis. Another important parameter of harmonic analysis is the observation of the difference in phase angle when only surface leakage current is considered. By observing the shape and magnitude of surface leakage current under various contaminated condition the insulating properties and condition of outdoor insulators can be monitored [29].

Farhadinejad et al [30] have investigated through experiments the change in leakage current of different silicone rubber insulators at different type of UV exposure conditions and at different polluted conditions. The results show that the effect of polluted solution on leakage current is rapidly increased as compare to the influence of UV radiation alone. In count, the leakage current will be increased significantly as the combination of UV radiation and pollution.

Joneidi et al [31] have examined the different aging effects of polluted silicone rubber insulators as per the standard of IEC 60507. The phenomena of leakage current characteristics were investigated by using Fourier transform method and variations in harmonic contents were estimated at the different polluted conditions of an insulators. They have concluded that flashover voltage of an old insulators is inversely proportional to the level of UV exposed aging at the different pollution and moisture conditions of an insulators.

Icing on high voltage lines may lead to flash over on the surface of outdoor insulators, tripping and collapse of transmission tower. For indicating ice flash over, shed overhang and shed spacing are two important parameters. A method based on image processing are presented for the natural icing of outdoor glass insulators. This method based on the calculation of graphical shed spacing and graphical shed overhang through identifying the degree of curvature of imperfection of the contours of an outdoor icing insulator using Grab Cut segmentation algorithm. Graphical shed overhang of outdoor icing insulator shows observable change due to icing. Based on this method serious condition of icing insulators can be recognized easily [32].

The rapid growth in the network of electrical energy distribution system and increasing demand for energy supply lead the distribution system to a stressed condition. Beside the rapid growth in distribution network, failure of power system components, failure in communication system, protection failure and uncertain demand required a reliable operation of electrical distribution system. The electrical energy utilities trying to efficiently monitor the power system components to keep the quality and reliability of the supply. An automated system is proposed for regular monitoring of 11kv insulators for defects such as sagging spans, traces of arcing, leaning poles and tree encroachment on switchgear. In the proposed method each pole of the distribution system has a remote terminal unit with video cameras installed on it, capable of capturing images from different directions of the insulators. The condition of insulators can be monitor not only in critical condition but also on periodic inspection. The images taken through cameras at each remote terminal unit are transmitted through different communication techniques to main protection center. Algorithm evaluate the features of these images and declare the condition of insulator on a GUI to the operator [33] [34].

The increasing use of outdoor insulators in contaminated and wet condition such as humidity, salt fog and severe contamination required continuous monitoring of outdoor insulators. Once a continuous wet layer on the surface of insulator formed due to condensed moisture then leakage current will start flowing through the wet surface by the applied electric field. Leakage current will cause thermal heating of the surface of insulator which led to the formation of dry band gaps due to evaporation of wet layer. These dry band will lead to a discharge once the electric field strength at these gaps reach the breakdown strength of air. A recurrent plot technique is presented to analyze the leakage current passing through the surface of insulators to monitor the performance of outdoor contaminated insulators during operation. Using wavelet transform technique, the leakage current was split into different frequency components. Using the phase-space reconstructed method the extracted frequency components of the leakage current was extended to an m-dimensional phase space. The recurrent plot technique shows that the components of high frequency is prominent and help to identify the non-linear discharge activities of the insulators [35].

Overhead lines used in power transmission may greatly affected by power interruption due to flash over of outdoor insulators. An artificial neural network is used to measure and classify the outdoor insulators on the basis of different types of arcing a commercial acoustic sensor. Experiments were performed in the laboratory by generating both corona and arcing under lab test condition. The acoustic sensor recorded the sound produced by dry band arcing, corona and acoustic noise. A three-class pattern recognition problem is considered which detect corona, dry band arcing and acoustic noise. By using an envelope detection technique, the acoustic signal is converted to a low frequency signal. The low frequency components (100Hz and 150Hz) of envelope were used as input feature vectors for the artificial neural network. Fast Fourier transform of these low frequency envelopes is performed before given as an input to the ANN. ANN system classification rate is 91.7% and successfully classify the different types of arcing measured [36].

