Studying Critical Flash Over of Different Types of High Voltage Insulator

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Abstract

The critical flashover CFO of an insulation structure is commonly used to describe the insulation structure lightening impulse strength. In this work, first CFO of polymer and porcelain each alone was measured and then, a new structural arrangement is represented to measure (CFO). This arrangements consists of three layers; fiberglass is placed between two layers of polymer and porcelain .All insulation materials are examined in dry and wet condition with positive and negative lightening impulse under (15,25 and 35) KV. The critical flashover voltage (CFO) of insulator is distributed on certain surface along with fiberglass distribution poles as an insulator. Also altitude of poles is taken into consideration in calculating critical flashover voltage for both insulator and structure. (CFO) voltages are added from fiberglass distribution pole to basic insulation component and are calculated based on the test result of the (CFO). The above measurements indicated that the total CFO voltage of new arrangements insulator under dry condition is much higher than under wet condition for the same impulse polarity and tested pole length.

Keywords: Insulation material, critical flashover, high voltage insulator, polymer insulator, porcelain insulator

الخلاصة

يستخدم الجهد الحرج للومضة اللحظية بشكل مالوف لوصف قوة الضوء النبضي للبنية العازلة. في هذا البحث تم قياس, اولا الجهد الحرج للومضة اللحظية لمواد عازلة من البوليمر والبورسلين كلا على حدة بعد ذلك تم القياس لترتيب بنية جديدة حيث يتالف هذا الترتيب من ثلاث طبقات، طبقة من الليف الزجاجي وضعت بين طبقتين من البوليمر مرة والبورسلين مرة اخرى. كل المواد اعلاه اختبرت تحت ظروف جافة ورطبة مع نبضات اضاءة موجبة وسالبة تحت (١٥،٢٥،٣٥ كيلو فولت) . يكون الجهد الحرج للومضة اللحظية للعازل متوزع على السطح المحدد بامتداد الاعمدة الموزعة للالياف الزجاجية. اخذ بنظر الاعتبار ارتفاع الاعمدة في حساب الجهد الحرج للومضة اللحظية لكلا من العازل والبنية. اضيفت الجهود الحرجة للومضة اللحظية من عمود الالياف الزجاجية الموزعة الى مكون العازل الاساسي وتكون محسوبة بالاستناد الى نتيجة الاختبارات للجهد الحرج للومضة اللحظية. القياسات اعلاه تشير الى ان الجهود الحرجة للومضة اللحظية لترتيب العازل الجديد تحت ظروف جافة يكون اعلى بكثير مقارنة مع الظروف الرطبة لنفس النبض القطبي ونفس طول عمود الاختبار.

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1. Introduction

The CFO voltage of an insulation structure is defined as the crest value of a standard impulse for which the insulation exhibits 50% probability of withstand (or 50% probability of failure) [1].

The breakdown in the air gap or flashover on the insulation material's surface is caused by a physical phenomenon called electronic avalanche [2]. An effective electronic avalanche possesses a statistical characteristic. As a result, the insulation strengths of different dielectrics such as gas, liquid, or solid exhibit a statistical nature [3].

For the purpose of insulation coordination, the voltage-withstand strength of the insulation structure is quite often expressed in terms of, Basic Insulation Level (BIL). For self-restoring insulation, such as gas dielectrics, BIL is understood by most utilities as the crest value of a standard impulse for which the insulation exhibits 90% probability of withstanding (or 10% probability of failure).

2. Theoretical Background of CFO

The CFO voltage can be measured through different types of laboratory methods. The up and down method was used to evaluate the CFO voltage of an insulation structure and it is described in IEEE Standard 4-1995 [4]. There are three steps in this method:

1. Applying a lightening impulse with a magnitude less than the expected flashover voltage of an insulation structure.
2. Increasing the magnitude of the lightening impulse by a very small amount (approximately 3~5 % of the expected flashover voltage) for subsequent impulses until flashover occurs.
3. Applying a series of 20 impulses. Decreasing the prospective voltage by about 3~5% after each flashover and increasing the prospective voltage by about 3~5% after each withstand during the series of these 20 impulses.
4. Average the values of the 20 impulses to obtain the CFO voltage.

