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A Critical Study on Detection of Pollution Level of Overhead Insulators

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ABSTRACT

The reliability of electric power transmission depends upon the reliability of its overhead insulators. Since the overhead insulators are installed in different geographical locations, they are subjected to various adverse conditions and get polluted by the contaminants of the respective fields. This contamination leads to flashover in wet conditions. Thus, it is very essential to identify the different pollutants and monitor the condition of insulators. This paper describes different geographical locations of insulators and the respective pollutants depositing on the insulator surface. Also, a number of methods for detection of pollution level of insulators have been discussed, along with their limitations.

Keywords – pollutants, flashover, electromagnetic radiation, acoustic emission, leakage current, pH, conductivity, ESDD.

I. INTRODUCTION

There has been a rapid growth in high voltage generation and transmission of bulk quantity of power over long distances in order to meet the growing demand for power. However, the efficient transmission of power invariably demands the reliable insulation system and particularly, the overhead insulators which form the fundamental structure of power transmission.Overhead power transmission lines pass through the areas having different environmental conditions. Therefore, overhead insulators are subjected to different adverse conditions and get contaminated by variety of pollutants such as saline deposits, industrial smoke, dust, etc. which are responsible for the degradation of insulation strength, flashovers and eventually failure of insulators. Thus, the knowledge of geographical locations of insulators and corresponding pollutants is very important in order to detect the pollution level of insulators [1].

The pollutants are of less concern in dry condition because of their low conductivity and hence the low risk of flashover. However, in wet conditions like rain, snow,fog or dew, the contaminants on the insulator surface dissolve to form a conductive layer and initiate leakage current and partial discharge activities which finally lead to flashover of insulator. A flashover of extended duration causes unequal expansion of the porcelain thereby shattering the insulator with big cracks and causing interruption of the supply. Therefore, it is very essential to monitor the pollution level of insulators to prevent any possibility of flashover and ensure the reliability of power transmission[3].

Over the past years, several methods have been presented for monitoring the contamination level of insulators. Those methods are based on various parameters such as electromagnetic radiations, acoustic emissions from the partial discharge phenomenon, leakage current flow, pH, conductivity, ESDD of the electrolytic layer formed on the surface of insulator. These methods for the identification of the pollution level of insulator surface have been briefly described in this paper. The limitations of above methods have also been discussed in this paper.

II. ADVERSE CONDITIONS OF INSULATORS

An insulator performs both electrical and mechanical functions. Mechanically, it holds the conductor or busbar at particular distance from earth while electrically, it provides the required insulation between the pole and conductor. Thus, insulators are said to be in adverse conditions when either or both of these functions are not being fulfilled anymore. The adverse conditions of insulators are basically as follows:

a. External stress

If an insulator has certain weak portion because of manufacturing fault, it may crack from that weak portion when it is subjected to mechanical stress by its conductors. Breaking can also be caused by heavy ice deposits or strong winds that cause applied mechanical stress to exceed its rated value.

b. Internal stress

The porcelain insulator mainly consists of three dissimilar materials i.e. main porcelain body, steel fitting arrangement and cement to fix the steel part with porcelain. Because of varying atmospheric conditions, these materials expand or contract with different rate causing internal stress. This non-uniform expansion or contraction of porcelain, cement, and steel is the main reason for cracking of insulator.

c. Short circuits

In case of pin insulators, the short circuiting of the conductor to earth takes place very frequently because of large birds and similar object. Such a situation is prevented by employing bird guards near the insulator on the crossbar. The situation can also be avoided by increasing the clearance of conductor from earthed parts or using suspension insulators instead of pin type.

d. Overvoltage

Overvoltage caused by lightening strokes, switching operations etc. result in abnormal voltage gradients along the surface of insulator. This may lead to flashover or even puncture of insulators. However, protective devices like surge arresters are being used in the system for limiting the over-voltage produced by both these situations.

e. Pollution-induced flashover

Flashover is one of the most common causes of failure of HV insulators. The pollutants on the insulator surface dissolve to form a conductive layer, and initiates leakage and partial discharge activity, which finally lead to flashover. A flashover of extended duration causes non-uniform expansion of the porcelain material thereby shattering the insulator with big cracks.This shattering of insulators results in the loss of power supply and a rise in the associated engineering and maintenance costs [3].

