IS 13118 (1991): High-Voltage Alternating-Current Circuit-Breakers [ETD 8: High Voltage Switchgear and Controlgear]

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(Reaffirmed 2002)

भारतीय मानक

उच्च-वोल्टता प्रत्यावर्ती धारा परिपथ ब्रेकर की विशिष्टि

Indian Standard

SPECIFICATION FOR HIGH-VOLTAGE ALTERNATING-CURRENT CIRCUIT-BREAKERS

BUREAU OF INDIAN STANDARDS
भारतीय मानक ब्यूरो

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
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Indian Standard

SPECIFICATION FOR HIGH-VOLTAGE ALTERNATING-CURRENT CIRCUIT-BREAKERS

NATIONAL FOREWORD

This Indian Standard which is identical with IEC Pub 56 (1987) 'High voltage alternating-current circuit-breakers' issued by the International Electrotechnical Commission (IEC), was adopted by the Bureau of Indian Standards on the recommendation of the High-Voltage Switchgear and Controlgear Sectional Committee (ETDC 58) and approval of the Electrotechnical Division Council.

The large scale manufacture of high-voltage circuit-breakers in this country underlined the need for adopting uniform specification for such equipment particularly in view of divergent practices being followed by the manufacturers because of their technical collaboration with different overseas manufacturers. In order to meet this need, the Indian Standards on circuit-breakers covering high voltage applications (for system voltages exceeding 1 000 V ac) were first published in 1963.

Application of these standards have brought in considerable amount of uniformity in trade of such equipment. Moreover, the standards being in line with corresponding International Standards have also helped export of equipment made in India.

Since then, considerable advancements have been made in understanding the complex phenomenon of circuit-breaking in the high-voltage ranges, which have brought in rethinking on the specified requirements and methods of tests for high-voltage circuit-breakers. The International Standards on the subject, have therefore undergone major revisions since then, to take these aspects into view.

This standard was first revised in 1980 to align it with the latest thinking then with the international community. Several modifications were introduced especially in terms of insulation performance and short-circuit duties besides elaboration of certain requirements in clear terms. These earlier versions were brought out in several parts and sections.

This version of the specificaton on high-voltage alternating-current circuit-breakers presents a distinct departure from the earlier practice in that, in view of extensive agreement obtained among participating interest, it has been brought out in the dual number format with the corresponding IEC Publication. This follows the strong need to align the Indian Standards with IEC Publications especially in an area like HV circuit-breakers where industry trends have indicated close alignment with requirements in international standards. As a consequence, this comprehensive version of the standard is also brought out as a single volume like the corresponding IEC Pub 56 (1987).

On the publication of the information contained in this standard, the following standards stand withdrawn:

IS 2516 Circuit-breakers :

(Part 1/Sec 2) : 1980 Part 1 General and definitions, Section 2 For voltages above 1 000 V ac *(first revision)*

(Part 2/Sec 2) : 1980 Part 2 Rating, Section 2 For voltages above 1 000 V ac *(first revision)*

(Part 3/Sec 2) : 1980 Part 3 Design and construction, Section 2 For voltages above 1 000 V ac *(first revision)*

(Part 4/Sec 2) : 1980 Part 4 Type tests and routine tests, Section 2 For voltages above 1 000 V ac *(first revision)*

(Part 5/Sec 2) : 1980 Part 5 Information to be given with enquiries, tenders and orders and rules for transport erection and maintenance, Section 2 For voltages above 1 000 V ac *(first revision)*

Users of this standard are advised to refer to the National Annex where specific clarifications and elaborations in the Indian context are provided in respect of certain provisions in this standard.

CROSS REFERENCES

In this adopted standard, reference appears to certain International Standards for which Indian standards also exist. The corresponding Indian standards which are to be substituted in their place are listed below along with their degree of equivalence for the editions indicated:

International Standard	*Corresponding Indian Standard (Which are Technically Equivalent)*
IEC Pub 50 (151) (1978) International electrotechnical vocabulary : Chapter 50 (151) Electrical and magnetic devices.	IS 1885 (Part 57) : 1982 Electrotechnical vocabulary : Part 57 Electric and magnetic circuits.
IEC Pub 50 (441) (1984) International electrotechnical vocabulary : Chapter 441 : Switchgear, controlgear and fuses.	IS 1885 (Part 17) : 1979 Electrotechnical vocabulary : Part 17 Switchgear and controlgear *(first revision)*
IEC Pub 50 (604) (1987) International electrotechnical vocabulary : Chapter 604 : Generation, transmission and distribution of electricity—Operation.	IS 1885 (Part 30) : 1971 Electrotechnical vocabulary: Part 30 Overhead transmission and distribution of electrical energy.
IEC Pub 60-1 (1973) High-voltage test techniques. Part 1 : General definitions and test requirements.	IS 2071 (Part 1) : 1974 Methods of high voltage testing : Part 1 General definitions and test requirements *(first revision)*
IEC Pub 68-2-5 (1975) Basic environmental testing procedures. Test Sa: Simulated solar radiation at ground level *(first edition)*	IS 9000 (Part 17) : 1985 Basic environmental testing procedures for electronic and electrical items: Part 17 Radiation test *(first revision)*
IEC Pub 68-2-17 (1978) Basic environmental testing procedures. Test Q : Sealing *(third edition)*	IS 9000 (Part 15/Sec 1 to 9) : 1982 Basic environmental testing procedures for electronic and electrical items : Part 15 Sealing test,Section 1 to 9.
IEC Pub 71-2 (1976) Insulation co-ordination. Part 2 : Application guide *(second edition)*	IS 3716 : 1978 Application guide for insulation co-ordination *(first revision)*
IEC Pub 129 (1984) Alternating current disconnectors (isolators) and earthing switches.	IS 9921 (in several parts) Alternating current disconnectors (isolators) and earthing switches for voltages above 1 000 V.
IEC Pub 137 (1984) Bushings for alternating voltages above 1 000 V *(third edition)*	IS 2099 : 1986 Bushings for alternating voltages above 1 000 volts *(second revision)*
IEC Pub 185 (1987) Current transformers *(second edition)*	IS 2705 (Parts 1 to 4) : 1981 Current transformers.
IEC Pub 296 (1982) Specification for unused mineral insultating oils for transformers and switchgear *(second edition)*	IS 335 : 1983 New insulating oils *(third revision)*.

The High Voltage Switchgear and Controlgear Sectional Committee has reviewed the provisions of the following IEC Publications and has decided that they are acceptable for use in conjunction with this standard:

IEC Pub 77 (1968) Rules for electric traction equipment (*second edition*)

IEC Pub 376 (1971) Specification and acceptance of new sulphur hexafluoride (*first edition*)

IEC Pub 427 (1973) Report on synthetic testing of high-voltage alternating current circuit-breakers (*first edition*)

IEC Pub 694 (1980) Common clauses for high-voltage switchgear and controlgear standards (*first editon).*

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CHAPTER I : SERVICE CONDITIONS, DEFINITIONS, RATING, CONSTRUCTION AND DESIGN

CHAPTER II : TESTS, SELECTION, ORDERS AND INSTALLATION

CHAPTER III : APPENDICES

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This standard has been prepared by Sub-Committee 17A: High-voltage Switchgear and Controlgear, of IEC Technical Committee No. 17: Switchgear and Controlgear.

This forms the fourth edition of IEC Publication 56 and replaces IEC Publications 56-1, 56-2, 56-3, 56-4, 56-4A, 56-5 and 56-6 and their amendments.

The text of this standard is based on the following documents:

Six Months' Rule	Reports on Voting
17A(CO)145	17A(CO)149
17A(CO)155	17A(CO)169
17A(CO)156	17A(CO)170
17A(CO)157	17A(CO)171
17A(CO)159+A	17A(CO)172
17A(CO)160	17A(CO)167
17A(CO)161	17A(CO)165
17A(CO)173	17A(CO)183+A
17A(CO)174	17A(CO)184+A
17A(CO)175	17A(CO)185+A
17A(CO)176, I, II, III	17A(CO)191
17A(CO)177	17A(CO)186+A
17A(CO)178	17A(CO)187+A
17A(CO)179	17A(CO)188
17A(CO)180	17A(CO)190
17A(CO)181	17A(CO)192
17A(CO)195	17A(CO)201

Further information can be found in the relevant Reports on Voting, indicated in the table above.

The supplementary sub-clauses are numbered from 101 onwards. The appendices and their figures are named. AA, BB, etc.

The following IEC publications are quoted in this standard:

Publication Nos. 50(151) (1978): International Electrotechnical Vocabulary (IEV), Chapter 151: Electrical and Magnetic Devices.
50(441) (1984): Chapter 441: Switchgear, Controlgear and Fuses.
50(604) (1986): Chapter 604: Generation, Transmission and Distribution of Electricity: Operation.
60-1 (1973): High-voltage Test Techniques, Part 1: General Definitions and Test Requirements.

68-2-5 (1975): Basic Environmental Testing Procedures, Part 2: Tests — Test Sa: Simulated Solar Radiation at Ground Level.

68-2-17 (1978): Test Q: Sealing.
71-2 (1976): Insulation Co-ordination, Part 2: Application Guide.
77 (1968): Rules for Electric Traction Equipment.
129 (1984): Alternating Current Disconnectors and Earthing Switches.
137 (1984): Bushings for Alternating Voltages Above 1 000 V.
185 (1966): Current Transformers.
296 (1982): Specification for Unused Mineral Insulating Oils for Transformers and Switchgear.
376 (1971): Specification and Acceptance of New Sulphur Hexafluoride.
427 (1973): Report on Synthetic Testing of High-voltage Alternating Current Circuit-breakers.
694 (1980): Common Clauses for High-voltage Switchgear and Controlgear Standards.

1. Scope

This standard is applicable to a.c. circuit-breakers designed for indoor or outdoor installation and for operation at frequencies up to and including 60 Hz on systems having voltages above 1 000 V.

It is only applicable to three-pole circuit-breakers for use in three-phase systems and single-pole circuit-breakers for use in single-phase systems. Two-pole circuit-breakers for use in single-phase systems are subject to agreement between manufacturer and user.

This standard is also applicable to the operating devices of circuit-breakers and to their auxiliary equipment. However, a circuit-breaker with a closing mechanism for dependent manual operation is not covered by this standard, as a rated short-circuit making-current cannot be specified, and such dependent manual operation may be objectionable because of safety considerations.

This standard does not cover circuit-breakers intended for use on motive power units of electrical traction equipment; these are covered by IEC Publication 77: Rules for Electric Traction Equipment.

Circuit-breakers for use with overhead lines which include series capacitors are not within the scope of this standard.

Note. — Tests to prove the performance under abnormal conditions should be subject to agreement between manufacturer and user. Such abnormal conditions are, for instance, cases where the voltage is higher than the rated voltage of the circuit-breaker, conditions which may occur due to sudden loss of load on long lines or cables.

This standard is not necessarily applicable to circuit-breakers for special conditions, for example, those produced by two earth faults on two different phases one of which occurs on one side of the circuit-breaker and the other on the other side.

2. Normal and special service conditions

Clause 2 of IEC Publication 694: Common Clauses for High-voltage Switchgear and Controlgear Standards, is applicable.

3. Definitions

In this clause reference is made to definitions in the following publications of the International Electrotechnical Vocabulary (IEV):

- 50(151) (1978): Chapter 151: Electrical and Magnetic Devices,
- 50(441) (1984): Chapter 441: Switchgear; Controlgear and Fuses,
- 50(604) (—): Chapter 604: Generation, Transmission and Distribution of Electricity: Operation (being printed).

For the purpose of this standard, the following definitions are applicable.

3.101 *General terms*

3.101.1 *Switchgear and controlgear* (441-11-01)

3.101.2 *Indoor switchgear and controlgear* (441-11-04)

3.101.3 *Outdoor switchgear and controlgear* (441-11-05)

3.101.4 *Short-circuit current* (441-11-07)

3.101.5 *Isolated neutral system*

A system which has no intentional connection to earth except through indicating, measuring or protective devices of very high impedance.

3.101.6 *Resonant earthed system; system earthed through an arc-suppression coil*

A system in which the neutral is earthed through a reactor, the reactance having a value such that during a single phase-to-earth fault, the power frequency inductive current passed by this reactor substantially neutralizes the power frequency capacitive component of the earth-fault current.

Note. — With resonant earthing of a system, the residual current in the fault is limited to such an extent that an arcing fault in air is usually self-extinguishing.

3.101.7 *Earthed neutral system*

A system in which the neutral is connected to earth, either solidly, or through a resistance or reactance of a value low enough to reduce materially any transient oscillations and to improve the conditions for selective earth-fault protection.

3.101.8 *Earth fault factor*

At a selected location of a three-phase system (generally the point of installation of an equipment) and for a given system configuration, the ratio of the highest r.m.s. phase-to-earth power-frequency voltage on a sound phase during a fault to earth (affecting one or more phases at any point) to the r.m.s. phase-to-earth power-frequency voltage which would be obtained at the selected location without the fault.

Notes 1. — This factor is a pure numerical ratio (higher than 1) and characterizes in general terms the earthing conditions of a system as viewed from the stated location, independently of the actual operating values of the voltage at that location.

The "earth fault factor" is the product of $\sqrt{3}$ and the "factor of earthing" which has been used in the past.

2. — The earth fault factors are calculated from the phase-sequence impedance components of the system, as viewed from the selected location, using for any rotating machines the subtransient reactances.

3. — If, for all credible system configurations, the zero-sequence reactance is less than three times the positive-sequence reactance and if the zero-sequence resistance does not exceed the positive-sequence reactance, the earth fault factor will not exceed 1.4.

3.101.9 *Ambient air temperature* (441-11-13)

3.101.10 *Temperature rise (of a part of a circuit-breaker)*

The difference between the temperature of the part and the ambient air temperature.

3.101.11 *Single capacitor bank*

A bank of shunt capacitors in which the inrush current is limited by the inductance of the supply system and the capacitance of the bank of capacitors being energized, there being no other capacitors connected in parallel to the system sufficiently close to increase the inrush current appreciably.

3.101.12 *Multiple (parallel) capacitor bank (back-to-back capacitor bank)*

A bank of shunt capacitors or capacitor assemblies each of them switched independently to the supply system, the inrush current of one unit being appreciably increased by the capacitors already connected to the supply.

3.101.13 *Overvoltage (in a system)* (604-03-09)

Any voltage between one phase and earth or between phases having a peak value or values exceeding the corresponding peak of the highest voltage for equipment.

3.101.14 *Out-of-phase conditions*

Abnormal circuit conditions of loss or lack of synchronism between the parts of an electrical system on either side of a circuit-breaker in which, at the instant of operation of the circuit-breaker, the phase angle between rotating vectors, representing the generated voltages on either side, exceeds the normal value and may be as much as 180° (phase opposition).

3.101.15 *Out-of-phase (as prefix to a characteristic quantity)*

A qualifying term indicating that the characteristic quantity is applicable to operation of the circuit-breaker in out-of-phase conditions.

3.101.16 *Unit test*

A test made on a making or breaking unit or group of units at the making current or the breaking current, specified for the test on the complete pole of a circuit-breaker and at the appropriate fraction of the applied voltage, or the recovery voltage, specified for the test on the complete pole of the circuit-breaker.

3.101.17 *Loop*

The part of the wave of the current embraced by two successive current zero crossings.