For self-restoring insulation, normal (Gaussian) distribution is the best model for approximating the probability density function of disruptive surface flashover [5]. Utilizing statistics for Gaussian distribution, the desired level of withstand can be calculated using the integral probability function, which is defined in equation (1).

$$Z=\frac{|VFO-CFO|}{\sigma} \qquad (1)$$

The VFO is the flashover voltage of an insulation structure with a specific probability of withstand. CFO voltage is the value from the up and down method. Sigma, s , is the standard deviation; for lightening impulses, s , is generally used as 3 % of the CFO voltage. Z is the number of standard deviations for a specific confidence factor (the probability of withstand), and it can be acquired from cumulative normal (Gaussian) distribution tables [6].

According to previous definition, VFO in Equation (1) is referred to as BIL when the probability of withstand of an insulation structure is equal to 90%.

Also, the value of Z is equal to 1.28 in this situation.

Therefore, the BIL voltages of an insulation structure can be calculated as:

$$BIL = CFO \times [1 - Z \times \frac{\sigma}{CFO}] \quad (2)$$

Since CFO is measured through the experiment, the BIL with 90% probability of withstand for self- restoring air insulation is:

$$BIL = CFO \times [1 - 1.28 \times (0.03)] = 0.9616 \times CFO \quad (3)$$

2. Experimental Procedures

The insulation components used in a power distribution system are polymer and porcelain with and without fiberglass pole, which can exhibit different lightening impulse strengths. Furthermore, different lightening impulse strengths are also expected among different combinations of the insulation components. It is necessary for a design engineer to know the CFO voltages and BIL values of available insulation structures when designing a power distribution system. In this work, the CFO voltages of insulators and the CFO voltages of the combined insulation structures need to be evaluated at first in order to calculate the added CFO voltages in combined insulation structures.

In a power distribution system, the available insulation components include insulators, poles, cross-arms, standoffs, etc. Different types of insulators were commonly used as the basic insulation component in a combined insulation structure. The CFO voltages of the insulators have been studied for a long time. It was found that the CFO voltages of the insulator depend on the insulator's configuration because the configuration of insulator would affect the discharge path when flashover occurs.

The CFO voltages of different types of polymer and porcelain insulators are reported under dry and wet conditions and at positive and negative lightening impulses.

2.1 The CFO Voltages of Polymer Suspension Insulators Plus Fiberglass Poles

In power distribution systems, the fiberglass pole can be used as a second or third insulation component in a combined insulation structure in order to improve the lightening impulse strength. Figure (1) shows the typical configuration of a distribution line structure where the pole serves as a second insulation component.

The total CFO voltages of polymer suspension insulators plus the fiberglass pole were evaluated under dry and wet conditions and at positive and negative lightening impulses. The rated voltages of tested insulators are 15 kV, 25 kV, and 35 kV. The tested insulation length of the fiberglass pole is from 0.3 m up to 2.4m.

2.2 The CFO Voltages of Porcelain Pin Insulators Plus Fiberglass Poles

The porcelain pin insulator is commonly used on power distribution systems and their lightening impulse strengths have also been studied for many years. The CFO voltages of 15 kV, 25 kV, and 35 kV porcelain pin insulators were evaluated. The tests were conducted under dry and wet conditions and positive and negative lightening impulses. The evaluated pole lengths were to be from 0.3m to 2.4 m.

3. Result and Discussion

The CFO voltages of different types of polymer and porcelain insulators are reported under dry and wet conditions and at positive and negative lightening impulses, as shown in Table (1).

From Table 1, it can be seen that the CFO voltages of these two types of insulators follow the same discharge principle as a non-uniform electrical field in the air. In other words, the CFO voltages at negative lightening impulse are always higher than at positive lightening impulse and the CFO voltages under wet conditions are less than under dry conditions [7].

3.1 The CFO Voltages of Polymer Suspension Insulators Plus Fiberglass Poles

The total CFO voltages of 15 kV, 25 kV, and 35 kV polymer suspension insulators plus fiberglass poles are presented in Tables 2-4.

For the CFO Voltages of Insulators Plus Fiberglass Poles in Figure 2 shows the total CFO voltages of 35 kV polymer suspension insulators plus fiberglass poles and the CFO voltages of fiberglass poles under dry and wet conditions and for a positive lightening impulse. Figure 3 shows the total CFO voltages of 35 kV polymer suspension insulators plus fiberglass poles and the CFO voltages of fiberglass poles under the dry and wet conditions and for a negative lightening impulse. Similar figures can be drawn from the CFO voltages of 15 kV or 25 kV polymer suspension insulators plus fiberglass poles.

