I E E E
No. 271
DEC. 1966

Technical Report on

SWITCHING SURGE TESTING

OF EXTRA-HIGH-VOLTAGE SWITCHES

(Published for Trial Use)

IEEE No. 271

PUBLISHED BY
THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, Inc.
345 EAST 47 STREET, NEW YORK, N. Y. 10017

FOREWORD

This document is published to provide guidance in the switching surge testing of extra-high-voltage air switches. For the design and safe application of extra-high-voltage air switches, it is believed essential to have uniformity of test environment, test procedure, and interpretation of data in order to correlate data gathered in different laboratories and eliminate the wide variations that are now apparent in test results.

The Air Switch Working Group of the Switch, Fuse, Insulator Subcommittee has prepared this report and recognizes its obligation to continue efforts to improve or revise it in the light of knowledge derived from tests conducted in accordance with the report. After an appropriate period of use the report will be thoroughly reviewed by the Air Switch Working Group and the up-dated document will be the basis for the preparation of an IEEE Standard for the Switching Surge Testing of Extra-High-Voltage Switches. It is anticipated that this material will eventually be incorporated into USA Standard C37.34 and the paragraph numbering has been chosen to fit in with the system in that document.

It should be clearly understood that this document relates *ONLY* to air switches and it is not intended to be used as a basis for testing other electric apparatus particularly where such tests would be destructive to insulation.

This document when balloted in the Switchgear Committee for IEEE publication elicited several negative votes which expressed concern in the areas identified by paragraph numbers 2.5.6, 2.5.7, 2.5.11, 2.6 and Appendix A. Footnotes which explain the nature of the concern expressed by the negative ballots as well as by those who approved with comment are published adjacent to the aforementioned items. Since there was not complete agreement in these areas, this report should be used with the understanding that these items are likely to be revised before final publication as an official Standard.

It is recommended for switching surge testing programs that there be a thorough documentation of parameters related to the test so that subsequent conversion of data might be possible without duplicating test effort.

ACKNOWLEDGMENT

The Institute wishes to acknowledge its indebtedness to those who have so freely given of their time and knowledge, and have conducted experimental work on which many of the IEEE publications are based.

This publication was prepared by the Air Switch Working Group of the Switch, Fuse, and Insulator Subcommittee of the Switchgear Committee of the IEEE Power Group, whose membership was:

C. W. Upton, *Chairman*

A. K. Alsaker — J. B. Owens

K. D. Hendrix — J. D. M. Phelps

F. R. Solis

Technical Report on

SWITCHING SURGE TESTING OF EXTRA-HIGH-VOLTAGE SWITCHES

34-2.5 Switching Surge Tests of Extra-High-Voltage Switches

2.5.1 *Equipment to be Tested.* Outdoor air switches rated 345 kV and above may be required to withstand long-duration switching surge voltages. The test procedures described herein are basically intended to be for design purposes. Tests should be conducted on single-pole units in accordance with the following paragraphs.

2.5.2 *Mounting Arrangement.* The single-pole sample to be tested should be mounted at the minimum expected service height above a ground plane extending in all directions from the switch base for a distance of at least twice the switch open gap dimension. In the absence of other specification, the mounting height should be such that the lowest point of the switch insulators is no more than 8 feet above the ground plane for 345-kV equipment. 12 feet above the ground plane for 500-kV equipment, and 16 feet above the ground plane for 700-kV equipment.

2.5.3 *Electric Conductors.* In the absence of other specification, an electric conductor of the size normally intended for use with the switch should be connected to each switch terminal and should extend horizontally for a distance of 10 feet. These conductors may be terminated with suitable shielding means to prevent flashover from their ends.

2.5.4 *Proximity of Other Objects.* The switch should be mounted in an environment which is free from objects which can significantly distort the electric field distribution when the switch is energized. Grounded metallic objects should be no closer to energized portions of the switch than 1.5 times the switch open gap dimension.

2.5.5 *Points of Application of Voltage.* Dielectric characteristics of the specimen should be determined by the application of positive and negative switching surge voltages as follows:

(1) With the switch closed and dry, test voltages should be applied between the energized parts and the grounded metal parts including the base.

(2) With the switch open and dry, test voltages should be successively applied between each terminal and the grounded metal parts including the base with the other terminal connected to ground.

(3) The above tests (1) and (2) should be repeated with wet conditions in accordance with USA Standard C77.1. As an alternate, wet conditions in accordance with IEC Publication 129 may be used.

2.5.6 *Number and Magnitude of Voltage Applications.* (See Footnote 1.) Dielectric characteristics should be determined by applying to the test switch a series of at least 20 standard surges of the same crest value at each of at least four voltage steps. The lowest voltage level test point should be such that three to five flashovers occur to ground. The highest voltage level test point should be such that 15 to 17 flashovers occur. The two intermediate points should be selected so that the spacing between the four points is approximately equal. For each voltage level, the number of flashovers and the number of withstands should be recorded.