Note. — A distinction is made between a major loop and a minor loop depending on the time interval between two successive current zero crossings being longer or shorter than the half-period of the alternating component of the current.

3.101.18 *Short-line fault*

A short-circuit on an overhead line at a short, but significant, distance from the terminals of the circuit-breaker.

Note. — As a rule this distance is not more than a few kilometres.

3.101.19 *Power factor (of a circuit)*

The ratio of the resistance to the impedance at power frequency of an equivalent circuit supposed to be formed by an inductance and a resistance in series.

3.101.20 *External insulation* (604-03-02)

The distances in air and the surfaces in contact with open air of solid insulation of the equipment, which are subject to dielectric stresses and to the effects of atmospheric and other external conditions such as pollution, humidity, vermin, etc.

3.101.21 *Internal insulation* (604-03-03)

The internal solid, liquid or gaseous parts of the insulation of equipment, which are protected from the effects of atmospheric and other external conditions.

3.101.22 *Self-restoring insulation* (604-03-04)

Insulation which completely recovers its insulating properties after a disruptive discharge.

3.101.23 *Non-self-restoring insulation* (604-03-05)

Insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge.

3.101.24 *Disruptive discharge*

Phenomena associated with the failure of insulation under electric stress, in which the discharge completely bridges the insulation under test, reducing the voltage between the electrodes to zero or nearly to zero.

Notes 1. — This term applies to discharges in solid, liquid and gaseous dielectrics and to combinations of these.

2. — A disruptive discharge in a solid dielectric produces permanent loss of dielectric strength (non-self-restoring insulation); in a liquid or gaseous dielectric, the loss may be only temporary (self-restoring insulation).

3. — The term "sparkover" is used when a disruptive discharge occurs in a gaseous or liquid dielectric. The term "flashover" is used when a disruptive discharge occurs over the surface of a solid dielectric in a gaseous or liquid medium. The term "puncture" is used when a disruptive discharge occurs through a solid dielectric.

3.102 *Switching devices*

3.102.1 *Switching device* (441-14-01)

3.102.2 *Mechanical switching device* (441-14-02)

3.102.3 *Circuit-breaker* (441-14-20)

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3.102.6 *Air circuit-breaker* (441-14-27)

3.102.7 *Oil circuit-breaker* (441-14-28)

3.102.8 *Vacuum circuit-breaker* (441-14-29)

3.102.9 *Gas-blast circuit-breaker* (441-14-30)

3.102.10 *Sulphur hexafluoride circuit-breaker* (441-14-31)

3.102.11 *Air-blast circuit-breaker* (441-14-32)

3.102.12 *Restrike-free circuit-breaker*

A circuit-breaker that interrupts without restrike during the capacitive current-breaking test duties specified in this standard.

3.103 *Parts of circuit-breakers*

3.103.1 *Pole* (441-15-01)

3.103.2 *Main circuit* (441-15-02)

3.103.3 *Control circuit* (441-15-03)

3.103.4 *Auxiliary circuit* (441-15-04)

3.103.5 *Contact* (441-15-05)

3.103.6 *Contact piece* (441-15-06)

3.103.7 *Main contact* (441-15-07)

3.103.8 *Arcing contact* (441-15-08)

3.103.9 *Control contact* (441-15-09)

3.103.10 *Auxiliary contact* (441-15-10)

3.103.11 *Auxiliary switch* (441-15-11)

3.103.12 *"a" contact, make contact* (441-15-12)

3.103.13 *"b" contact, break contact* (441-15-13)

3.103.14 *Sliding contact* (441-15-15)

3.103.15 *Rolling contact* (441-15-16)

3.103.16 *Release* (441-15-17)

3.103.17 *Arc control device* (441-15-18)

3.103.18 *Position indicating device (indicator)* (441-15-25)

3.103.19 *Connection (bolted or the equivalent)*

Two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent.

3.103.20 *Terminal* (151-01-03)

A component provided for the connection of a circuit-breaker to external conductors.

3.103.21 *(Making or breaking) unit*

A part of a circuit-breaker which in itself acts as a circuit-breaker and which in series with one or more identical and simultaneously operated making or breaking units forms the complete circuit-breaker.

Notes 1. — Making units and breaking units may be separate or combined. Each unit may have several contacts.

2. — The means controlling the voltage distribution between units may differ from unit to unit.

3.103.22 *Module (of a pole of a circuit-breaker)*

An assembly which generally comprises making or breaking units, post-insulators and mechanical parts and which is mechanically and electrically connected to other identical assemblies to form a pole of a circuit-breaker.

3.104 *Operation*

3.104.1 *Operation* (441-16-01)

3.104.2 *Operating cycle* (441-16-02)

3.104.3 *Operating sequence* (441-16-03)

3.104.4 *Closing operation* (441-16-08)

3.104.5 *Opening operation* (441-16-09)

3.104.6 *Auto-reclosing* (441-16-10)

3.104.7 *Positive opening operation* (441-16-11)

3.104.8. *Positively driven operation* (441-16-12)

3.104.9 *Dependent manual operation* (441-16-13)

3.104.10 *Dependent power operation* (441-16-14)

3.104.11 *Stored energy operation*

An operation by means of energy stored in the mechanism itself prior to the switching operation and sufficient to complete the specified operating cycle under predetermined conditions.

3.104.12. *Independent manual operation* (441-16-16)

3.104.13 *Closed position* (441-16-22)

3.104.14 *Open position* (441-16-23)

3.104.15. *Fixed trip circuit-breaker* (441-16-30)

3.104.16 *Trip-free circuit-breaker* (441-16-31)

3.104.17 *Instantaneous release* (441-16-32)

3.104.18 *Making-current release*

A release which permits a circuit-breaker to open, without any intentional time delay, during a closing operation, if the making current exceeds a predetermined value, and which is rendered inoperative when the circuit-breaker is in the closed position.

3.104.19 *Over-current release* (441-16-33)

3.104.20 *Definite time-delay over-current release* (441-16-34)

3.104.21 *Inverse time-delay over-current release* (441-16-35)

3.104.22 *Direct over-current release* (441-16-36)

3.104.23 *Indirect over-current release* (441-16-37)

3.104.24 *Shunt release* (441-16-41)

3.104.25 *Under-voltage release* (441-16-42)

3.104.26 *Reverse current release (d.c. only)* (441-16-43)

3.104.27 *Operating current (of an over-current release)* (441-16-45)

3.104.28 *Current setting (of an over-current release)* (441-16-46)

3.104.29 *Current setting range (of an over-current release)* (441-16-47)

3.104.30 *Anti-pumping device* (441-16-48)

3.104.31 *Interlocking device* (441-16-49)

3.104.32 *Circuit-breaker with lock-out preventing closing* (441-14-23)

3.105 *Characteristic quantities of circuit-breakers**

3.105.1 *Rated value* (151-04-03)

A quantity value assigned, generally by a manufacturer, for a specified operating condition of a component, device or equipment.

3.105.2 *Prospective current (of a circuit and with respect to a circuit-breaker)* (441-17-01)

3.105.3 *Prospective peak current*

The peak value of the first major loop of the prospective current during the transient period following initiation.

Note. — The definition assumes that the current is made by an ideal circuit-breaker, i.e. with instantaneous and simultaneous transition of its impedance across the terminals of each pole from infinity to zero. The peak value may differ from one pole to another; it depends on the instant of current initiation relative to the voltage wave across the terminals of each pole.

3.105.4 *Peak current*

The peak value of the first major loop of current during the transient period following initiation.

3.105.5 *Prospective symmetrical current (of an a.c. circuit)* (441-17-03)

3.105.6 *Maximum prospective peak current (of an a.c. circuit)* (441-17-04)

3.105.7 *Prospective making current (for a pole of a circuit-breaker)* (441-17-05)

* Figures 1 to 7 (pages 90 to 97) illustrate some definitions of this sub-clause.

Time quantities, see definitions 3.105.32 to 3.105.45, are expressed in milliseconds or in cycles. When expressed in cycles, the power frequency should be stated in brackets.

In the case of circuit-breakers incorporating switching resistors, a distinction is made, where applicable, between time quantities associated with the contacts switching the full current and the contacts switching the current limited by switching resistors.

Unless otherwise stated the time quantities referred to are associated with the contacts switching the full current.

3.105.8 *(Peak) making current*

The peak value of the first major loop of the current in a pole of a circuit-breaker during the transient period following the initiation of current during a making operation.

Notes 1. — The peak value may differ from one pole to another and from one operation to another as it depends on the instant of current initiation relative to the wave of the applied voltage.

2. — Where, for a polyphase circuit, a single value of (peak) making current is referred to, this is, unless otherwise stated, the highest value in any phase.

3.105.9 *Prospective breaking current (for a pole of a circuit-breaker)*

The prospective current evaluated at the instant corresponding to the initiation of the arc during a breaking process.

3.105.10 *Breaking current* (441-17-07)

3.105.11 *Critical (breaking) current*

A value of breaking current, less than rated short-circuit breaking current, at which the arcing time is a maximum and is significantly longer than at the rated short-circuit breaking current.

3.105.12 *Breaking capacity** (441-17-08)

3.105.13 *Line-charging (line off-load) breaking capacity*

A breaking capacity for which the specified conditions of use and behaviour include the opening of an overhead line operating at no load.

3.105.14 *Cable-charging (cable off-load) breaking capacity*

A breaking capacity for which the specified conditions of use and behaviour include the opening of an insulated cable operating at no load.

3.105.15 *Capacitor bank breaking capacity*

A breaking capacity for which the specified conditions of use and behaviour include the opening of a capacitor bank.

3.105.16 *Making capacity** (441-17-09)

3.105.17 *Out-of-phase (making or breaking) capacity*

A making or breaking capacity for which the specified conditions of use and behaviour include the loss or the lack of synchronism between the parts of an electrical system on either side of the circuit-breaker.

3.105.18 *Short-circuit making capacity* (441-17-10)

3.105.19 *Short-circuit breaking capacity* (441-17-11)

3.105.20 *Short-time withstand current* (441-17-17)

* *Note concerning the rated values:*

In English, the terms "rated making current" and "rated breaking current" are being used where formerly "rated making capacity" and "rated breaking capacity" were used, the intended meaning being adequately conveyed by the use of "rated". In French, the terms "pouvoir de fermeture assigné" and "pouvoir de coupure assigné" continue to be used.

3.105.21 *Peak withstand current* (441-17-18)

3.105.22 *Applied voltage* (441-17-24)

3.105.23 *Recovery voltage* (441-17-25)

3.105.24 *Transient recovery voltage (TRV)* (441-17-26)

3.105.25 *Prospective transient recovery voltage (of a circuit)* (441-17-29)

3.105.26 *Power frequency recovery voltage* (441-17-27)

3.105.27 *Peak arc voltage* (441-17-30)

3.105.28 *Clearance* (441-17-31)

3.105.29 *Clearance between poles* (441-17-32)

3.105.30 *Clearance to earth* (441-17-33)

3.105.31 *Clearance between open contacts* (441-17-34)

3.105.32 *Opening time*

The opening time of a circuit-breaker is defined according to the tripping method as stated below and with any time delay device forming an integral part of the circuit-breaker adjusted to its minimum setting:

a) For a circuit-breaker tripped by any form of auxiliary power, the opening time is the interval of time between the instant of energizing the opening release, the circuit-breaker being in the closed position, and the instant when the arcing contacts have separated in all poles.

b) For a circuit-breaker tripped by a current in the main circuit without the aid of any form of auxiliary power, the opening time is the interval of time between the instant at which, the circuit-breaker being in the closed position, the current in the main circuit reaches the operating value of the overcurrent release and the instant when the arcing contacts have separated in all poles.

Notes 1. — The opening time may vary significantly with the breaking current.

2. — For circuit-breakers with more than one interrupting unit per pole the instant when the arcing contacts have separated in all poles is determined as the instant of contact separation in the first unit of the last pole.

3. — The opening time includes the operating time of any auxiliary equipment necessary to open the circuit-breaker and forming an integral part of the circuit-breaker.

3.105.33 *Arcing time* (441-17-38)

3.105.34 *Break time* (441-17-39)

3.105.35 *Closing time*

The interval of time between energizing the closing circuit, the circuit-breaker being in the open position, and the instant when the contacts touch in all poles.

Note. — The closing time includes the operating time of any auxiliary equipment necessary to close the circuit-breaker and forming an integral part of the circuit-breaker.

3.105.36 *Make time*

The interval of time between energizing the closing circuit, the circuit-breaker being in the open position, and the instant when the current begins to flow in the first pole.

Notes 1. — The make time includes the operating time of any auxiliary equipment necessary to close the circuit-breaker and forming an integral part of the circuit-breaker.

2. — The make time may vary due to the variation of the pre-arcing time.

3.105.37 *Pre-arcing time*

The interval of time between the initiation of current flow in the first pole during a closing operation and the instant when the contacts touch in all poles.

Notes 1. — The pre-arcing time depends on the instantaneous value of the applied voltage during a specific closing operation and therefore may vary considerably.

2. — This definition for pre-arcing time for a circuit-breaker should not be confused with the definition for pre-arcing time for a fuse.

3.105.38 *Open-close time (during auto-reclosing)*

The interval of time between the instant when the arcing contacts have separated in all poles and the instant when the contacts touch in the first pole during a reclosing operation.

3.105.39 *Dead time (during auto-reclosing)*

The interval of time between final arc extinction in all poles in the opening operation and the first re-establishment of current in any pole in the subsequent closing operation.

Note. — The dead time may vary due to the variation of the pre-arcing time.

3.105.40 *Reclosing time*

The interval of time between the beginning of the opening time and the instant when the contacts touch in all poles during a reclosing operation.

3.105.41 *Re-make time (during reclosing)*

The interval of time between the beginning of the opening time and the first re-establishment of current in any pole in the subsequent closing operation.

Note. — The re-make time may vary due to the variation of the pre-arcing time.

3.105.42 *Close-open time*

The interval of time between the instant when the contacts touch in the first pole during a closing operation and the instant when the arcing contacts have separated in all poles during the subsequent opening operation.

Note. — Unless otherwise stated, it is assumed that the opening release incorporated in the circuit-breaker is energized at the instant when the contacts touch in the first pole during closing. This represents the minimum close-open time.

3.105.43 *Make-break time*

The interval of time between the initiation of current flow in the first pole during a closing operation and the end of the arcing time during the subsequent opening operation.

Notes 1. — Unless otherwise stated, it is assumed that the opening release of the circuit-breaker is energized one half-cycle after current begins to flow in the main circuit during making. It should be noted that the use of relays with shorter operating times may subject the circuit-breaker to asymmetrical currents that are in excess of those provided for in Sub-clause 6.106.5.

2. — The make-break time may vary due to the variation of the pre-arcing time.

3.105.44 *Minimum trip duration*

The minimum time the auxiliary power has to be applied to the opening release to ensure complete opening of the circuit-breaker.

3.105.45 *Minimum close duration*

The minimum time the auxiliary power has to be applied to the closing device to ensure complete closing of the circuit-breaker.

3.105.46 *Re-ignition* (441-17-45)

3.105.47 *Restrike* (441-17-46)

3.105.48 *Normal current*

The current which the main circuit of a circuit-breaker is capable of carrying continuously under specified conditions of use and behaviour.