From Figure 2 and Figure 3, the total CFO voltages of polymer suspension insulators plus fiberglass poles have a linear relationship with the pole length. It is almost directly proportional to the pole length, regardless of the test condition and impulse polarity. The insulation failure of a combined insulation structure was caused by either the surface flashover or breakdown in the air. These two discharge phenomena are associated with the breakdown in the gaseous dielectric. Therefore, the measured CFO voltages should conform to the principle of breakdown of the gaseous dielectric, in spite of the types of discharges occurring in the combined insulation structure. In a gaseous dielectric, the flashover voltage is higher for a negative lightening impulse than for a positive lightening impulse when it is broken down. This principle was validated in the conducted tests for 15 kV, 25 kV, and 35 kV polymer suspension insulators plus fiberglass poles. The total CFO voltages of polymer suspension insulators plus fiberglass poles under dry conditions are much higher than under wet conditions for the same impulse polarity and tested pole length because the insulation strengths of dielectrics are much lower in the wet conditions. The CFO voltage of a polymer suspension insulator plus a fiberglass pole is higher than that for wood pole under the same test condition, impulse polarity, and pole length. For example, when the tested pole length is 0.3m , the CFO voltage of a 15 kV polymer suspension insulator plus a fiberglass pole is 299 kV under dry conditions for a positive lightening impulse. The CFO voltage of a 15 kV polymer suspension insulator plus a wood pole is 250 kV under dry conditions for a positive lightening impulse. Based on the previous statement, the fiberglass pole can improve the lightening impulse strength of the distribution line structure when used as a second insulation component in the distribution line structure. When the individual insulation components are used in a combined insulation structure, their lightening impulse strengths would be changed slightly due to different insulation structures. Therefore, the total CFO voltage of a combined insulation structure is not equal to the sum of the CFO voltages of those individual insulation components. The results from the experiments show that the summation of the CFO voltage of the fiberglass pole and the CFO voltage of the insulator is not equal to the measured total CFO voltage of the combined insulation structure with the same insulator and pole length. The total CFO voltages of polymer suspension insulators plus fiberglass poles are presented in Figure 4. The rated voltages of the tested polymer suspension insulators are 15 kV, 25 kV, and 35 kV.

3.2 The CFO Voltages of Porcelain Pin Insulators Plus Fiberglass Poles

The porcelain pin insulator is commonly used in power distribution systems and its lightening impulse strengths have also been studied for many years [8]. The CFO voltages of 15 kV, 25 kV, and 35 kV porcelain pin insulators were evaluated and the results are presented in Table 1. The tests were conducted under dry and wet conditions and positive and negative lightening impulses. The evaluated pole lengths are from 0.3m to 2.4m. The CFO voltages of 15 kV, 25 kV, and 35 kV porcelain pin insulators plus fiberglass poles are presented in Table 5-7 .

The CFO voltages of a porcelain pin insulator plus a fiberglass pole have relationship with the tested pole lengths that increase linearly. The insulation failure of this type of combined insulation structure is also related to the surface flashover. Therefore, the CFO voltage of porcelain pin insulator plus a fiberglass pole under a negative lightening impulse is higher than that found under a positive lightening impulse. Also, the CFO voltage is higher under dry conditions than under wet conditions because the lightening impulse strength in the wet test is less than in the dry test.

4. Conclusions

Reviewing the results obtained from the CFO tests, the following conclusions on the fiberglass pole may be stated:

The CFO voltages of fiberglass poles have a linear relationship with the tested pole lengths. When the tested pole lengths are the same, the CFO voltage has the smallest value under wet conditions for positive lightening impulses and the highest value under dry conditions for negative lightening impulses.

The CFO voltages of an insulator plus a fiberglass pole are higher than a fiberglass pole when measured under the same test conditions, lightening impulse polarities, and pole lengths. When a fiberglass pole serves as a second insulation component in a distribution line structure, the added CFO voltages from a fiberglass pole to a polymer suspension or a porcelain pin insulator are higher than the added CFO voltages from a wood pole, especially under wet conditions. The fiberglass pole can greatly improve the lightening impulse strength of a distribution line structure based on the test results in this work.

