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Study on Steep Front Impulse Test Voltage Value of Disc Insulators with Variation in the Number of Units of Insulator String

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Abstract

The insulators used in power transmission and distribution networks should withstand abnormal system-generated switching impulses and natural lightning impulses. To avoid the failure of insulators in the field, the impulse puncture strength evaluation of the ceramic insulators is important. IEC 61211 standard stipulates the procedure to evaluate the ceramic disc insulators' strength to withstand steep front impulses. In this test, the test voltage is determined by using a short standard string of five insulators. This paper presents the variation in the impulse stresses across the disc insulator units in the string due to non-linear voltage distribution under impulse flashover. This paper also correlates the test voltage values defined by the IEC standard with the highest stress on insulator units under impulse flashover of string insulators by using voltage distribution. The correlation study has been carried out with insulator strings having different arcing distances by using a different number of units.

Keywords: Cap and Pin Insulator, Lightning Critical Flashover Voltage, Test Voltage (2.8pu), V-t Characteristics, Voltage Distribution

1. Introduction

Ceramic insulators are widely used in power transmission networks. The insulators in the field are exposed to system-generated and natural impulse surges. Therefore, the insulators in the field should withstand high magnitude and short-duration impulse surge voltages[1]. The impulse surge voltage stresses cause puncturing of the disc insulator solid insulation of about 20-25mm[2,3]. Hence, the disc insulators should have the strength to withstand such voltage surges.

The voltage distribution in an insulator string is non-uniform due to the presence of shunt capacitances between the metal parts of the insulators and the earthed tower. The overvoltage distribution is influenced by line construction, tower earthing resistance and pre-discharges between conductors (corona) and insulators[4]. Hence, an insulator unit should withstand 3 to 5 times 50% lightning impulse flashover voltage without puncture[5].

The assessment of the overvoltage on a single insulator unit is based on capacitive voltage distribution. During impulse flashover in a string, few insulators will expose to very high voltage stress due to non-linear voltage distribution. Due to the very high voltage sharing of the few insulators, the insulators will face the front of the voltage wave according to their voltage-time characteristics[4]. This may lead to the failure of the particular insulators. Hence, insulator units should have the strength to withstand such kinds of stresses. IEC 61211 standard defines steep front impulses to verify the withstand capability of the disc insulators.

In the steep front impulse voltage test, the factors influencing the test results are the definition of test voltage, test procedure and accuracy of measurement. The test voltage is the most important factor in the specification of this test. The test voltage is derived from the 50% impulse flashover voltage of a short string consisting of 5 insulator

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units. This test voltage is chosen to produce the required steepness of 2500kV/µS[6].

This paper presents the study of variation in the share of impulse flashover voltage across the insulator units by a change in the number of units in the string. The study has been carried out by using the strings with 5 (five), 10 (ten) and 15 (fifteen) units. The sphere gap method of voltage distribution is used for calculating voltage sharing across insulators in the strings. The voltage-time characteristics of the disc insulator are also presented. The correlation of the steep front test voltage values derived from the standard stipulated method and the highest voltage stress across an insulator unit under impulse flashover of the string is presented.

2. Sample Details

The cap-and-pin type normal profile porcelain disc insulators are used in this study. The insulators tested have a diameter (Φ) = 255 mm and spacing h = 146 mm. The arcing distance is 220mm and the creepage distance is 320 mm. Figure 1 shows the particulars of the insulator.

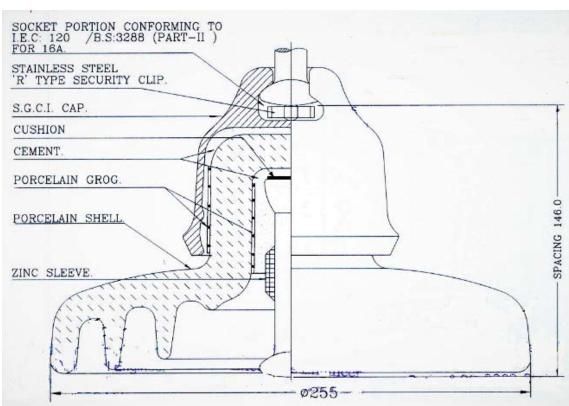

Figure 1. Image of an insulator.