3.105.49 *Peak factor (of the line transient voltage)*

The ratio between the maximum excursion and the initial value of the line transient voltage to earth of a phase of an overhead line after the breaking of a short-line fault current.

Note. — The initial value of the transient voltage corresponds to the instant of arc extinction in the pole considered.

3.105.50 *First-pole-to-clear factor (of a three-phase system, at the location of a circuit-breaker)*

The ratio of the power frequency voltage between the sound phase and the other two phases during a two-phase short-circuit, which may or may not involve earth, at the location of the circuit breaker, to the phase-to-neutral voltage which would be obtained at the same location with the short-circuit removed.

3.105.51 *Insulation level* (604-03-46)

For a circuit-breaker a characteristic defined by one or two values indicating the insulation withstand voltages.

3.105.52 *Power frequency withstand voltage* (604-03-39)

The r.m.s. value of sinusoidal power frequency voltage that the circuit-breaker can withstand during tests made under specified conditions and for a specified time.

3.105.53 *Impulse withstand voltage*

The peak value of the standard impulse voltage wave which the insulation of the circuit-breaker withstands under specified test conditions.

Note. — Depending on the shape of wave, the term may be qualified as "switching impulse withstand voltage" or "lightning impulse withstand voltage".

3.106 *Index of definitions*

4. Rating

A circuit-breaker in correct condition of maintenance and adjustment shall be able to withstand all stresses that occur in service provided that these do not exceed its rated characteristics.

The characteristics of a circuit-breaker, including its operating devices and auxiliary equipment, that shall be used to determine the rating are the following:

(A) *Rated characteristics to be given for all circuit-breakers*

a) Rated voltage.
b) Rated insulation level.
c) Rated frequency.
d) Rated normal current.
e) Rated short-time withstand current.
f) Rated peak withstand current.
g) Rated duration of short circuit, for circuit-breakers not fitted with direct over-current release.
h) Rated supply voltage of closing and opening devices and of auxiliary circuits.
i) Rated supply frequency of closing and opening devices and of auxiliary circuits.
j) Rated pressures of compressed gas supply for operation and for interruption, if applicable.
k) Rated short-circuit breaking current.
l) Rated transient recovery voltage for terminal faults.
m) Rated short-circuit making current.
n) Rated operating sequence.

(B) *Rated characteristics to be given in the specific cases indicated below*

o) Rated characteristics for short-line faults, for three-pole circuit-breakers designed for direct connection to overhead transmission lines and rated at 52 kV and above and at more than 12.5 kA rated short-circuit breaking current.
p) Rated line-charging breaking current, for three-pole circuit-breakers intended for switching overhead transmission lines and rated at 72.5 kV and above.

(C) *Rated characteristics to be given on request*

q) Rated out-of-phase breaking current.
r) Rated cable-charging breaking current.
s) Rated single capacitor bank breaking current.
t) Rated back-to-back capacitor bank breaking current.
u) Rated capacitor bank inrush making current.
v) Rated small inductive breaking current.
w) Rated time quantities.

4.1 *Rated voltage*

Sub-clause 4.1 of IEC Publication 694 is applicable.

Note. – The rated voltage 27 kV is also used in the United States of America and Canada.

4.2 *Rated insulation level*

Sub-clause 4.2 of IEC Publication 694 is applicable.

4.2.1 *For rated voltages up to and including 72.5 kV*

Sub-clause 4.2.1 including Table I of IEC Publication 694 is applicable with the exception of columns (3), (5), (7) and the note and with the following addition:

For series II (based on current practice in the United States of America and Canada, for 60 Hz only), Table I is applicable:

TABLE I

Series II (based on current practice in the United States of America and Canada, for 60 Hz only)

Rated voltage U (r.m.s. value)	Rated lightning impulse withstand voltage (peak value) To earth, between poles and across open circuit-breaker	Rated power frequency withstand voltage (r.m.s. value) To earth, between poles and across open circuit-breaker	
		1 min dry test	10 s wet test*
(kV)	(kV)	(kV)	(kV)
(1)	(2)	(3)	(4)
4.76	60	19	–
8.25	95	36	–
15.0	95	36	–
15.5	110	50	45
25.8 and 27.0	150	60	50
38.0	200/150**	80	75
48.3	250	105	95
72.5	350	160	140

* Applicable only to outdoor circuit-breakers. Test requirements are given in IEC Publication 60-1: High-voltage Test Techniques, Part 1: General Definitions and Test Requirements.

** Applicable only to indoor circuit-breakers.

4.2.2 *For rated voltages from 100 kV to 245 kV*

Sub-clause 4.2.2 including Table III of IEC Publication 694 is applicable with the exception of columns (3), (5) and the note.

4.2.3 *Rated voltages 300 kV and above*

Sub-clause 4.2.3 of IEC Publication 694 is applicable with the following addition:

The standard value of rated switching impulse withstand voltage across the open circuit-breaker is given in column (5) of Table IV of IEC Publication 694. However, for special circuit-breakers intended for use in synchronizing operation simultaneously with a substantial switching surge, such as from the line energization, the insulation of a standard circuit-breaker may be insufficient. In such cases which are subject to agreement between manufacturer and user, it is suggested either to use a standard circuit-breaker having a higher rated voltage or to use a special circuit-breaker, increasing the severity of the test with the circuit-breaker open. In this last case, the rated switching impulse withstand voltage across the open circuit-breaker is given in column (6) of Table IV of IEC Publication 694.

4.3 *Rated frequency*

Sub-clause 4.3 of IEC Publication 694 is applicable.

4.4 *Rated normal current and temperature rise*

Sub-clauses 4.4.1 and 4.4.2 of IEC Publication 694 are applicable with the following additions:

The values of rated normal currents shall be selected from the following standard values:

400 A; 630 A; 800 A; 1 250 A; 1 600 A; 2 000 A; 2 500 A; 3 150 A; 4 000 A; 5 000 A; 6 300 A.

Note. — The above values are selected from the R 10 series, and, if required, higher values than those shown should also be selected from this series.

If the circuit-breaker is fitted with a series connected accessory, such as a direct over-current release, the rated normal current of the accessory is the r.m.s. value of the current which the accessory shall be able to carry continuously without deterioration at its rated frequency, with a temperature rise not exceeding the values specified in Table V of IEC Publication 694.

Current transformers shall comply with IEC Publication 185: Current Transformers.

4.5 *Rated short-time withstand current*

Sub-clause 4.5 of IEC Publication 694 is applicable with the following addition:

The rated short-time withstand current is equal to the rated short-circuit breaking current (see Sub-clause 4.101).

4.6 *Rated peak withstand current*

Sub-clause 4.6 of IEC Publication 694 is applicable with the following addition:

The rated peak withstand current is equal to the rated short-circuit making current (see Sub-clause 4.103).

4.7 *Rated duration of short-circuit*

Sub-clause 4.7 of IEC Publication 694 is applicable with the following addition:

A rated duration of a short-circuit need not be assigned to a circuit-breaker fitted with a direct over-current release provided that, when connected in a circuit the prospective breaking current of which is equal to its rated short-circuit breaking current, the circuit-breaker shall be capable of carrying the resulting current for the break-time required by the circuit-breaker with the over-current release set for the maximum time lag, when operating in accordance with its rated operating sequence.

4.8 *Rated supply voltage of closing and opening devices and auxiliary circuits*

Sub-clause 4.8 of IEC Publication 694 is applicable with the following addition:

The specified upper limit of the supply voltage for a closing solenoid shall be 105% of the rated supply voltage.

4.9 *Rated supply frequency of closing and opening devices and auxiliary circuits*

Sub-clause 4.9 of IEC Publication 694 is applicable.

4.10 *Rated pressures of compressed gas supply for operation and for interruption*

The values of the pressures to which the circuit-breaker is filled.

Sub-clause 4.10 of IEC Publication 694 is applicable to the pressure of the compressed gas supply for operation.

No standard values are given for rated pressure of compressed gas supply for interruption.

4.101 *Rated short-circuit breaking current*

The rated short-circuit breaking current is the highest short-circuit current which the circuit-breaker shall be capable of breaking under the conditions of use and behaviour prescribed in this standard in a circuit having a power-frequency recovery voltage corresponding to the rated voltage of the circuit-breaker and having a transient recovery voltage equal to the rated value specified in Sub-clause 4.102. For three-pole circuit-breakers the a.c. component relates to a three-phase short-circuit. Where applicable the provisions of Sub-clause 4.105 concerning short-line faults shall be taken into account.

The rated short-circuit breaking current is characterized by two values:

– the r.m.s. value of its a.c. component, termed "rated short-circuit current" for shortness, and

– the percentage d.c. component.

Note. – If the d.c. component does not exceed 20%, the rated short-circuit breaking current is characterized only by the r.m.s. value of its a.c. component.

For determination of the a.c. and d.c. components, see Figure 8, page 98.

The circuit-breaker shall be capable of breaking any short-circuit current up to its rated short-circuit breaking current containing any a.c. component up to the rated value and associated with it any percentage d.c. component up to that specified, under the conditions mentioned above.

The following applies to a standard circuit-breaker:

a) At voltages below the rated voltage, it will be capable of breaking its rated short-circuit breaking current.

Note. – For circuit-breakers with rated voltages not exceeding 72.5 kV having proved rated short-circuit breaking currents I at two different rated voltages U, intermediate characteristics may be assigned from the straight line drawn between the two proved rating points on a plot of log U versus log I. In case of doubt, tests should be carried out to check the validity of the interpolation.

b) At voltages above the rated voltage, no short-circuit breaking current is guaranteed except to the extent provided for in Sub-clause 4.106.

4.101.1 *A.C. component of the rated short-circuit breaking current*

The r.m.s. value of the a.c. component of the rated short-circuit breaking current shall be selected from the following values:

6.3 kA; 8 kA; 10 kA; 12.5 kA; 16 kA; 20 kA; 25 kA; 31.5 kA; 40 kA, 50 kA; 63 kA; 80 kA; 100 kA

Note. – The above values are selected from the R 10 series, and, if required, higher values than those shown should also be selected from this series.

4.101.2 *D.C. component of the rated short-circuit breaking current*

The value of the percentage d.c. component shall be determined as follows:

a) For a circuit-breaker which can be tripped by the short-circuit current without the aid of any form of auxiliary power, the percentage d.c. component shall correspond to a time interval τ equal to the minimum opening time of the circuit-breaker.

b) For a circuit-breaker which is intended to be tripped solely by a form of auxiliary power, the percentage d.c. component shall correspond to a time interval τ equal to the minimum opening time of the circuit-breaker plus one-half cycle of rated frequency.

The minimum opening time mentioned above is the shortest opening time of the circuit-breaker obtainable under any service conditions whether in a breaking operation or a make-break operating cycle.

The percentage value of the d.c. component is dependent on the time interval τ and standard values are given in Figure 9, page 99.

Note. — In special applications, for example, if a circuit-breaker is close to a generator, the percentage d.c. component corresponding to the circuit-breaker opening time may be higher than the value given in Figure 9, which is based on negligible decrement of the a.c. component of the short-circuit current and on an exponential decay of the d.c. component to an 80% value in 10 ms, i.e. a time constant of approximately 45 ms. In this case, the required percentage d.c. component should be specified in the enquiry and testing should be subject to agreement between manufacturer and user.

4.102 *Rated transient recovery voltage for terminal faults*

The rated transient recovery voltage (TRV) for terminal faults, relating to the rated short-circuit breaking current in accordance with Sub-clause 4.101, is the reference voltage which constitutes the limit of the prospective transient recovery voltage of circuits which the circuit-breaker shall be capable of breaking in the event of a short-circuit at its terminals.

4.102.1 *Representation of transient recovery voltage waves*

The waveform of transient recovery voltages varies according to the arrangement of actual circuits.

In some cases, particularly in systems with a voltage greater than 100 kV, and where the short-circuit currents are relatively large in relation to the maximum short-circuit current at the point under consideration, the transient recovery voltage contains first a period of high rate of rise, followed by a later period of lower rate of rise. This waveform is generally adequately represented by an envelope consisting of three line segments defined by means of four parameters*.

In other cases, particularly in systems with a voltage less than 100 kV, or in systems with a voltage greater than 100 kV in conditions where the short-circuit currents are relatively small in relation to the maximum short-circuit currents and fed through transformers, the transient recovery voltage approximates to a damped single frequency oscillation. This waveform is adequately represented by an envelope consisting of two line segments defined by means of two parameters*.

Such a representation in terms of two parameters is a special case of representation in terms of four parameters.

The influence of local capacitance on the source side of the circuit-breaker produces a slower rate of rise of the voltage during the first few microseconds of the TRV. This is taken into account by introducing a time delay.

It appears that every part of the TRV wave may influence the interrupting capability of a circuit-breaker. The very beginning of the TRV may be of importance for some types of circuit-breakers.

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* Methods of drawing TRV envelopes are given in Appendix FF.

This part of the TRV, called initial TRV (ITRV), is caused by the initial oscillation of small amplitude due to reflections from the first major discontinuity along the busbar. The ITRV is mainly determined by the busbar and line bay configuration of the substation. The ITRV is a physical phenomenon which is very similar to the short-line fault. Compared with the short-line fault, the first voltage peak is rather low, but the time to the first peak is extremely short, that is within the first microseconds after current zero. Therefore the thermal mode of interruption may be influenced.

If the circuit-breaker has a short-line fault rating the ITRV requirements are considered to be covered if the short-line fault tests are carried out using a line without time delay (see Sub-clause 6.104.5.2).

Since the ITRV is proportional to the busbar surge impedance and to the current, the ITRV requirements can be neglected for metal-enclosed switchgear because of the low surge impedance and for all switchgear with a rated short-circuit breaking current of less than 25 kA.

4.102.2 *Representation of rated TRV*

The following parameters are used for the representation of rated TRV:

a) Four-parameter reference line (see Figure 10, page 99):
u_1 = first reference voltage, in kilovolts
t_1 = time to each u_1, in microseconds
u_c = second reference voltage (TRV peak value), in kilovolts
t_2 = time to reach u_c, in microseconds

b) Two-parameter reference line (see Figure 11, page 100):
u_c = reference voltage (TRV peak value), in kilovolts
t_3 = time to reach u_c, in microseconds

c) Delay line of TRV (see Figures 10 and 11):
t_d = time delay, in microseconds
u' = reference voltage, in kilovolts
t' = time to reach u', in microseconds

the delay line starts on the time axis at the rated time delay and runs parallel to the first section of the reference line of rated TRV and terminates at the voltage u' (time-coordinate t').

d) ITRV (see Figure 12, page 101):
u_i = reference voltage (ITRV peak), in kilovolts
t_i = time to reach u_i, in microseconds

the rate of rise of the ITRV is dependent on the short-circuit current interrupted and its amplitude depends upon the distance to the first discontinuity along the busbar. The rated ITRV is expressed firstly as a straight line drawn between the origin and the point (u_i, t_i) and secondly as a horizontal straight line drawn from the point (u_i, t_i) to intersect the delay line of the specified TRV at point A.

4.102.3 *Standard values of rated TRV*

Standard values of rated TRV for three-pole circuit-breakers of rated voltages below 100 kV, make use of two parameters. Values are given in Table IIA for rated voltages Series I. Table IIB for rated voltages Series II is under consideration.

