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Comments:

These are the corrections that were submitted to Michele Turner

Regards.

Ruben Garzon

C37.09

IEEE Std C37.09-1999
(Revision of
IEEE Std C37.09-1979)

IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

Sponsor

**Switchgear Committee
of the
IEEE Power Engineering Society**

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IEEE-SA Standards Board

Abstract: The testing procedures for all high-voltage circuit breakers that include all voltage ratings above 1000 V ac and comprise both indoor and outdoor types having the prefered ratings as listed in ANSI C37.06-1997 are covered. Typical circuit breakers covered by these standards have maximum voltage ratings from 4.76 kV through 800 kV, and continuous current ratings of 600 A, 1200 A, 2000 A, and 3000 A associated with the various maximum voltage ratings. The test procedures verify all assigned ratings, including continuous current, dielectric withstand voltages, short-circuit current, transient recovery voltage, and capacitor switching, plus associated capabilities such as mechanical endurance, load current, and out-of-phase switching. Production test procedures are also included. This standard does not cover generator circuit breakers as these are covered in IEEE Std C37.013-1993.
Keywords: fast transient recovery voltage, indoor, initial, mechanical endurance, operating duty, outdoor, power frequency, short-circuit current, short-line fault, single-phase testing, test data reporting, three-phase testing, unit test, voltage distribution synthetic test.

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ANSI C37.54-1996, American National Standard for Switchgear—Indoor Alternating-Current High-Voltage Circuit Breakers Applied as Removable Elements in Metal-Enclosed Switchgear Assemblies—Conformance Test Procedures.

1995

ANSI C84.1-1982, Voltage Ratings for Electric Power Systems and Equipment (60 Hz).

ASME Boiler and Pressure Vessel Code, Section X, Fiberglass-Reinforced Plastic Pressure Vessels.[2]

ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels.

IEC 60056-1987, High Voltage Alternating Current Circuit Breakers.[3]

IEC 60068-2-17-1994, Basic Environmental Test Procedures—Part 2: Tests—Test Q: Sealing.

IEC 60694-1996, Common Specifications for High-Voltage Switchgear and Controlgear Standards.

IEEE Std 4-1978, IEEE Standard Techniques for High-Voltage Testing.[4]

NOTE—This standard is specifically referenced because its latest revision does not include critical test techniques needed for circuit breaker testing. When the latest issue of this standard is suitably revised, it will be officially recognized and will become part of this revision.

IEEE Std 119 Aug. 1950, IEEE Recommended Practice for General Principles of Temperature Measurement as Applied to Electrical Apparatus. Test Code for Temperature Measurements.[5]

IEEE Std C37.04-1999, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.

IEEE Std C37.010-1999, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.011-1994, IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.013-1997, IEEE Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.015-1993, IEEE Application Guide for Shunt Reactor Current Switching.

IEEE C37.081-1981 (R1988), IEEE Guide for Synthetic Fault Testing of AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.11-1997, IEEE Standard Requirements for Electrical Control for High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.20.2-1993, IEEE Standard for Metal-Clad and Station Type Cubicle Switchgear.

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[2]ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5990, USA (http://www.asme.org/).

[3]IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembé, CH-1211, Genève 20, Switzerland/Suisse (http://www.iec.ch/). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[4]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://www.standards.ieee.org/).

[5]IEEE Std 119 Aug. 1950 has been withdrawn; however, copies can be obtained from Global Engineering, 15 Inverness Way East, Englewood, CO 80112-5704, USA, tel. (303) 792-2181 (http://global.ihs.com/).

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4.8.1 Test conditions

4.8.1.1 Power factor

For short-circuit current interrupting tests, the power factor of the testing circuits shall not exceed 5.9% lagging, equivalent to X/R = 17 at 60 Hz or 7.1% lagging equivalent to X/R = 14 at 50 Hz.

4.8.1.2 Frequency of test circuit

Tests demonstrating short-circuit current interrupting capabilities shall be made at rated power frequency. When performing tests at a frequency other than the rated power frequency, special consideration shall be given to the rate of change of current at current zero, since performance of some interrupters is strongly influenced by the rate of change of current (di/dt) at the instant of current zero.

If a circuit breaker contains interrupters that are not affected significantly by the di/dt, then tests performed at 50 Hz can be used to demonstrate the performance at 60 Hz and vice versa. However, for rated power frequencies above 60 Hz or below 50 Hz, which are beyond the scope of this standard, other test considerations may be required.

4.8.1.3 Current asymmetry

Interrupting tests are required with both symmetrical and asymmetrical currents. Any interrupting test in which the asymmetry of the current, in all phases at contact parting time, is less than 20% is considered a symmetrical test. Asymmetry of less than 20% is considered to have negligible influence on the performance in a circuit that has a time constant of 45 ms (corresponding to X/R values of 14 and 17 for rated power frequencies of 50 and 60 Hz respectively). At this level of asymmetry, the total current is increased by less than 4% and furthermore, the instantaneous value of the power frequency recovery voltage, at the instant of arc extinction at the end of a major current loop, is within 2% of the peak value, while at the end of a minor current loop, within 6%.

For the asymmetrical tests, the current value is determined at the instant of contact part, and since the asymmetry decreases with time, the value of the dc component at the time of contact separation shall be equal to the value obtained from Figure 1 for an elapsed time corresponding to the circuit breaker under test. This required percent of the dc component is specified in Figure 1 for a time constant of 45 ms. Figure 2 may be used to determine the required percentage of the dc component for tests where the manufacturer may want to demonstrate the asymmetrical interrupting current capability for X/R ratios other than 17 at 60 Hz.

The defining equation for these curves is

$$\%dc = 100\, e^{-(t/\tau)} \quad (1)$$

where

t = contact parting time (s)

τ = time constant $= \frac{X/R}{2\pi f}$

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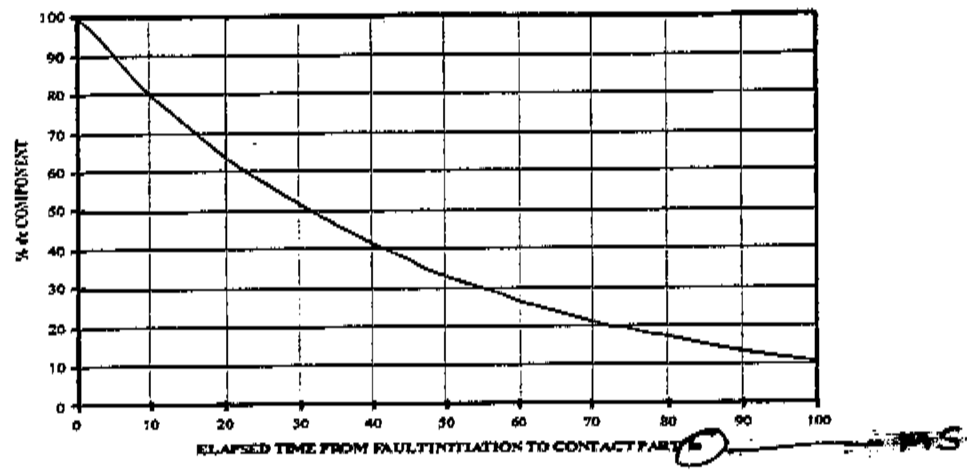

Figure 1—Percent dc required at contact part for asymmetrical tests (values based on a time constant of 45 ms equivalent to X/R of 17)

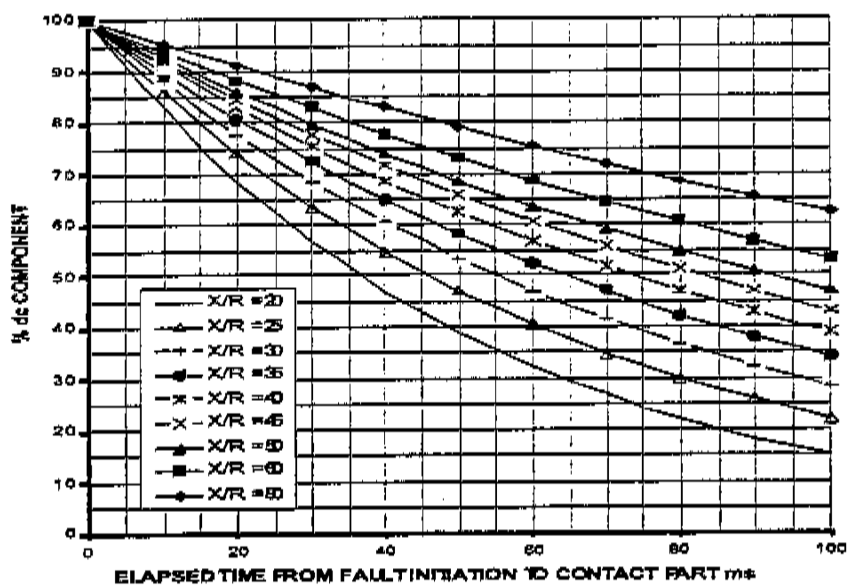

Figure 2—Percent dc required at contact part for asymmetrical tests (values based on a range of X/R factors at 60 Hz)

The elapsed time as shown in Figure 1 and Figure 2 is equal to the sum of 1/2 cycle of relay time (on the basis of the applicable rated power frequency) plus the shortest contact opening time of the circuit breaker as determined in 4.8.5.2.

NOTE—To convert the 60 Hz based X/R factors to a 50 Hz base multiply the X/R factor shown in Figure 2 by 0.833. To convert X/R to time constants, multiply the 60 Hz X/R by 2.652 or the 50 Hz X/R by 3.183. The result is the time constant in ms.

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4.8.1.4 Obtaining the most severe switching conditions

To demonstrate the required interrupting capability of a circuit breaker, it is necessary to show that the circuit breaker is capable of meeting the requirements for the rated interrupting time, the rated short circuit current, and related required capabilities in accordance with the requirements set forth in IEEE Std C37.04-1999 and ANSI C37.06-1997, under the most severe switching conditions. The most severe conditions are considered to be those where the maximum arcing energy input is seen by the interrupter during interruption as a result of variations of the arcing time that are due to the relationship between contact parting time of the circuit breaker and the natural current zeros of the short-circuit current. It must be shown that the circuit breaker is capable of interrupting the rated current, within its limitations for asymmetry and interrupting time, with the current zeros occurring in such relation to the contact parting as to yield approximately the longest arcing time.

To satisfy the above conditions the opening operations for test duties 4, 5, 6, and 7 of Table 1 shall have the corresponding arcing times, in ms, as outlined below. For each test duty, the minimum arcing time shall be specified by the manufacturer.

4.8.1.4.1 Single-phase symmetrical current tests

$$\text{Arcing time} = \text{minimum arcing time} + 0.75 \times t_1 \quad (2)$$

where t_1 = time for ~~one~~-half cycle of rated power frequency (10 or 8.33 ms for 50 or 60 Hz respectively)

4.8.1.4.2 Single-phase asymmetrical current tests

$$\text{Arcing time} = \text{minimum arcing time} + \text{length of major loop} - 1\text{ ms} \quad (3)$$

(The length of major loop is shown in Figure 3.)