III. POLLUTANTS CORRESPONDING TO DIFFERENT GEOGRAPHICAL LOCATIONS

a. Industrial areas

The insulators which are placed in industrial areas get heavily polluted by smoke, chimney ash, and soot from the industries. The chemical properties of the pollutants vary with respect to the type of industry. The field close to steel industry will have Bassanite ($CaSO_4.1/2\ H_2O$) as the main soluble constituent and SiO_2, Fe_2O_3, CaO, MgO as eh non-soluble pollutants. However, a site close to a thermal power plant primarily consists of SiO_2 and other soluble constituents which arise from dust and dirt[1].

b. Coastal areas

In coastal areas, the overhead insulators are subjected to strong winds blowing from the sea. These winds carry sodium chloride (NaCl) in large amount. These winds also carry magnesium chloride ($MgCl_2$) which readily takes up and retains the moisture from atmosphere. As a result, insulators get strongly contaminated by sodium chloride (NaCl) and magnesium chloride ($MgCl_2$)[2].

c. Desert areas

The insulators which are installed in desert areas get heavily deposited by sand, dust and other pollutants, as the self-cleaning effect is not there because of very little rain. The main soluble components in desert areas include sodium chloride (NaCl), calcium sulphate ($CaSO_4$), and potassium chloride (KCl). The deserts which are close to seacoast have NaCl in large quantity because of saline winds blowing from the sea. Calcium Oxide (CaO) is the main non-soluble component found in desert areas[2].

d. Inland areas

The insulators which are placed in inland areas, get their surfaces accumulated by sand and soil blown by the winds.The main components of sand and soil include calcium sulphate ($CaSO_4$), sodium nitrate ($NaNO_3$), calcium nitrate ($Ca(NO_3)_2$). In addition to this, other salts such as sodium chloride (NaCl), magnesium chloride ($MgCl_2$), magnesium sulphate ($MgSO_4$), potassium chloride (KCl) have also been found to a certain extent [2].

e. Agricultural areas

The main soluble component found in agricultural areas is calcium sulphate ($CaSO_4$). In addition to this, ions like phosphates, nitrates etc. which are electrically conductive have also been found in agricultural fertilizers. These components by means of winds or birds get deposited on the insulator surface and degrade its performance [2].

f. Biological areas

The insulators installed in biological areas get their bottom surface occupied with algae and fungi. The growth of algae and fungi are favoured by wet conditions. Such biological growth in the form of algae and fungi possesses soluble salts like NaCl which decrease the insulation strength to a great extent [2].

IV. STAGES OF INSULATOR FLASHOVER

a. Different soluble as well as non-soluble pollutants get deposited on insulator surface.
b. Under wet conditions such as fog, drizzle, dew, etc. an electrolytic layer is formed and the resistivity is decreased to a considerable extent.
c. Leakage current starts to flow through this electrolytic layer and Ohmic heating takes place at points of high current density.
d. Heating causes drying of the layer by fast evaporation of the moisture. This stage is generally known as dry band formation.
e. Dry bands cause most of the applied voltage to drop across them and lead to partial discharges.
f. Partial discharges propagate over the insulator surface and finally bridge the whole insulator and result in flashover of the insulator[3].

V. METHODS FOR DETECTING POLLUTION LEVEL OF INSULATORS

Several parameters have been found to be closely associated with the pollution level of insulators. Thus, measuring one or more of these parameters, the pollution level can be detected. Following are the parameters based on which various methods have been discovered.

a. EM radiations

The electromagnetic radiations from the leakage current on the insulator surface are used as the basis for identification of pollution severity. In this method, EM signals produced by leakage current are received and processed in a manner similar to that of a radio receiver. The output of the processor is taken through the amplifier which could be either Intermediate Frequency (IF) amplifier or Audio Frequency (AF) amplifier. There is an automatic hazardous pulse monitor employed in the measuring system. This pulse monitor drives an alarm system whenever the magnitude of pulse exceeds a specified value.