For rated voltages of 100 kV and above, four parameters are used. Values are given in Table IIC for a first-pole-to-clear factor of 1.3 for rated voltages from 100 kV to 170 kV. Table IID gives values appropriate to a first-pole-to-clear factor of 1.5 for this range of rated voltages. Table IIE gives values for rated voltages of 245 kV and above.

For rated breaking currents greater than 50 kA and voltages 100 kV and above, it may be justified and more economical to use circuit-breakers having lower capabilities in terms of rate of rise of the TRV. Such cases shall be subject to agreement between manufacturer and user.

TABLE IIA

Standard values of rated transient recovery voltage
Rated voltages Series I
Representation by two parameters—First-pole-to-clear factor 1.5

Rated voltage	TRV peak value	Time	Time delay	Voltage	Time	Rate of rise
U (kV)	u_c (kV)	t_3 (μs)	t_d (μs)	u' (kV)	t' (μs)	u_c/t_3 (kV/μs)
3.6	6.2	40	6	2.1	19	0.15
7.2	12.3	52	8	4.1	25	0.24
12	20.6	60	9	6.9	29	0.34
17.5	30	72	11	10	35	0.42
24	41	88	13	14	42	0.47
36	62	108	16	21	52	0.57
52	89	132	7	30	51	0.68
72.5	124	166	8	41	64	0.75

$u_c = 1.4 \cdot 1.5 \sqrt{\frac{2}{3}} U$; $t_d = 0.15\, t_3$ for $U < 52$ kV;

$u' = \frac{1}{3} u_c$; $t_d = 0.05\, t_3$ for $U \geq 52$ kV.

TABLE IIB

Standard values of rated transient recovery voltage
Rated voltages Series II
Representation by two parameters — First-pole-to-clear factor 1.5

Under consideration.

TABLE IIC

Standard values of rated transient recovery voltage
Rated voltages 100 kV to 170 kV
Representation by four parameters—First-pole-to-clear factor 1.3

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
100	106	53	149	159	2	53	29	2.0
123	131	65	183	195	2	65	35	2.0
145	154	77	215	231	2	77	40	2.0
170	180	90	253	270	2	90	47	2.0

$u_1 = 1.3 \sqrt{\frac{2}{3}} U$; $t_2 = 3\, t_1$; $u_c = 1.4\, u_1$; $u' = \frac{1}{2} u_1$.

TABLE IID

Standard values of rated transient recovery voltage
Rated voltages 100 kV to 170 kV
Representation by four parameters—First-pole-to-clear factor 1.5

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
100	122	61	171	183	2	61	33	2.0
123	151	75	211	225	2	75	40	2.0
145	178	89	249	267	2	89	46	2.0
170	208	104	291	312	2	104	54	2.0

$u_1 = 1.5 \sqrt{\frac{2}{3}}\, U;\ t_2 = 3\, t_1;\ u_c = 1.4\, u_1;\ u' = \frac{1}{2}\, u_1.$

TABLE IIE

Standard values of rated transient recovery voltage
Rated voltages from 245 kV and above
Representation by four parameters—First-pole-to-clear factor 1.3

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
245	260	130	364	390	2	130	67	2.0
300	318	159	446	477	2	159	82	2.0
362	384	192	538	576	2	192	98	2.0
420	446	223	624	669	2	223	113	2.0
525	557	279	780	837	2	279	141	2.0
765	812	406	1 137	1 218	2	406	205	2.0

$u_1 = 1.3 \sqrt{\frac{2}{3}}\, U;\ t_2 = 3\, t_1;\ u_c = 1.4\, u_1;\ u' = \frac{1}{2}\, u_1.$

The tables also indicate values of rate of rise, taken as u_c/t_3 and u_1/t_1, in the two-parameter and four-parameter cases respectively, which together with TRV peak values u_c may be used for purposes of specification of TRV.

The values given in the tables are prospective values. They apply to circuit-breakers for general transmission and distribution in three-phase systems having service frequencies of 50 Hz or 60 Hz and consisting of transformers, overhead lines and short lengths of cable.

In the case of single-phase systems or where circuit-breakers are for use in an installation having more severe conditions, the values shall be subject to agreement between manufacturer and user, particularly for the following cases:

a) circuit-breakers adjacent to generator circuits;

b) circuit-breakers directly connected to transformers without appreciable additional capacitance between the circuit-breaker and the transformer which provides more than 50% of the rated short-circuit breaking-current of the circuit-breaker;

c) circuit-breakers adjacent to series reactors.

In circuits having large cable networks directly on the source side, it may be more economical to use circuit-breakers having a lower rate of rise of rated transient recovery voltage, but in this case the values shall be subject to agreement between manufacturer and user.

The rated transient recovery voltage corresponding to the rated short-circuit breaking current on the occurrence of a terminal fault is used for testing at short-circuit breaking currents equal to the rated value. However, for testing at short-circuit breaking currents less than 100% of the rated value, other values of transient recovery voltage are specified (see Sub-clause 6.104.5), further additional requirements apply to circuit-breakers rated at 52 kV and above and having rated short-circuit breaking currents exceeding 12.5 kA, which may be called upon to operate in short-line fault conditions (see Sub-clause 4.105).

4.102.4 *Standard values of rated ITRV*

TABLE III

Standard values of rated initial transient recovery voltage
Rated voltages 100 kV and above

Rated voltage U (kV)	Multiplying factor to determine u_i as function of the r.m.s. value of the short-circuit breaking current I* f_i (kV/kA)		Time t_i (μs)
	50 Hz	60 Hz	
100	0.046	0.056	0.4
123	0.046	0.056	0.4
145	0.046	0.056	0.4
170	0.058	0.07	0.5
245	0.069	0.084	0.6
300	0.081	0.098	0.7
362	0.092	0.112	0.8
420	0.092	0.112	0.8
525	0.116	0.139	1.0
765	**	**	**

* The actual initial peaks are obtained by multiplying the figures of this column with the r.m.s. value of the short-circuit breaking current.

** Under consideration.

Note. — The values of Table III are deemed to cover both three-phase and single-phase faults and are based on the assumption that the busbar, including the elements connected to it (supports, current and voltage transformers, disconnectors, etc.), can be roughly represented by a resulting surge impedance Z_i of about 260 Ω. The relation between f_i and t_i is then:

$$f_i = t_i \cdot Z_i \cdot \omega \quad \sqrt{2}$$

ω corresponding to the rated frequency of the circuit-breaker

4.103 *Rated short-circuit making current*

The rated short-circuit making current, see Figure 8, page 98, of a circuit-breaker is that which corresponds to the rated voltage, and shall be 2.5 times the r.m.s. value of the a.c. component of its rated short-circuit breaking current (see Sub-clause 4.101).

4.104 *Rated operating sequence*

There are two alternative rated operating sequences as follows:

a) $$\mathrm{O}-t-\mathrm{CO}-t'-\mathrm{CO}$$

Unless otherwise specified:

t = 3 min for circuit-breakers not intended for rapid auto-reclosing

t = 0.3 s for circuit-breakers intended for rapid auto-reclosing (dead time)

t' = 3 min

Note. — Instead of t' = 3 min, other values: t' = 15 s (for rated voltages less than or equal to 52 kV) and t' = 1 min are also used for circuit-breakers intended for rapid auto-reclosing.

b) $$\mathrm{CO}-t''-\mathrm{CO}$$

with:

t'' = 15 s, for circuit-breakers not intended for rapid auto-reclosing

where:

O represents an opening operation

CO represents a closing operation followed immediately (that is, without any intentional time-delay) by an opening operation

t, t' and t'' = time-intervals between successive operations

t and t' = should always be expressed in minutes or in seconds

t'' = should always be expressed in seconds

If the dead time is adjustable, the limits of adjustment shall be specified.

4.105 *Rated characteristics for short-line faults*

Rated characteristics for short-line faults are required for three-pole circuit-breakers designed for direct connection to overhead transmission lines and having a rated voltage of 52 kV and above and a rated short-circuit breaking current exceeding 12.5 kA. These characteristics relate to the breaking of a single-phase earth fault in a system with earthed neutral.

Note. — For the purpose of this standard, a single-phase test at the voltage to earth is deemed to cover all types of short-line fault. In this context it is considered immaterial that in isolated neutral systems, single-phase earth faults do not subject a circuit-breaker to short-line fault conditions.

The short-line fault circuit is taken as composed of a supply circuit on the source side of the circuit-breaker and a short-line on its load side (see Figure 13, page 102), with the following rated characteristics:

a) Rated supply circuit characteristics:

Voltage equal to the phase-to-earth voltage $U/\sqrt{3}$ corresponding to the rated voltage U of the circuit-breaker.

Short-circuit current, in case of terminal fault, equal to the rated short-circuit breaking current of the circuit-breaker.

Prospective transient recovery voltage, in case of terminal fault, given by the standard values in Tables IVA, IVB and IVC.

ITRV characteristics derived from Table III.

b) Rated line characteristics:

Standard values of rated surge impedance Z, rated peak factor k and time delay t_{dL} are given in Table V.

The method for calculation of transient recovery voltages from rated characteristics is given in Appendix AA.

TABLE IVA

Standard values of rated transient recovery voltage of the supply circuit for short-line faults

Rated voltages Series I—Representation by two parameters

Rated voltage U (kV)	TRV peak value u_c (kV)	Time t_3 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_c/t_3 (kV/μs)
52	59	132	7	20	51	0.45
72.5	83	166	8	28	64	0.50

$u_c = 1.4 \sqrt{\frac{2}{3}} U$; $t_d = 0.05\, t_3$; $u' = \frac{1}{3} u_c$.

TABLE IVB

Standard values of rated transient recovery voltage of the supply circuit for short-line faults

Rated voltages Series II — Representation by two parameters

Under consideration.

TABLE IVC

Standard values of rated transient recovery voltage of the supply circuit for short-line faults

Rated voltages 100 kV and above—Representation by four parameters

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
100	82	41	114	123	2	41	22	2.0
123	100	50	141	150	2	50	27	2.0
145	118	59	166	177	2	59	32	2.0
170	139	69	194	207	2	69	37	2.0
245	200	100	280	300	2	100	52	2.0
300	245	122	343	366	2	122	63	2.0
362	296	148	414	444	2	148	76	2.0
420	343	171	480	513	2	171	88	2.0
525	429	214	600	642	2	214	109	2.0
765	625	312	874	936	2	312	158	2.0

$u_1 = \sqrt{\frac{2}{3}} U$; $t_2 = 3\, t_1$; $u_c = 1.4\, u_1$; $u' = \frac{1}{2} u_1$.

TABLE V

Standard values of rated line characteristics for short-line faults

Rated voltage U (kV)	Number of conductors per phase	Rated surge impedance Z (Ω)	Rated peak factor k	RRRV factor s* (kV/μs kA) 50 Hz	RRRV factor s* (kV/μs kA) 60 Hz	Time delay t_{dl}** (μs)
≤170	1 to 4	450	1.6	0.200	0.240	0.2
≥245						0.5

* For the RRRV factor s, see Appendix AA.

** A local capacitance on the line side of the circuit-breaker (e.g. disconnector, current and voltage transformer) produces a slower rate-of-rise of the line side voltage in its very initial stage. This is taken into account by introducing a line side time delay t_{dL}. This capacitance does not have any influence upon the surge impedance of the actual line.

For determination of the line side time delay and the rate-of-rise of the line side voltage, see figure 14, page 102.

4.106 *Rated out-of-phase breaking current*

The rated out-of-phase breaking current is the maximum out-of-phase current that the circuit-breaker shall be capable of breaking under the conditions of use and behaviour prescribed in this standard in a circuit having a recovery voltage as specified below.

The specification of a rated out-of-phase breaking current is not mandatory. If a rated out-of-phase breaking current is assigned, the following applies:

a) The power frequency recovery voltage shall be $2.0/\sqrt{3}$ times the rated voltage for earthed neutral systems and $2.5/\sqrt{3}$ times the rated voltage for other systems.

b) The transient recovery voltage shall be in accordance with table:

- VIA, for circuit-breakers with rated voltages below 100 kV intended to be used in systems other than earthed neutral systems.
- VIB, for circuit-breakers with rated voltages from 100 kV up to and including 170 kV intended to be used in earthed neutral systems.
- VIC, for circuit-breakers with rated voltages from 100 kV up to and including 170 kV intended to be used in systems other than earthed neutral systems.
- VID, for circuit-breakers with rated voltages 245 kV and above intended to be used in earthed neutral systems.

c) The rated out-of-phase breaking current shall be 25% of the rated short-circuit breaking current, unless otherwise specified.

The standard conditions of use with respect to the rated out-of-phase breaking current are as follows:

- Opening and closing operations carried out in conformity with the instructions given by the manufacturer for the operation and proper use of the circuit-breaker and its auxiliary equipment.
- Earthing condition of the neutral for the power system corresponding to that for which the circuit-breaker has been tested.
- Absence of a fault on either side of the circuit-breaker.

TABLE VIA

Standard values of rated transient recovery voltage for out-of-phase breaking
Rated voltages Series I—Representation by two parameters
Systems other than earthed neutral systems

Rated voltage U (kV)	TRV peak value u_c (kV)	Time t_3 (μs)	Rate of rise u_c/t_3 (kV/μs)
3.6	9.2	80	0.12
7.2	18.4	104	0.18
12	30.6	120	0.26
17.5	45	144	0.31
24	61	176	0.35
36	92	216	0.43
52	133	264	0.50
72.5	185	336	0.55

$u_c = 1.25 \cdot 2.5 \sqrt{\frac{2}{3}} U.$

TABLE VIB

Standard values of rated transient recovery voltages for out-of-phase breaking
Rated voltages 100 kV to 170 kV—Representation by four parameters
Earthed neutral systems

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Rate of rise u_1/t_1 (kV/μs)
100	163	106	204	318	1.54
123	201	130	251	390	1.54
145	237	154	296	462	1.54
170	278	180	347	540	1.54

$u_1 = 2 \sqrt{\frac{2}{3}} U;\ u_c = 1.25\ u_1;\ t_2 = 3\ t_1.$

TABLE VIC

Standard values of rated transient recovery voltages for out-of-phase breaking
Rated voltages 100 kV to 170 kV—Representation by four parameters
Systems other than earthed neutral systems

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Rate of rise u_1/t_1 (kV/μs)
100	204	122	255	366	1.67
123	251	150	314	450	1.67
145	296	178	370	534	1.67
170	347	208	434	624	1.67

$u_1 = 2.5 \sqrt{\frac{2}{3}} U;\ t_2 = 3\ t_1;\ u_c = 1.25\ u_1.$

TABLE VId

Standard values of rated transient recovery voltage for out-of-phase breaking

Rated voltages 245 kV and above—Representation by four parameters

Earthed neutral systems

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Rate of rise u_1/t_1 (kV/μs)
245	400	260	500	780	1.54
300	490	318	612	954	1.54
362	591	384	739	1 152	1.54
420	686	446	857	1 338	1.54
525	857	558	1 071	1 674	1.54
765	1 249	812	1 562	2 436	1.54

$u_1 = 2\sqrt{\frac{2}{3}}U$; $t_2 = 3\,t_1$; $u_c = 1.25\,u_1$.

4.107 *Rated line-charging breaking current*

The rated line-charging breaking current is the maximum line-charging current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard and without exceeding the maximum permissible switching over-voltages specified by the manufacturer. Suggested values are given in Table IX.