To achieve outstanding performance under various contaminated condition anti-dry band design for textured surfaces were used for outdoor insulators. A silicon polymeric rubber insulator was used for the artificial pollution test with clean dry layer test in accordance with IEC60507 standard. The leakage current and voltage signals were measured and digitized to processed for other parameters of the test. These parameters can be compared and used for the design of outdoor insulators under AC and DC voltages. the formation and location of dry regions on the surface of insulators can be identified by using IR camera to evaluate the temperature distribution along the insulator profile. These tests suggest that textured design of polymeric insulators improve the performance of outdoor insulators for AC and positive DC voltages [37].

Online Techniques

The conventional methods like Shunt Resistor for the detection of leakage current and for the detection of partial discharge High Frequency Current Transformer are used. But these methods are well operative when the insulator is wet due to snow, rain or fog etc. But in dry conditions these methods are not much productive. If a weather remains dry for a long period, then there is high probability of increase in contamination level which lead towards the flashover. Different techniques are suggested by authors based on research and experience. Microwave radiometry and reflectometry are online techniques used for finding out the pollution level on the insulator surface. These both techniques are based on the principle of electromagnetic energy. Insulators emits different EM waves in contaminated and unpolluted scenarios. Keeping this principle microwave radiometer detects the contamination on the insulator using an antenna operating on a particular frequency. While in case of microwave reflectometer, RF signal is transmitted and after colliding with the insulator surface the RF signal reflect back and captured by the receiver the values of power and time delay etc. is noted. If an insulator has contamination on the surface, then the power level based on reflected EM show different results as compared to uncontaminated insulator [38].

Faulty insulators in high voltage transmission lines highly effect the power system operational capability. For the detection of faulty insulator current sensor is deployed on towers carrying electric cables. This current sensor sends leakage current signal to the receiver from where for analysis purpose the information in the signal is extracted. For analysis of the signal there are two methods which are Fast Fourier Transform (FFT) and comparison of corona signal phase pulsate. Using FFT, in power frequency domain a spectrum of leakage pulse is observed by including faulty insulator in the system and without faulty insulator. For results, a comparison of characteristic spectrum is taken under consideration. If there is a corona discharge, then comparison method of corona pulse phase is very effective. In general, it is two-step process, first receiving corona signal then next step is the analysis of the pulse distribution over an insulator [39].

can monitor the different parameters such as humidity, temperature and light intensity to improve the deficiencies. It was based on the standard of NI USB 6251 hardware and Lab VIEW remote panel technology. The warning system was also installed. The warning will be activated if the parameters exceed limitations.

There is another method of transferring information with accumulation, in which not a symbol-by-symbol comparison is produced, but a comparison of the entire combination as a whole. This method is easier to implement, but it provides worse results [40], [41], [42], [43]. Thus, high noise immunity of the method of information transmission by spontaneous accumulation is based on the fact that the signal and interference in the channel do not depend on each other and vary according to different laws (the signal is periodic and the interference is random), so the repeating combination in each transmission will be, as a rule, distorted in different ways. As a consequence, at reception the accumulation, that is summation of the signal, increases in proportion to the number of repetitions, while the sum of the interference increases according to another law. If we assume that the interference and the signal are independent, then the mean squares are summed and the mean square of the sum increases in proportion to the first power. Therefore, in n repetitions, the signal-to-noise ratio increases by the n factor, and this happens without increasing the signal power. However, the equipment becomes more complex and the transmission time increases. In systems with IF increasing reliability of the transmission is achieved by repeating the information only in the presence of an error, whereas in systems without feedback (during transmission with accumulation), the repetition is carried out regardless of the message distortion. Therefore, in systems with IF information redundancy is much less than in systems with no feedback: it is minimal in the absence of distortion and increases with errors. In systems with IF the quality of the reverse channel must be no worse than the quality of the direct channel in order to avoid distortions that can increase the number of repetitions [37], [38], [39], [40]. Proceeding from the analysis of specificity of changes in the parameters of the external insulation of the HVPL showing that the processes of deterioration of insulation are rather slow, the interrogation of its state occurs at intervals per hour, and because the introduction of feedback would lead to a significant complication and increase in cost of equipment, it is rational to use simpler methods of information transfer (the method of repetition or accumulation). This is confirmed by the results of testing this transmission method that ensures high reliability