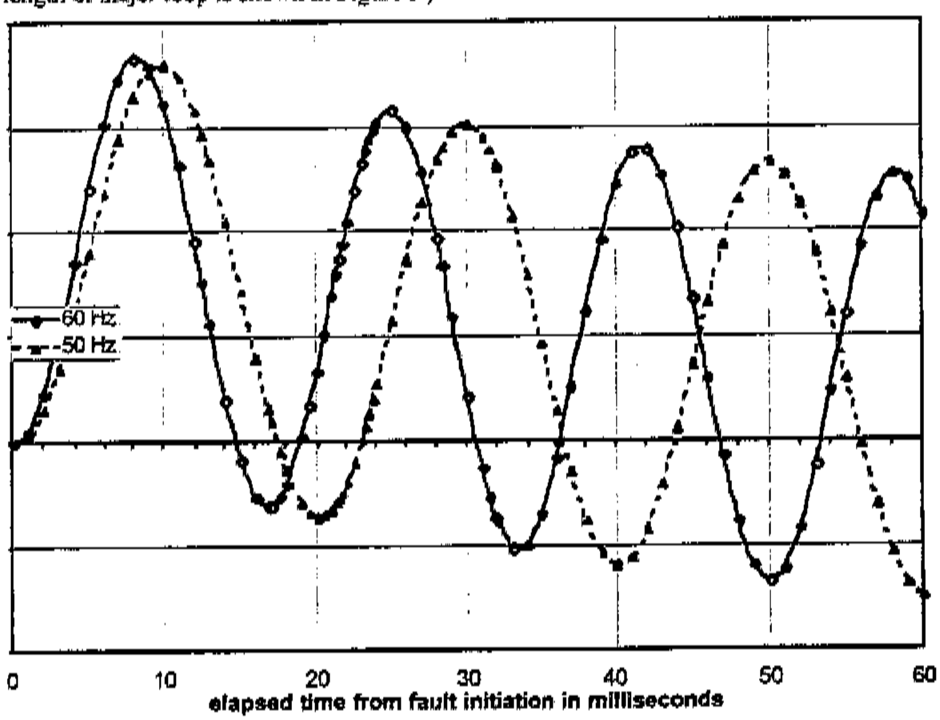

Figure 3—Single-phase asymmetrical currents with a 45 ms time constant for 50 and 60 Hz

3. Definitions

The terms and definitions applicable to this standard and to the related standards for ac high-voltage circuit breakers shall be in accordance with IEEE Std C37.100-1992. These definitions are not intended to embrace all possible meanings of the terms. They are intended solely to establish the meanings of terms used in power switchgear.

4. Service conditions

4.1 Usual service conditions

Circuit breakers conforming to this standard shall be suitable for operating at their standard ratings

a) Where the temperature of the ambient is not above 40 °C or below –30 °C;
b) Where the altitude is not above 1000 m;
c) Where the effect of solar radiation is not significant (the principles stated in IEEE Std C37.24-1986 may be used for guidance);
d) Where the seismic conditions do not exceed those defined in 6.3.1.3; and
e) Where unusual conditions as listed in IEEE Std C37.010-1999 do not exist.

4.2 Unusual service conditions

Unusual service conditions are listed in IEEE Std C37.010-1999. Such conditions should be brought to the attention of those responsible for the application, manufacture, and operation of the equipment, and the guidelines for application given in IEEE Std C37.010-1999 should be followed.

5. Ratings

The rating of a circuit breaker is a designated limit of operating characteristics that is based upon usual service conditions as specified in 4.1. The rating of a circuit breaker shall include the following parameters (for values of preferred ratings of circuit breakers, see ANSI C37.06-1997):

~~a) For operation (5.?);~~
a) ~~b) Out-of-phase switching current (5.12)~~ rated maximum voltage (5.1);
b) Rated power frequency (5.2);
c) Rated continuous current (5.3);
d) Rated dielectric withstand capability (5.4);
e) Rated standard operating duty (standard duty cycle) (5.5);
f) Rated interrupting time (5.6);
g) Rated short-circuit current (5.8);
h) Rated transient recovery voltage (TRV) (5.9);
i) Rated capacitance current switching (5.11) (NOTE—Definite purpose is an optional rating.);
j) Rated control voltage (5.15);
k) Rated operating pressure for insulation and/or interruption (5.16);
l) Rated operating pressure for mechanical operation (5.17);
m) Out-of-phase switching current capability (5.12) (out-of-phase switching current is an optional rating that may be assigned where applicable).

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4.8.1.4.3 Three phase symmetrical current tests

In order to obtain the most severe condition for these tests it is sufficient to modify the contact parting time of the test circuit breaker by 40 electrical degrees (approximately 2 ms) between each operation.

4.8.1.4.4 Three phase asymmetrical current test

The contact parting time shall be adjusted such that:

a) In one test, the first phase to clear is the one with the required % dc component and where arc extinction occurs after a major loop of current (see Figure 4). Interruption at the end of a minor loop following arcing through a major loop is permissible as long as the maximum interrupting time is not exceeded.

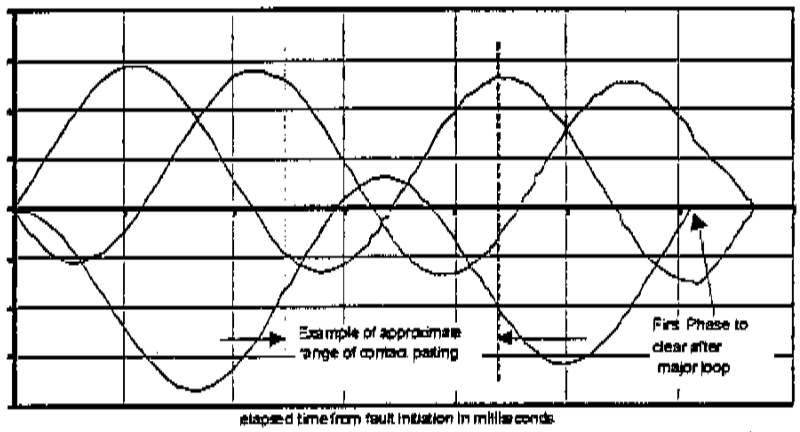
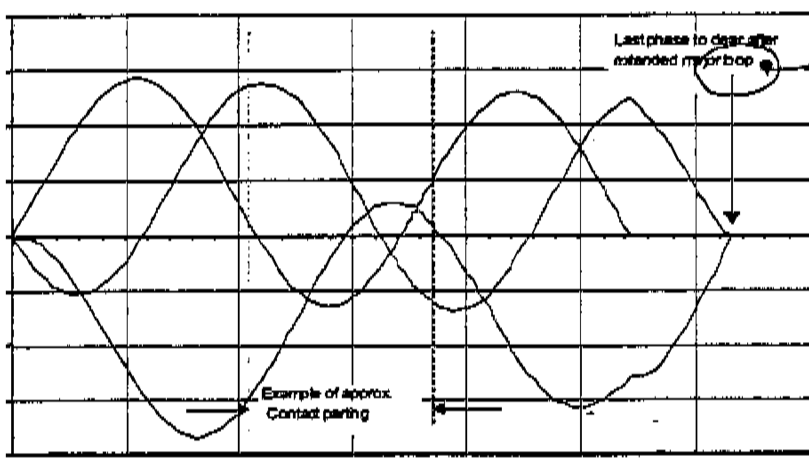


Figure 4—Three-phase asymmetrical current case, a) of 4.8.1.4.4 (example shows ungrounded system)

b) In another test, arc extinction for the last phase to clear must occur in a phase that has the required % dc component and after a major extended loop or the greatest part of that loop (see Figure 5).



Loop.

Elapsed time from fault initiation in milliseconds

Figure 5—Three-phase asymmetrical current case, b) of 4.8.1.4.4 (example shows ungrounded system)

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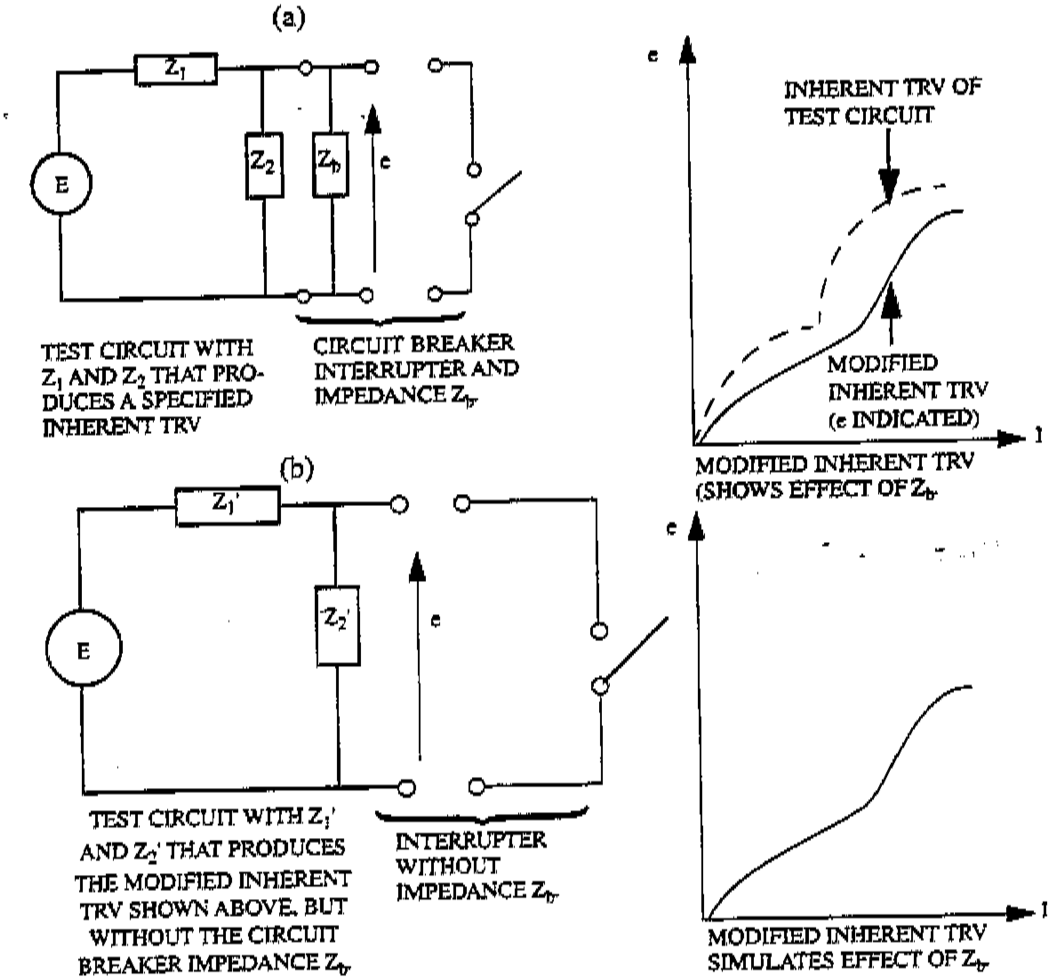

Figure 6—A test circuit designed to simulate the effect of circuit breaker modifying impedance

4.8.1.6 Short-line fault test conditions

The short-line fault tests are performed on circuit breakers that are intended to be connected directly to an overhead line.

