EFFECT OF HUMIDITY ON THE BREAKDOWN VOLTAGE OF INSULATORS AT VARYING HUMIDITY AND TEMPERATURE CONDITIONS

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Abstract: Breakdown voltage of insulators is strongly affected by atmospheric conditions such as temperature and humidity. Since the insulators are usually used at different atmospheric conditions from the test condition, it is essential to use a correction factor to obtain the real breakdown voltage from the test results. Some differences between the correction factors related to air gaps defined by IEC60060-1 and the ones resulted from current investigations, enhance the need of more studies to be done on breakdown voltage of insulators. We have tested 17 of 20 kV insulators comprised porcelain, glass, and composite with different arcing distances at varying atmospheric conditions. The corresponding humidity varied homogeneously from 1 gm/m^3 to 13 gm/m^3 in the 6*4*3.3 m testing room. Using the IEC humidity correction factors, the breakdown voltages measured in test conditions were turned into the voltages corresponding to standard conditions in order to make it possible to verify the accuracy of IEC humidity correction factor equations. Results obtained from comparison show that although the IEC gives good estimation for humidity correction factors, it needs modification in some cases.

1 INTRODUCTION

The power system is the largest system for energy transmission, so its equipments must be reliable. Insulators are one of these equipments and their BIL should be tested before installation. Since the insulators are usually used at different atmospheric conditions from the test condition, it is essential to use a correction factor to obtain the real breakdown voltage from the test results. Some differences are seen between the humidity correction factors defined by IEC60060-1(1989) [1] and the ones resulted from current investigations on air gap breakdown voltage [2, 3]. On the other hand, the studies about the effect of humidity on insulators breakdown voltage are less than the ones done on air gaps [3-5]. So this paper investigates the effect of humidity on insulators breakdown voltage and compares the experimental correction factor with IEC.

The accurate correction factor is important for us because we are about to certificate insulators in our high voltage laboratory that is placed in Tehran where its humidity is usually low. So we tested some insulators in the range of 1 gm/m^3 to 13 gm/m^3.

2 ATMOSPHERIC CORRECTION FACTOR

According to IEC60060-1(1989) the standard atmospheric condition is:

Temperature	t_0 = 20 °C
Pressure	b_0 = 101.3 kPa
Absolute humidity	h_0 = 11 gm/m^3

The IEC correction factor (K_t) consists of two parts: air density correction factor (k_1) and humidity correction factor (k_2). So the total factor is:

$$K_t = k_1 * k_2 \tag{1}$$

And:

$$U_0 = U/K_t \tag{2}$$

where: U = Breakdown voltage in real condition in Volt (V)
U_0 = Breakdown voltage in standard condition in Volt (V)
K_t = Correction factor

Air density correction factor (k_1) can be generally expressed as:

$$k_1 = \delta^m \tag{3}$$

Where m is an exponent given in IEC60060-1(1989) (Figure 4), and δ is the relative air density which can be expressed as:

$$\delta = (b/b_0)*(273+t_0)/(273+t) \tag{4}$$

where: b = Real atmospheric pressure in kiloPascals (kPa)
b_0 = Standard atmospheric pressure in kiloPascals (kPa)
t = Real temperature in degrees Celsius (°C)
t_0 = Standard temperature in degrees Celsius (°C)

The humidity correction factor (k_2) can be expressed as:

$$k_2 = k^w \tag{5}$$

Where w is an exponent given in IEC60060-1(1989) (Figure 4), and k can be obtained as a function of the ratio of absolute humidity, h, to the relative air density, δ and is given in IEC60060-1(1989) Figure 4.

3 SETUP AND PROCEDURE

3.1 Experimental setup

The experimental setup consists of one AC voltage source 220 V 50 Hz, one autotransformer 0-220 V, a 220 V/200 kV 10 kVA two stages cascade transformer, and a 2 MΩ 60 W resistor for current limitation. The breakdown voltage was measured by a capacitor voltage divider with a scale factor 2000:1. The circuit was shown in Figure 1.

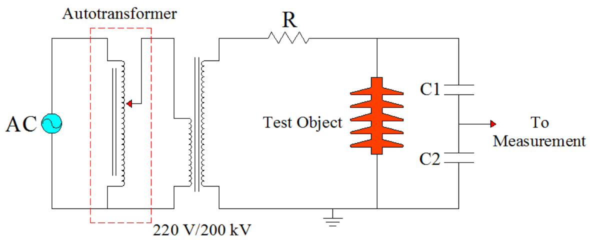

Figure 1: Experimental circuit

The test circuit was in a 6*4*3.3 m testing room, in a Faraday cage.

