Qualitative Analysis of Contamination Severity between NaCl and $CuSO_4$ for Outdoor Insulator

Sanmoy Chakraborty, Sanjoy Podder, Suhas Deb
Department of Electrical Engineering
Jadavpur University, India

Sudeshna Nath
Department of Electrical Engineering
BBIT College, India

***Abstract*—This paper presents a new criterion for insulator flashover condition prediction based on percentage 5th to 3rd harmonic component. These harmonics are extracted from leakage current of insulator employing FFT. In this context, a threshold limit of this ratio has been mentioned. To investigate experimentally, leakage current of an 11 kV glass disc insulator (contaminated at three different levels) has been recorded at different applied voltages. For contamination purpose two different types of salt are taken as contaminants, one is NaCl and other is $CuSO_4$. Above mentioned ratio has been calculated for both types of contamination separately and compared. Results show that contamination due to NaCl is more severe than that of $CuSO_4$.**

Keywords— *Leakage current, insulators, ESDD, FFT, humidity, NaCl, $CuSO_4$.*

I. Introduction

Insulator is one of the key components of modern day power system. About 70% of line outages occur due to contamination flashover of insulator [1]. Most of the transmission line insulators remain exposed to various atmospheric states at distinct geographic areas. So, insulators get contaminated easily. Paper [2] reports that, contaminants at dry condition do not create any surface activity. Contaminants in presence of moisture form a conducting layer over the surface of insulator. Hence, leakage current starts to flow. Density of leakage current is non-uniform due to unequal wetting of insulator surface. In this regard, huge current density comes in sight at some portion of insulator which subsequently gives rise to localized heating. This heating effect leads towards partial evaporation of moisture to those places. As a result dry band region appears on the insulator surface. Formation of dry band interrupts the flow of leakage current. It is reported in [2] that, voltage stress across this dry band grows up to a very huge value which is enough to cause breakdown in the form of arc. These arcing phenomena may leads towards a complete flashover [3-10], unless get checked in proper time. Therefore, condition monitoring of insulator is very much essential for uninterrupted power supply.

Existing literatures reveal that, estimation of equivalent salt deposit density (ESDD), non-soluble deposit density (NSDD), are the most commonly applied techniques to ascertain the pollution severity for any kind of insulators [3-5]. However, these methods are time consuming and difficult to automate [6]. Considering the limitation of above mentioned method, researchers have focused on analyzing the leakage current for diagnosis of insulator surface condition. In this context, analysis of lower order harmonic contents is very much helpful to extract needful information about the surface condition of insulator [7-8]. It is mentioned in [7] that, percentage ratio of 5th to 3rd harmonic component is a very important indicating parameter for the contamination level of insulator. Threshold limit of this ratio of is also been mentioned in [7].

This proposed technique is a suitable way out towards predicting the probable flashover condition. In this regard, an 11 kV glass disc insulator has been tested with two different salts as contaminants (NaCl and $CuSO_4$) at three different contamination levels. For each contamination level, percentage 5th to 3rd harmonic component ratio has been calculated and compared between two types of pollutants. From the result, authors have tried to predict whether NaCl contamination is more severe than that of $CuSO_4$ contamination or vice-versa. The proposed technique has been checked several times to investigate its effectiveness. All the necessary experiments carried out here follow IEC 60507 standard.

II. Setup

A 11kV glass disc insulator has been utilized for laboratory test purpose. Various characteristics of glass insulator are presented in table 1. A test set up has been organized in laboratory according to IEC 60507 standards[4]. Diagram of test set up is given in fig 2. Testing transformer of rating 150 kVA, 500kV/250 V, single phase 50 Hz is used for applying voltage to the conductor [2]. Transformer output voltage is fed to the insulator via a series connected protective resistance of rating 180 kΩ. Earth link of the above mentioned insulator is connected by a 10 kΩ resistor which works as a current shunt, connected parallel to the measuring device [2]. Potential drop across current shunt has been calculated from measuring device, and the leakage current passing by the shunt is measured from there [2]. Protection due to overvoltage condition is required to avert any harm that may happen in measuring instruments owing to any collapse in the system [2]. Had resistance for protection been attached to secondary of the transformer gets harmed owing to any accidental case at the time of flashover, the potential drop across 10 kΩ resistor will build up to a very huge magnitude [2]. At this condition protection for voltage surge starts to operate and guards both data recording instruments and CRO [2].