3. Volt Time Characteristics of an Insulator

The short-duration strength of insulation is found from the volt-time curve. The standard lightning impulse wave shape is used for obtaining this curve. The self-restoring insulations are only tested in this method.

The test procedure for obtaining the Volt-time (V-t) characteristics is by applying higher and higher levels of voltage and recording the flashover time[7]. The test circuit for this test is shown in Figure 2.

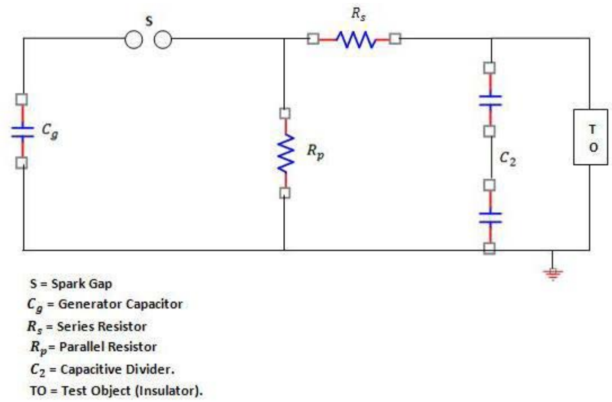

Figure 2. Test circuit for impulse voltage test.

The volt-time curve for positive and negative polarity is plotted in Figure 3 and Figure 4 respectively. The asymptotic value of the volt-time curve is equal to the lightning Critical Flashover Voltage (CFO)[7].

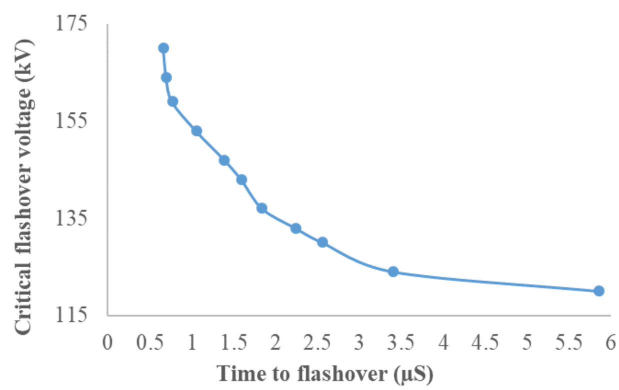

Figure 3. V- t curve (positive polarity).

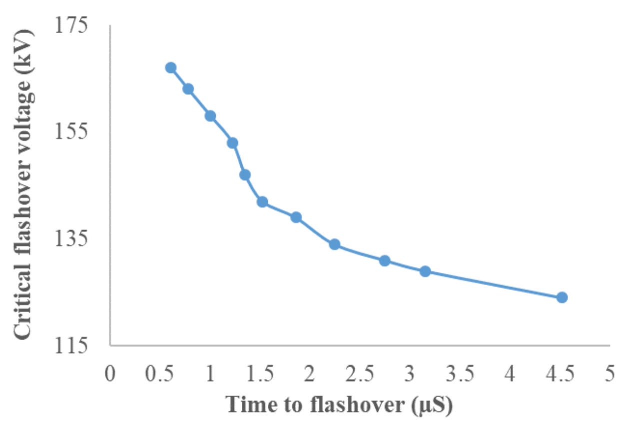

Figure 4. V-t curve (negative polarity).

The CFO takes place for a flashover time of about 3.15µs and it is likely to flatten out. Therefore, the peak voltage tends to be approximately the same for the flashover time of 3.15µs and beyond that level.

4. Determination of Lightning Critical Flashover Voltage of Insulator Strings

The lightning CFO is the peak value of a standard lightning impulse for which the insulation exhibits a 50% probability of withstanding. It is used in insulation coordination studies to describe the lightning impulse strength of high-voltage insulators[8,9]. Therefore, it is very essential to determine the CFO when designing the high-voltage insulators accurately.