Short-line fault tests are made on a single-phase basis. The tests may be performed on a single pole of a three-phase circuit breaker, or in the case of hermetically sealed interrupters, on a single interrupter provided that the conditions listed in 4.8.2.2 are met.

For these tests the bus (source) voltage should be equal to 0.58 V, and the magnitude of the short-circuit current at the circuit breaker terminals shall be as shown in Table 1. $K_a \times 0.58\sqrt{2}$ V

The peak value E_2 for the source side component of the TRV is equal to where K_a = Amplitude factor = 1.4 for circuit breakers above 100 kV or 1.54 for circuit breakers below 100 kV. This amplitude is obtained for a grounded fault at the circuit breaker terminals only. Additional line reactance is then used to reduce the current to the test value. This reactance also reduces the amplitude of the source side component of TRV by a factor of $1 + (K_a - 1)M$.

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Table 1—Single-phase or three-phase test duties for short-circuit current tests

Test duty	Operating duty	Test voltage kV	Making I kA (pk)	I @ contact part kA	% asymmetry
1	Three Os	E		0.1 I	see 4.8.3.1
2	Three Os	E		0.3 I	see 4.8.3.1
3	Three Os	E		0.6 I	see 4.8.3.1
4	O - t - CO - t' - CO or (4a) and (4b)	E	F x I	I	< 20
4a	C - t' - C	E	F x I		
4b	O - t - O - t' - O	E		I	< 20
5	Three Os	E		see 4.8.3.3	> 20
		Single-phase tests			
6	O	.58 V		I	< 20
7	O	.58 V		see 4.8.3.4	> 20
		Single-phase short-line fault tests			
8	Three Os	.58 V		.7 I to .8 I	< 20
9	Three Os	.58 V		.9 I to .95 I	< 20
		Short-time test			
10	Closed position		F x I	I for T seconds	

All F x I

This should be located at 4.8.3 on page 25. All variables (E, F, V, etc.) are identified in 4.8.3

The sawtooth line-side component of the recovery voltage can be described in terms of:

a) The line inductance L_L;
b) Frequency f_L; and
c) An amplitude constant, d, which is the ratio of the peak of the sawtooth component to the peak of the voltage to ground, at the circuit breaker terminals, at the instant of interruption.

Let MI be the desired test current, where M represents the ratio of the test current to I. Then the line inductance L_L is:

$$L_L = \frac{0.58\ V}{M\omega I}(1 - M) \text{ Henrys} \quad (4)$$

The TRV rate of the line-side component R_L for a short-line fault is the surge impedance Z multiplied by the slope of the current at current zero:

$$R_L = \sqrt{2}\omega MIZ \times 10^{-6} \text{kV}/\mu\text{s} \quad (5)$$

If the peak amplitude constant of the line-side component is d, the first peak, e, is:

$$e = d(1 - M)\sqrt{2}(0.58V)kV \quad (6)$$

The time T_L to the line-side peak is then:

$$T_L = \frac{e}{R_L}\ \mu s \quad (7)$$

and the frequency is:

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interruption and must then withstand the high recovery voltage of the second source. In this manner, the duty of interrupting the high current at the high voltage is simulated.

The accuracy with which a synthetic test represents a test in which the same voltage causes the current to flow and provides the recovery voltage, as in Methods I and II, depends on several conditions. These are listed below and must be considered in planning and evaluating a synthetic test.

a) The arc voltage should be relatively low and should cause little or no distortion of the current wave. Since the magnitude of the arc voltage is larger with respect to the voltage of the current source than it is with respect to the voltage of the circuit being represented, the arc voltage has a greater effect in reducing the magnitude and shortening the duration of those loops of current during which arcing takes place. If the current distortion is appreciable, the interrupted current assigned to the test should be the product of the value measured in the conventional way, at contact parting, and a factor that compensates for the distortion.
b) The TRV should appear across the terminals of a pole unit in the same manner as the TRV does in the tests made in accordance with Methods I and II, and that is:
   1) It should appear at the precise instant of arc extinction.
   2) The circuit TRV should increase at least as rapidly and to at least as high a value as the circuit TRV being simulated.
   3) The parameters of the high-voltage sources should be such that the effect of post-arc conductivity on the TRV is no greater than that in the circuit being simulated; or failing this, the characteristics of the TRV should be judged on the basis of the actual voltage appearing across the circuit breaker contacts instead of the circuit TRV.
c) The arcing time should be controlled so that it covers the range of arcing time that will occur when the circuit breaker actually interrupts the power being simulated.

Put Table 1 here

4.8.3 Test duties

The test duties used to demonstrate the performance of a circuit breaker are listed in Table 1, where the test parameters are identified as follows:

a) Test voltage, E (for test duties 1 through 5)
   1) For three phase tests,
      E = rated maximum voltage, V.
   2) For single phase test,
      E = 0.87 × rated maximum voltage V for circuit breakers rated 100 kV and below
      E = 0.75 × rated maximum voltage V for circuit breakers rated above 100 kV
      where V = rated maximum voltage as given in ANSI C37.06-1997.
b) Test current, I, is equal to the maximum rated rms symmetrical interrupting current.
c) Time, t, is equal to:
   1) 15 s for circuit breakers that are not rated for re closing duty; and
   2) 0.3 s for circuit breakers rated for re closing duty.
d) Time, t', is equal to 3 min.
e) Time, T, is equal to the specified time shown in IEEE Std C37.04-1999 under the subclause for Rated closing, latching, and short-time current carrying capability.
f) F = 2.6 for 60 Hz or 2.5 for 50 Hz.

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4.8.3.1 Test duties 1, 2, and 3

Test duties 1, 2, and 3 shown in Table 1 consist of at least two symmetrical (< 20% dc) and one asymmetrical (between 40% and 60%) current interruption tests made with the appropriate current values, where I represents the rated short circuit interrupting current value. At the discretion of the manufacturer, the tests may also be performed as a O - t - CO - t' - CO, provided that for two opening operations the test current must be symmetrical at the time of contact part. In the case of three-phase tests the symmetry requirement is applicable only to one of the phases. For convenience in testing it is permissible to perform three C - O operations or a complete duty cycle O - t - CO - t' - CO instead of the O operations.

These tests demonstrate the capability of the circuit breaker for switching low magnitudes of symmetrical short-circuit currents. The circuit TRV used in test duties 1, 2, and 3 shall be in accordance with the related capability envelope given in IEEE Std C37.04-1999 and modified in accordance with the corresponding TRV multipliers given in ANSI C37.06-1997 or ANSI C37.06.1-1997.

one word, not two

4.8.3.2 Test duty 4

Test duty 4 in Table 1 demonstrates the standard operating duty and/or the re closing duty cycle at rated short-circuit capability by interrupting a symmetrical current I of the rated value with a power frequency recovery voltage associated with the rated maximum voltage and with a circuit TRV defined by the rated or adjusted exponential-cosine envelope for circuit breakers rated above 100 kV, or by the rated or adjusted, one minus-cosine envelope for circuit breakers rated 100 kV and below.

For these tests the current must be symmetrical (< 20% dc) at the time of contact part for all three opening operations. This requirement can be met by delaying the opening, which follows the close operation.

In the event that operating test duty 4 can not be performed as shown, due to limitations of the test laboratory, the alternate methods 4a and 4b may be applied.

Refer to 4.8.1.4 for specific requirements for demonstrating the most severe switching conditions.

4.8.3.3 Test duty 5

Test duty 5 in Table 1 consists of three asymmetrical opening operations made not more than 15 min apart. The required degree of asymmetry shall be determined in accordance with Figure 1 and where the elapsed time from fault initiation shall be equal to 1/2 cycle of rated power frequency plus the actual measured opening time of the circuit breaker with maximum control voltage.

The required dc component must be attained at the time of contact separation in one phase during one of the interruptions.

Refer to 4.8.1.4 for specific requirements for demonstrating the most severe switching conditions.

4.8.3.4 Test duties 6 and 7

Test duties 6 and 7 in Table 1 are single-phase tests made at 58% of the maximum rated voltage. These tests are intended to demonstrate the capabilities of the circuit breaker for interrupting a single phase-to-ground fault under the most severe switching condition for the circuit breaker.

Test duty 6 is performed with a symmetrical current equal to the maximum rated symmetrical rms current and with a maximum arcing time as indicated in 4.8.1.4.1.

Test duty 7 is made with an asymmetrical current having a dc component, which is determined as described in 4.8.1.3, and a maximum arcing time corresponding to those specified in 4.8.1.4.2.

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c) The opening time of the circuit breaker shall not exceed 110% of the corresponding initial value measured before the test.

4.8.5.6 Voltage withstand tests

The tests described below shall be performed after completion of short-circuit current interruption tests.

a) For circuit breakers rated below 72.5 kV:

   A one-minute power frequency withstand tests at 80% of the original rated withstand value.

b) For circuit breakers rated 72.5 kV and above, but below 362 kV:

   A withstand test applying a test voltage having a peak value equal to 80% of the product of $\sqrt{2}$ times the rated power frequency withstand voltage. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

c) For circuit breakers rated 362 kV and above:

   An impulse voltage test with a peak voltage equal to 90% of the rated switching impulse withstand voltage. The waveform for this test shall be the same as that used for switching impulse tests.

The IEC 60056-1987 test method outlined below can be used as an alternate demonstration of capability.

a) For circuit breakers rated 72.5 kV and below:

   A one-minute power frequency withstand test at 80% of the original rated withstand value.

b) For circuit breakers rated above 72.5 kV, and up to 245 kV:

   An impulse voltage test with a peak voltage equal to 60% of the corresponding rated lighting impulse. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

lightning

c) For circuit breakers rated above 300 kV and up to 420 kV:

   An impulse voltage test with a peak voltage equal to 80% of the corresponding rated switching impulse. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

d) For circuit breakers rated 550 kV and up to 800 kV:

   An impulse voltage test with a peak voltage equal to 90% of the corresponding rated switching impulse. The waveform shall be similar to that of the applicable rated TRV as used in test duty 1 of Table 1.

4.8.6 Suggested short-circuit current interruption performance data form

Test data is preferably presented in a form with an accompanying tabulation of pertinent data similar to that shown in Annex A.

4.9 Load current

4.9.1 Load current switching test conditions

Load current switching tests shall be made under the following conditions to demonstrate the capability of the circuit breaker to switch load currents such as may be encountered in normal service:

a) The test current levels shall be at:

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4.10.3 Testing conditions

4.10.3.1 Power factor

For capacitance current switching tests, the power factor of the testing circuit shall not exceed 0.15 leading.

4.10.3.2 Frequency of test circuit

±

Tests demonstrating capacitance current switching capabilities of circuit breakers are to be made at the rated power frequency of 60 Hz ± 5%. If tests are made outside this frequency range (for example, 50 Hz), the instantaneous recovery voltage across the current interrupting contacts of the circuit breaker, during the first 8.33 ms shall not be less than that which would occur for a 60 Hz test.

