J. Basic. Appl. Sci. Res., 2(4)4299-4303, 2012
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ISSN 2090-4304
Journal of Basic and Applied Scientific Research
www.textroad.com

Effect of Humidity on the Flashover 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. On the other hand, lack of a specified correction factors for measuring flashover voltage of insulators in IEC60060-1(2010), which are necessary for giving certification, enhances the need of more studies to be done on breakdown voltage of insulators. In this article we surveyed the validity of applying IEC sparkover atmospheric corrections to insulators flashover. 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 there should be more studies to find appropriate correction factors for flashover voltages like the ones done for sparkover voltages.

KEY WORDS: AC Breakdown Voltage, Atmospheric Conditions, Effect of Humidity, Electrical Insulator, Humidity Correction Factor.

I. 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. By applying correction factors, a disruptive discharge voltage measured in given test conditions (temperature t, pressure b, humidity h) may be converted to the value that would have been obtained under the standard reference atmospheric conditions (t_0, b_0, h_0). Conversely, a test voltage specified for given reference conditions can be converted into the equivalent value under the test conditions. 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.

In order to be able to compare the insulators from the aspect of flashover voltages, different laboratories being responsible to give certifications to manufacturers must use the same atmospheric correction factor to convert the results from the test conditions to the standard condition. Some of the organizations that prepare and publish international standards for electrical technologies, have defined such correction factors. In Iran, IEC's standards are the main ones used. However, IEC60060-1(2010) [1] has specified humidity correction factors for sparkover voltage that is so reliable according to current investigations on air gap breakdown voltage [3], [4], it emphasizes not to apply atmospheric corrections to flashover [1]. On the other hand, although IEEE Std 4-1995 [2] defines the same atmospheric corrections with IEC60060-1(2010) ones, it has not mentioned not to use atmospheric correction factors with flashover voltages. The same story is about IEC60060-1(1989) [5].

Therefore, the necessity of having an accurate correction factor for flashover voltages and to investigate the validity of atmospheric corrections specified by IEC60060-1(2010) and IEEE Std 4-1995 for flashover voltages, motivated us to study the insulators breakdown voltages by performing several tests on them.

II.ATMOSPHERIC CORRECTION FACTOR

According to IEC60060-1(2010) the standard atmospheric condition is:

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

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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:

$$K_t = k_1 * k_2$$

And:

$$U_0 = \frac{U}{K_t}$$

U = Breakdown voltage in real condition (V)
U_0 = Breakdown voltage in standard condition (V)
K_t = Correction factor
Air density correction factor (k_1) can be generally expressed as:

$$k_1 = \delta^m$$

Where m is an exponent given in IEC60060-1(2010) [1], and δ is the relative air density which can be expressed as:

$$\delta = \frac{b}{b_0} \frac{273 + t_0}{273 + t}$$

b = Real atmospheric pressure (kPa)
b_0 = Standard atmospheric pressure (kPa)
t = Real temperature (°C)
t_0 = Standard temperature (°C)
The humidity correction factor (k_2) can be expressed as:

$$k_2 = k^w$$

Where w is an exponent given in IEC60060-1(2010) [1], 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(2010) [1].

III. SETUP AND PROCEDURE

III.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 Fig. 1 and Fig. 2. The test circuit was in a 6*4*3.3 m testing room, in a Faraday cage.

III.2. *TEST OBJECTS*

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

III.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" [3]. The voltage rose at a rate of 1 kV/sec and recorded as an average of 10 measurements for each object.