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TABLE I. INSULATOR CHARACTERISTICS

Characteristic	Value
Leakage Distance Length	280 (mm)
Height	146 (mm)
Voltage Rating	11 KV

Fig. 1. Diagram of glass insulator

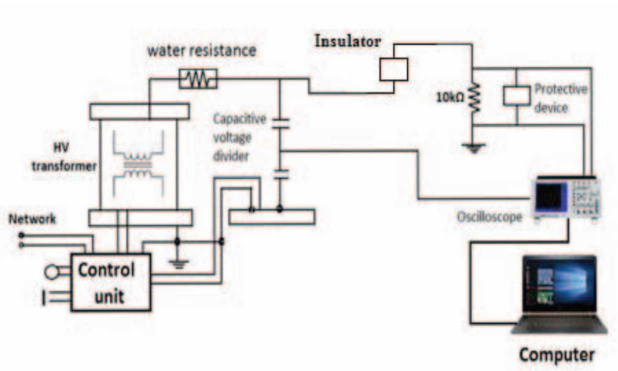

Fig. 2. Test set up

III. TEST MECHANISM

A. Development of contamination coating

The Equivalent Salt Deposit Density (ESDD) method is applied to determine the pollution extremity of insulator surface [3-5]. Various atmospheric conditions like temperature, humidity etc is considered during experimental procedure [2]. NSDD (Non Soluble Deposit Density) and ESDD give an useful information about the contamination severity for different contaminated zone[8]. It will yield needful information regarding maintenance of insulators at every proper interval. The sea-salt contaminations are not only restricted in the adjoining areas of sea coast but also cover a significant area due to wind. Generally high voltage insulators come in contact with NaCl salt which gets deposited on the surface of insulator [2]. Due to this fact surface of insulators can be damaged easily and recurrent replacement are essential. To contaminate insulator NaCl salt is applied in the necessary amount along with 40 g/l of kaolin [2]. For our experimental purpose copper sulphate ($CuSO_4$) is also used along with NaCl.

Fig. 3. artificially contaminated insulator

B. Experimental method

According to IEC 60507standard solid layer method (SLM), is applied to create uniform contamination layers on the surface of glass disc insulators [4].

Environmental chamber temperature is kept fixed at 30^{o}C and average humidity is maintained within 50%-80% range. After arranging temperature and humidity, voltage is varied from 12kV to 20kV in steps of 2kV. Leakage current data has been collected from Cathode Ray Oscilloscope (CRO) at each of these above mentioned voltages. Same procedure is replicated for various pollution levels [2].

C. ESDD measurement

According to specifications given in IEC 60507, first of all the conductivity of the related surface contamination was measured with the help of a small square section of the contamination sample of area 64cm^2 dissolved in 100ml of water. Then with the help of the following formulae and related tables the conductivities at different temperatures were converted to 20^{0}C and then the ESDD values were calculated individually for the different degrees of contamination.

TABLE II. MEASURED CONDUCTIVITY AND ESDD

Nature	σ_{20} (S/cm)	ESDD (mg/cm^2)
Low Contamination	0.5-1.2	0.06
Medium Contamination	1.2-3.0	0.12
High Contamination	>3.0	0.32

IV. TEST RESULT & DISCUSSION

Transmission line insulators gets affected by pollutants like dirt, dust, sea salt, various chemicals which ultimately leads towards flashover, therefore, the efficiency and reliability of insulators get degraded. Contaminants accumulated on the surface of insulator become conductive when insulator surface comes in touch with moisture, humidity, rain or fog etc. Leakage current flows through the insulator surface and grows gradually and ultimately leads towards flashover [2]. Flashover mechanism is divided into 5 different steps [2]. The steps are mentioned below:

a. Accumulation of salt
b. Development of dry band zone
c. Initiation of arc
d. Lengthening of arc
e. Total flashover

Above mentioned processes lead toward flashover. Graphical analysis of data has been done using MATLAB. Some of the results are shown below.

For a given ESDD, the value of total harmonic distortion (THD) increases with the increase of applied voltage.