4.10.3.3 Recovery voltage

In the switching of capacitance currents, because of the charge that is trapped on the capacitive load, the recovery voltage across the circuit breaker contacts of the first phase to interrupt starts from a very low value at current interruption (determined by the system regulation when the capacitive load is removed) and then, following the fundamental frequency, increases to a value that can reach a peak value approximately between 2 E_{max} and 3 E_{max} (phase) at a time 1/2 cycle after current interruption. The actual value that the recovery voltage can attain is determined by the system and shunt capacitor bank grounding, the system regulation when the capacitive load is removed, transmission line or cable configuration or construction, whether the current is interrupted at a natural current zero (that is, not chopped), or the sequence of interruption in the second or third phases. For several typical types of capacitive loads that a circuit breaker may have to switch, the approximate maximum peak recovery voltage that can appear across the contacts of the first phase to interrupt 1/2 cycle after interruption may reach the following values:

Type of capacitive circuit	Times E_{max} phase-to-ground
Grounded shunt capacitor bank on grounded system	2
Unloaded cables (with individual ground sheaths)	2
Unloaded transmission line ($C_1 = 2\ C_0$)	2.4
Shunt capacitor bank when either bank or system, or both, is ungrounded:	
1) If second and third phases interrupt at next natural current zero	2.5
2) If second and third phases do not interrupt at next current zero	3

In general, the phenomena occurring in the switching of a grounded shunt capacitor bank or an unloaded cable on a grounded system is simply as would occur in three single-phase circuits. In the case of the unloaded transmission line, part of the capacitance is grounded and part is ungrounded, and in the ungrounded shunt capacitor bank all the capacitive load is ungrounded. Through the coupling between phases, recovery voltages greater than 2 E_{max} (phase) are produced across the contacts. In some cases, even higher recovery voltages are possible, generally resulting from wide variations in primary arcing contact parting between phases or one phase remaining connected to the system.

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These recovery voltages will be slightly lower under field conditions due to the regulation occurring when the capacitance is switched off. The system voltage regulation, or voltage change, when the capacitive load is switched, is equal to:

$$\text{Percent voltage change} = \frac{\text{kvar}_0}{\text{kVA}_0 - \text{kvar}_0} \times 100\% \qquad (13)$$

where

kVA_0 = symmetrical three-phase short circuit kVA at the point of the capacitive load; and
kvar_0 = nominal three-phase kvar determined from open circuit voltage (same as used for kVA_0) and the capacitance of the load.

In most short-circuit test laboratories, this voltage change may be considerably larger because of lower available kVA_0 than on a system, for a given amount of capacitive load.

In recognition of this generally larger voltage change during laboratory capacitance current switching tests and the variation in recovery voltage conditions depending on the type of capacitive load and grounding, factors are specified in 4.10.4 that define test voltages for three-phase and single-phase laboratory tests. Based on these factors, the recovery voltages across the circuit breaker contacts 1/2 cycle after interruption will be equivalent to those obtained under actual system conditions.

4.10.4 Test voltage

4.10.4.1 Test voltage, three-phase tests

If three-phase laboratory tests are made to demonstrate the capacitance current switching rating of a circuit breaker, the capacitive load shall be connected with its neutral either grounded or ungrounded, as required for the type of test being conducted, or for simulation of unloaded transmission lines, one-half of the total capacitive load shall be ungrounded and one-half shall be grounded. The neutral of the source may be grounded. In order to obtain a recovery voltage across the circuit breaker contacts that is equivalent to the voltage that occurs in a system operating at rated maximum voltage and having negligible voltage change when the capacitive load is removed, it may be necessary to have an open circuit test voltage that is less than rated maximum voltage depending on regulation of the laboratory circuit.

The open circuit test voltage E_o is determined as follows:

$$EC = A(E_o) \qquad (14)$$

where

$$A = \frac{I_{sc}}{I_{sc} - I_c}$$

and

E_c = closed circuit line-to-line voltage,
E_o = open circuit line-to-line voltage,
I_{sc} = available short-circuit current, and
I_c = rms capacitance current.

change EC to E_c to match

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The nominal recovery voltage across the circuit breaker 1/2 cycle after current interruption will be proportional to the peak value of:

$$\frac{E_o + E_c}{2} = \frac{E_o + AE_o}{2} = \frac{E_o(1 + A)}{2} \tag{15}$$

Therefore, the proper open circuit line-to-line test voltage, E_o, to result in a recovery voltage proportional to rated maximum voltage, V, in a system where A is very close to 1.0 may be determined by:

$$E_o \frac{(1 + A)}{2} = V \tag{16}$$

$$E_o = V\left(\frac{2}{1 + A}\right)$$

4.10.4.2 Test voltage, single-phase tests

By proper choice of test voltage to produce recovery voltages equivalent to those occurring in three-phase tests, single-phase tests may be made to demonstrate the capacitance current switching ratings of circuit breakers. Because of the phenomena occurring in three-phase capacitance current switching operations described in 4.10.3.3, a factor, B, must be considered in choosing open circuit test voltage E_{o1} for single-phase tests, in addition to the factor *A* described in 4.10.4.1.

For grounded shunt capacitor bank or cable charging current switching tests on a three-phase basis:

$B = 1.0$

For ungrounded shunt capacitor bank current switching tests on a three-phase basis:

$B = 1.5$

For overhead line charging current switching tests on a three-phase basis:

$(C_1 = 2\,C_0)$, $B = 1.2$

Therefore, the open circuit phase-to-ground test voltage for single-phase tests is:

$$E_{o1} = 0.58\, V\left(\frac{2}{1 + A}\right) B \tag{17}$$

where

$$A = \frac{I_{sc}}{I_{sc} - I_c}$$

and

I_{sc} and I_c = single-phase values of available short-circuit current and capacitance current.

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NOTE—The methods described in 4.10.4.1 and 4.10.4.2 for the determination of laboratory test voltage are approximate because of the dependence of the prospective short-circuit current and, therefore, A, on the open circuit voltage. These methods, however, can be used to define conditions for reasonable test recovery voltages, particularly where laboratory short-circuit current is not large.

4.10.5 Control voltage and mechanism operating pressure

Rated values of control voltage and rated pressure for mechanical operation shall be maintained for the closing and tripping circuits.

4.10.6 Interrupter pressure

Circuit breakers that depend on external energy or pressure to drive an interrupting gas or fluid and that have a minimum permissible pressure specified, shall be capable of performing at minimum permissible pressure as specified in Table 3 and Table 4 2 3.

4.10.7 Contact speeds during single-pole and unit interrupter tests

During single-pole and unit interrupter tests, the closing and opening speeds of the contacts through the arcing zone shall be no greater than during a corresponding test on a complete circuit breaker.

4.10.8 Grounding on the circuit breaker and test circuit

The normally grounded parts of the circuit breaker shall be grounded.

During three-phase tests, the neutral of the source circuit may be grounded.

The neutral of the capacitive load shall be grounded or ungrounded as specified IEEE Std C37.04-1999, depending on the type of capacitance current switching test being made.

During single-phase tests, the test circuit may be grounded.

When single-phase tests are made on a circuit breaker with the three poles in one tank, the other poles shall be grounded.

4.10.9 Reversal of test connections

On circuit breakers that have unsymmetrical insulation paths, the connections to the source and to the capacitive load shall be reversed for half of the 100% capacitance current switching tests listed in Table 3 and Table 4 3 2.

4.10.10 Obtaining the most severe switching conditions

In capacitance current switching operations, the voltage regulation is small when the capacitance current is interrupted (that is, A is very close to 1.0, as would generally prevail on a system), the current is usually interrupted at the first or second current zero after contact separation. In circuit breakers that have a contact gap or arc path that increases in a generally linear relation to time, for example oil circuit breakers, the recovery voltage stress will be imposed on a relatively short contact gap. In a test laboratory where the voltage change at current interruption is larger, the final interruption may be delayed, allowing a larger contact gap at the time of the maximum recovery voltage than would occur on a system. In testing, it is desirable to duplicate system conditions in this respect as closely as possible. One method of increasing the probability of interruption at the first or second current zero after contact separation is by the addition of capacitance to the source side of the test circuit breaker to reduce the natural frequency, and thereby the rate-of-change of

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to cantilever stress in a circuit breaker application, a representative of each porcelain element, after all glazing, firing, and grinding operations are completed, shall withstand for five minutes a total stress equivalent to the end plate loading from maximum allowable working pressure plus three times the maximum rated cantilever stress.

Where applicable, the maximum rated cantilever stress shall be based on the load on the porcelain element resulting from:

a) The combination of the short-circuit forces internally of the circuit breaker plus rated line pull withstand and a 40 mi/s (90 mi/h) wind velocity withstand; and
b) From the combination of rated line pull withstand and the 0.2 g (static) earthquake shock withstand, whichever is the more severe duty; rated requirements for line pull factors will be available in a future ANSI/IEEE standard.

NOTE—1 Pascal (Pa) = 1.45 x 10^{-4} psi

40 m/s (meters/second)

4.16.2 Pressurized non-ceramic components

4.16.2.1 Non-isolating vessels

Components that neither isolate nor separate high voltage elements of 1000 V or higher shall be tested in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section X, Fiberglass-Reinforced Plastic Pressure Vessels.

4.16.2.2 Isolating vessels

Non-ceramic components that electrically isolate or separate high voltage elements of 1000 V or higher and that are pressurized at a constant pressure (where the pressure typically varies only due to diurnal pressure variations and are minimal compared to the static ambient pressure) shall be tested and meet the requirements described in 4.16.1.

4.16.2.3 External components

External components that electrically isolate or separate high voltage elements of 1000 V or higher and that undergo significant pressure cycling variations due to the operation of the circuit breaker shall be tested as per 4.16.1. Additionally, a design cyclic pressure and burst tests, in accordance with applicable subclauses 4.16.3.1, 4.16.3.2, or 4.16.3.3, shall be performed.

These tests shall be made in a prototype of each design of non-ceramic vessel, insulator, or tube having an internal or external gas pressure exceeding 208 kPa (absolute pressure) (15 psig) and having an inside diameter exceeding 152 mm (6 in), after all coating, curing, and fabrication operations are completed.

Where applicable, the prototype vessel(s) shall be so loaded as to create the magnitude of bending and shear stresses expected to occur under service conditions. The maximum rated cantilever stress shall be based on the load on the plastic element resulting from:

a) The combination of the short-circuit forces internal to the circuit breaker plus the rated line pull withstand and a 40 mi/s (90 mi/h) wind velocity withstand; and
b) From the combination of rated line pull withstand and the 0.2 g (static) earthquake shock withstand, whichever is the more severe duty; rated requirements for line pull factors will be available in a future ANSI/IEEE standard.

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h) Control and secondary wiring check tests
i) Clearance and mechanical adjustment check tests
j) Mechanical operation tests
k) Timing tests
l) Stored energy system tests
m) Conductivity of current path test
n) Power frequency withstand voltage tests on primary insulation components
o) Power frequency withstand voltage tests on control, secondary wiring, and components, to include motors, release coils, etc.
p) For indoor circuit breakers used in enclosures interchangeability test refer to IEEE Std C37.20.2-1993

5.2 Current and linear coupler transformer tests

All current transformers used with high voltage circuit breakers shall be designed in accordance with the ANSI/IEEE standards for transformers (IEEE Std C57.13-1993).