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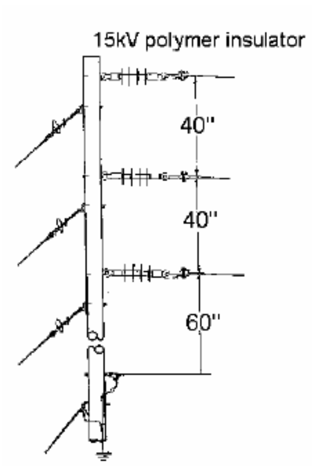

Fig. 1 The Typical Configuration of a 15 kV Distribution Line Structure

Table (1) The CFO Voltages of Polymer Suspension Insulators and Porcelain Pin Insulators

Test Condition & Impulse Polarity / Insulator type And Voltage level,(kV)		Dry Condition		Wet Condition	
		Positive (KV)	Negative (KV)	Positive (KV)	Negative (KV)
Polymer Suspension Insulator	15	163	187	159	174
	25	241	304	230	281
	35	310	384	309	354
Porcelain Suspension Insulator	15	106	137	103	117
	25	119	139	118	127
	35	152	164	142	152

Table 2 The CFO Voltages of a 15 kV Polymer Suspension Insulator Plus a Fiberglass Pole .

Fiberglass pole Length (m) \ Test Condition & Impulse Polarity		Dry Condition		Wet Condition	
		Positive (KV)	Negative (KV)	Positive (KV)	Negative (KV)
15 KV Insulator Plus Fiberglass pole	0.3	299	٣٣٧	٢٧٠	٣٢٣
	0.6	487	٤٩٠	٤٤٣	٤٤٠
	0.9	641	٦٤٥	٥٨٩	٦٠٩
	1.2	796	٨١٢	٧٣٨	٧٧٢
	1.5	929	٩٦٤	٨٤١	٩٠٠
	1.8	1017	١١٢٥	٩٣١	٩٩٩
	2.1	1196	١٢١٢	١٠٦٩	١١٦٦
	2.4	1307	١٣٥١	١١٧٢	١٢٥٣

Table 3 The CFO Voltages of a 25 kV Polymer Suspension Insulator Plus a Fiberglass Pole.

Fiberglass pole Length (m) \ Test Condition & Impulse Polarity		Dry Condition		Wet Condition	
		Positive (KV)	Negative (KV)	Positive (KV)	Negative (KV)
25 KV Insulator Plus Fiberglass pole	0.3	336	407	311	396
	0.6	505	546	460	490
	0.9	648	679	608	647
	1.2	828	849	762	815
	1.5	961	991	889	943
	1.8	1152	1199	1000	1063
	2.1	1290	1345	1160	1189
	2.4	1358	1388	1264	1288

Table 4 The CFO Voltages of a 35 kV Polymer Suspension Insulator Plus a Fiberglass Pole.

Test Condition & Impulse Polarity / Fiberglass pole Length (m)		Dry Condition		Wet Condition	
		Positive (KV)	Negative (KV)	Positive (KV)	Negative (KV)
35 KV Insulator Plus Fiberglass pole	0.3	463	531	406	429
	0.6	534	620	475	497
	0.9	675	742	623	659
	1.2	833	879	789	842
	1.5	981	1077	932	973
	1.8	1168	1221	1021	1089
	2.1	1281	1364	1191	1228
	2.4	1399	1443	1335	1353