3.2 Test objects

The test objects were 17 20 kV insulators comprised porcelain, glass, and composite with different arcing distances in a range of 145 mm to 400 mm shown in Figure 2 and Figure 3. Some arcing distances have been reached by cascading two or three insulators. Some of test objects were shown in Figure 2 and Figure 3.

Figure 2: Composite insulators

Figure 3: Porcelain and glass insulators

3.3 Test procedure

The humidity is controlled uniformly in the whole test room. The absolute humidity was changed in rage of 1 g/m^3 to 13 g/m^3. In order to prevent water condensation on insulators surfaces leading to errors in measurements, an oven was used to make the insulators dry and isothermal with the air in the room. The humidity and temperature was read by a humidity-temperature meter.

The breakdown voltage was measured by “Successive Discharge Method” [2]. The voltage rose at a rate of 1 kV/sec and recorded as an average of 10 measurements for each object.

4 RESULTS

The breakdown voltage for two objects was shown in Figure 4 and Figure 5.

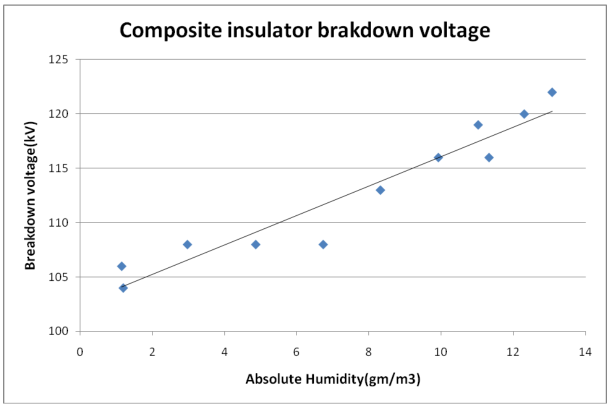

Figure 4: Breakdown voltage enhancement with absolute humidity for a composite insulator

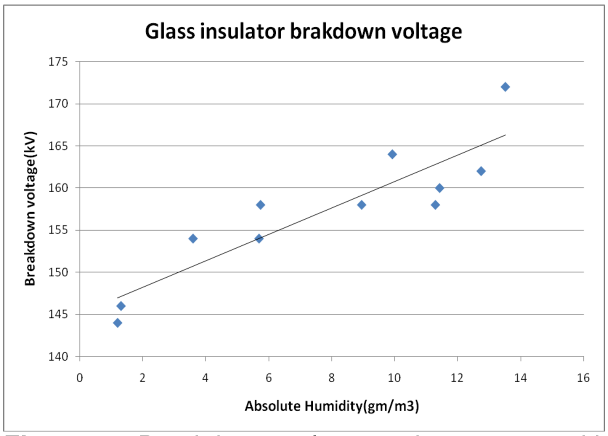

Figure 5: Breakdown voltage enhancement with absolute humidity for a glass insulator

In order to increase arcing distance, we cascaded similar insulators up to three ones to measure the breakdown voltages for various arcing distances in same conditions [4].

Figure 6 and Figure 7 shows the breakdown voltage for various arcing distances versus absolute humidity for similar insulators cascaded.

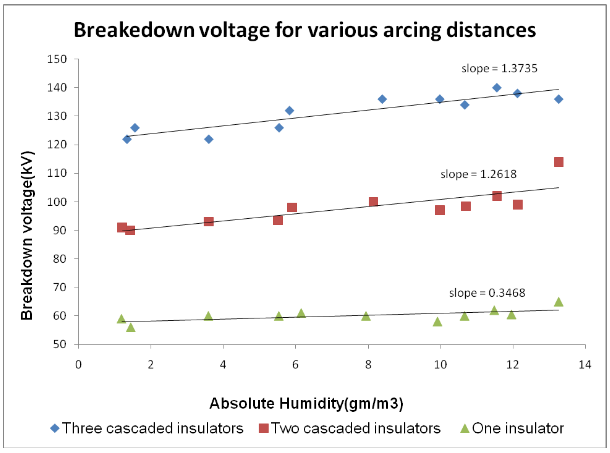

Figure 6: Growth in slope of breakdown voltage enhancement with the arcing distance increased by cascading similar insulators