Current and linear coupler transformers shall receive the following tests where applicable:

a) Each transformer shall be checked for presence of correct nameplate, terminal, and polarity markings.
b) Each transformer shall be checked electrically to ensure proper direction of winding to give the correct polarity.
c) Each transformer shall be given sufficient tests to ensure that the electrical and magnetic properties are within the necessary limits to meet the ratio and accuracy classification requirements.
    1) Relaying transformers shall receive ratio or mutual reactance tests to ensure proper turn ratios. Multi-ratio transformers are given sufficient ratio tests to ensure the correctness of the winding for each tap section. For bushing current transformers, two check points on the excitation curve may be made to ensure that the unit meets its relaying accuracy classification.
    2) Metering transformers shall receive ratio and phase angle tests at 10% and 100% rated primary current at one burden to ensure that the unit meets its metering accuracy classification.
d) After installation in the circuit breaker, each transformer shall be given a 1 min power frequency withstand test of 2500 V between the shorted secondary winding (including leads) and ground (see also 5.16). In addition, each unit will receive a polarity and ratio check to ensure correct installation in the circuit breaker. 5.17

5.3 High-voltage circuit breaker bushings tests

High-voltage circuit breaker bushings for outdoor circuit breakers shall be tested in accordance with IEEE Std C57.19.00-1991.

5.4 Gas receiver tests

5.4.1 Metal vessels

All metal vessels, except those having an internal or external operating gas pressure not exceeding 208 kPa (absolute pressure) (15 psig) (with no limitation on size) or those having an inside diameter not exceeding 150 mm (6 in), (with no limitation on pressure), shall be tested in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels, and any state and local codes that apply at the point of original installation.

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5.16 Power-frequency withstand voltage tests on major insulation components

Power-frequency withstand voltage tests shall be made for one minute either on completely assembled circuit breakers at the voltages and conditions specified in 4.4.3.1 or on major insulation components, such as bushings, insulation braces, and operating rods.

5.17 Power-frequency withstand voltage tests on control and secondary wiring

All control wiring associated with current and linear coupler transformer secondaries and potential device secondaries shall receive a power-frequency withstand test of 2500 V for one minute. All other control wiring shall receive a power-frequency withstand test of 1500 V for one minute or 1800 V for one second.

If the circuit breaker control circuit includes a motor, the motor may be disconnected during the dielectric test on the control circuit and subsequently tested, in place, at its specified dielectric withstand voltage but at not less than 900 V.

6. Conformance test

lightning

6.1 Outdoor circuit breakers

6.1.1 Method of conducting conformance tests for lighting impulse withstand voltage

When conformance tests are required for lighting impulse voltage, the tests are to be made in accordance with 4.4.4, 4.4.4.1, and 4.4.4.2, with the following exceptions:

lightning

a) The peak voltage value shall not be required to be greater than the rated switching impulse voltage values specified.

b) The time to half-value on the tail of the wave shall not be required to be in excess of 50 μs.

6.1.2 Method of conducting conformance tests for switching impulse withstand voltage

Conformance tests are to be made in accordance with 4.4.7, with the following exceptions:

a) The peak voltage value shall not be required to be greater than the rated switching impulse voltage values specified.

b) The time to half-value on the tail of the wave shall not be required to be in excess of 2500 μs.

6.1.3 Method of conducting conformance tests for line closing switching surge factor on an operating system

A purchaser may perform a field test with the circuit breaker on an actual operating system in order to determine if its test performance conforms to requirements for its rated line closing switching surge factor. The circuit breaker will be considered to have passed its conformance test when the circuit breaker is closed on a random time basis into trapped line charges, if in 20 tests there are no overvoltage factors greater than the rated line closing switching surge factor; or only one such event out of 34 tests; or two out of 48 tests; or three out of 62 tests. Four factors greater than the rated factor, or any factor greater than 1.2 times the rated line closing switching surge factor, represent nonconformance.

If the actual system is not greatly different from the standard reference power system, it is expected that the field test results will not differ significantly from the results obtained from the simulated study used to establish the rated line closing switching surge factor. However, if the circuit breaker fails to meet the above

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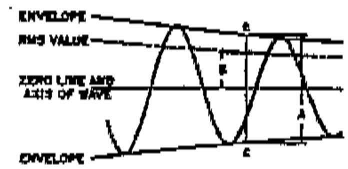
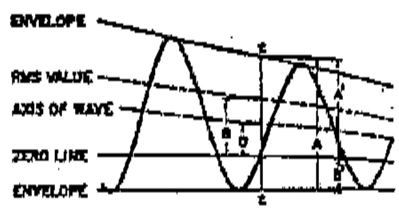


Figure 14—Measurement of the rms value of a symmetrical wave

7.1.4 RMS value of an asymmetrical sinusoidal wave at a particular instant

An asymmetrical sinusoidal wave can be considered to be composed of two components: an alternating current component and a direct current component. The rms value of such a current at a given instant is the square root of the sum of the squares of the dc and ac components of current at the instant the measurement is made (see Figure 15).



t = Instant for which measurement is made
A' = Major ordinate
B' = Minor ordinate
A = Peak-to-peak value of alternating component
= A' + B'
D = Direct component $\frac{A' - B'}{2}$

B = rms value

$$\sqrt{\left(\begin{array}{c}\text{rms value of}\\ \text{alternating component}\end{array}\right)^2 + \left(\begin{array}{c}\text{direct}\\ \text{component}\end{array}\right)^2}$$

$$\sqrt{\left(\frac{A}{2.828}\right)^2 + D^2}$$

Figure 15—Measurement of the rms value of an asymmetrical wave

7.1.4.1 Alternating component

The alternating component has a peak-to-peak value (A) equal to the distance between the upper and lower envelopes of the current, and the axis of the wave is located midway between the envelopes. The peak value of this current is given by:

$$\text{Peak value of alternating component} = \frac{\textit{Major ordinate} + \textit{Minor ordinate}}{2} = \frac{A + B}{2} \quad (18)$$

A′ + B′

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7.1.4.2 Direct component

The amplitude of the direct current component is measured with respect to the displaced axis of the alternating component and is equal to:

$$\frac{\text{Major ordinate} - \text{Minor ordinate}}{2} = \frac{A - B}{2} \quad A' - B' \tag{19}$$

7.1.4.3 Calculation of the rms value of an asymmetrical sinusoidal wave

See Figure 15 for the method of calculation.

7.1.5 Alternate methods of stating the making current

The making current may be stated as either an rms current, measured from the envelope of the current wave at the time of the maximum peak, or as the instantaneous value of the current at the peak. These values are equally significant in the description of asymmetrical making currents, but the units must be clearly stated to avoid confusion. The ratio of the peak value of current to the rms value varies with asymmetry (Table 5) as follows:

The ratio of the peak value to the rms value is 1.69 ±2% if the asymmetry is between 22% and 94% and 1.69 ±3% if the asymmetry is from 20% to 100%. The variation in this ratio is so small that 1.69 can be used without introducing serious error. Currents having 20% or less asymmetry are considered to be symmetrical and should not be used for demonstrating required I making capability.

Table 5—Asymmetrical currents tabulated values

% Asymmetry	Peak value	RMS value	Peak value to rms value
100	2.83	1.73	1.63
90	2.69	1.62	1.66
80	2.55	1.51	1.69
70	2.40	1.41	1.71
60	2.26	1.31	1.73
50	2.12	1.23	1.73
40	1.98	1.15	1.72
30	1.84	1.09	1.69
24	1.75	1.06	1.66
20	1.70	1.04	1.63
10	1.56	1.01	1.54
0	1.41	1.00	1.41

7.1.6 Measurement of the rms value of a current during a short circuit of several cycles duration

The oscillogram shown in Figure 16 represents a record of a short circuit of several cycles duration. Time is shown on the axis 0X and the current values on the 0Y axis. The origin 0 of the coordinates represents the beginning of the short circuit, and 0T represents the duration of the current flowing through the circuit breaker.

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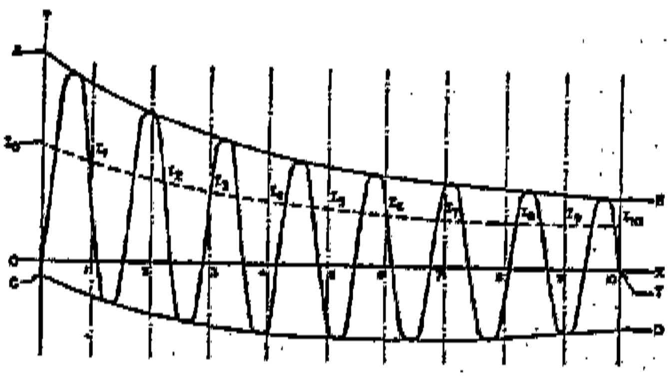

OT = duration of short circuit
AB = upper envelope of current wave
CD = lower envelope of current wave
I_0 - I_{10} = rms value of asymmetrical current at each instant

Figure 16—Determination of the equivalent rms value of a short-time current

The rms value of the current I_{rms} during the time interval 0 to T is given by the following formula:

$$I_{rms} = \sqrt{\frac{1}{T}\int_0^T i^2 dt} \quad (20)$$

where

i = instantaneous value of the current

The equivalent rms value of the current may be determined with sufficient accuracy by the following application of the Simpson's formula:

a) Divide the time interval OT into 10 equal parts
b) For the eleven instants 0 through 10, determine the total rms currents, I_0 through I_{10} (the method described in 7.1.4.3 may be used). The values then are substituted in the formula below:

$$I_{rms} = \sqrt{\frac{1}{30}[I_0^2 + I_{10}^2 + 4(I_1^2 + I_3^2 + I_5^2 + I_7^2 + I_9^2) + 2(I_2^2 + I_4^2 + I_6^2 + I_8^2)]} \quad (21)$$

In using this formula on currents with a dc component that decays to less than 5% of its initial value during the first time interval, it is more accurate to ignore the dc component than to consider it.

In some cases, the duration of a test demonstrating short-circuit current carrying may not be exactly as specified. However, since the heating of the current carrying parts is very nearly proportional to i^2dt, and the time for cooling is short, the rms test current I_A determined by this method is considered to demonstrate the ability of the circuit breaker to carry the specified current I_B, if the duration T_A of the short-circuit current is within 25% of the specified time T_B and if $I_A^2 T_A$ is equal or greater than $I_B^2 T_B$.

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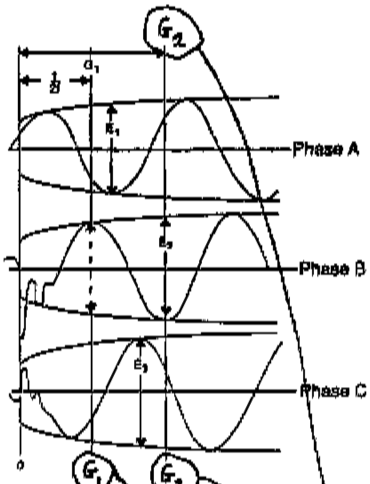
I_A or

7.2 Power-frequency recovery voltage

Power-frequency recovery voltage shall be determined from the envelope of each voltage wave at a point in time coincident with that peak that occurs more than 1/2 cycle and not more than one cycle after final arc extinction in the last phase to clear. The power frequency phase-to-phase recovery voltage for a three-phase short circuit shall be taken as 1.73 times the average of the three values obtained in this manner for the three voltage waves (see Figure 17).