In electric transmission lines porcelain post insulator provides support and insulation to high voltage. Breakdown in porcelain post insulator causes deterioration and disrupt the power system operation. For detecting the defects in porcelain post insulators an online method is suggested which is vibrio acoustic characteristic monitoring by Finite Element Method (FEM). FEM model was designed in simulation software solid works and then transferred to ANSYS software tool. Using various mathematical modelling methods, the model was analyzed under different varying defects. Based on Power Spectral Density (PSD) it was concluded that in case of defect the value of frequency will differ. When there is a defect in an insulator then frequency blistering is appeared [44]

Pollution level on an insulator can be monitored using leakage current and Equivalent Salt Deposit Density (ESDD). Reference [45] uses ESDD for online monitoring of contamination on insulator through optical technology. The concept of this technique is based on the optical field distribution and light energy emission loss from the dielectric. After collection of experimental results, an Artificial Neural Network (ANN) was intend to create an association between ESDD and measured values. This technique was tested in same environment in which polluted insulator was compared with quartz glass rod. It was also observed that the ESDD on the polluted insulator and the quartz glass rod has a destined correlation. In areas where fall of snow is high the insulators are subjected to ice increase the problem in delivery of electrical power, collapse in voltage and induced outage problems arise. For detecting snow and its effect on an insulator, an online detection technique was presented based on video surveillance. This surveillance is based on automatic image analysis. The aim was to analyze the effect of varying weather and lightning on an insulator. Hybrid technique comprised of histograms, correlation and boundaries was developed. This test was carried out for full winter season and it was concluded that proposed method is robust in nature. The results of detection from this system on average was 93%. The results can be improved by improving image capturing system [46].

Online monitoring system based on radio local area network for an insulator helpful in determining the leakage current, continuous arching and partial discharges. The metal band fitted and wound over an insulator helpful in analyzing the different frequency current components. After separating low and high frequency components, their graphical trend is observed which then provide support in conceiving the contamination level model. RLAN is an efficient system for detection, recording the data and then transmitting the pollution data to data acquisition center [47].

The extraction of temporal and spectral information using analysis of Time Frequency Distribution make a way to determine the leakage current. The proposed system was efficient in determining the behavior of insulators and effect of surface discharges on an insulator. Using Spectral information spectrogram helpful in detecting the surface health and order of an insulating material. Another important aspect of online monitoring system present in the paper is that it shows leakage current characteristics in time domain, Fast Fourier Transform and Root Mean Square etc. With pollution severity the voltage stress increases and the voltage stress has a direct relation with Leakage Current (LC) amplitude. The LC signal shape describe the behavior that whether it is capacitive, non- linear or symmetrical [48].

In paper [49] for online monitoring a comprehensive system was developed which was comprised of LC sensor, Optical data communication link and Data Acquisition Centre. During test in laboratory environment it was noticed that limited number of flashovers did not affect the power system transmission and distribution. A simulation was designed based on Finite Element Method which efficiently described the arc ignition.