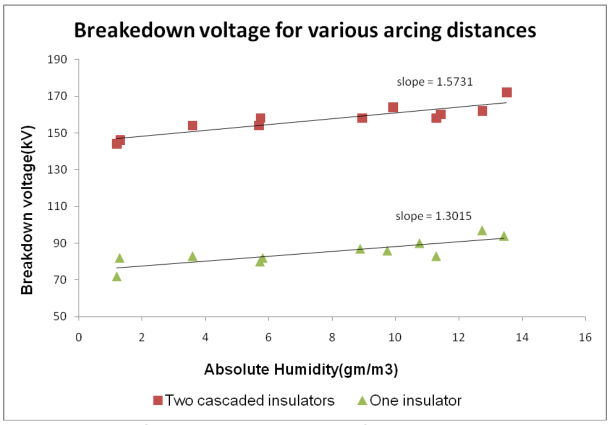

Figure 7: Growth in slope of breakdown voltage enhancement with the arcing distance increased by cascading another similar insulators

Some of the results of the tests performed are listed in tables 1-3. The amounts of the air temperature, T, and the ratio of absolute humidity, h, to relative air density, δ, are reported to define the atmospheric conditions for each test. The pressure of the air was 868 mbar in all of the tests performed.

In order to find accuracy of IEC60060-1(1989) humidity correction factor, we calculate the IEC correctrion factor in each situation and turned the measured breakdown voltage to standard situation mentioned as U0 [6]. In tables 1-3, comparison is made between the values of U0 obtained at various atmospheric conditions for the same insulator.

Table 1: IEC calculated correction factors and errors in standard converted breakdown voltages for a composite insulator

T (°C)	h/δ	Um (kV)	K	U0 (kV)	%Error
23.5	13.37	116	0.977	118.68	-4.55
21.1	9.74	113	0.971	116.35	-6.42
20.9	7.88	108	0.969	111.43	-10.38
21.7	**15.34**	**122**	**0.981**	**124.33**	**0.00**
21.9	14.45	120	0.980	122.49	-1.48
22.3	12.96	119	0.976	121.92	-1.94
21.9	5.72	108	0.962	112.27	-9.70
21.6	3.49	108	0.955	113.11	-9.03
17.6	1.39	104	0.955	108.94	-12.38
17	1.34	106	0.953	111.21	-10.55
20.6	11.60	116	0.975	118.96	-4.32

Table 2: IEC calculated correction factors and errors in standard converted breakdown voltages for two cascaded glass insulators

T (°C)	h/δ	Um (kV)	K	U0 (kV)	%Error
22.90	13.46	160	0.982	162.90	-0.95
21.60	10.50	158	0.977	161.69	-1.69
21.10	6.72	158	0.968	163.24	-0.74
22.10	15.88	172	0.985	174.67	6.21
22.30	**14.98**	**162**	**0.985**	**164.47**	**0.00**
22.70	13.29	158	0.983	160.81	-2.22
22.00	6.68	154	0.969	158.93	-3.36
21.80	4.22	154	0.962	160.09	-2.66
18.60	1.52	146	0.961	151.96	-7.60
17.60	1.39	144	0.962	149.63	-9.02
20.60	11.60	164	0.978	167.62	1.92

Table 3: IEC calculated correction factors and errors in standard converted breakdown voltages for a porcelain insulator

T (°C)	h/δ	Um (kV)	K	U0 (kV)	%Error
23.80	12.93	124	0.974	127.30	-5.31
21.70	10.49	124	0.969	127.99	-4.80
21.20	6.74	118	0.961	122.79	-8.67
22.10	**16.50**	**132**	**0.982**	**134.45**	**0.00**
22.10	14.68	124.5	0.980	127.09	-5.47
22.70	12.62	110	0.980	112.23	-16.53
22.20	6.55	106	0.968	109.53	-18.53
21.80	4.22	108	0.960	112.55	-16.29
18.60	1.50	104	0.957	108.71	-19.14
17.70	1.40	105	0.956	109.81	-18.33
20.70	12.05	116	0.978	118.67	-11.74

In each table, one test performed under an atmospheric condition that is closer to the standard reference condition is marked with bold text. The value of U0 obtained in this test is taken as the reference test value. The values of U0 obtained from other atmospheric conditions for the same insulator are compared with values of the reference test. The differences are given in the table in percentage. If the IEC60060-1(1989) humidity correction factor is accurate, all the values of U0 for the same insulator should be the same with only marginal errors. Tables 1-3 show these amounts and errors for some objects.

5 CONCLUSION

The results can be concluded as follow:

1- The breakdown voltage increases with the rise in absolute humidity.

2- As we could see from Figure 6 and Figure 7, the slope of breakdown voltage enhancement becomes greater as the arcing distance increases. Hence the influence of humidity was greater at the larger arcing distances.

3- As we understand from results of experiment presented in tables, although the IEC gives good estimation for humidity correction factors, the IEC humidity correction factor needs modification in some cases.

6 REFERENCES

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