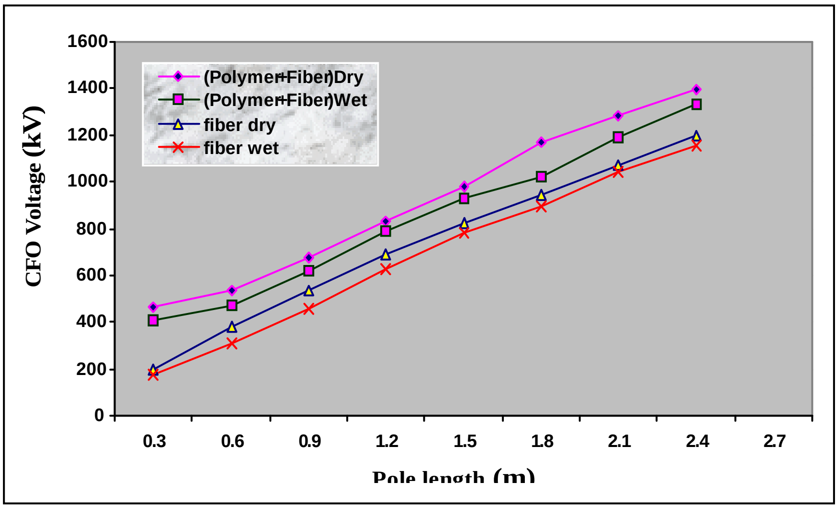

Fig. 2 The CFO Voltages of 35 kV Polymer Suspension Insulators Plus Fiberglass Poles and the CFO Voltages of Fiberglass Poles Alone under Dry and Wet Conditions for Positive Lightening Impulse.

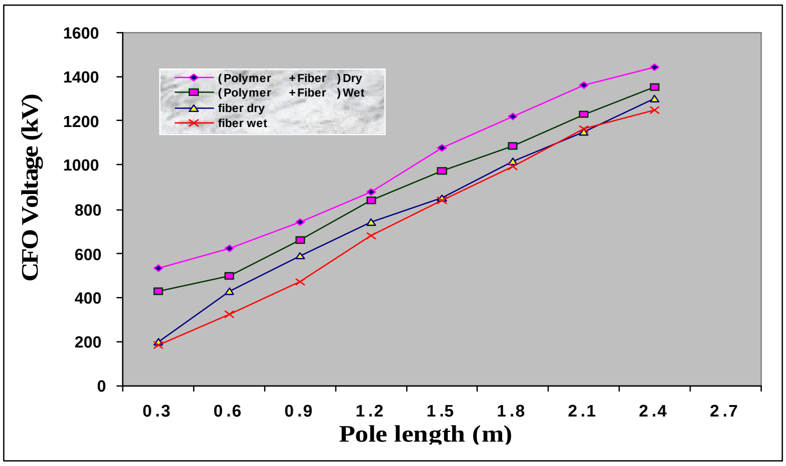

Fig. 3 The CFO Voltages of 35 kV Polymer Suspension Insulators Plus Fiberglass Poles and the CFO Voltages of Fiberglass Poles Alone under Dry and Wet Conditions for Negative Lightening Impulses

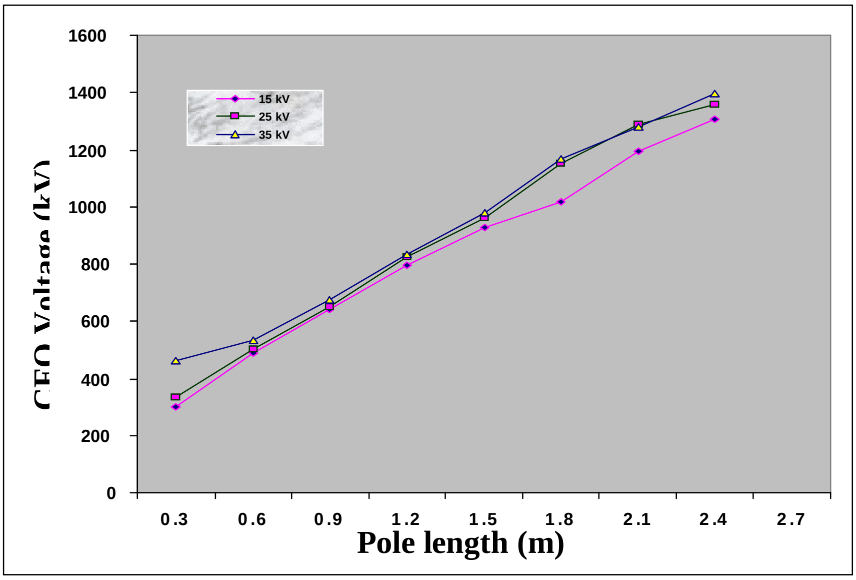

Fig. 4 The CFO Voltages of 15 kV, 25 kV, and 35 kV Polymer Suspension Insulators Plus Fiberglass Poles under Dry Conditions for Positive Lightening Impulses.