The specification of a rated line-charging breaking current is confined to circuit-breakers intended to be used for switching three-phase overhead lines and having a rated voltage equal to or greater than 72.5 kV. Standard values are given in Table VII.

TABLE VII

Standard values of rated line-charging breaking current

Rated voltage U (kV)	Rated line-charging breaking current I_l (A)
72.5	10
100	20
123	31.5
145	50
170	63
245	125
300	200
362	315
420	400
525	500

Note. — For single conductor overhead lines operating at 50 Hz, the rated line-charging breaking currents indicated in Table VII imply a length in kilometres approximately equal to 1.2 times the rated voltage of the circuit-breaker in kilovolts.

4.108 *Rated cable-charging breaking current*

The rated cable-charging breaking current is the maximum cable-charging current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard and without exceeding the appropriate maximum permissible switching overvoltages specified by the manufacturer. Suggested values are given in Table IX.

The specification of a rated cable-charging breaking current to a circuit-breaker is not mandatory but is made on request, and is considered unnecessary for circuit-breakers of rated voltages equal to or less than 24 kV. If assigned, it is recommended that the rated cable-charging breaking current be in accordance with Table VIII.

TABLE VIII

Standard values of rated cable-charging breaking current

Rated voltage U (kV)	Rated cable-charging breaking current I_c (A)
3.6	10
7.2	10
12	25
17.5	31.5
24	31.5
36	50
52	80
72.5	125
100	125
123	140
145	160
170	160
245	250
300	315
362	355
420	400
525	500

Note. — The values of Table VIII correspond to the normal maximum requirements of the majority of power systems. Cable-charging currents in excess of these values should be the subject of special agreement between manufacturer and user.

4.109 *Rated single capacitor bank breaking current*

The rated single capacitor bank breaking current is the maximum capacitor current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard and without exceeding the maximum permissible switching overvoltages specified by the manufacturer. Suggested values are given in Table IX, columns B.

This breaking current refers to the switching of a shunt capacitor bank where no shunt capacitors are connected to the source side of the circuit-breaker.

The specification of a rated single capacitor bank breaking current is not mandatory.

Values of rated single capacitor bank breaking currents should be selected from the R 10 series.

4.110 *Rated back-to-back capacitor bank breaking current*

The rated back-to-back capacitor bank breaking current is the maximum capacitor current that the circuit-breaker shall be capable of breaking at its rated voltage under the conditions of use and behaviour prescribed in this standard and without exceeding the maximum permissible switching overvoltages specified by the manufacturer. Suggested values are given in Table IX, columns B.

This breaking current refers to the switching of a shunt capacitor bank where one or several shunt capacitor banks are connected to the source side of the circuit-breaker giving an inrush making current equal to the rated capacitor bank inrush making current.

The specification of a rated back-to-back capacitor bank breaking current is not mandatory.

Values of rated back-to-back capacitor bank breaking currents should be selected from the R 10 series.

Note. — Similar conditions could apply for switching of cables.

4.111 *Rated capacitor bank inrush making current*

The rated capacitor bank inrush making current is the peak value of the current that the circuit-breaker shall be capable of making at its rated voltage and with a frequency of the inrush current appropriate to the service conditions (see Appendix BB).

The specification of a rated capacitor bank inrush making current is mandatory for circuit-breakers that have a rated back-to-back capacitor bank breaking current.

Values of rated capacitor bank inrush making currents should be selected from the R 10 series.

Notes 1. — In service, the frequency of the inrush current is normally in the range 2-5 kHz.

2\. — The circuit-breaker is considered to be suitable for any frequency of the inrush current lower than that for which it has been tested.

TABLE IX

Suggested values of maximum permissible switching overvoltages when interrupting line-charging, cable-charging and single capacitor bank breaking current

Rated voltage (r.m.s. value)	Rated lightning impulse withstand voltage* (peak value)	Maximum permissible switching overvoltage to earth			
		A		B	
(kV)	(kV)	(Peak value) (kV)	$\frac{\text{Col. (3)}}{\text{Col. (1)}\sqrt{\frac{2}{3}}}$ (p.u.)	(Peak value) (kV)	$\frac{\text{Col. (5)}}{\text{Col. (1)}\sqrt{\frac{2}{3}}}$ (p.u.)
(1)	(2)	(3)	(4)	(5)	(6)
3.6	20 40	8.8 13.2	3 4.5	7.3 7.3	2.5 2.5
7.2	40 60	17.6 26.4	3 4.5	14.7 14.7	2.5 2.5

TABLE IX *(continued)*

Rated voltage (r.m.s. value) (kV)	Rated lightning impulse withstand voltage* (peak value) (kV)	Maximum permissible switching overvoltage to earth			
		A		B	
		(Peak value) (kV)	$\frac{\text{Col. (3)}}{\text{Col. (1)} \sqrt{\frac{2}{3}}}$ (p.u.)	(Peak value) (kV)	$\frac{\text{Col. (5)}}{\text{Col. (1)} \sqrt{\frac{2}{3}}}$ (p.u.)
(1)	(2)	(3)	(4)	(5)	(6)
12	60 75	29.5 39.2	3 4	24.5 24.5	2.5 2.5
17.5	75 95	43 57	3 4	35.7 35.7	2.5 2.5
24	95 125	59 74	3 3.8	49 49	2.5 2.5
36	145 170	88 112	3 3.8	73 73	2.5 2.5
52	250	149	3.5	106	2.5
72.5	325	207	3.5	148	2.5
100	380 450	246 286	3 3.5	204 204	2.5 2.5
123	450 550	302 352	3 3.5	251 251	2.5 2.5
145	550 650	356 415	3 3.5	297 297	2.5 2.5
170	650 750	417 487	3 3.5	348 348	2.5 2.5
245	850 950 1 050	540 600 600	2.7 3 3	400 400 400	2 2 2
300	950 1 050	637 735	2.6 3	490 490	2 2
362	1 050 1 175	710 800	2.4 2.7	592 592	2 2
420	1 300 1 425	790 895	2.3 2.6	688 688	2 2
525	1 425 1 550	900 985	2.1 2.3	858 858	2 2
765	1 800 2 100	1 125 1 250	1.8 2	1 125 1 250	1.8 2

* The insulation level is indicated in this table by the rated lightning impulse withstand voltage; the corresponding rated power-frequency or switching impulse withstand voltage can be ascertained from Tables I to IV of IEC Publication 694.

Notes 1. — These values apply only to the test conditions of Sub-clause 6.111. Other overvoltages such as, for instance, those appearing when reclosing a line with trapped charges and when breaking a small inductive current, as well as phase-to-phase overvoltages, are not covered by this table.

2. — These values cannot always guarantee that phase-to-phase flashovers will not occur.

3. — Maximum permissible switching overvoltages for rated voltages of Series II, which are based on current practice in the United States of America and Canada, are under consideration.

4. — The values of columns A apply to circuit-breakers for general use intended for switching unloaded lines and cables of the types most generally used in power systems.

The values of columns B apply to circuit-breakers for special use intended for switching capacitor banks or no-load lines and cables in power systems where there are special insulation co-ordination problems such as, for instance, limitation of energy absorption by surge diverters, spark-over of spark-gaps, etc.

5. — At 245 kV and above, only earthed neutral systems and capacitor banks, if any, with earthed neutral, are considered for the application of the values of columns B.

4.112 *Rated small inductive breaking current*

Under consideration.

4.113 *Rated time quantities*

Rated values may be assigned to the following time quantities:

- opening time;
- break time;
- closing time;
- open-close time;
- reclosing time;
- close-open time.

Rated time quantities are based on:

- rated values for supply voltages of closing and opening devices and auxiliary circuits (see Sub-clause 4.8);
- rated value for supply frequency of closing and opening devices and auxiliary circuits (see Sub-clause 4.9);
- rated values for pressures of compressed gas supply for operation and for interruption (see Sub-clause 4.10);
- rated value for pressure of hydraulic supply for operation;
- an ambient air temperature of 20 ± 5°C. If tests are carried out at other ambient temperatures, agreement between manufacturer and user may be necessary for interpretation of the results.

Note. — Usually it is not practical to assign a rated value of make time or of make-break time due to the variation of the pre-arcing time.

4.113.1 *Rated break time*

The maximum break time determined during Test-duties 2, 3 and 4 of Sub-clauses 6.106.2, 6.106.3 and 6.106.4 with the circuit-breaker operated at auxiliary supply voltage and frequency and pressures of pneumatic or hydraulic supply at their rated values and at an ambient air temperature of 20 + 5°C (see Sub-clause 4.113) shall not exceed the rated break time.

Notes 1. — According to Sub-clause 6.102.2 the basic short-circuit test-duties should be carried out at minimum voltage or pressure of the operating devices. In order to verify the rated break time during these test-duties the recorded maximum break time should be amended to take account of the lower auxiliary supply voltage and pressure as follows:

$t_b \geqslant t_1 - (t_2 - t_3)$

where:

t_b = rated break time
t_1 = maximum recorded break time during Test-duties 2, 3 and 4.
t_2 = opening time recorded on no-load with auxiliary supply voltage and pressures of compressed gas supply as used during Test-duties 2, 3 and 4
t_3 = rated opening time

If the break time determined according to this procedure exceeds the rated break time the test-duty which has given the longest break time may be repeated with auxiliary supply voltage and frequency and pressure of pneumatic or hydraulic supply at their rated values and if applicable, at rated pressure of the interrupting medium.

2. — For single-phase tests simulating a three-phase operation, the recorded break time, amended according to Note 1, may exceed the rated break time by 0.1 cycle because in these cases the current zeros occur less frequently than in the three-phase case.

3. — The break time during a make-break operation of Test-duty 4 should not exceed the rated break time by more than 0.5 cycle.

4.114 *Co-ordination of rated values*

Co-ordinated values of rated voltages (Sub-clause 4.1), short-circuit breaking-currents (Sub-clause 4.101) and rated normal currents (Sub-clause 4.4) are given in Tables XA to XC.

The co-ordination tables are not mandatory and are intended to be used as a guide for preferred values. Therefore a circuit-breaker with another combination of the rated values is not outside the IEC Standard for circuit-breakers.

TABLE XA

Co-ordination table of rated values for circuit-breakers

Rated voltage U (kV)	Rated short-circuit breaking current I_{sc} (kA)	Rated normal current I_n (A)							
3.6	10	400							
	16		630		1 250				
	25				1 250	1 600		2 500	
	40				1 250	1 600		2 500	4 000
7.2	8	400							
	12.5	400	630		1 250				
	16		630		1 250	1 600			
	25		630		1 250	1 600		2 500	
	40				1 250	1 600		2 500	4 000
12	8	400							
	12.5	400	630		1 250				
	16		630		1 250	1 600			
	25		630		1 250	1 600		2 500	
	40				1 250	1 600		2 500	4 000
	50				1 250	1 600		2 500	4 000
17.5	8	400	630		1 250				
	12.5		630		1 250				
	16		630		1 250				
	25				1 250				
	40				1 250	1 600		2 500	
24	8	400	630		1 250				
	12.5		630		1 250				
	16		630		1 250				
	25				1 250	1 600		2 500	
	40					1 600		2 500	4 000
36	8		630						
	12.5		630		1 250				
	16		630		1 250	1 600			
	25				1 250	1 600		2 500	
	40					1 600		2 500	4 000
52	8			800					
	12.5				1 250				
	20				1 250	1 600	2 000		
72.5	12.5			800	1 250				
	16			800	1 250				
	20				1 250	1 600	2 000		
	31.5				1 250	1 600	2 000		

Note. — The values of the rated voltage are those given Sub-clause 4.1.1 of IEC Publication 694 for Series I. The values of the rated short-circuit breaking current and rated normal current are selected from those given in Sub-clauses 4.101.1 and 4.4.

TABLE XB

The values given in this table show for information the present practice in the United States of America and Canada

Maximum rated voltage (kV)	Rated short-circuit breaking current at maximum rated voltage (kA)*	Minimum rated voltage (kV)*	Rated short-circuit breaking current at minimum rated voltage (kA)*	Rated normal current (A)					
4.76	6.1	2.3	13		1 250				
	8.8	3.5	12		1 250				
	18.0	3.5	24		1 250				
	29.0	3.85	36		1 250	2 000			
	41.0	4.0	49		1 250		3 150		
8.25	3.5	2.3	13	630					
	7.0	2.3	25	630	1 250	2 000			
	17.0	4.6	30		1 250				
	33.0	6.6	41		1 250	2 000			
15.0	5.8	4.0	22	630	1 250				
	9.3	6.6	21		1 250				
	9.8	4.0	37		1 250				
	18.0	11.5	23		1 250	2 000			
	19.0	6.6	43		1 250	2 000			
	28.0	11.5	36		1 250	2 000			
	37.0	11.5	48		1 250		3 150		
15.5	8.9	5.8	24	630					
	18.0	12.0	23		1 250				
	35.0	12.0	45		1 250				
	56.0	12.0	73			2 000	3 150	4 000	
	93.0	12.0	120						5 000
25.8	5.4	12.0	12	630					
	11.0	12.0	24		1 250				
38.0	22.0	23.0	36		1 250		3 150		
	36.0	24.0	57			2 000			
48.3	17.0	40.0	21		1 250				
72.5	19.0	60.0	23		1 250				
	37.0	66.0	41			2 000			

* Values more in line with IEC standard values are under consideration.

Note. — The values of the maximum rated voltage are those given in Sub-clause 4.1.1 of IEC Publication 694 for Series II. The values of rated normal current are selected from those given in Sub-clause 4.4. See note in Sub-clause 4.101 regarding interpolation of short-circuit breaking currents for intermediate voltages.

TABLE XC

Co-ordination table of rated values for circuit-breakers

Rated voltage U (kV)	Rated short-circuit breaking current I_{sc} (kV)	Rated normal current I_n (A)					
123	12.5	800	1 250				
	20		1 250	1 600	2 000		
	25		1 250	1 600	2 000		
	40			1 600	2 000		
145	12.5	800	1 250				
	20		1 250	1 600	2 000		
	25		1 250	1 600	2 000		
	31.5		1 250	1 600	2 000	3 150	
	40			1 600	2 000	3 150	
	50				2 000	3 150	
170	12.5	800	1 250				
	20		1 250	1 600	2 000		
	31.5		1 250	1 600	2 000	3 150	
	40			1 600	2 000	3 150	
	50			1 600	2 000	3 150	
245	20		1 250	1 600	2 000		
	31.5		1 250	1 600	2 000		
	40			1 600	2 000	3 150	
	50				2 000	3 150	
300	16		1 250	1 600			
	20		1 250	1 600	2 000		
	31.5		1 250	1 600	2 000	3 150	
	50			1 600	2 000	3 150	
362	20				2 000		
	31.5				2 000		
	40			1 600	2 000	3 150	
420	20			1 600	2 000		
	31.5			1 600	2 000		
	40			1 600	2 000	3 150	
	50				2 000	3 150	4 000
525	40				2 000	3 150	
765	40				2 000	3 150	

Note. — The values of rated voltage are those given in Sub-clauses 4.1.2 of IEC Publication 694, omitting 100 kV. The values of rated short-circuit breaking current and rated normal current are selected from those given in Sub-clauses 4.101.1 and 4.4.