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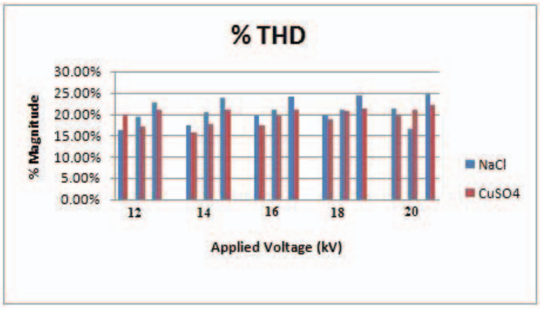

Fig. 4. THD variation with Voltage

THD increases with applied voltage for both NaCl and $CuSO_4$. Distortion, in case of NaCl contaminated insulator is little bit more than that of $CuSO_4$ contamination.

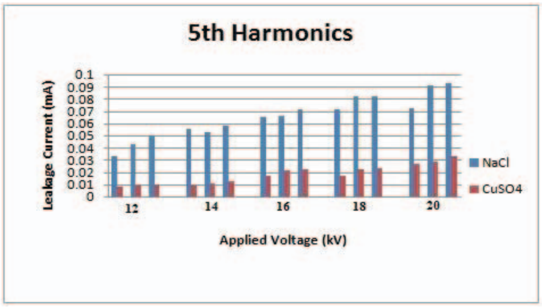

Fig. 5. Leakage current 5th harmonic component at low contamination

At pure or low value contamination of insulator, 5th harmonic component of current waveform remains greater than 3rd harmonic component but when insulator becomes highly contaminated, 3rd harmonic component is the key component towards forecasting pollution level of insulator.

Leakage current depends on level of applied voltage as well as on the severances' of contamination level. Fig. 6 makes clear that 3rd harmonic component of leakage current begins to increase from 12kV to 20kV gradually at moderate contamination level. From fig.6 it is clear that growth of 3rd harmonic component is very uniform for the case of NaCl contaminated insulator whereas for $CuSO_4$ contaminated insulator it is non-uniform. Keeping this fact in mind, authors have done a comparative study between intensity of contamination of two salts (NaCl and $CuSO_4$). Here, NaCl and $CuSO_4$ act as contaminants. Main objective of this paper is to show which of the prior mentioned contaminants is more severe for outdoor insulator. To establish this fact percentage of 5th to 3rd harmonic component ratio is very much effective [7].

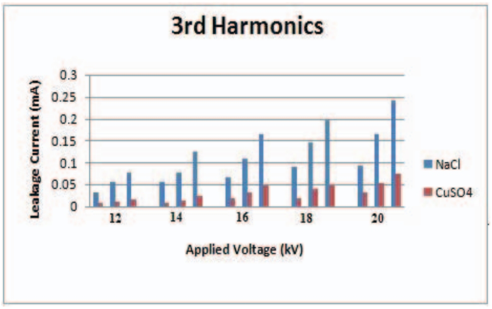

Fig. 6. Leakage current 3rd harmonic component at moderate contamination

From fig.5 &6 it is evident that growth of 5th and 3rd harmonic component is more rapid for NaCl polluted insulator in comparison to that of $CuSO_4$. In this regard percentage of 5th to 3rd harmonic component ratio will be helpful towards predicting probable flashover condition [7]. Flashover can happen when this ratio falls below 30% [7]. For pure insulator this ratio is always above or at 100%. No flashover occurs at this condition and as a result insulator remains safe. For contaminated insulators this ratio falls below 100%. Condition of insulator starts to degrade when this ratio fall below 100% [7]. Results for contaminated insulator are presented below.

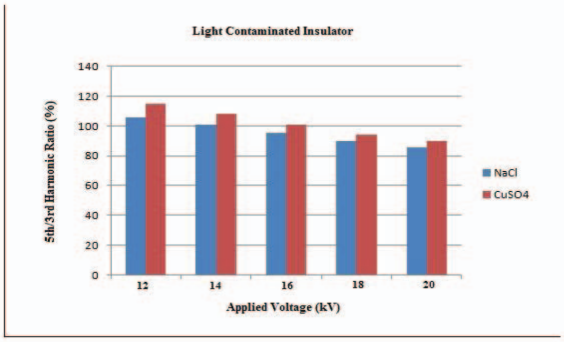

Fig. 7. Percentage 5th /3rd Harmonic ratio (Lightly contaminated insulator)

Fig. 7 shows that percentage of 5th /3rd harmonic ratio lies near 100% upto 16 kV, after which it falls below 100%. Percentage of 5th /3rd harmonic ratio is always greater for $CuSO_4$ contaminated insulators than that of NaCl contaminated ones.