Offline Techniques

The contamination and pollution on insulators deployed in transmission and distribution system is of serious concern from years that at what appropriate time effective action is required. The need of personnel in filed operation is also based on this problem. For monitoring of pollution on insulators predictive monitoring devices are of special interest. Reference [50] discuss the monitoring of pollution and testing of flashover. For examining the behavior of flashover on insulators it is necessary to undergo various flashover laboratory tests, on the basis of these tests' threshold level is defined. Different cost-effective methods were suggested and one of the devices for monitoring pollution severity is Directional Deposit Gauge (DDG). DDG installation cost is less, measurements from DDG is easy. Another important aspect is that for collection of data no insulator is required. A direction from where pollution came on insulators is determined by this device. Based on laboratory tests a chart was developed which comprised of pollution severity performance. This chart provides a standard threshold level of pollution after which an action is needed. The flow of leakage current over an insulator is due to contamination on the surface of insulators. The electrolytic dissociation increases with increase in leakage current which leads to the formation of dry bands on insulator surface. Due to non-linearity in the surface of an insulator change in harmonics take place. For monitoring of overhead insulators, the leakage current measurement is steady and sure method. The main issue is the extraction of information from leakage current measurement catalogue in diversify harmonic conditions. Beside harmonics, time integral is also very helpful in monitoring of leakage current when used as a low-sensitive parameter. It has been observed that if leakage current is present on the insulators then it was noted that the system voltage harmonics have a meaningful effect on the characteristics leakage current harmonics. Time integral basically calculates the absolute area under the leakage current waveform. In the leakage current order of harmonics change with the change in voltage harmonics of the system. Due to this reason a small change in harmonics of the voltage formed a change in the time integral of the leakage current. The experimental setup comprised of high voltage harmonic waveform generator, Test sample, voltage divider, shunt resistor, protective unit and Digital Oscilloscope. Leakage current on an insulator can also be determined by peak value and level crossing [51]

Using Finite Element Method (FEM) the formation of corona rings and effect of electric stress was observed. Corona is a luminous discharge due to non- uniform electric fields. Under varying outside and inside temperature test was conducted to check correlational effect on an insulator. Infrared (IR) and Ultraviolet (UV) sensors are helpful in examining the surface clean and contaminated insulators. In case of using IR sensors, the sensors detect and captures the radiation emitting by the insulator and this radiation is in direct relation with fourth power of the absolute temperature. The nature and effect of temperature is distinguishing on the basis of thermal image scale. For precise measurement of temperature, the important parameters like humidity, temperature, reflection, convection and conduction must be taken into consideration. When corona occurs due to partial discharge and high electric field then an invisible ultraviolet radiation is emitted. The emission can be visualizing during night time. For detection of corona a filter is designed by which a solar radiation is transmitted to the test object in the band of 250nm and 280nm blocking all other wavelengths. The system is comprised of two channels, one channel helpful in visualizing corona using UV radiations while second channel thrust form an image of visible insulator. The images from both channels are superimposed to effectively analyze the output image. It has been observed that internal temperature of an insulator can be determined by measuring surface temperature [52]

Measurement of leakage current in outdoor insulator for monitoring the performance of insulators in polluted environment is a technique used to minimize system losses [53] By measuring of leakage current difference in severity of pollution can be detected. The performance of insulators in different pollutants environment can be analyzed by considering leakage current that is continuous, periodic or increasing with time. The maximum permissible value of leakage current for flash over is different for different types of insulators. Insulators with lower leakage currents will not necessarily have better operating performance. The insulator profile can affect the adoption of pollutants, which define their performance in pollutant environment [54]

The insulator design can control the leakage current which depend on the type of pollutants. Flash over risk due to leakage current must be defined by the type of pollutants and there is no unique solution which can predict the flash over of insulator on the basis of leakage currents. It means flash over occur at different values of leakage current for the same insulator for different types of pollutants. [55].

Muniraj et al [56] carried out the investigation of leakage current calculations of different polymeric insulators at different pollution conditions of the insulators. To measure the harmonics of higher order and Signal Noise Ratio (SNR) the Min-Norm spectral analysis was used to do this work. To analyze the function of frequency, Choi-Williams Distribution (CWD) function was employed on the leakage current signal. The final results indicate that the outdoor polymer insulators could be identified from the harmonics of higher order and signal noise ratio values.

Jayaprakash Narayanan et al [57] done the investigation on polymeric insulators with partial discharge measurements aged under the thermal process. The process done in the laboratory is Accelerated aging process. The measurements of partial discharge signals were done by using advanced ultra-wide band PD measuring system. The most significant structures were mined from the partial discharge phase resolved pattern. To develop the condition monitoring system neural networks technique was applied and to predict the pollution severity and flashover of polymeric insulators.