2.5.7 *Switching Surge Wave Shape.* (See Footnotes 2 and 2a.) The switching surge wave for dielectric testing purposes should consist of a unidirectional surge voltage, rising to its crest value in a time in the range of 70-250 microseconds and decaying to one-half value in a time not less than 3000 microseconds. The time to crest should be taken as 1.67 times the time required to reach 90 percent of crest on the front of the wave. When due to instrumentation the zero time is

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Footnote 1

It was proposed that a more accurate withstand determination could be made with fewer tests if statistical methods were used.

Footnote 2

The stipulation of a wave shape and the way to measure it drew the most comment. The Air Switch Working Group will be most receptive to considering industry wide proposals that are made before attempting to have this item become a final IEEE Standard.

It should be noted that the alternate method proposed in this report varies slightly from the IEC impulse method of 1.67 times the time from 30 percent to 90 percent voltage. It is felt that 2 rather than 1.67 gives a better measure of actual time to crest.

It is recommended that when the waves as recorded on oscillograms are being measured as specified, that the time to crest as determined visually also be recorded for purposes of correlation at a later date.

Footnote 2a

As of the date of publication of this report the Techniques for Dielectric Tests Subcommittee of the Power System Instrumentation and Measurements Committee of IEEE (also USASI C68) has taken action to recommend to the industry the visual or real-time method of measurement of switching surge wave shape characteristics recorded on oscillograms.

difficult to determine accurately, the virtual zero time point may be taken as the intersection with the zero line of a line drawn between the 30 percent and 90 percent voltage points on the front of the wave. The time to crest value in these cases should then be taken as two times the difference between the time to reach 30 percent and 90 percent of the crest value.

2.5.8 *Determination of 50 Percent (Critical) Flashover Voltage.* Percentage of flashover as a function of crest voltage should be determined by plotting the data obtained in paragraph 2.5.6 on probability paper (Keuffel & Esser Company 358-23 or equivalent) and interpolating with a straight line. The scale of probability paper is such that the integral of a Gaussian distribution curve becomes a straight line. In the event that any of the points deviate appreciably from a straight line, the most probable straight line should be determined by the modified linear regression method as shown in Appendix A.

The 50 percent (critical) flashover voltage is determined from the intersection of voltage plot with the 50 percent ordinate, or as determined in the method shown in Appendix A.

2.5.9 *Determination of Dispersion (Standard Deviation).* The dispersion in percent is given by the formula —

$$d = 100\ (V_{50} - V_{16})/V_{50}$$

Where d = dispersion in percent

V_{50} = voltage corresponding to a 50 percent probability of flashover

V_{16} = voltage corresponding to a 16 percent probability of flashover

The measured dispersion should be increased to allow for expected random variations in voltage measurement, and to compensate for the practical consideration of relatively small test samples, etc. The assumed maximum dispersion D may be determined from the formula —

$$D = \sqrt{d^2 + a^2}$$

Where d = measured dispersion in percent

a = allowance for uncertainty in determination of d. Recommended value with good laboratory technique is 2 percent

2.5.10 *Determination of Withstand Voltage.* The withstand voltage two standard deviations below the 50 percent (critical) flashover may be determined from the formula —

$$V_w = V_{50}(100 - 2D)/100$$

The withstand voltage determined from the foregoing formula provides a 97.7 percent probability that the assigned withstand voltage will not cause insulation flashover. The withstand voltage should always be published with the 50 percent (critical) flashover voltage so that interpolations for other probabilities can be made.

2.5.11 *Corrections* (See Footnote 3)

2.5.11.1 *Standard Conditions.* Voltage values for dry tests should be corrected for relative air density and vapor pressure to provide values corresponding to the following conditions:

Barometric Pressure 760 millimeters of mercury (29.92 inches)

Temperature 25°C (77°F)

Vapor Pressure 15.45 millimeters of mercury (0.6085 inch)

Voltage values for wet tests should be corrected for relative air density only.

2.5.11.2 *Relative Air Density.* Relative air density may be determined from barometric pressure and temperature by use of the Air Density Correction Factor formula found in USASI C68.1 and IEEE 4.

2.5.11.3 *Vapor Pressure.* The vapor pressure should be determined by the following procedure.

Humidity should be measured with wet- and dry-bulb thermometers, the air being circulated past the thermometers at a velocity of 3 meters (9.84 feet) or more per second, or with the sling psychrometer. The measurements shall be reduced to vapor pressure with the assistance of the Smithsonian Meteorological Tables and related formulas for reduction of psychrometric data.