As per IEC 61211, the test voltage is obtained from the 50% lightning impulse flashover voltage of a short string consisting of 5 insulator units. In this present work, the test voltage is derived by varying the arcing distances i.e., by using three different numbers of insulators (5, 10 & 15 units) in insulator strings.

4.1 Test Procedure and Test Setup

To verify the insulation level of the insulator strings, the 50% impulse flashover voltages were determined by applying an up-and-down method as given in accordance with IEC 60060-1[10]. The impulse analyzing system and capacitor voltage divider are used to measure impulse voltages. The test circuit for the lightning impulse voltage test is shown in Figure 1 and the experimental setup is shown in Figure 5.

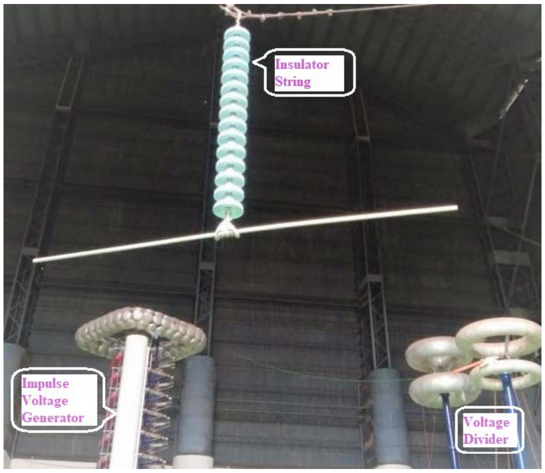

Figure 5. Experimental setup for impulse flashover voltage test.

The 50% impulse flashover voltage (U_{50}) of each unit is arrived at by dividing the value of the flashover voltage of the insulator string by the number of units (5, 10 & 15) in the given strings. For disc insulators, the test voltage (Ut) is 2.8 p.u of the U_{50} value of each unit.

4.2 Test Results

The U_{50} value of insulator strings and test voltage for each unit are mentioned in Table 1 and Table 2 respectively.

Table 1. 50% Impulse flashover voltage of insulator strings

No.of Units / String	Arcing Distance in mm	U_{50} Value of String in kVp	
		Positive Polarity	Negative Polarity
5	770	517	521
10	1475	911	960
15	2210	1318	1321

The lowest value is taken as the base value of Ut for practical reasons irrespective of polarity.

Table 2. 50% impulse flashover voltage of insulator unit and test voltage

No. of Units / String	U_{50} Value of String in kVp (Lowest)	U_{50} Value / Unit in kVp (p.u)	Base Value of Ut (2.8p.u) in kVp
5	517	103	290
10	911	91	255
15	1318	88	246

From Table 2, it is observed that there is a considerable reduction in the magnitude of steep front test voltage as compared to a short string of 5 units. It is noticed that there is an 11.87% (10 units/string) and 15% (15 units/string) reduction in magnitude concerning short string.

5. Determination of Voltage Distribution Across Insulator Strings

The number of insulators coupled in a string is more for a higher operating voltage of a transmission line. The shunt capacitances are formed between each cap and pin junction and the earthed tower. The self-capacitances are formed between the cap and pin of each unit. The shunt and self-capacitances determine the Voltage Distribution (VD). The presence of shunt capacitances leads to non-uniform voltage sharing among the insulators in the string[11]. As a result, the insulator nearest to the conductor is subjected to more stress[12]. The VD across each insulator string consists of 5, 10 and 15 units measured.

5.1 Test Procedure

A small sphere gap unit is calibrated by increasing the power frequency voltage till the spark is over across the gap. The voltage at which spark over occurs in the sphere gap is "X". This unit is kept across each of the insulator discs starting from the line end successively. The voltage applied across the entire string gradually increases until the spark over the sphere gap. The spark over voltage of the sphere gap across the string is "Y".

Voltage distribution across each disc = (X*100)/Y.

The total voltage distribution shall be obtained by adding the individual disc's voltage distribution.