At pure condition, 5th harmonic component of leakage current remains greater than other harmonic components [7]. Therefore, percentage ratio of 5th to 3rd harmonic component is greater than 100%. During contaminated condition 3rd harmonic component of leakage current increases faster than other odd harmonic components. So, the ratio starts to decrease. At lightly contaminated condition till voltage of 16 kV, growth of 3rd harmonic component is slow for both NaCl and $CuSO_4$ contamination. Hence, this ratio remains above or near 100%. Beyond 16kV, electric stress increases which in turn increases the 3rd harmonic component of leakage current. As a result the ratio falls below 100%.

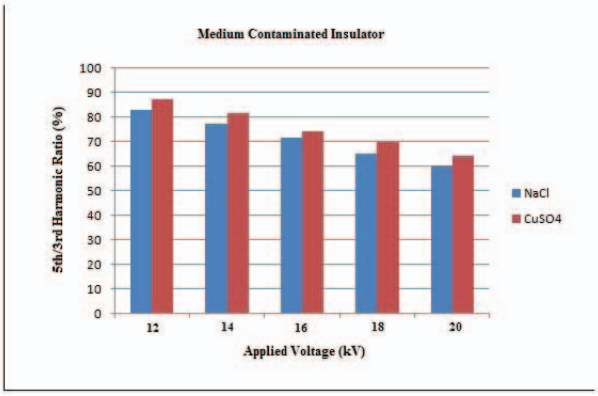

Fig. 8. Percentage 5th /3rd harmonic ratio (Medium contaminated insulator)

Fig. 8 indicates that this ratio decreases upto 60% at 20 kV. Here growth of 3rd harmonic component of leakage current is very fast as compared to 5th harmonic component. Due to this, percentage of 5th to 3rd harmonic ratio is well below 100% for both the contaminants. Again this ratio is low for NaCl contaminated insulator than $CuSO_4$ for every applied voltage.

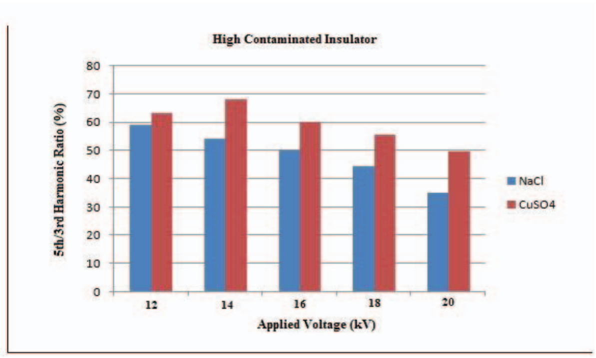

Fig. 9. Percentage 5th /3rd harmonic ratio (High contaminated insulator)

Fig 9 depicts that percentage of 5th to 3rd harmonic ratio decreases towards 30%. For NaCl contaminated insulator this ratio decreases rapidly and almost uniformly whereas for $CuSO_4$ contamination it is not uniform. At high value of contamination growth of 3rd harmonic component is very rapid. Due to rapid growth of 3rd harmonic component, severe distortion in leakage current waveform appears as well as dry band arcing starts to occur frequently. This kind of surface activity becomes prominent when this ratio comes near 30%. Obviously, this ratio comes near 30% for NaCl polluted insulator better than that of $CuSO_4$ polluted insulator. Therefore, surface activities and probability of flashover occurrence is more for NaCl contamination than $CuSO_4$ contamination. From above analysis it is obvious that sea salt (NaCl) pollution is more dangerous than that of industrial pollutants like $CuSO_4$.

V. Conclusion

This work proposes a novel method for predicting eminent flashover condition of overhead insulator through leakage current harmonic analysis. In this regard, an 11 kV glass disc insulator is contaminated at three different levels by NaCl and $CuSO_4$ separately according to IEC 60507. An experimental set up has been arranged to record leakage current at different voltages as well as different contamination levels. FFT has been applied on leakage current to extract 5th and 3rd harmonic components. From which percentage 5th to 3rd harmonic component ratio has been calculated separately for NaCl and $CuSO_4$ contaminated insulator. The value of this ratio is always less for NaCl contamination than that of $CuSO_4$ contamination. Analysis of data indicates that probability of flashover occurrence is more for NaCl contaminated insulator.

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