G1G1

Phase A = first to open circuit
00 = instant of final arc extinction

G_1G_1 = instant after interval $\frac{1}{2f}$ from 00

G_2G_2 = instant after interval $\frac{1}{f}$ from 00

$\frac{E_1}{2.828}$ = power frequency recovery voltage, Phase A

$\frac{E_2}{2.828}$ = power frequency recovery voltage, Phase B

$\frac{E_3}{2.828}$ = power frequency recovery voltage, Phase C

Average power frequency pole-unit recovery voltage

$$= \frac{(E_1/2.828 + E_2/2.828 + E_3/2.828)}{3}$$

Power frequency phase-to-phase recovery voltage

$$= \sqrt{3}\begin{pmatrix}\text{Average power frequency}\\ \text{pole-unit recovery voltage}\end{pmatrix}$$

Figure 17—Determination of the power-frequency pole unit recovery voltage

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A.2.3 Rating assigned by manufacturer

a) Voltage (kV)
b) Rated continuous current (A)
c) Rated power frequency (Hz)
d) Short-circuit breaking current:
   1) RMS value of the ac component of current (kA)
   2) Percentage dc component
e) Minimum opening time (ms)
f) TRV:
   1) Peak value (kV)
   2) Rate-of-rise (kV/µs)
g) Short-line fault surge impedance (Ω and amplitude factor)
h) Short-circuit peak making current (kA)
i) Out-of-phase breaking current (kA)
j) Duration of short circuit (s)
k) Operating sequence
l) Line-charging breaking current (A)
m) Cable charging breaking current (A)
n) Capacitor bank breaking (and making) current (A)
o) Small inductive breaking current (A)
p) Supply voltages (V):
   1) Closing device
   2) Opening device
q) Operating gas pressure range (mPa or bars)

MPa (mega pascals), not mPa (milli pascals)

A.2.4 Test conditions for each series of tests

a) Number of poles
b) Power factor
c) Frequency (Hz)
d) Generator neutral (grounded or isolated)
e) Transformer neutral (grounded or isolated)
f) Short-circuit point or load-side neutral (grounded or isolated)
g) Diagram of test circuit including connection(s) to ground

A.2.5 Short-circuit breaking and making tests

a) Operating sequence and time intervals
b) Applied voltage (kV)
c) Making current (peak value) (kA)
d) Breaking current:
   1) RMS value of ac component for each phase and average (kA)
   2) Percentage dc component

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e) Power frequency recovery voltage (kV)
f) Prospective TRV
g) Arcing time (ms)
h) Opening time (ms)
i) Interrupting time (ms)
Where applicable, break times up to the instant of extinction of the main arc and up to the instant of the breaking of resistance current shall be given.
j) Physical behavior:
 1) Emission of flame, gas, oil, etc.; and
 2) Behavior, conditions, and remarks.

A.2.6 Short-time current test

a) Current
 1) RMS value (kA)
 2) Peak value (kA)
b) Duration (s)
c) Physical behavior

A.2.7 No load operation

a) Before making and breaking tests
b) After making and breaking tests

A.2.8 Out-of-phase making and breaking tests

a) Breaking current in each phase (kA)
b) Voltage across each phase (kV)
c) Gas pressure before tests (when applicable) (mPa or bars)
d) Break time (ms)
e) Resistor current in each phase (when applicable) (A)

MPa (megapascals), not mPa (millipascals)

A.2.9 Capacitive current switching tests

a) Test voltage (kV)
b) Breaking current in each phase (A)
c) Peak values of the voltage between each phase and ground (kV):
 1) Supply side of circuit breaker
 2) Load side of circuit breaker
d) Number of restrikes (if any)
e) Number of test operations
f) Details of point-on-wave setting
g) Details of test circuit used
h) Behavior of circuit breaker during test
i) Condition of circuit breaker after test

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Annex B

(Informative)

Test tables from C37.09-1979

Note: In Annex B, unless otherwise indicated, all references to clauses are to those in ANSI/IEEE C37.09-1979.

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C37.04

Introduction

MICHELE TURNER 732-562-3825

(This introduction is not part of IEEE Std C37.04-1999, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.)

In 1964, consolidated standards for circuit breakers rated on a symmetrical current basis were published to take the place of standards established on the total current basis of rating. This 1999 revision was undertaken to update the standard to reflect today's circuit breaker technology and application on modern power systems. The revision also continues harmonization with IEC 60056 Ed. 4.0b: 1987, a process that first began in 1951.

This document makes significant changes in the rating structure for circuit breakers, such as the change of the voltage range factor, K, and the standard duty cycle. With these changes, information needed to properly apply circuit breakers rated in accordance with the 1979 or 1964 editions of IEEE Std C37.04 are eliminated from this new edition. Accordingly, users must refer to the prior editions of the relevant standards (including IEEE Std C37.04-1999, ANSI C37.06, IEEE Std C37.09-1999, etc.) in order to properly select and apply circuit breakers rated in accordance with the older standards.

NOTE—These older standards are part of the IEEE archives. Contact the IEEE Standards Association for ordering information.

The changes in this standard are explained in the following clause-by-clause summary:

1. Scope—The scope was expanded to clarify the type of circuit breakers specifically covered by this standard.
2. References—A complete updated listing of references is supplied.
3. Definitions—No substantial changes.
4. Service conditions—The usual and unusual service conditions are given. Information given on how to deal with unusual service conditions has been moved to IEEE Std C37.010-1999.
5. Ratings—The rated voltage range factor, K, defined in earlier versions of IEEE Std C37.04 is commonly recognized as being equal to 1.0 for modern interrupting technologies; consequently, the rating structure has been simplified, because the use of a K factor of 1.0 has effectively eliminated K from the rating structure. The rated permissible tripping delay, Y, has been incorporated in the rated closing, latching, and short-time current carrying capability (5.8.2.3).

   5.1 Rated maximum voltage—No major changes.

   5.2 Rated power frequency—No major changes.

   5.3 Rated continuous current—Changes were made to Table 1 (Limits of temperature and temperature rise for various parts and materials of circuit breakers). This table has been brought into better harmony with IEC.

   5.4 Rated dielectric withstand capability—Changes clarify basic dielectric requirements.

   5.5 Rated standard operating duty (standard duty cycle)—Changed and expanded to include circuit breakers for rapid reclosing and to coordinate with IEC.

   5.6 Rated interrupting time—The definition was clarified and updated for modern circuit breaker performance.

   5.7 Contact parting time—This definition was modified to alert users of high-voltage circuit breakers that it may be necessary to add external delay to account for fault deionization times on power systems.

   MINIMUM RECLOSING TIME

   5.8 Rated short-circuit current and related required capabilities

   5.8.1 Rated short-circuit current—No major changes.

   5.8.2 Related required capabilities—The required asymmetrical interrupting capability for three-phase faults (5.8.2.2) defines the percent dc component based on the standard time constant of 45 ms (corresponding to an X/R of 17 for 60 Hz or 14 for 50 Hz). This

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3. Definitions

The terms and definitions applicable to this standard and to the related standards for ac high-voltage circuit breakers shall be in accordance with IEEE Std C37.100-1992. These definitions are not intended to embrace all possible meanings of the terms. They are intended solely to establish the meanings of terms used in power switchgear.

4. Service conditions

4.1 Usual service conditions

Circuit breakers conforming to this standard shall be suitable for operating at their standard ratings

a) Where the temperature of the ambient is not above 40 °C or below –30 °C;

b) Where the altitude is not above 1000 m;

c) Where the effect of solar radiation is not significant (the principles stated in IEEE Std C37.24-1986 may be used for guidance);

d) Where the seismic conditions do not exceed those defined in 6.3.1.3; and

e) Where unusual conditions as listed in IEEE Std C37.010-1999 do not exist.

4.2 Unusual service conditions

Unusual service conditions are listed in IEEE Std C37.010-1999. Such conditions should be brought to the attention of those responsible for the application, manufacture, and operation of the equipment, and the guidelines for application given in IEEE Std C37.010-1999 should be followed.

5. Ratings

The rating of a circuit breaker is a designated limit of operating characteristics that is based upon usual service conditions as specified in 4.1. The rating of a circuit breaker shall include the following parameters (for values of preferred ratings of circuit breakers, see ANSI C37.06-1997):

a) ~~For operation (5.17);~~

b) Out-of-phase switching current (5.12), rated maximum voltage (5.1);

c) Rated power frequency (5.2);

d) Rated continuous current (5.3);

e) Rated dielectric withstand capability (5.4);

f) Rated standard operating duty (standard duty cycle) (5.5);

g) Rated interrupting time (5.6);

h) Rated short-circuit current (5.8);

i) Rated transient recovery voltage (TRV) (5.9);

j) Rated capacitance current switching (5.11)
(NOTE—Definite purpose is an optional rating.);

k) Rated control voltage (5.15);

l) Rated operating pressure for insulation and/or interruption (5.16);

m) Rated operating pressure for mechanical operation (5.17);

Out-of-phase switching current capability (5.12) (out-of-phase switching current is an optional rating that may be assigned where applicable).

Rated

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NOTES TO TABLE 1

1—According to its function, the same part may belong to several categories as listed Table 1. In this case, the permissible maximum values of total temperature and temperature rise to be considered are the lowest among the relevant categories.

2—For sealed interrupters, the values of total temperature and temperature-rise limits are not applicable for parts inside the sealed interrupter. The remaining parts shall not exceed the values of temperature and temperature rise given in Table 1.

3—The temperatures of conductors between contacts and connections are not covered in Table 1, as long as the temperature at the point of contact between conductors and insulation does not exceed the limits established for the insulating material.

4—The classes of insulating materials are those given in IEC 60694 Ed. 2.0b: 1996.

60°C

5—The top oil (upper layer) temperature shall not exceed 40 °C rise or 80 °C total. The 5 °C and 90 °C values refer to the hottest spot temperature of parts in contact with oil.

6—When contact parts have different coatings, the permissible temperatures and temperature rises shall be those of the part having the lower value permitted in Table 1.

7—The quality of the coated contacts shall be such that a layer of coating material remains at the contact area

a) After making and breaking tests (if any);

b) After short-time withstand current tests;

c) After the mechanical endurance test; according to the relevant specifications for each piece of equipment. Otherwise, the contacts shall be regarded as "bare."

8—When connection parts have different coatings, the permissible temperatures and temperature rises shall be those of the part having the lower value permitted in Table 1.

9—When materials other than those given in Table 1 are used, their properties shall be considered in order to determine the maximum permissible temperature rises.

10—The values of temperature and temperature rise are valid even if the conductor to the terminals is bare.

11—The temperature shall not reach a value where the temper of the material is impaired.