A 2000kVA, 600kV/3.33A, 50Hz testing transformer is used as a voltage source for this study. The experimental setup is shown in Figure 6.

Figure 6. Experimental setup for voltage distribution test.

5.2 Test Results

The percentage voltage shared by the insulators in insulator strings with 5, 10 and 15 units (discs) have been determined and the results are shown in Figure 7 to Figure 9.

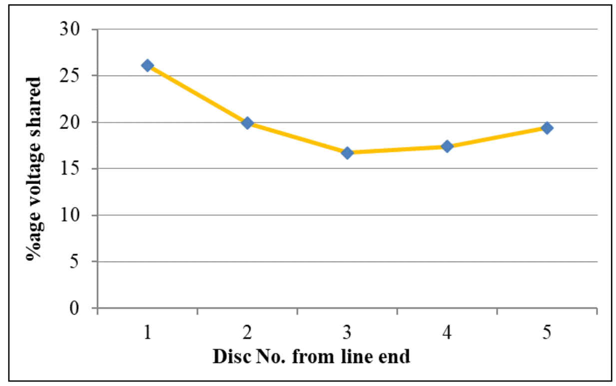

Figure 7. VD of insulator string (5 units string).

From Figure 7, in the 5 units string, it is observed that the insulator near to conductor i.e., disc 1 shares 26.10% of voltage across the string. Disc 2 and disc 3 shares 19.88% and 16.70% respectively.

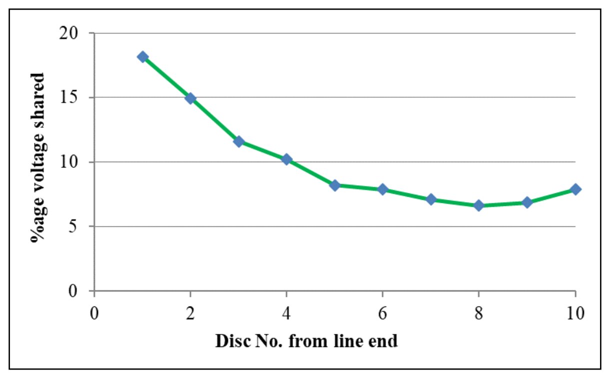

Figure 8. VD of Insulator String (10 Units In String).

From Figure 8, in the 10 units string, it is seen that disc 1 shares 18.18% of string voltage. Disc 2 and disc 3 shares 14.93% and 11.61% respectively.

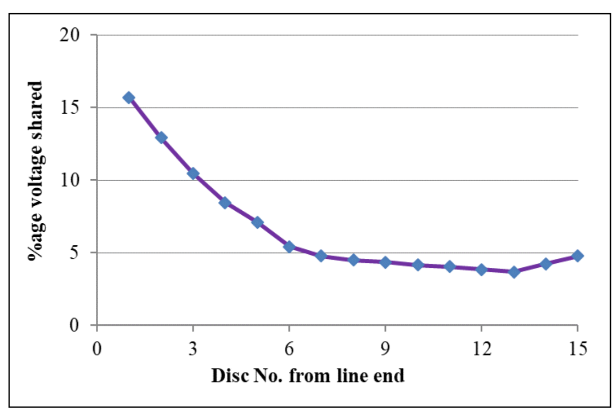

Figure 9. VD of insulator string (15 units string).

From Figure 9, in the 15 units string, it is noted that disc 1 shares 15.70% of voltage across the string. There is 12.93% and 10.47% of voltage across disc 2 and disc 3 respectively.

6. Calculation of CFO Sharing by Insulator Units Based on Voltage Distribution of Insulator String

The 50% impulse flashover voltage of each string is distributed with the percentage voltage distribution of the respective string and the over voltage sharing across each insulator is calculated. The results are shown in Figure 10 to Figure 12.