Table 5 The CFO Voltages of 15 kV Porcelain Pin Insulators Plus Fiberglass Poles
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Fiberglass pole Length (m) \ Test Condition & Impulse Polarity		Dry Condition		Wet Condition	
		Positive (KV)	Negative (KV)	Positive (KV)	Negative (KV)
15 KV Insulator Plus Fiberglass pole	0.3	291	326	189	229
	0.6	387	486	308	323
	0.9	564	634	470	504
	1.2	714	771	632	696
	1.5	831	890	787	863
	1.8	985	1027	911	1005
	2.1	1082	1155	1068	1168
	2.4	1211	1304	1175	1246

Table 6 The CFO Voltages of 25 kV Porcelain Pin Insulators Plus Fiberglass Poles
.

Fiberglass pole Length (m) \ Test Condition & Impulse Polarity		Dry Condition		Wet Condition	
		Positive (KV)	Negative (KV)	Positive (KV)	Negative (KV)
25KV Insulator Plus Fiberglass pole	0.3	317	339	295	314
	0.6	489	524	416	441
	0.9	601	674	567	566
	1.2	761	810	707	751
	1.5	883	934	848	903
	1.8	1004	1035	979	1013
	2.1	1133	1165	1104	1170
	2.4	1240	1311	1228	1257

Table 7.The CFO Voltages of 35 kV Porcelain Pin Insulators Plus Fiberglass Poles .

Fiberglass pole Length (m) \ Test Condition & Impulse Polarity		Dry Condition		Wet Condition	
		Positive (KV)	Negative (KV)	Positive (KV)	Negative (KV)
35KV Insulator Plus Fiberglass pole	0.3	٣٢٥	٣٤٣	٣٢٣	٣٤٠
	0.6	٤٩٦	٥٥٦	٤٣٤	٤٦٧
	0.9	٦٤٣	٦٩٧	٥٧٥	٥٩٠
	1.2	٧٧٥	٨٤٨	٧١٠	٧٧٧
	1.5	٩٠٧	٩٥٠	٨٥٩	٩١١
	1.8	١٠٢٢	١٠٦٥	١٠٠٠	١٠٤٩
	2.1	١١٤٠	١١٨١	١١١٢	١١٨٧
	2.4	١٢٧٤	١٣١٨	١٢٣٧	١٢٦٤

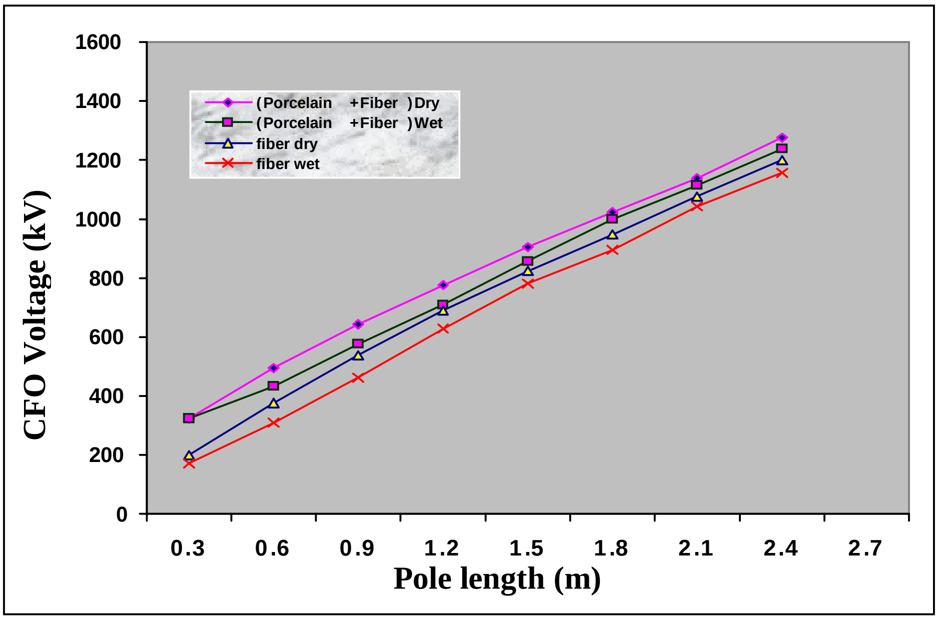

Fig. 5 The CFO Voltages of 35 kV Porcelain Suspension Insulators Plus Fiberglass Poles and the CFO Voltages of Fiberglass Poles Alone under Dry and Wet Conditions for Positive Lightening Impulse .