Limitation-The main problem associated with this method is the interference from the variety of other sources in the vicinity of insulator, which makes it very difficult to identify the source of partial discharge on the surface of insulator[3].

b. Acoustic emission

There is a continuous emission of different energies in the process of partial discharge including acoustic energy. The magnitude of acoustic signals varies depending upon the propagation of partial discharge. Hence, the acoustic emission is used for the detection of pollution level of insulator. In this method, acoustic signals from the discharge source are converted to electrical signal with the help of transducer. The spectrum analysis of the acoustic signals is carried out through a broad bandwidth acoustic transducer. This spectrum analysis helps to understand the characteristic signals and the process of discharge. The signal processing unit amplifies the electrical signals and processes it to the desired voltage level. Finally, the contamination is displayed in the form of voltage signal on the oscillograph.

Limitation- In this method also, there is a problem of interference from several other sources near the insulator. Also, the characteristics of acoustic signals generated from the polluted insulators are still largely unexplored[5].

c. Leakage current surge

When insulator gets polluted, leakage current starts to flow because of the electrolytic layer formed on the surface. As the contamination level on the surface rises, the leakage current surges become more frequent. Thus, leakage current surges are used to monitor the contaminated insulators. Several surge counters are employed for monitoring the leakage current surges. The number of surges over an interval of one hour is counted every say 5 hours. It is observed that, 20-25 surges per hour of current in excess of 100mA is an adequate level of warning for flashover.

Limitation-This method requires reconstructing insulators in order to install highly specialised current transducers. This not only makes the apparatus expensive but also creates difficulty in installation[3].

d. pH Value

pH is nothing but negative logarithm of H^+ ion concentration in the given solution. The increase or decrease of the contamination invariably affects the pH of the electrolytic layer formed on the surface of insulator. Thus, pH value of electrolytic layer is used for detecting the contamination level of the insulator surface. In this method, the contaminant samples are taken by washing the insulator surface with specific amount of distilled water. pH value of contaminant is measured using pH meter with range from 0-14.

Limitation-The variation in the pH of the electrolytic layer is different for different pollutants. Thus, identification ofall the pollutants is mandatory before the application of this method[4].

e. Conductivity

The insulator surface, contaminated by different kinds of soluble and non-soluble salts, has conductivity developed over the surface. This conductivity varies with the quantity of electrolytic substance accumulated and moistened on the insulator surface. Thus, several monitors based on conductivity are commercially used to detect the pollution level of insulator. The conductivity of polluted surface of insulators is measured using a portable conductivity meter with all the desired specifications in terms of range, resolution, accuracy, etc. depending upon the dimensioning of insulators under pollution. This conductivity (mS/cm) is used to detect the pollution level of insulators[6].

f. ESDD

The pollutants depositing on the insulator surface include various soluble as well as non-soluble salts. The conductivity of the electrolytic layer depends upon the ionic activities in the salt solution. The amount of sodium chloride (NaCl) that would produce the same conductivity at a given natural pollution is known as the Equivalent Salt Deposit Density (ESDD). In order to measure the ESDD, the polluted insulators are washed with a specific amount of distilled water and then its conductivity is measured. Now, the amount of salt that produces the same conductivity divided by the surface area of insulator, gives the value of ESDD in mg/cm^2 as shown below.

$$ESDD = \frac{0.5 \;\; * V}{A} \left[\frac{\sigma}{1 + 0.0 \;\; (T_W - 2 \;\; {}^{O}C)} \right]$$

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Where, V is volume of distilled water with which the insulator surface was washed (ml), σ is conductivity of the solution after washing the insulator (mS/cm), T_w is ambient temperature (wet) (^oC) and A is the area of disc[6].

VI. CONCLUSION

Thus, it can be concluded that overhead insulators are subjected to different adverse conditions and get contaminated by variety of pollutants leading to flashover.The knowledge of geographical locations of insulators and corresponding pollutants is very important in order to detectthe pollution level of insulators.Various methods, based onEM radiations, acoustic emission, leakage current surges, pH, conductivity, ESDD etc. for the detection of pollution level of overhead insulators,have been studied and their limitations have also been stated in this paper.

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