5. Design and construction

5.1 *Requirements for liquids in circuit-breakers*

Sub-clause 5.1 of IEC Publication 694 is applicable.

5.2 *Requirements for gases in circuit-breakers*

Sub-clause 5.2 of IEC Publication 694 is applicable.

5.3 *Earthing of circuit-breakers*

Sub-clause 5.3 of IEC Publication 694 is applicable.

5.4 *Auxiliary equipment*

Auxiliary equipment is used in the control and auxiliary circuits of circuit-breakers.

Sub-clause 5.4 of IEC Publication 694 is applicable with the following additions:

- Connections shall withstand the stresses imposed by the circuit-breaker, especially those due to mechanical forces during operations.
- In the case of outdoor circuit-breakers all auxiliary equipment including the wiring shall be adequately protected against rain and humidity.
- Where auxiliary switches are used as position indicators, they shall indicate the end position of the circuit-breaker at rest, open or closed.
- Where special items of control equipment are used, they shall operate within the limits specified for supply voltages of auxiliary and control circuits, quenching and operating media, and be able to switch the loads which are stated by the circuit-breaker manufacturer.
- Special items of auxiliary equipment such as liquid-indicators, pressure indicators, relief valves, filling and draining equipment, heating and interlock contacts shall operate within the limits specified for supply voltages of auxiliary and control circuits and/or within the limits of use of quenching and operating media.
- The power consumption of heaters at rated voltage shall be within the tolerance of ±10% of the values stated by the manufacturer.

5.5 *Dependent power closing*

Sub-clause 5.5 of IEC Publication 694 is applicable with the following addition:

A circuit-breaker arranged for dependent power closing with external energy supply shall also be capable of opening immediately following the closing operation with the rated short-circuit making current.

5.6 *Stored energy closing*

Sub-clause 5.6 of IEC Publication 694 is applicable with the following addition to the first paragraph:

A circuit-breaker arranged for stored energy closing shall also be capable of opening immediately following the closing operation with the rated short-circuit making current.

5.7 *Operation of releases*

Sub-clause 5.7 of IEC Publication 694 is applicable with the following additions:

5.7.101 *Over-current release*

5.7.101.1 *Operating current*

An over-current release shall be marked with its rated normal current and its current setting range.

Within the current setting range, the over-current release shall always operate at currents of 110% and above of the current setting, and shall never operate at currents of 90% and below of this current setting.

5.7.101.2 *Operating time*

For an inverse time delay over-current release, the operating time shall be measured from the instant at which the over-current is established until the instant at which the release actuates the tripping mechanism of the circuit-breaker.

The manufacturer shall provide tables or curves, each with the applicable tolerances, showing the operating time as a function of current, between twice and six times the operating current. These tables or curves shall be provided for the extreme current settings together with the extreme settings of time delay.

5.7.101.3 *Resetting current*

If the current in the main circuit falls below a certain value, before the time delay of the over-current release has expired, the release shall not complete its operation and shall reset to its initial position.

The relevant information shall be given by the manufacturer.

5.7.102 *Multiple releases*

If a circuit-breaker is fitted with multiple releases for the same function, a defect in one release shall not disturb the function in the others.

5.8 *Low and high pressure interlocking devices*

Sub-clause 5.8 of IEC Publication 694 is replaced by the following:

All circuit-breakers having an energy storage in gas receivers or hydraulic accumulators (see Sub-clause 5.6.1 of IEC Publication 694) and all circuit-breakers except sealed pressure devices, using compressed gas for interruption (see Sub-clause 5.103) shall be fitted with low pressure interlocking device, and can also be fitted with high pressure interlocking device, set to operate at, or within, the appropriate limits of pressure stated by the manufacturer.

5.9 *Nameplates*

Sub-clause 5.9 of IEC Publication 694 is applicable with the following additions:

The nameplates of a circuit-breaker and its operating devices shall be marked in accordance with Table XI.

Coils of operating devices shall have a reference mark permitting the complete data to be obtained from the manufacturer.

Releases shall bear the appropriate data.

In addition, it is desirable that the year of manufacture of the circuit-breaker is recognizable.

The nameplate shall be visible in the position of normal service and installation.

5.101 *Requirements for simultaneity of poles*

When no special requirement with respect to simultaneous operation of poles is stated, the maximum difference between the instants of contacts touching during closing and the maximum difference between the instants of contacts separating during opening shall not exceed one half cycle of rated frequency.

Notes 1. — In some circumstances, the permissible deviation differs considerably from one half cycle (see e.g. Sub-clause 6.111.7) and in others (e.g. single-pole operation), this requirement is not applicable.

2. — For a circuit-breaker having separate poles the requirement is applicable when these operate in the same conditions; after a single-pole reclosing operation, the conditions of operation for the three mechanisms may not be the same.

5.102 *General requirement for operation*

A circuit-breaker including its operating devices shall be capable of completing its rated operating sequence (Sub-clause 4.104) in accordance with the relevant provisions of Sub-clauses 5.5 to 5.8 and Sub-clause 5.103.

This requirement is not applicable to auxiliary manual operating devices; where provided, these shall be used only for maintenance and for emergency operation on a dead circuit.

TABLE XI

Nameplate information

	Abbreviation	Unit	Circuit-breaker	Operating device	Condition: Marking required only if
(1)	(2)	(3)	(4)	(5)	(6)
Manufacturer			X	X	
Type designation and serial number			X	X	
Rated voltage	U	kV	X		
Rated lightning impulse withstand voltage	U_w	kV	X		
Rated switching impulse withstand voltage	U_s	kV	y		Rated voltage 300 kV and above
Rated frequency	f	Hz	y		Rating is not applicable at both 50 Hz and 60 Hz
Rated normal current	I_n	A	X		
Rated duration of short-circuit	t_{th}	s	y		Different from 1 s
Rated short-circuit breaking current	I_{sc}	kA	X		
First-pole-to-clear factor			y		Different from 1,3 for rated voltages 100 kV to 170 kV
Rated out-of-phase breaking current	I_d	kA	(X)		
Rated line-charging breaking current	I_l	A	y		Rated voltage 72.5 kV and above
Rated cable-charging breaking current	I_c	A	(X)		
Rated single capacitor bank breaking current	I_{sb}	A	(X)		
Rated back-to-back capacitor bank breaking current	I_{bb}	A	(X)		
Rated capacitor bank inrush making current	I_{bi}	kA	(X)		

TABLE XI *(continued)*

	Abbreviation	Unit	Circuit-breaker	Operating device	Condition: Marking required only if
(1)	(2)	(3)	(4)	(5)	(6)
Rated gas pressure for operation	p_{op}	MPa or bar		(X)	
Rated gas pressure for interruption	p_{cb}	MPa or bar	(X)		
Rated supply voltage of closing and opening devices		V		(X)	
Rated supply frequency of closing and opening devices		Hz		(X)	
Rated supply voltage of auxiliary circuits	U_a	V		(X)	
Rated supply frequency of auxiliary circuits		Hz		(X)	
Mass (including oil for oil circuit-breakers)	m	kg	y	y	More than 300 kg
Rated operating sequence			X		
Year of manufacture			(X)		
Temperature class			y	y	Different from −5 °C indoor −25 °C outdoor

X = the marking of these values is mandatory; blanks indicate the value zero.

(X) = the marking of these values is optional.

y = the marking of these values to the conditions in column (6).

Note. — The abbreviations in column (2) may be used instead of the terms in column (1). When terms of column (1) are used the word "rated" need not appear.

5.103 *Pressure limits of compressed gas for interruption in gas blast circuit-breakers*

The manufacturer shall state the maximum and minimum pressures of the compressed gas for interruption at which the circuit-breaker is capable of performing according to its ratings and at which the appropriate low and high-pressure interlocking devices shall be set (see Sub-clause 5.8).

For double-pressure gas-blast circuit-breakers, the manufacturer may specify pressure limits at which the circuit-breaker is capable of each of the following performances:

a) breaking its rated short-circuit breaking current i.e. an "O" operation;

b) making its rated short-circuit making current immediately followed by breaking its rated short-circuit breaking current i.e. a "CO" operating cycle;

c) for circuit-breakers intended for rapid auto-reclosing; breaking its rated short-circuit breaking current followed after a time interval t of the rated operating sequence (Sub-clause 4.104) by making its rated short-circuit making current immediately followed by again breaking its rated short-circuit breaking current i.e. an "O-t-CO" operating sequence.

The circuit-breakers shall be provided with energy storage of sufficient capacity for satisfactory performance of the appropriate operations at the corresponding minimum pressures stated.

Furthermore, for circuit-breakers having individual pumps or compressors the output of the pump or compressor and the capacity of the receivers shall be sufficient to provide for the performance of the rated operating sequence (Sub-clause 4.104) at all currents up to the rated short-circuit making and breaking currents of the circuit-breaker. The pressure at the commencement of the operating sequence shall be equal to the appropriate minimum pressure stated by the manufacturer in accordance with the above requirements, and with the pump or compressor operating normally. When appropriate the manufacturer may specify pressure limits for the operation of the pump or compressor.

5.104 *Vent outlets*

Vent outlets of circuit-breakers shall be so situated that a discharge of oil or gas or both will not cause electrical breakdown and is directed away from any location where persons may be present.

The construction shall be such that gas cannot collect at any point where ignition can be caused, during or after operation, by sparks arising from normal operation of the circuit-breaker or its auxiliary equipment.

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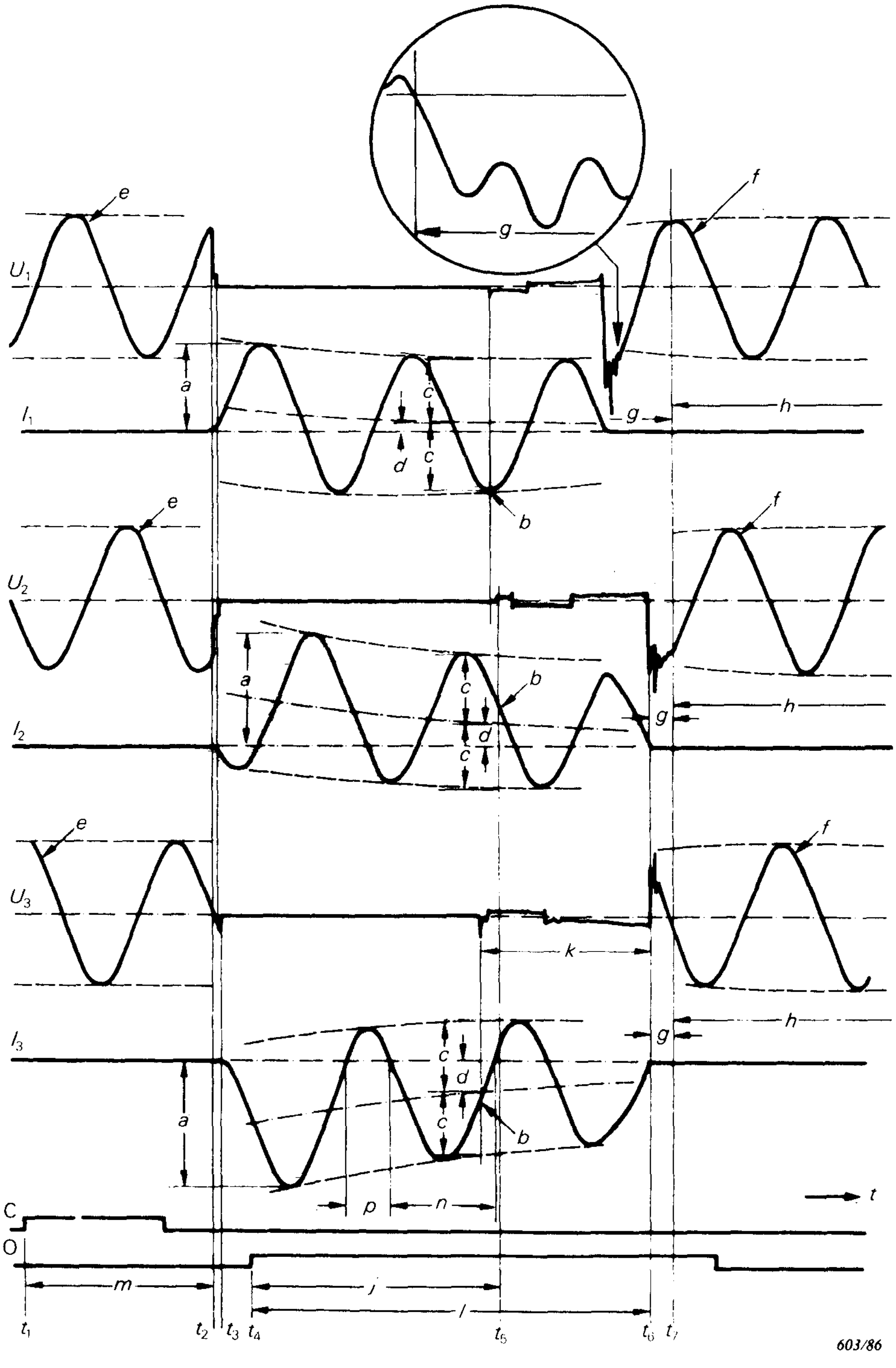

FIG. 1. — Typical oscillogram of a three-phase short-circuit make-break cycle.

Legend to Figure 1, opposite:

U_1	= voltage across the terminals of the first pole to clear	*a*	= (peak) making current
		b	= breaking current
I_1	= current in the first pole to clear	*c*	= peak value of the alternating component
U_2, U_3	= voltage across the terminals of the two other poles	*d*	= direct current component
I_2, I_3	= current in the two other poles	*e*	= applied voltage
C	= closing command, e.g. voltage across the terminals of the closing circuit	*f*	= recovery voltage
		g	= transient recovery voltage (restriking voltage)
O	= opening command, e.g. voltage across the terminals of the opening release	*h*	= power frequency recovery voltage
		j	= opening time
t_1	= the instant of initiation of the closing operation	*k*	= arcing time
t_2	= the instant when the current begins to flow in the main circuit	*l*	= break time
		m	= make time
t_3	= the instant when the current is established in all poles	*n*	= major loop
		p	= minor loop
t_4	= the instant of energizing the opening release		
t_5	= the instant when the arcing contacts have separated (or instant of initiation of the arc) in all poles		
t_6	= the instant of final arc extinction in all poles		
t_7	= the instant when the transient voltage phenomena have subsided in the last pole to clear		

Notes to the following Figures 2 to 7:

Notes 1. — In practice, there will be a time spread between the travel of the contacts of the three poles. For clarity the travel of the contacts in the figures is indicated with a single line for all three poles.

2. — In practice, there will be a time spread between both the start and end of current flow in the three poles. For clarity, both the start and end of current flow in the figures is indicated with a single line for all three poles.