12—For indoor circuit breakers used on switchgear assemblies, the temperature limits given in IEEE Std C37.20.2-1993 shall not be exceeded.

5.3.2.2 Limitations on main contacts

The temperature of the main contacts used in circuit breakers shall not exceed the values listed in Table 1.

5.3.2.3 Limitations on connections

a) The temperature of connections in the main power circuit of a circuit breaker shall not exceed the values listed in Table 1.

b) Terminals of circuit breakers designed for direct cable connection shall not exceed 45 °C rise or 85 °C hottest spot total temperature when connected to an 85 °C maximum insulated cable, rated for the full continuous current rating of the circuit breaker.

c) Connections of indoor circuit breakers to switchgear assemblies shall conform only to the thermal requirements given in IEEE Std C37.20.2-1993.

5.3.2.4 Limitations for parts subject to contact by personnel

Circuit breaker parts handled by the operator in the normal course of duty shall have no higher total temperature than 50 °C. Circuit breakers having external surfaces accessible to an operator in the normal course of duty shall have no higher total temperature on the surfaces than 70 °C.

5.3.2.5 Limitations on materials

Materials shall be chosen so that the maximum temperatures to which they may be subjected shall not cause accelerated deterioration over the life of the circuit breaker.

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5.6 Rated interrupting time

The rated interrupting time of a circuit breaker is the maximum permissible interval between the energizing of the trip circuit at rated control voltage and rated operating pressure for mechanical operation, and the interruption of the current in the main circuit in all poles. The interrupting time for a close-open operation shall not exceed the rated interrupting time by more than 1 cycle of rated power frequency for circuit breakers with interrupting times of 5 cycles or more, and 1/2 cycle for circuit breakers with interrupting times of 3 cycles or less. (Cycles are based on corresponding rated power frequency.)

5.7 Contact parting time

The arcing contact parting time shall be considered equal to the sum of 1/2 cycle (practical minimum relay time) plus the minimum opening time of the particular circuit breaker specified by the manufacturer (see IEEE Std C37.010-1999).

5.8 Rated short-circuit current and related required capabilities

The short-circuit current rating of a circuit breaker is the symmetrical component of short-circuit current in rms amperes (5.8.1) to which all required short-circuit capabilities are related. All values apply to both grounded and ungrounded short-circuits on predominantly inductive three-phase circuits, with rated power frequency and phase-to-phase recovery voltage equal to the rated maximum voltage.

5.8.1 Rated short-circuit current

The rated short-circuit current of a circuit breaker is the highest value of the symmetrical component of the three-phase, short-circuit current in rms amperes measured from the envelope of the current wave at the instant of primary arcing contact separation that the circuit breaker shall be required to interrupt at rated maximum voltage and on the standard operating duty. It also establishes, by fixed ratios as defined in 5.8.2, the highest currents that the circuit breaker shall be required to close and latch against, to carry, and to interrupt. For numerical values of rated short-circuit current, refer to the tables of preferred ratings in ANSI C37.06-1997.

5.8.2 Required related capabilities

The circuit breaker shall have the required related capabilities described in 5.8.2.1 through 5.8.2.5.

5.8.2.1 Required symmetrical interrupting capability for three-phase faults

For three-phase faults, the required symmetrical interrupting capability of a circuit breaker is the value of the symmetrical component of the short-circuit current in rms amperes at the instant of arcing contact separation that the circuit breaker shall be required to interrupt at a specified operating voltage, on the standard operating duty cycle, and with a direct current component of less than 20% of the current value of the symmetrical component.

peak

5.8.2.2 Required asymmetrical interrupting capability for three-phase faults

The required asymmetrical current interrupting capability of a circuit breaker is the value of the total rms short-circuit current (I_t) at the instant of the arcing contact separation that the circuit breaker shall be required to interrupt at a specified operating voltage and on the standard operating duty cycle.

The required percent value of the dc component is based on a standard time constant of 45 ms (corresponding to X/R values of 17 and 14 for 60 Hz and 50 Hz, respectively) and an assumed relay time of 1/2 cycle, as

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illustrated in Figure 1. The elapsed time shown in Figure 1 is equal to the sum of 1/2 cycle of relay time (on the basis of the applicable rated power frequency) plus the contact opening time of the circuit breaker.

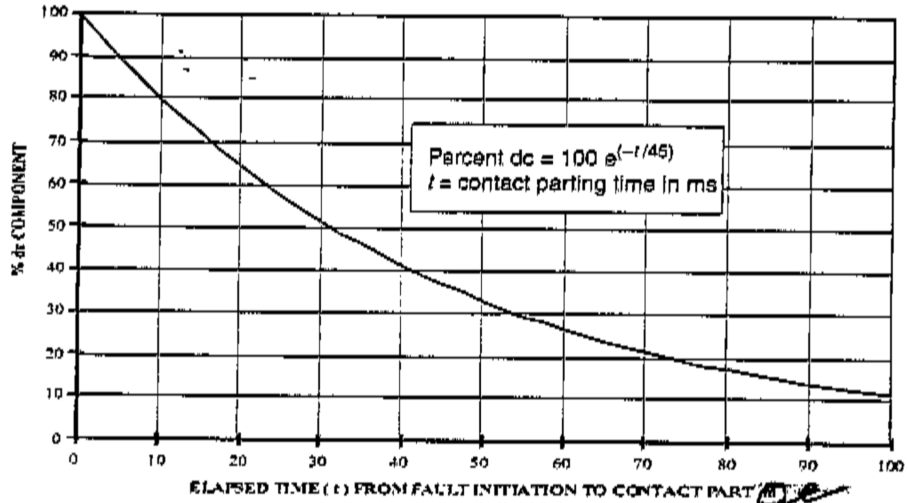

Figure 1—Percent dc component of asymmetric current as a function of contact parting time

The required asymmetrical current interrupting capability shall be determined from the rated value of the symmetrical and the direct current component of the current, expressed as a percentage of the peak value of the symmetrical current, I_{sym}, in accordance with the following formula:

$$I_t = I_{sym}\sqrt{1 + 2\left(\frac{\%dc}{100}\right)^2} \quad (2)$$

NOTE—For time constants greater than 45 ms, see IEEE Std C37.09-1999 and IEEE Std C37.010-1999.

5.8.2.3 Rated closing, latching, and short-time current carrying capability

The circuit breaker shall be capable of the following:

a) Closing and latching any power frequency making current whose maximum peak (peak making current) is equal to or less than 2.6 for 60 Hz power rated frequency or 2.5 for 50 Hz power rated frequency times the rated short-circuit current; and

b) Carrying a short-circuit current (short-time current), I, for a period of time as specified in ANSI C37.06-1997 under the list of preferred ratings. These time durations establish the maximum permissible tripping time delay, Y, for each circuit breaker group.

5.8.2.4 Required reclosing capability

Derating factors for interrupting capacity for reclosing duty cycles other than the standard operating duty can be determined, when required, using the method contained in IEEE Std C37.010-1999.

5.8.2.5 Service capability duty requirements

The circuit breaker shall be capable of the following interrupting performance:

The rated time to peak of the 1-cosine wave, E_2, varies with circuit breaker rated voltage, as given in ANSI C37.06-1997 and ANSI C37.06.1-1997.

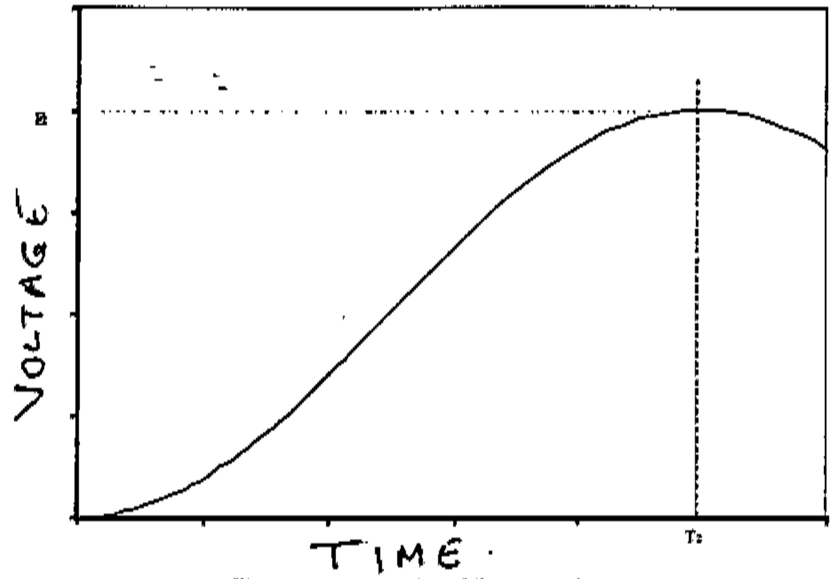

Figure 2—1-cosine TRV waveform

5.9.1.2 Circuit breakers rated 100 kV and above

For circuit breakers rated 100 kV and above, the rated TRV waveshape is defined by the higher of an exponential waveform and a 1-cosine waveform, as shown in Figure 3. The magnitude of the exponential component, E_1, is

$$E_1 = K_f \times \left(\frac{\sqrt{2}}{\sqrt{3}}\right) \times V \tag{5}$$

where

K_f = first pole-to-clear factor = 1.3;

or

$E_1 = 1.06 \times V.$

Since most, if not all, systems operating at 100 kV and above are effectively grounded, a first pole-to-clear factor of 1.3 is required.

The rate of rise of the exponential component, R, has been established as 2 kV/μs, as shown in ANSI C37.06-1997.

The rated magnitude of the exponential cosine component, E_2, in ANSI C37.06-1997 is

$$E_2 = K_a \times K_f \times \left(\frac{\sqrt{2}}{\sqrt{3}}\right) \times V$$

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$$E_2 = 1.4 \times 1.3 \times \left(\frac{\sqrt{2}}{\sqrt{3}}\right) \times V = 1.49 \times V \quad (6)$$

NOTE—A transient amplitude factor of 1.4 is used for circuit breakers rated 100 kV and above, instead of the 1.54 value used for circuit breakers rated below 100 kV.

The rated times to peak of the 1-cosine component, T_2, vary with circuit breaker rated voltage, as given in ANSI C37.06-1997.

Figure 3 shows a slight delay, T_1, in the initial build-up of the TRV wave. This delay is due to the capacitance of the circuit breaker, faulted bus, and any other connected equipment. The rated values of T_1 are shown in ANSI C37.06-1997 and ANSI C37.06.1-1997. T_1 does not apply to circuit breakers rated below 100 kV.

