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application guide for
capacitance current switching for
ac high-voltage circuit breakers
rated on a symmetrical current basis

ANSI C37.0731-1973 — IEEE Std 342-1973



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ANSI
C37.0731-1973

IEEE
Std 342-1973

An American National Standard

**Application Guide for
Capacitance Current Switching for
AC High-Voltage Circuit Breakers
Rated on a Symmetrical Current Basis**

Sponsor

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

Approved March 21, 1972

IEEE Standards Committee

Secretariat

**Edison Electric Institute
Institute of Electrical and Electronics Engineers
National Electrical Manufacturers Association**

Published by

**Institute of Electrical and Electronics Engineers
345 East 47th Street, New York, N. Y. 10017**

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Foreword

(This Foreword is not a part of American National Standard Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, C37.0731-1973, IEEE Std 342-1973.)

This standard is one of a series of complementary standards on ac high-voltage circuit breakers rated on a symmetrical current basis as follows:

C37.03-1964 (R 1969)	Definitions for AC High-Voltage Circuit Breakers
C37.04-1964 (R 1969)	Rating Structure for AC High-Voltage Circuit Breakers (Including Supplements)
C37.05-1964 (R 1969)	Methods for Determining the Values of a Sinusoidal Current Wave and a Normal Frequency Recovery Voltage for AC High-Voltage Circuit Breakers
C37.06-1971	Schedules of Preferred Ratings and Related Required Capabilities for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis
C37.07-1969	Interrupting Capability Factors for Reclosing Service for AC High-Voltage Circuit Breakers
C37.09-1964 (R 1969)	Test Procedure for AC High-Voltage Circuit Breakers (Including Supplement)
C37.010-1972	Application Guide for AC High-Voltage Circuit Breakers
C37.11-1972	Requirements for Electrical Control for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis and a Total Current Basis
C37.12-1969	Guide Specifications for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis and a Total Current Basis

American National Standard C37.0731-1973 is one of several additional standards being developed on specific subjects applicable to ac high-voltage circuit breakers rated on a symmetrical current basis. Each will be published as soon as the work is completed and it has been approved, rather than waiting until all are complete to effect a complete revision of the basic standards. This approach will make the standards more readily available to the industry. It is planned in the future to integrate these standards into revisions of the basic American National Standards on circuit breakers.

The additional standards are:

C37.071-1969	Requirements for Line Closing Switching Surge Voltage Control
C37.072-1971	Requirements for Transient Recovery Voltage
C37.0721-1971	Application Guide for Transient Recovery Voltage
C37.0722-1971	Schedules of Preferred Transient Recovery Voltage Ratings and Related Required Capabilities
C37.073-1972	Requirements for Capacitance Current Switching
C37.0731	Application Guide for Capacitance Current Switching
C37.0732-1972	Schedule of Preferred Ratings for Capacitance Current Switching
C37.074-1972	Requirements for Switching-Impulse Voltage Insulation Strength
C37.076-1972	Requirements for Pressurized Components
C37.077	Requirements for Current Transformers
C37.078-1972	Requirements for External Insulation (Outdoor)
C37.0781	Schedule of Dielectric Test Values for External Insulation (Outdoor)
C37.079	Guide to the Testing of Circuit Breakers with Respect to Out-of-Phase Switching

American National Standards C37.073-1972, C37.0731-1973, and C37.0732-1972 are intended to satisfy an important need in the industry on requirements for capacitance current switching for ac high-voltage circuit breakers rated on a symmetrical current basis. See Sections 1 and 2 on scope and purpose.

This standard was written as a guide to aid in the selection and application of ac high-voltage circuit breakers rated in accordance with American National Standards C37.073-1972 and C37.0732-1972. It is intended to supplement the American National Standard Application Guide for AC High-Voltage Circuit Breakers C37.010-1964 (R 1969), and specifically to enlarge on Section 4.14.3, Capacitor Switching, and Section 4.14.4, Line Charging Switching.

Suggestions for improvement gained in the use of this standard will be welcome. They should be sent to the American National Standards Institute, 1430 Broadway, New York, N. Y. 10018.

The Standards Committee on Power Switchgear C37, which reviewed and approved this standard, had the following personnel at the time of approval:

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An American National Standard

Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis

1. Scope

This application guide for capacitance current switching applies to ac high-voltage circuit breakers rated in accordance with American National Standard Requirements for Capacitance Current Switching for AC High-Voltage Circuit Breakers, C37.073-1972. It is intended to supplement the American National Standard Application Guide for AC High-Voltage Circuit Breakers, C37.010-1972 (IEEE Std 320-1972), and specifically, to enlarge on Section 4.14.3, Capacitor Switching, and Section 4.14.4, Line Charging Switching. Circuit breakers rated and manufactured to meet other standards should be applied in accordance with application procedures adapted to their specific ratings.