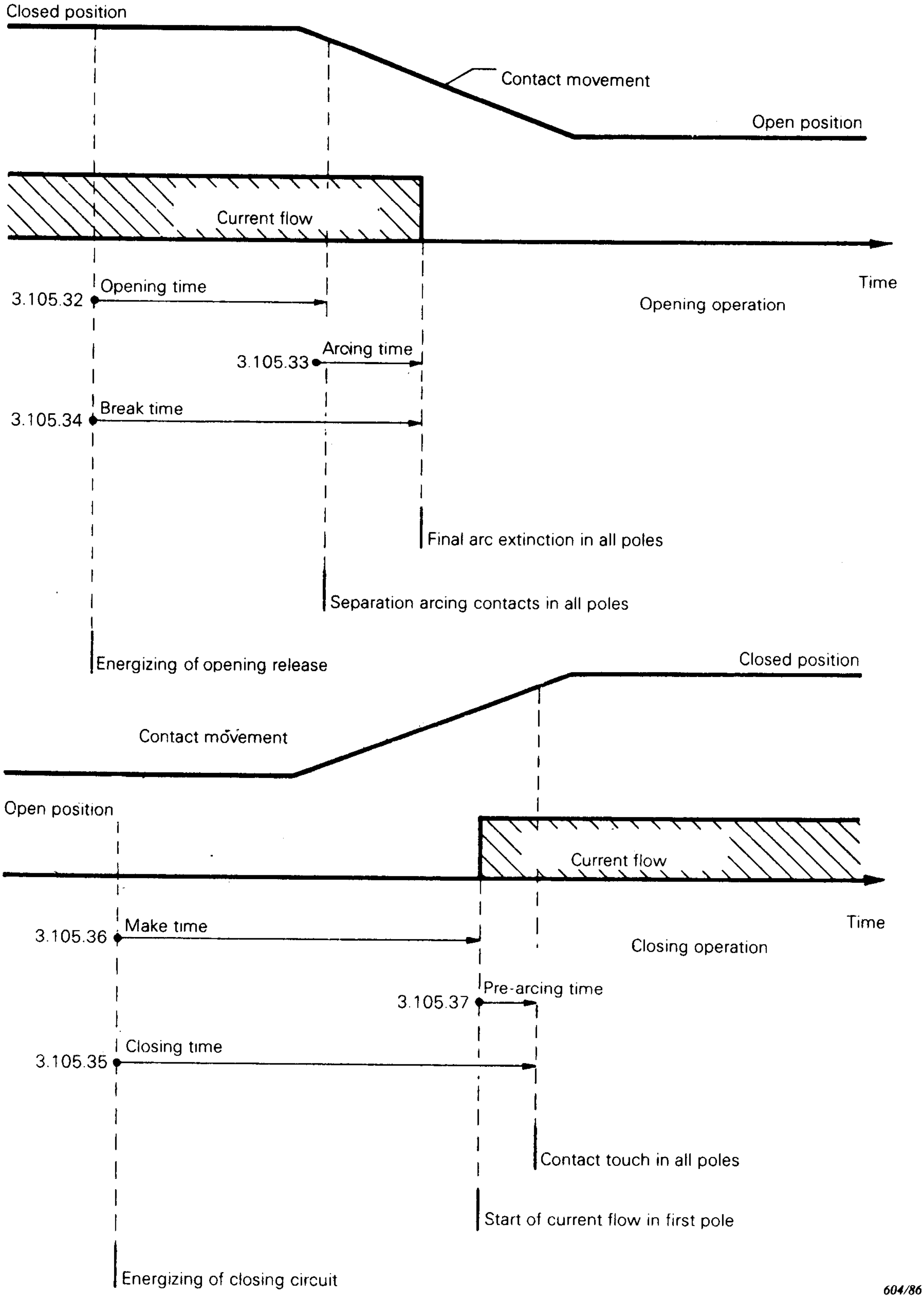

FIG. 2. — Circuit-breaker without switching resistors. Opening and closing operations.

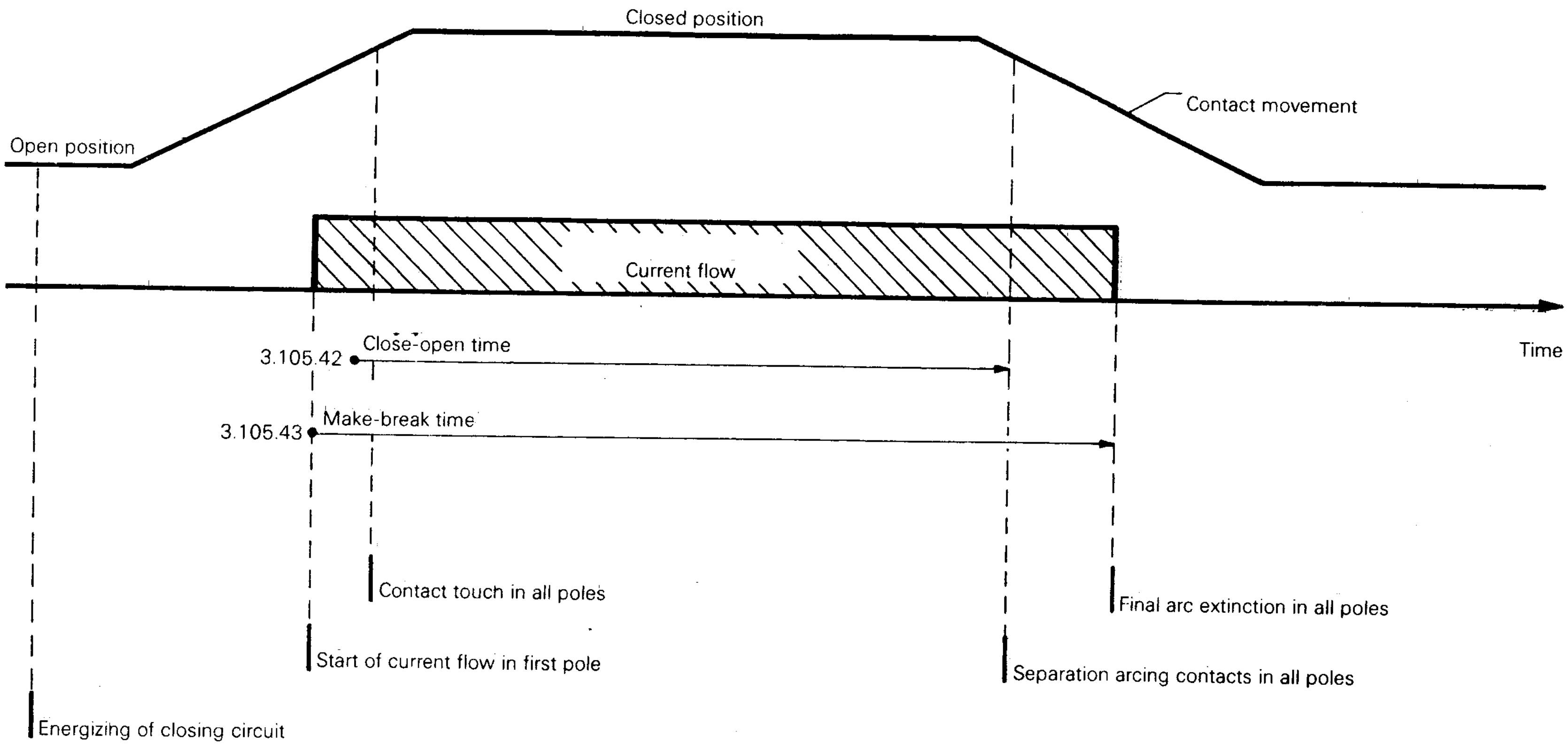

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FIG. 3. — Circuit-breaker without switching resistors. Close-open cycle.

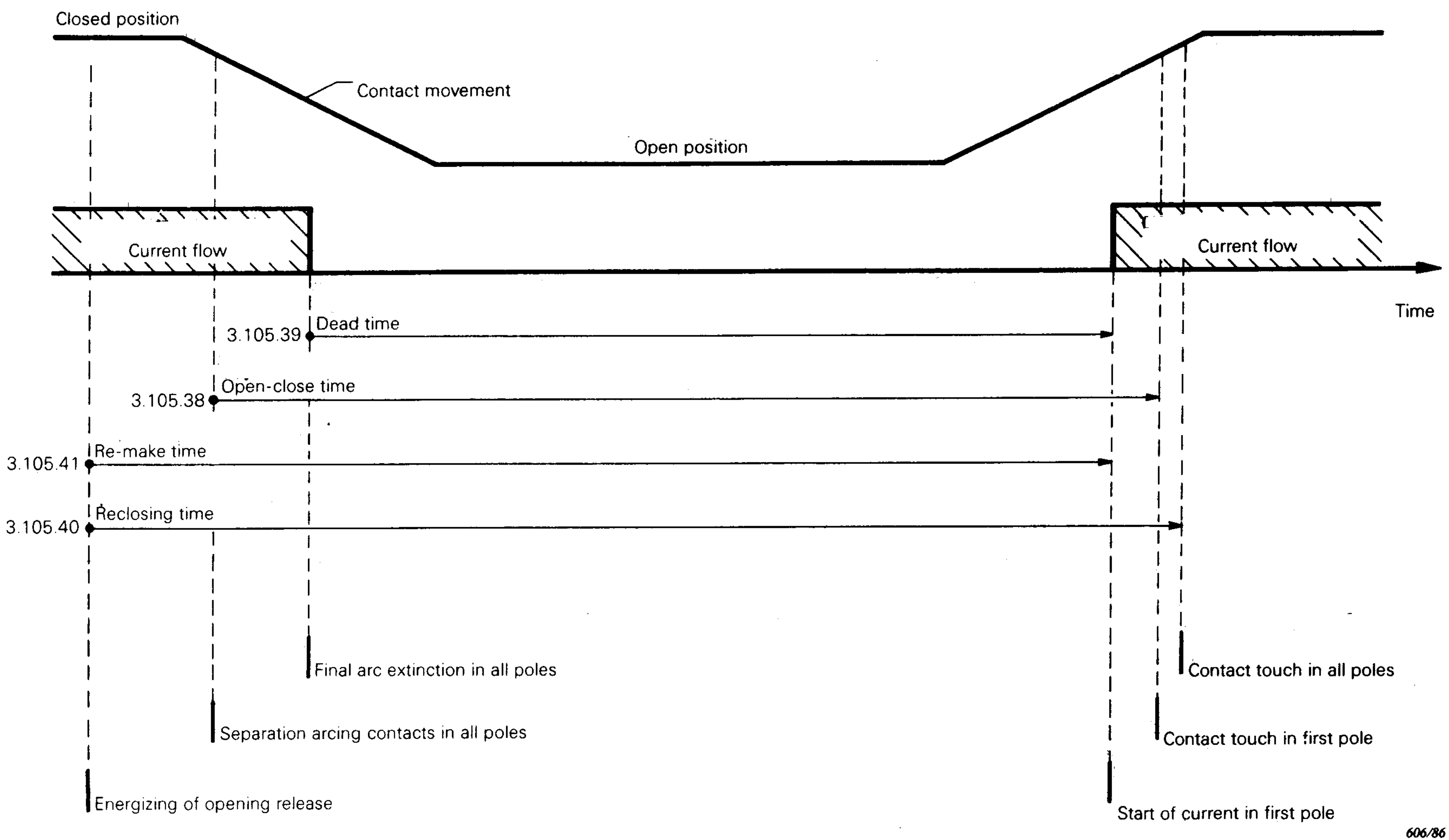


FIG. 4. — Circuit-breaker without switching resistors. Reclosing (auto-reclosing).

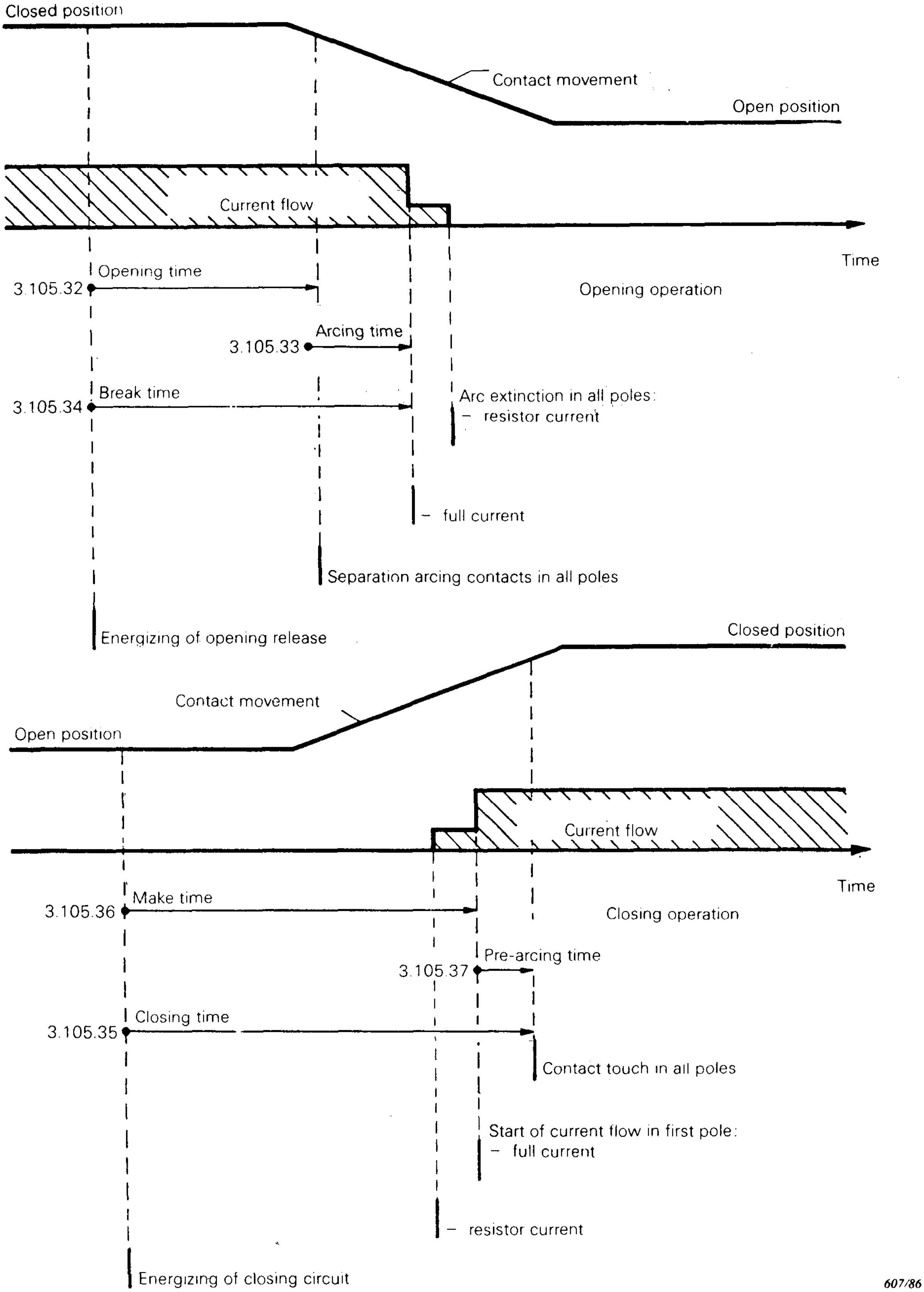


FIG. 5. — Circuit-breaker with switching resistors. Opening and closing operations.