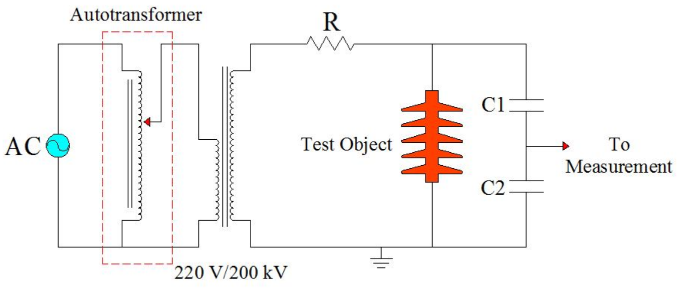

Fig. 1.Schematics of experimental circuit

Fig. 2. Experimental circuit

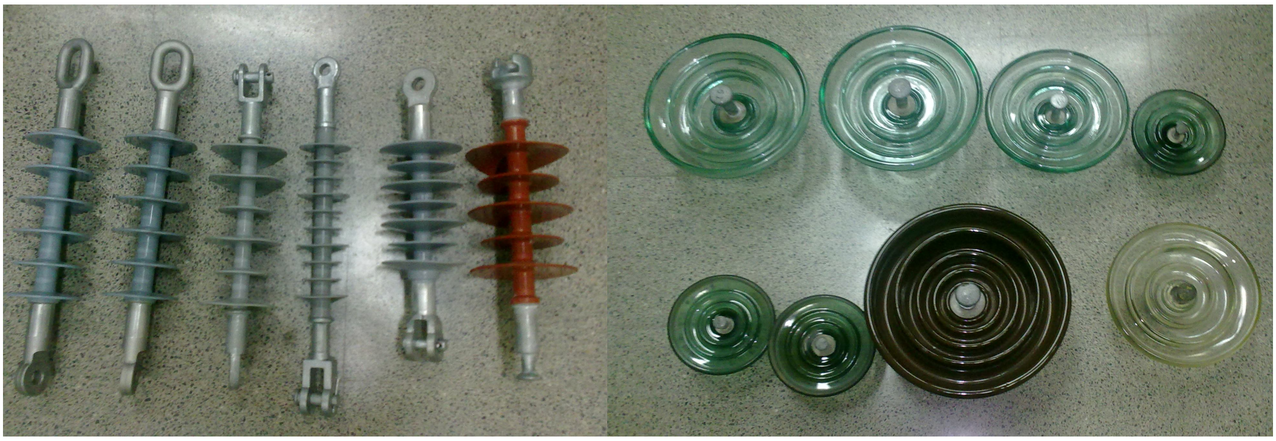

Fig. 3. Test objects

IV. RESULTS

The breakdown voltage for two objects was shown in Fig. 4.

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 [6].

Fig. 5 shows the breakdown voltage for various arcing distances versus absolute humidity for similar insulators cascaded.

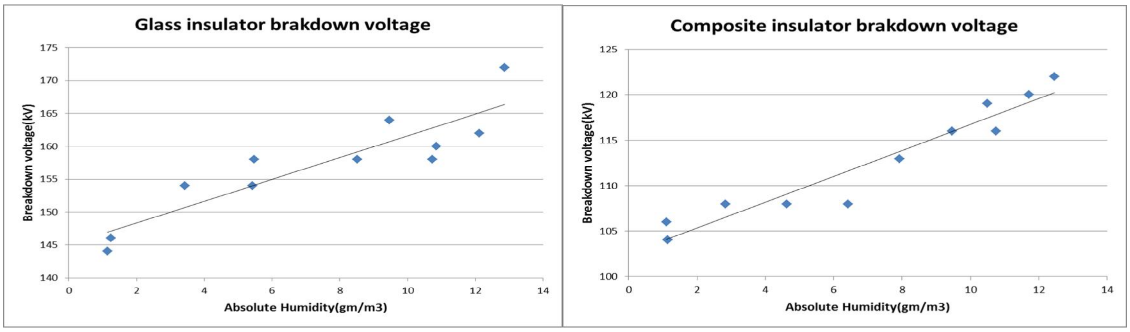

Fig. 4. Breakdown voltage enhancement with absolute humidity

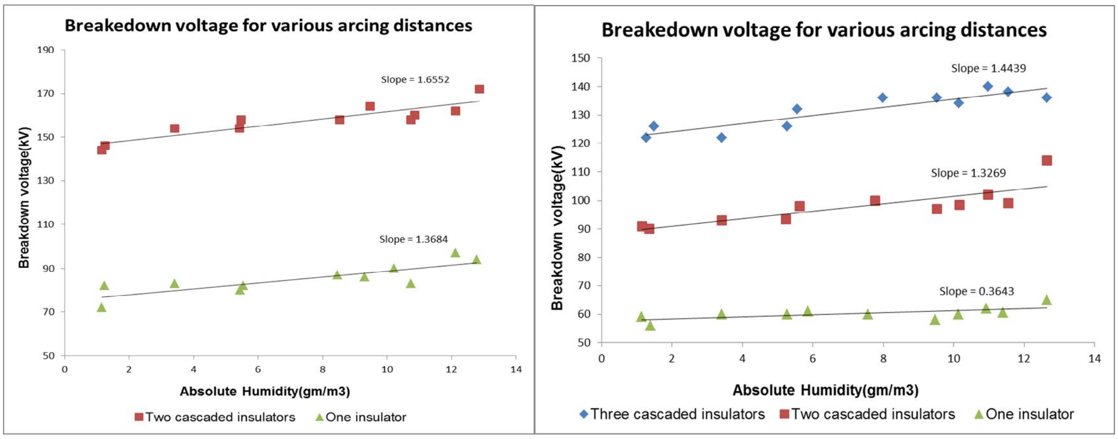

Fig. 5. Growth in slope of breakdown voltage enhancement with the arcing distance increased by cascading similar insulators

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 evalute the validity of IEC60060-1(2010) humidity correction factor for flashover voltages, we calculated the IEC correction factor in each situation and turned the measured breakdown voltage to standard situation mentioned as *U0* [7]. In tables 1-3, comparison is made between the values of *U0* obtained at various atmospheric conditions for the same insulator.