In [58] the author used optoelectronic sensor for real time monitoring of leakage currents on a 13.8kv power line insulator. Ultra-bright green LED driven by leakage current produce an AM light signal. A 1-mm plastic optical fibre is used to couple high intensity encoded signal and transmitted over from measurement point to a remote area. The leakage current values are demodulated through a data logger and sent through GPRS communication to a 150km remote station. Deterioration of composite insulator due to severe weather condition and their destruction are usually unnoticeable. Many techniques are used to detect the condition of composite insulator. One of the techniques used to predict the deterioration of composite insulator is the Partial Discharge analysis technique [59] Statistical parameter used in this technique are Skewness, Kurtosis, mean and deviation. Partial Discharge analysis of these materials provide some characterization of pollution condition which shows a typical value of average and maximum PD. The statistical analysis of Kurtosis distribution gives quantities results for monitoring of surface conditioning [60] In reference [61] the author

monitors the deterioration of insulator using analysis of Partial Discharge signals. Within the electrical field the partial discharge signals are produced due to localized ionization of the field. Finite Element method can predict the deterioration of insulators by providing information of partial discharge resulted from the numerical analysis of the electric field. This method has advantage of measuring charge density and electric field intensity through the analysis of partial discharge.

Comparison of both methods

Each method suggested by researchers and scientists for monitoring of outdoor insulators has different pros and cons. Each online and offline techniques reflect its unique identity which distinguish with other methods used for insulators monitoring. In online techniques main focus was on the transmission of acquired information from outdoor field to Data analysis center. For this different method was suggested use of optical technology etc. For monitoring of insulators leakage current and Equivalent Salt Deposit Density has an important role. Using the principle of electromagnetism microwave radiometry and reflectometry online techniques were designed in which an antenna of specific frequency and RF signals are used to detect the pollution severity on an insulator. Current sensor was deployed for detection of faulty insulators and then information is extracted from the signals coming from sensors. In case of energy loss from an insulators optical technology was designed to detect the ESDD value for monitoring of contamination on an insulator. Radio Local Area Network technique record the data and then transmit it to Data Acquisition Centre (DAC). A technique was presented based on acoustic emission to detect sound signal when flashover occurs. The most common numerical model technique used was Finite Element Method (FEM). For monitoring the surface of insulators and the quality of material used in insulators Spectral information spectrogram is used. For comparison of two different insulators type Artificial Neural Network Technique is used for creating association between them. In an offline techniques Directional Deposit Gauge was used for pollution severity. Analysis of harmonics generate due to leakage current is also very helpful. Ultraviolet and Infrared rays are used in examining the contaminated surface of insulators. Using Amplitude Modulated light signal the optoelectronic sensor was designed which is driven by leakage current. Using statistical parameters for example skewness, mean and deviation etc. partial discharge analysis used in predicting the deterioration of insulators base on the type of material used in insulators manufacturing. By providing the data of partial discharge signals generate in electrical fields deterioration of insulators can be predicted via numerical analysis using Finite Element Method.

Conclusion

The main focus of this paper is on review of online and offline techniques in the monitoring of insulators. Through this review, number of techniques and approaches were discussed. It was coming into consideration that each techniques and methods has its own uniqueness and specialty. Using leakage current and ESDD number of techniques were presented. Automated system was designed in which video surveillance system was used to monitor the insulators by capturing images from different direction of insulators. Recurrent plot technique is used to analyze the leakage current; it identifies the non-linear discharge activity of an insulator. Techniques used for detection of contamination via radio and antenna communication are Microwave radiometry, Reflectometry and RLAN. During flashover a specific hissing noise is produced on the basis of this noise acoustic energy emission detection technique was created for pollution level monitoring on insulators. For mathematical analysis Finite Element Technique are commonly used. With FEM formation of corona ring and effect of electric stress can be easily observed. Another important method is the use of Artificial Neural Network classifier techniques used to train and comparing data of two different type of insulators and effect of different environment on an insulator. For fast communication optical data communication link effectively transfer data of an insulator deployed in field to the Data Acquisition Centre. Use of IR and UV sensors are used in monitoring the surface of insulators in clean and polluted environment.

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