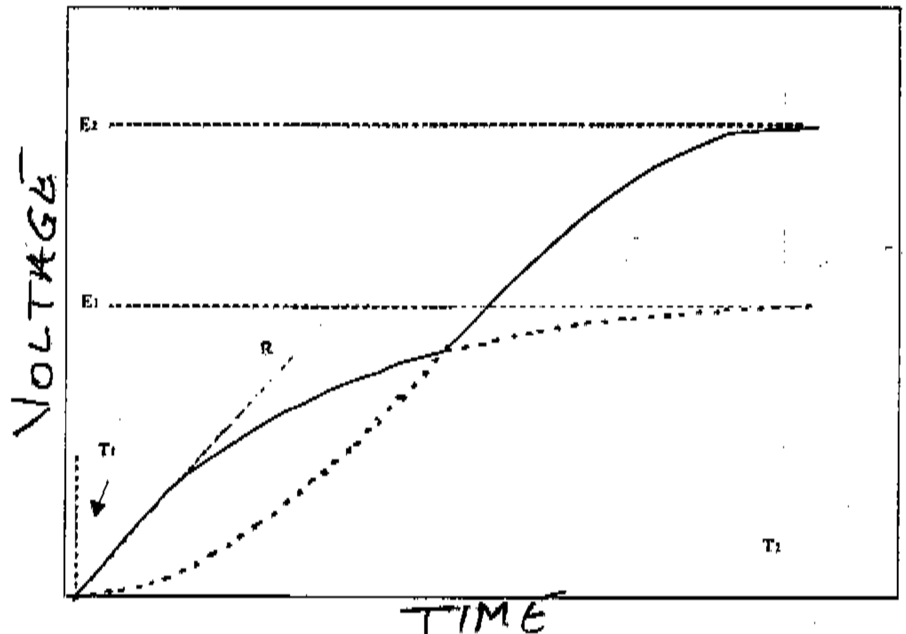

Figure 3—Exponential-cosine TRV waveform

The rated TRV parameters are summarized in Table 2 and are further described in IEEE Std C37.011-1994.

Table 2—Rated TRV parameters

Breaker rating	Envelope	E_2	T_2	R	E_1	T_1
Below 100 kV	1-cos Figure 2	1.88 × V	See ANSI C37.06-1997	NA	NA	NA
100 kV and above	Exp-cos Figure 3	1.49 × V	See ANSI C37.06-1997	See ANSI C37.06-1997	1.06 × V	See ANSI C37.06-1997

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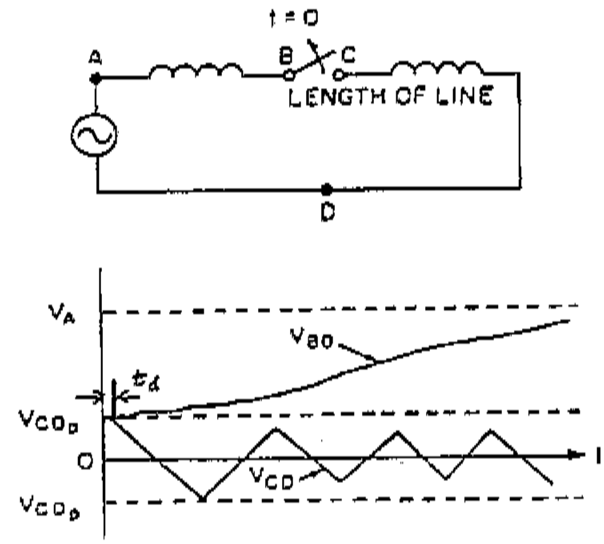
The TRV for this shortline fault is illustrated in Figure 6. The voltage, V_{BD}, represents the source side transient which, for purposes of this illustration, is indicated as an exponential-cosine with a time delay, t_{dL}, starting at an initial voltage of V_{CDo}.

Figure 6 shows that there is a time delay of the lineside recovery voltage as a result of the capacitance of apparatus on the lineside.



$$d = \frac{(V_{CD_o} - V_{CD_p})}{V_{CD_o}}$$ = amplitude constant

Figure 6—Shortline fault terminology

5.9.2.3 Initial TRV

Circuit breakers rated 100 kV and above, with rated short-circuit currents of 31.5 kA and above, shall have an initial TRV capability for phase-to-ground faults as defined by the envelope shown in Figure 7.

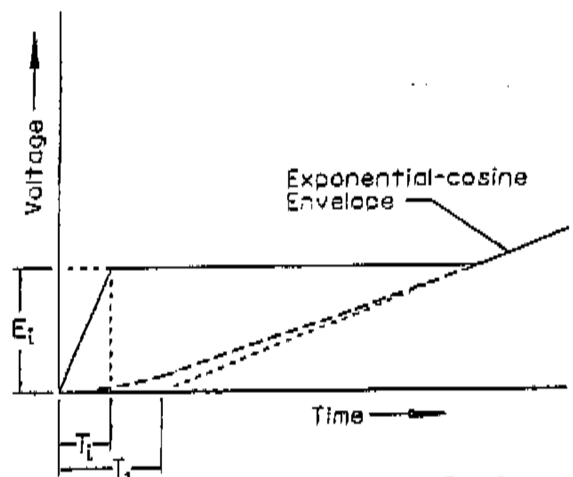


Figure 7—Initial TRV Envelope

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The initial TRV envelope rises linearly from the origin to the first peak voltage, E_i, at time T_i (see Table 3). The first peak voltage and the time to the first peak voltage are determined by the fault current, bus surge impedance, bus wave velocity, and the distance from the circuit breaker to the first major discontinuity of bus surge impedance.

NOTE—As an example, the first major discontinuity of bus surge impedance may be a lumped capacitance of 1000 pF or more connected to the bus or a reduction of the bus surge impedance (i.e., the interconnection of two or more buses or lines). The apparent wave velocity is approximately 280 m/µs for outdoor substations.

The times to first peak voltage, T_i, for phase-to-ground faults are given in Table 3.

Table 3—Time to first peak of initial TRV

Rated maximum voltage (kV rms)	Time to first peak voltage (T_i µs)
123	0.3
145	0.4
170	0.5
245	0.6
362	0.8
550	1.0
800	1.1

The first peak voltage, E_i, is

$$E_i = \omega \times \sqrt{2} \times I \times Z_b \times T_i \times 10^{-6} (\text{kV}) \qquad (7)$$

where

Z_b (the bus surge impedance) = 450 Ω (outdoor substations, phase-to-ground faults only); 260 Ω
T_i is in microseconds;
I is in kA;
$\omega = 2\pi f$ (see IEEE Std C37.09-1999).

For breakers installed in gas-insulated substations, the initial TRV can be neglected because of low bus surge impedance and small distances to the first major discontinuity.

5.10 Rated operating endurance capabilities

The rated operating endurance capabilities specified in ANSI C37.06-1997 are the types and numbers of complete closing-opening operations that the circuit breaker shall be capable of performing. The frequency of user operation shall not exceed 20 in 10 min or 30 in 1 h.

5.11 Rated capacitance current switching

NOTE—Requirements for capacitance switching are currently under review by a joint IEEE/IEC Working Group.

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2 times the rated maximum voltage divided by $\sqrt{3}$ for grounded systems, and 2.5 times the rated maximum voltage divided by $\sqrt{3}$ for ungrounded systems (see IEEE Std C37.09-1999). If a circuit breaker has an assigned out-of-phase switching current rating, the preferred rating shall be 25% of the rated (symmetrical) short-circuit current expressed in kA, unless otherwise specified.

5.12.2 Interrupting time for out-of-phase switching

The interrupting time for out-of-phase switching is permitted to exceed the rated interrupting time by

a) 50% for five or more cycle circuit breakers;
b) One cycle for three or fewer cycle circuit breakers.

5.13 Shunt reactor current switching capability

This applies to circuit breakers intended for switching shunt reactors. Since shunt reactor switching is required for only certain circuit breaker applications, it is not included as a standard rating for general purpose circuit breakers.

IEEE Std C37.015-1993 can be used to evaluate the shunt reactor switching application for specific circuit breakers.

5.14 Rated line closing switching surge factor

The rated line closing switching surge factor is the rated value assigned to a circuit breaker rated 362 kV and above (rated maximum voltage), which has been specifically designed to control the line closing switching surge maximum voltage. The rating establishes that the circuit breaker is capable of controlling line closing switching surge voltages with a 98% probability of not exceeding the rated factor when switching the standard reference transmission line from the standard reference power source. Furthermore, all of the line closing switching surge factors shall remain below 1.2 times the rated line closing switching surge factor when switching the standard reference line with the standard reference source (see ANSI C37.06-1997, IEEE Std C37.09-1999, and IEEE Std C37.010-1999.)

5.15 Rated control voltage

8

The rated control voltage of a circuit breaker is the designated voltage as specified by Table 9 of ANSI C37.06-1997. The transient voltage in the entire control circuit, due to the interruption of the control current, shall be limited to 1500 V, peak.

5.16 Rated operating pressure for insulation and/or interruption (P_{re})

The pressure in Pascals (Pa), for insulation and/or for interruption, refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, to which the assembly is filled before being put into service or automatically replenished.

NOTE—1 Pa = 1.45×10^{-4} psia

5.16.1 Alarm pressure for insulation and/or interruption

The pressure in Pascals, for insulation and/or for interruption, refers to the standard atmospheric air conditions of +20 °C and 101.3 kPa (absolute) (or density), which may be expressed in relative or absolute terms, at which a monitoring signal may be provided to indicate that replenishment is necessary.

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6.7.3 Power-operated mechanism

The mechanism shall be trip-free and have an anti-pump feature (for definitions, see 6.9 and IEEE Std C37.100-1992).

6.7.4 Shunt release (trip) device with necessary control auxiliary switches

A shunt release coil with necessary control auxiliary switches shall be capable of tripping the circuit breaker when any voltage throughout the control voltage range is applied (see ANSI C37.06-1997).

6.7.5 Stored energy indicator

A stored energy indicator that can easily be read by the local operator shall be supplied. For stored energy systems using compressed gas, a pressure gauge shall be supplied. For stored energy systems using springs, a reliable indicator with the following colors shall be provided:

a) Yellow background with black lettering to indicate "charged" mechanism; and
b) White background with black lettering to indicate "discharged" mechanism.

6.7.6 Manual releases

Indoor circuit breaker mechanisms shall have a manual release to OPEN the circuit breaker, and a manual release to CLOSE the circuit breaker. They shall be labeled clearly so that a local operator can easily read and operate them. Manual releases for outdoor circuit breaker mechanisms, if provided, shall meet the same requirements described in 6.7.5.

Manual releases shall have the following colors:

a) Red background with the word "open" and/or "trip" in contrasting letters to indicate that the release opens the circuit breaker; and
b) Green or black background with the word "close" in contrasting letters to indicate that the release closes the circuit breaker.

6.7.7 Functional interlocking components—Indoor drawout circuit breakers

All indoor drawout circuit breakers shall have the necessary drawout position (racking) and mechanism interlocks, primary and secondary disconnects, primary insulation, and control wiring to fully correlate and coordinate with IEEE Std C37.20.2-1993 requirements.

6.8 Stored energy requirements for operating mechanisms

Operating mechanism stored energy requirements depend on time to recharge after a CO (close-open) operation of the circuit breaker. Mechanism recharging requirements given in Table 5 are the maximum permissible recharging times for recharging the operating mechanism to restore rated conditions of energy storage (i.e., spring charge, pneumatic pressure, hydraulic pressure, etc.) after one CO operation starting at rated conditions. Rated control voltages shall be used in determining the recharge time.

6.9 Operating mechanism requirements

a) The circuit breaker operating mechanism(s) shall be designed so that the tripping function shall prevail over the closing function. (Trip-free function)

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