2. Purpose

This guide is intended for general use in the application of circuit breakers for capacitance current switching. Familiarity with other American National Standards applying to circuit breakers is assumed, and provisions of those standards are indicated herein only when necessary for clarity in describing application requirements.

3. General Application Conditions

See Section 3 of American National Standard C37.010-1972 (IEEE Std 320-1972).

4. Application Considerations

4.1 Maximum Voltage for Application. The operating voltage should not exceed the rated

maximum voltage since this is the upper limit for operation.

4.2 Frequency. The rated frequency for circuit breakers is 60 Hz. Special consideration should be given to applications other than 60 Hz. At lower frequencies, the capacitance current switching ability will be adequate, but ac control devices may not be suitable for the application.

4.3 Capacitance Current. Circuit breakers are designed for application where the capacitance current, whether on an overhead line, cable, or capacitor bank, does not exceed the rated value, at any voltage, up to rated maximum voltage. For altitudes exceeding 3300 ft, the capacitance current does not have to be corrected, provided it does not exceed the corrected rated continuous current.

4.4 Interrupting Time. The interrupting time of a circuit breaker on capacitance current switching is the interval between the energizing of the trip circuit at rated control voltage and the interruption of the main circuit in all poles on an opening operation. Since capacitance currents are less than 25 percent of the required asymmetrical interrupting capability, the time required for interruption may be greater than the rated interrupting time. For circuit breakers equipped with resistors, the interrupting time of the resistor current may be longer. Note also that the interrupting time may be longer for close-open operations. (See American National Standard Rating Structure for AC High-Voltage Circuit Breakers, C37.04-1964 (R 1969), Section 4.8.)

4.5 Transient Overvoltage. An important consideration for application of circuit breakers for capacitance current switching is the transient overvoltage which may be generated