2.5.11.4 *Dry Test Correction Factors.* Voltage values during the dry switching surge tests should be corrected to those values corresponding to a relative air density of 1.0 and a vapor pressure of 15.45 millimeters (0.6085 inch) through the use of correction factors determined from Fig-

Footnote 3

At this time complete agreement throughout the industry has not been reached on specific correction factors and their use. Until such time as agreement is reached and Standards are published, it is suggested that corrections presented herein be used. It is further suggested that atmospheric conditions of pressure, temperature, and humidity be recorded throughout a test program so that subsequent conversion of data can be made when industry-wide agreement is reached.

ure 1 and Figure 2. The voltage value corresponding to standard conditions is determined by multiplying the observed voltage value by K_p and K_h.

2.5.11.5 *Wet Test Correction Factors.* Voltage values for wet tests should be corrected for relative air density only by being multiplied by the correction factor K_p determined by Figure 2.

34-2.6 OPEN GAP INSULATION COORDINATION. (See Footnote 4)

Tests to indicate open gap insulation coordination, wet and dry, should be made with the switch mounted in accordance with paragraphs 2.5.2, 2.5.3, and 2.5.4. A series of at least 40 positive and 40 negative switching surges of equal crest value should be applied to each terminal, with the base and other terminal grounded. The crest value of the switching surges during this test should be chosen for 80 percent to 100 percent probability of insulator flashover to ground. During the series of switching surges, at least four applications of voltage must result in freedom from insulator flashover. The number of switching surge applications may be increased above 40 to achieve the required number of insulator withstands. Insulation coordination is achieved if no more than one open gap flashover occurs during a series of 40 voltage applications.

Switching surge voltages applied to the open switch in the determination of the line-to-ground insulation characteristics may be used as part of the proof of open gap insulation coordination provided these voltages existed in the range of 80 percent to 85 percent probability of line-to-ground insulator flashover and provided no open gap flashovers occurred during this program.

Footnote 4

Concern was expressed as to whether the proposed method provides adequate open gap coordination. The need for studying the effects of bias was also expressed.

APPENDIX A (See Footnote 5)

MODIFIED LINEAR REGRESSION METHOD FOR EVALUATION OF PROBABILITY TEST INFORMATION

In drawing a curve of probability of flashover as a function of voltage, the criterion for the best fit to observed test data is that the sum of the squares of the differences between the test points and the corresponding points on the curve is to be a minimum.

The method to be followed can best be understood by an examination of Table I. In preparing such a tabulation and drawing the final probability line, the following procedure should be used.

1. Insert test data in columns 2 and 5.
2. Determine d_n from Table II and insert in column 6.
3. Determine the average $\overline{X}$ and $\overline{y}$ from formulas 2 and 3.
4. Calculate column 3 and then columns 4 and 7 respectively.
5. Determine the standard deviation s from formula 4.
6. Use formula 5 to determine the 50 percent probability flashover point.
7. Use formulas 6 and 7 to calculate D.
8. Use formula 8 to determine Withstand Voltage.

NOTE: A sample probability plot is shown on Figure 3. This was obtained by drawing a straight line between the plotted kV_{50} and kV_w values as calculated in Table I. Test points are included for reference.

TABLE I

DETERMINATION OF DISPERSION AND WITHSTAND

1. Test Sequence No.(n)	2. kV_n	3. $(kV_n - \overline{X})$	4. $(kV_n - \overline{X})^2$	5. Flash-over/ Tests	6. d_n	7. $(d_n - \overline{y})$	8. $(kV_n - \overline{X})(d_n - \overline{y})$
1	1220	−60	3600	3/20	−1.04	−0.75	45.0
2	1250	−30	900	4/20	−0.84	−0.55	16.5
3	1300	+20	400	9/20	−0.13	0.16	3.2
4	1350	+70	4900	16/20	+0.84	1.13	79.1
	5120		9800		−1.17		143.8

Formula 1. N = Number of test sequences = 4

Formula 2. $\overline{X} = \frac{\Sigma\,(kV_n)}{N} = \frac{5120}{4} = 1280\text{ kV}$

Formula 3. $\overline{y} = \frac{\Sigma\,(d_n)}{N} = \frac{-1.17}{4} = -0.29$

Formula 4. $s = \frac{\Sigma\,(kV_n - \overline{X})^2}{\Sigma\,(kV_n - \overline{X})(d_n - \overline{y})} = \frac{9800}{143.8} = 68\text{ kV}$

Formula 5. $kV_{50} = \overline{X} - \overline{y}s = 1280 - (-0.29 \times 68) = 1300\text{ kV}$

*Formula 6. $d = \frac{100(s)}{kV_{50}} = \frac{100 \times 68}{1300} = 5.2$ Percent

*Formula 7. $D = \sqrt{d^2 + a^2} = \sqrt{(5.2)^2 + (2.0)^2} = 5.6$ Percent

*Formula 8. Withstand Voltage, $kV_w = kV_{50}\,(100 - 2D) = 1300\,(100 - 11.2) = 1150\text{ kV}$

* From paragraph 2.5.9.