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 condition is taken as the reference test value and is shown as $U0_{REF}$. The values of *U0* obtained from other atmospheric conditions for the same insulator are compared with value of the reference test. The differences are given in the table in percentage. If the IEC60060-1(2010) humidity correction factor was appropriate for flashover voltages, 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. The mentioned errors were calculated in this way:

$$\%Error = \frac{U0 - U0_{REF}}{U0_{REF}} * 100$$

TABLE I

IEC CALCULATED CORRECTION FACTORS AND ERRORS IN STANDARD CONVERTED BREAKDOWN VOLTAGES FOR A COMPOSITE INSULATOR

($U0_{REF}$ = 124.30 KV)

T (°C)	h/δ	Um (kV)	K	U0 (kV)	%Error
23.5	12.70	116	0.978	118.56	-4.62
21.1	9.30	113	0.973	116.12	-6.58
20.9	7.52	108	0.972	111.12	-10.60
21.7	**14.62**	**122**	**0.981**	**124.30**	**0.00**
21.9	13.76	120	0.980	122.43	-1.51
22.3	12.34	119	0.977	121.82	-1.99
21.9	5.45	108	0.965	111.90	-9.97
21.6	3.33	108	0.958	112.70	-9.33
17.6	1.33	104	0.959	108.45	-12.76
17	1.28	106	0.957	110.74	-10.91
20.6	11.08	116	0.976	118.80	-4.43

According to table 1, as an example of the test results, for a composite insulator, although the pressure was constant, changing the humidity itself causes the breakdown voltages vary from 104 kV to 122 kV. Furthermore, changing the pressure intensifies this variation. So applying a correction factor to breakdown voltages is undoubtedly necessary while IEC60600-1(2010) has not specified any correction factor in this case. Now, which criteria should be used to standardize the results of breakdown voltage tests in different atmospheric conditions?

TABLE II
IEC CALCULATED CORRECTION FACTORS AND ERRORS IN STANDARD CONVERTED BREAKDOWN VOLTAGES FOR TWO CASCADED GLASS INSULATORS ($U0_{REF}$ = 164.08 KV)

T (°C)	h/δ	Um (kV)	K	U0 (kV)	%Error
22.90	12.80	160	0.985	162.45	-0.99
21.60	10.01	158	0.980	161.14	-1.79
21.10	6.41	158	0.972	162.56	-0.92
22.10	15.12	172	0.987	174.30	6.23
22.30	**14.26**	**162**	**0.987**	**164.08**	**0.00**
22.70	12.64	158	0.985	160.37	-2.26
22.00	6.37	154	0.973	158.24	-3.56
21.80	4.02	154	0.967	159.32	-2.90
18.60	1.46	146	0.966	151.13	-7.89
17.60	1.33	144	0.968	148.81	-9.31
20.60	11.08	164	0.981	167.11	1.85

V. 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 Fig. 5, 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 experiments presented in tables, more studies needs to be done to find appropriate correction factors for flashover voltages.

TABLE III
IEC CALCULATED CORRECTION FACTORS AND ERRORS IN STANDARD CONVERTED BREAKDOWN VOLTAGES FOR A PORCELAIN INSULATOR ($U0_{REF}$ = 134.52 KV)

T (°C)	h/δ	Um (kV)	K	U0 (kV)	%Error
23.80	12.27	124	0.975	127.24	-5.41
21.70	10.00	124	0.970	127.88	-4.94
21.20	6.43	118	0.963	122.53	-8.91
22.10	**15.71**	**132**	**0.981**	**134.52**	**0.00**
22.10	13.97	124.5	0.980	127.04	-5.56
22.70	12.00	110	0.982	112.04	-16.71
22.20	6.24	106	0.971	109.15	-18.86
21.80	4.02	108	0.963	112.11	-16.65
18.60	1.44	104	0.961	108.17	-19.58
17.70	1.34	105	0.961	109.28	-18.76
20.70	11.50	116	0.979	118.48	-11.92

Acknowledgements

This work was supported by High Voltage Laboratory of University of Tehran.

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