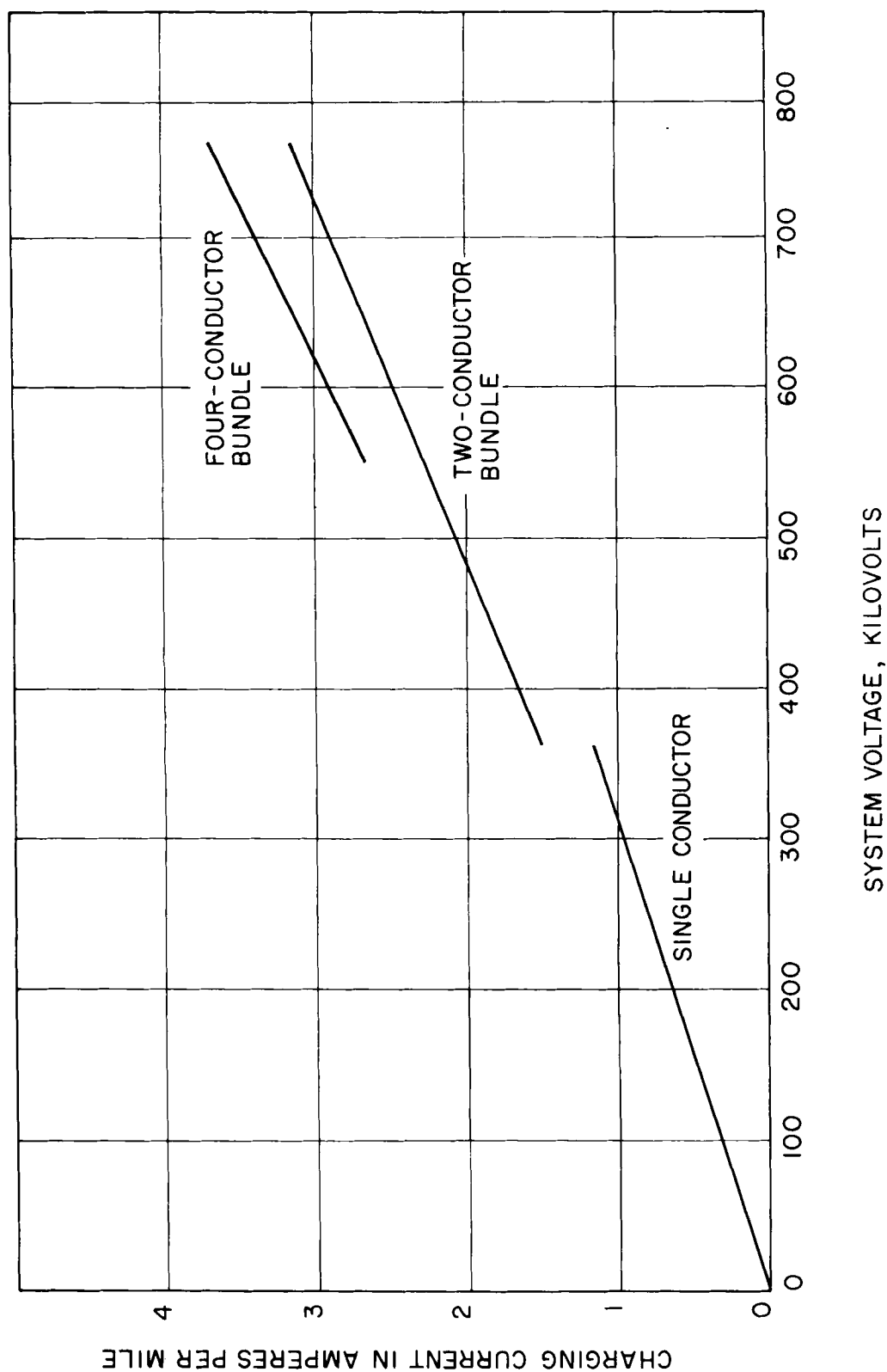


Fig 1 RMS Charging Current Versus System Voltage for Single-Conductor and Two-Conductor Bundle Lines

by restrikes during the opening operation. In American National Standard C37.073-1972, a transient overvoltage factor is defined as the ratio of the transient voltage appearing between a circuit breaker disconnected terminal and the neutral of the disconnected capacitance during opening to the operating line-to-neutral crest voltage prior to opening. The rated transient overvoltage factor is specified for two types of circuit breakers:

(1) General-purpose circuit breakers. The transient overvoltage factor should not exceed 3.0.

(2) Definite-purpose circuit breakers. The transient overvoltage factor shall not exceed the following more than once in 50 random three-phase operations:

(a) 2.5 for circuit breakers rated 72.5 kV and below

(b) 2.0 for circuit breakers rated 121 kV and above

The selection of the type of circuit breaker to be applied should be coordinated with the insulation capability of other components on the system.

4.6 Overhead Lines. A circuit breaker may be required to energize or deenergize an unloaded overhead transmission line during its normal operating duties. Prior to energization, the line may or may not contain a trapped charge. The test program of American National Standard C37.073-1972, Section 5, recognizes the possible conditions encountered during the switching of overhead lines. The application of either general or definite-purpose circuit breakers to overhead line switching is determined by the overhead line current rating assigned in American National Standard Schedule of Preferred Ratings for Capacitance Current Switching for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, C37.073-1972, Tables 1 through 4A.

4.6.1 Overhead Line Current. When considering the assigned overhead line current rating, application is determined by the value of the line charging current. This current is a function of system voltage, line length, and line configuration.

For a first approximation of single- and double-circuit overhead line charging currents, the capacitive reactance at 60 Hz can be estimated as follows:

Single conductor 0.18 MΩ per phase per mile (0.29 MΩ per phase per kilometer)

Two-conductor bundle — 0.14 MΩ per phase per mile (0.23 MΩ per phase per kilometer)

Three-conductor bundle — 0.13 MΩ per phase per mile (0.21 MΩ per phase per kilometer)

Four-conductor bundle — 0.12 MΩ per phase per mile (0.19 MΩ per phase per kilometer)

The curve of Fig 1 shows rms charging current in amperes per mile¹ as a function of system voltage for single-conductor and two-conductor bundle lines.² If the estimated current is greater than 90 percent of the preferred line current rating, a more accurate calculation based on the actual line configuration and methods similar to that discussed in reference [1] should be used.³

These calculations assume a transposed line and neglect the rise in voltage at the open end (Ferranti effect). The voltage rise has the effect of increasing the line charging current and is a function of line length.