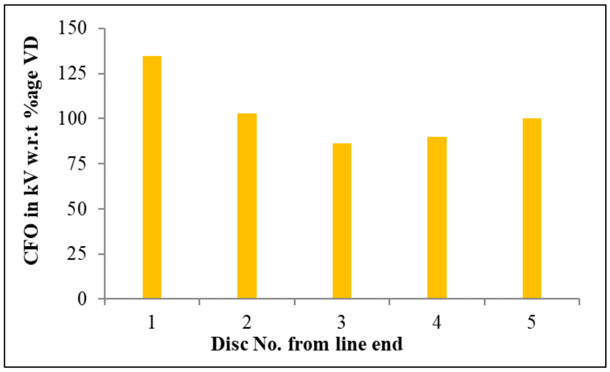

Figure 10. CFO sharing of insulator units (5 units string).

From Figure 10, it is observed that disc 1 is stressed to 135kVp. Disc 2 and disc 3 have stressed to 103 kVp and 86 kVp respectively.

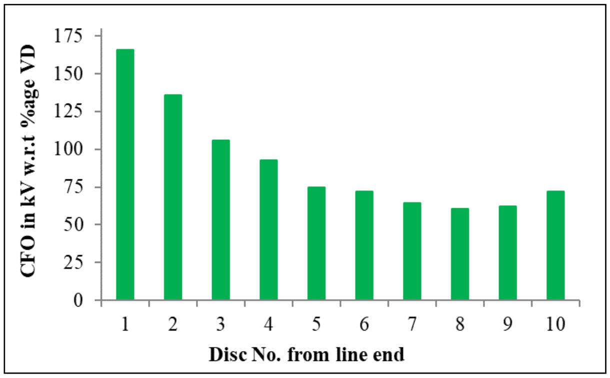

Figure 11. CFO sharing of insulator units (10 units string).

From Figure 11, it is seen that the disc 1 stressed to 166kVp. Disc 2 and disc 3 have stressed 136 kVp and 106 kVp respectively.

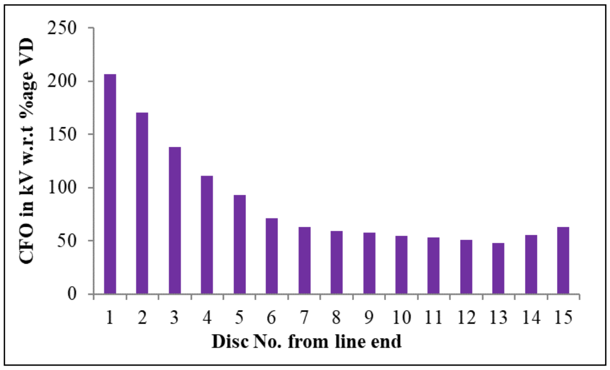

Figure 12. CFO sharing of insulator units (15 units string).

From Figure 12, it is noted that disc 1 is stressed to 207 kVp. There is 170 kVp and 138 kVp of Voltage in disc 2 and disc 3 respectively.

The percentage VD of disc 1 i.e, nearest to the conductor is correlated with CFO for each unit of respective strings and given in Table 3.

Table 3. Steep front test voltages with different approaches

No.of Units / String	Test Voltage (Ut = 2.8p.u) in kVp	Sharing of CFO w.r.t VD in kVp	3*CFO from V-t character-istics in kVp
5	290	135	369
10	255	166	
15	246	207	

7. Conclusions

The experimental determination of volt-time characteristics of disc unit, 50% lightning impulse flashover voltage and voltage distribution of strings consisting of 5, 10 and 15 insulator units have been conducted and the results are presented.

From Table 3, it is observed that the magnitude of steep front test voltage is reduced for the more number of units in a string as compared to short string as per standard stipulated procedure whereas the sharing of CFO by an insulator unit based on voltage distribution is increasing with the number of units in the insulator string. The steep front test voltage is lesser than 3(three) times of CFO of the insulator unit from V-t characteristics.

As per IEC 61211, the test voltage decreases with the increase in the number of units in a short string. However, the actual sharing of the CFO by line end disc increases with the increase in several units. Hence, the short string consisting of 5(five) units gives the required stress for the steep front impulse voltage test, which may simulate higher stresses at EHV and UHV-rated insulator strings.

8. Acknowledgement

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9. References

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