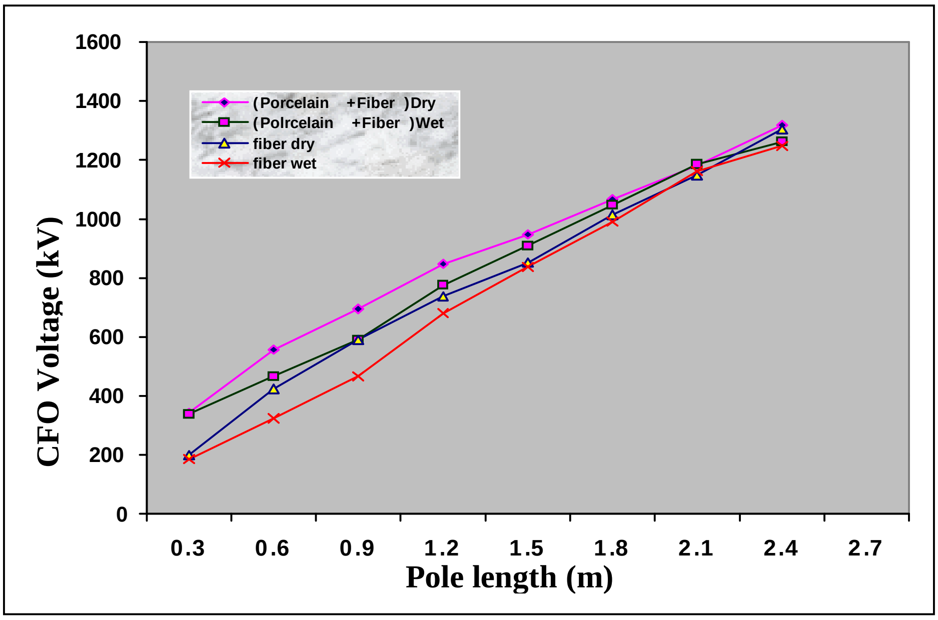

Fig. 6 The CFO Voltages of 35 kV Porcelain Suspension Insulators Plus Fiberglass Poles and the CFO Voltages of Fiberglass Poles Alone under Dry and Wet Conditions for Negative Lightening Impulses .

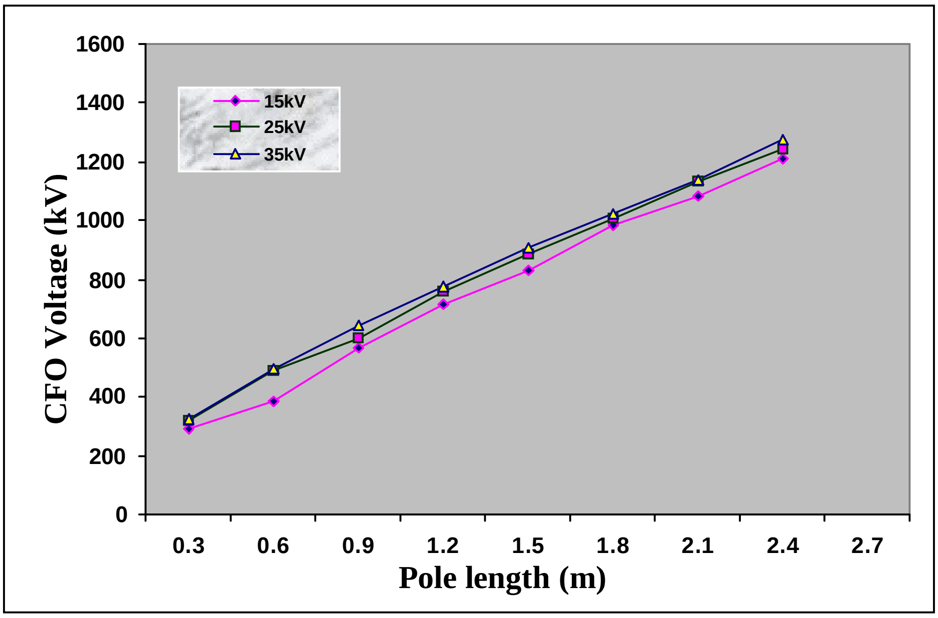

Fig. 7 The CFO Voltages of 15 kV, 25 kV, and 35 kV Porcelain Suspension Insulators Plus Fiberglass Poles under Dry Conditions for Positive Lightening Impulses.