Footnote 5

Concern was expressed relative to the method to use for determining the best line for the test points plotted.

TABLE II

TABLE TO DETERMINE d_n

Flashover/ Tests	d_n
3/20	−1.04
4/20	−0.84
5/20	−0.67
6/20	−0.52
7/20	−0.39
8/20	−0.25
9/20	−0.13
10/20	0.00
11/20	+0.13
12/20	+0.25
13/20	+0.39
14/20	+0.52
15/20	+0.67
16/20	+0.84
17/20	+1.04

TABLE III

PROBABILITY TABLE

Probability Percent	Deviations
99.87	+3D
97.72	+2D
84.13	+ D
50.00	0
15.87	− D
2.28	−2D
0.13	−3D

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(3) USA Standard for Measurement of Voltage in Dielectric Tests, USAS C68.1, 1953.

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For statistical reference:

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(2) *Elements of Statistical Method,* A. E. Waugh — McGraw-Hill.

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(4) *Statistical Theory in Research,* Anderson and Bancroft — McGraw-Hill.

ATMOSPHERIC CORRECTION FACTORS

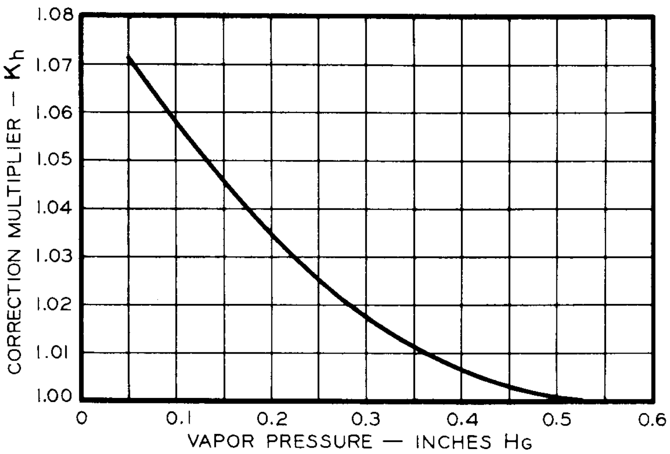

FIGURE 1—HUMIDITY

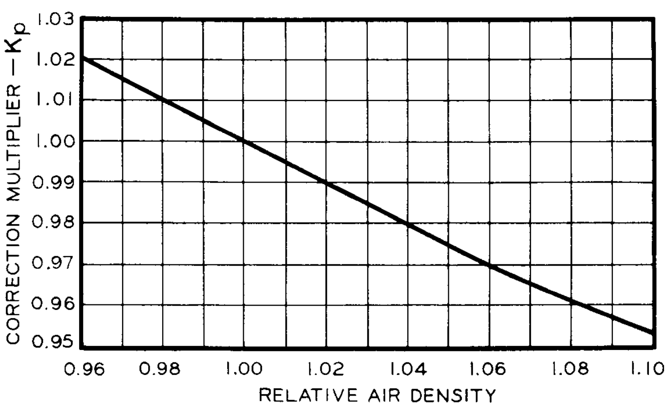

FIGURE 2—R.A.D.

$$Kp = \frac{1}{(RAD)^{0.5}}$$

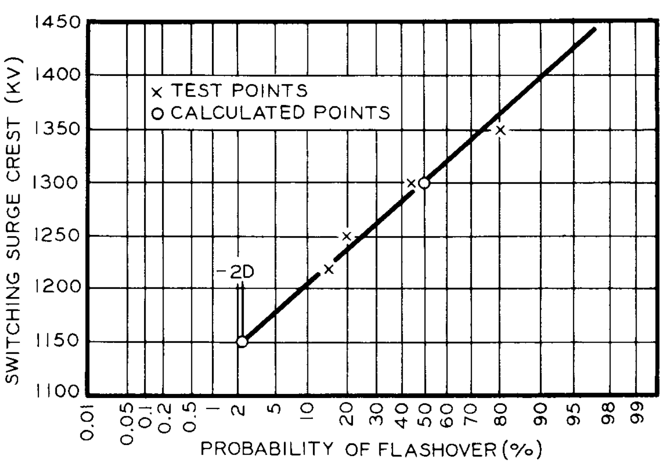

FIGURE 3—SAMPLE PROBABILITY PLOT
DATA FROM TABLE I.