The additional current can be calculated using, for example, *ABCD* constants and considering the line open-circuited at the receiving end. The magnitude of the charging current is then

$$|I_c| = \frac{|V_s| \tanh \sqrt{-X_L/X_C}}{\sqrt{X_L X_C}} \approx \frac{|V_s|}{X_C} \left[1 + \frac{1}{3} \frac{X_L}{X_C} \right]$$

where

$|V_s|$ = magnitude of sending end line-to-ground voltage

X_C = line positive-sequence capacitive reactance per phase, in ohms

X_L = line positive-sequence inductive reactance per phase, in ohms

The term in brackets is a modifying factor which is applied to the current determined previously (see Fig 1) and, for a single-conductor line with 0.8 Ω per phase per mile inductive reactance and 0.18 MΩ per phase

¹ 1 mile = 1.61 km.

² When using the quantity MΩ per phase per mile, it should be remembered that the shunt capacitive reactance in megohms for more than one mile decreases because the capacitance increases. For more than one mile of line, therefore, the value of shunt-capacitive reactance as given above should be divided by the number of miles of line.

³ An example of this calculation is given in Appendix A.

per mile capacitive reactance, the current magnitude is approximately

$$|I_c| = |I_c'| \left[1 + \frac{1}{3} \frac{0.8 (100S)}{0.18 \times 10^6 / (100S)} \right]$$

$$= |I_c'| [1 + 0.0148S^2]$$

where

$$|I_c'| = \text{uncorrected current}$$

$$S = \text{line length, in hundreds of miles}$$

The corresponding equation for a two-conductor bundle with 0.6 Ω per phase per mile inductive reactance and 0.14 M Ω per phase per mile capacitive reactance is

$$|I_c| = |I_c'| [1 + 0.0143S^2]$$

Examination of these equations indicates an error of approximately 1.5 percent at 100 mi. The Ferranti effect can be neglected for lines less than this length.

4.6.2 Compensated Overhead Line Current. Extremely long lines are often compensated with shunt reactors to reduce the amount of charging current required of the system. The compensation factor F_c is defined as

$$F_c = \frac{X_C}{X_R} \quad (\text{Eq 1})$$

where

$$X_R = \text{inductive reactance of compensating reactor}$$

The factor F_c times 100 is the "percent compensation." If X_R is greater than X_C the line is undercompensated, if X_R is less than X_C the line is overcompensated. The compensated line charging current is then given by

$$I_{lc} = I_c' (1 - F_c) \quad (\text{Eq 2})$$

where

$$I_{lc} = \text{compensated line charging current}$$

$$I_c' = \text{uncompensated line current (see Section 4.6.1)}$$

$$F_c = \text{compensation factor (Eq 1)}$$

Assuming a line compensated at 60 percent, the line charging current is

$$I_{lc} = I_c' (1 - 0.6) = 0.4I_c'$$

or 40 percent of the uncompensated value. If the breaker rating is chosen based on I_{lc} , the

line could not be switched without the compensating reactor(s) connected. The voltage rise caused by the Ferranti effect and also the location of the reactor(s) will change the line current slightly.

4.6.3 Line Charging Transient Recovery Voltage. The overhead line current rating is assigned on the basis of a standard transient recovery voltage associated with this type of circuit. The tests discussed in American National Standard C37.073-1972, Section 5, which demonstrate performance, are based on the test voltages of American National Standard C37.073-1972, Section 5.4.1. The overhead line charging current switching tests require a maximum voltage of 2.4 times rated maximum line-to-ground voltage across the circuit breaker one half-cycle after interruption (assumes $C_1 = 2 C_0$ where C_1 is the positive-sequence capacitance and C_0 is the zero-sequence capacitance). This is the difference voltage of the source and line sides, including the effects of coupled voltage on the first phase to clear. The test voltage requires a 1-cosine waveshape.

Deviations from the test voltage characteristics may increase or decrease the probability of the circuit breaker restriking. For example, if the line is compensated, the line side component is not a trapped voltage but is an oscillation with a frequency determined by the compensating reactors and the line capacitance. The resonant frequency of the compensated line is approximated by

$$f_L = \frac{1}{2\pi\sqrt{LC}} = f_s \sqrt{\frac{X_C}{X_R}} \quad (\text{Hz}) \quad (\text{Eq 3})$$

where

$$f_L = \text{line resonant frequency, in hertz}$$

$$L = \text{reactor inductance, in henrys}$$

$$C = \text{total capacitance of line, in farads}$$

$$f_s = \text{system frequency, in hertz}$$

A simple substitution indicates

$$f_L = f_s \sqrt{F_c} \quad (\text{Hz}) \quad (\text{Eq 4})$$

Since F_c , the compensation factor, is usually less than 1, the line resonant frequency is correspondingly less than the system frequency.