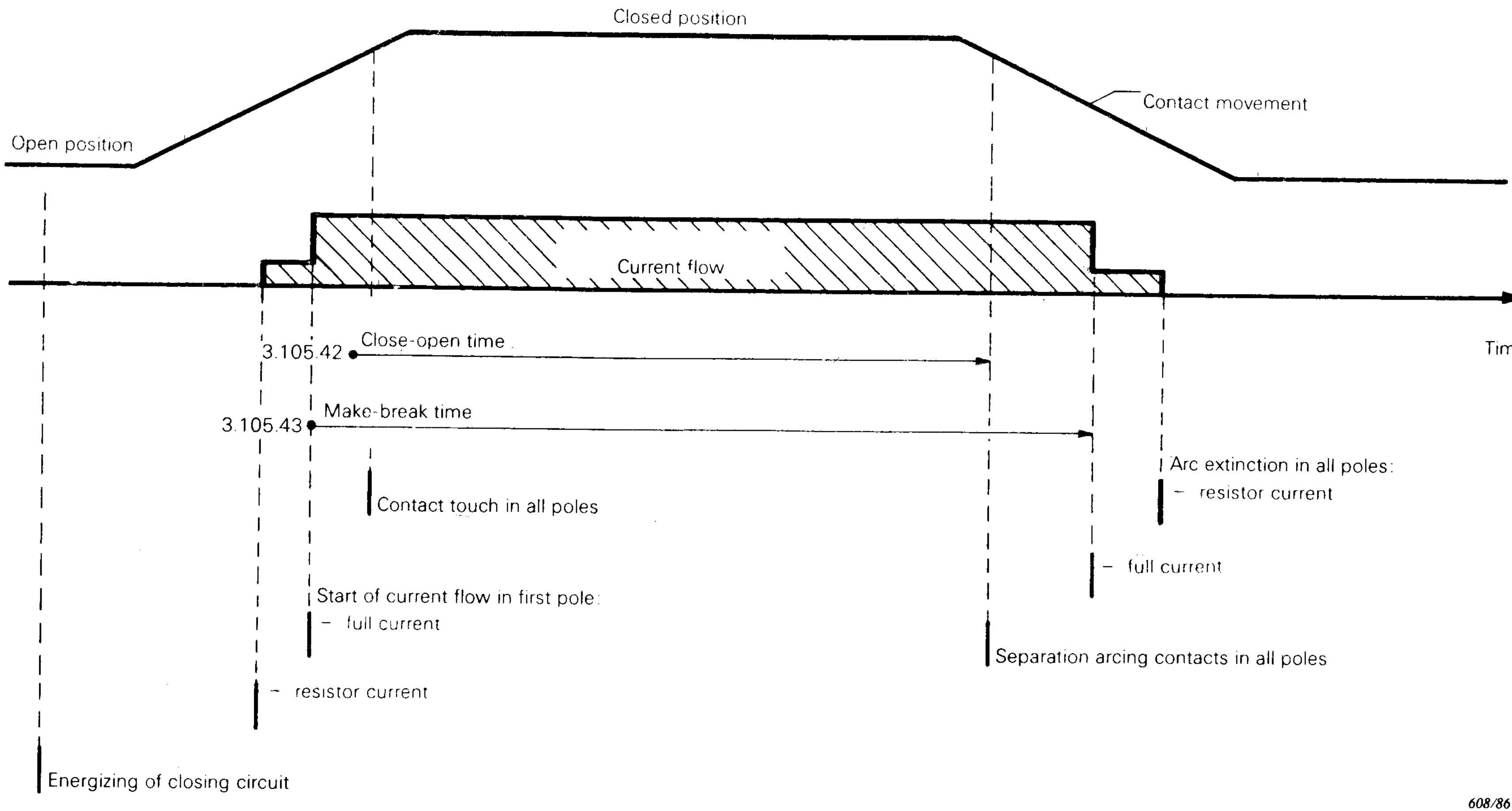


FIG. 6. — Circuit-breaker with switching resistors. Close-open cycle.

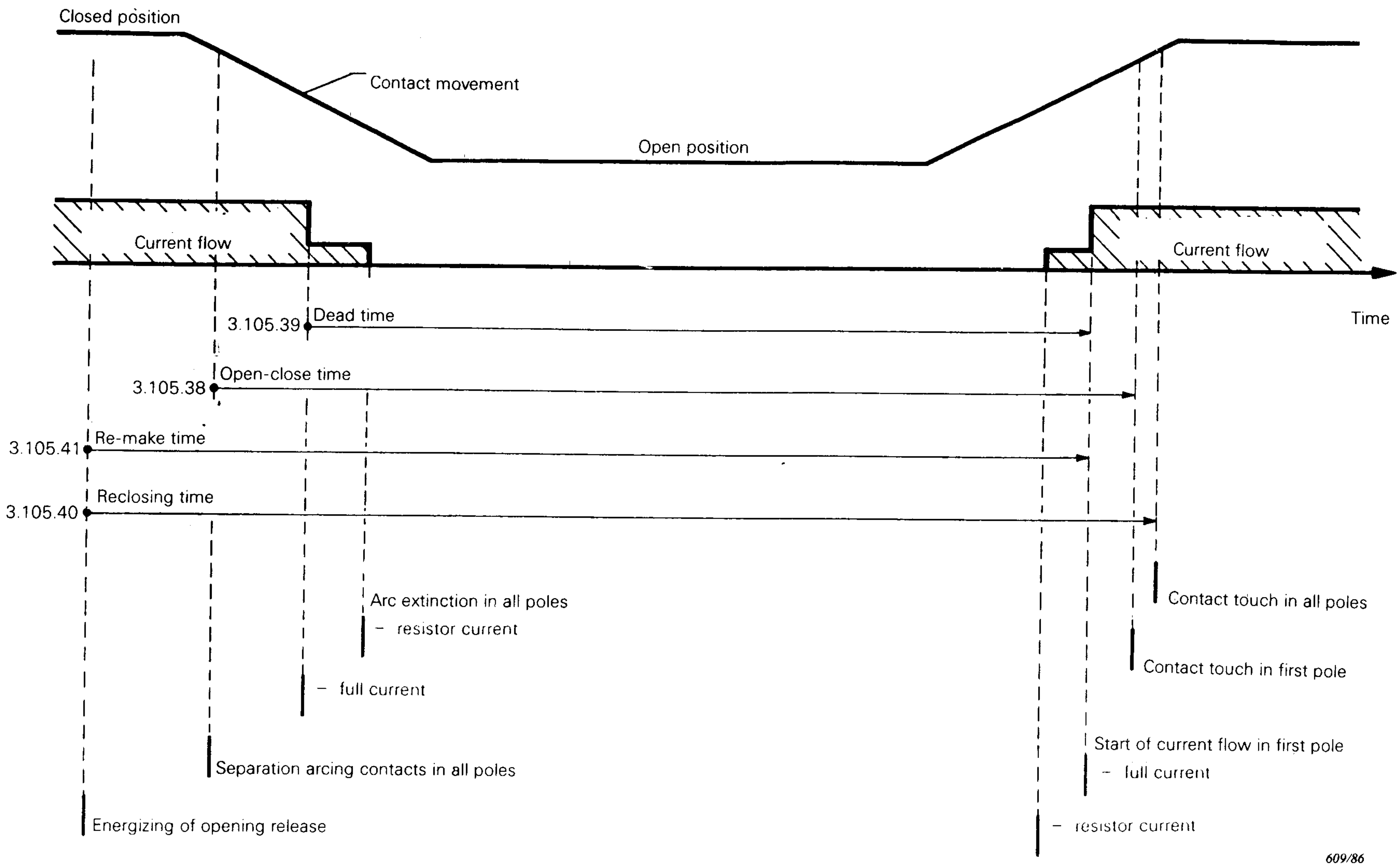
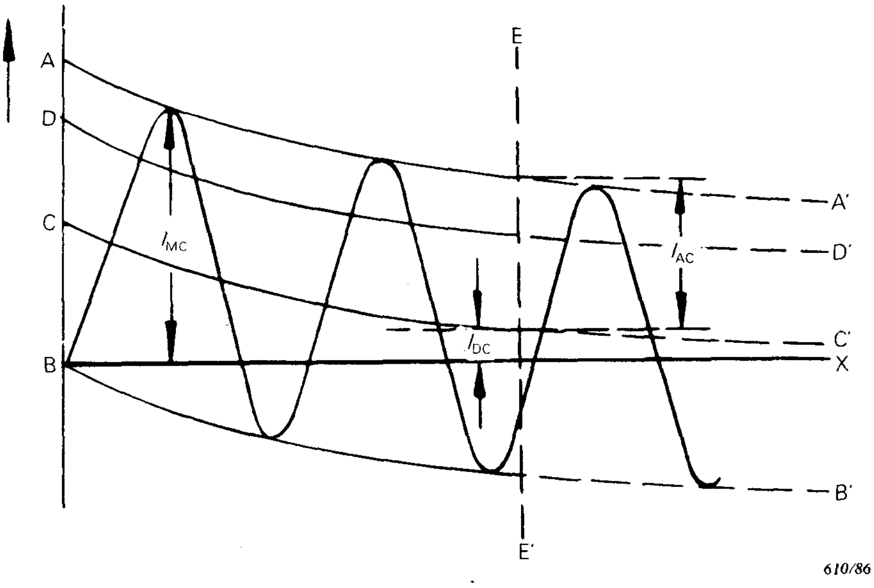


FIG. 7. — Circuit-breaker with switching resistors. Reclosing (auto-reclosing)



AA' BB'	=	envelope of current-wave
BX	=	normal zero line
CC'	=	displacement of current-wave zero-line at any instant
DD'	=	r.m.s. value of the a.c. component of current at any instant, measured from CC'
EE'	=	instant of contact separation (initiation of the arc)
I_{MC}	=	making current
I_{AC}	=	peak value of a.c. component of current at instant EE'
$\frac{I_{AC}}{\sqrt{2}}$	=	r.m.s. value of the a.c. component of current at instant EE'
I_{DC}	=	d.c. component of current at instant EE'
$\frac{I_{DC} \times 100}{I_{AC}}$	=	percentage value of the d.c. component

FIG. 8. — Determination of short-circuit making and breaking currents, and of percentage d.c. component.

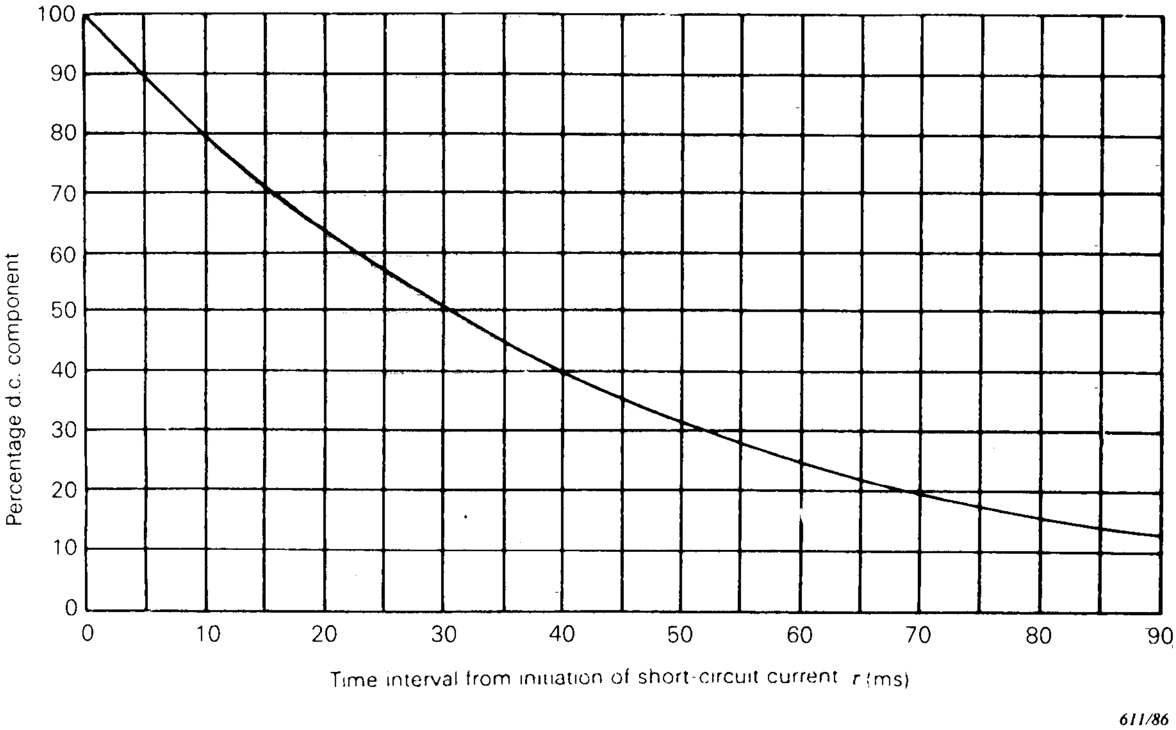


FIG. 9. — Percentage d.c. component in relation to time interval τ.

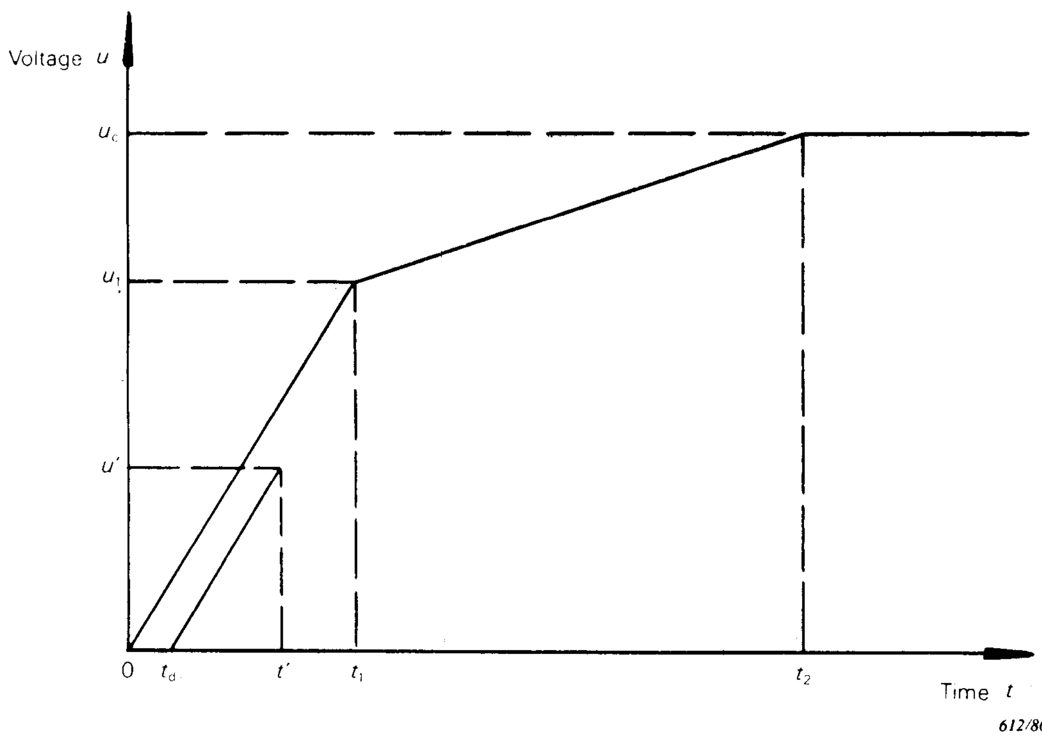


FIG. 10. — Representation of a specified TRV by a four-parameter reference line and a delay line.

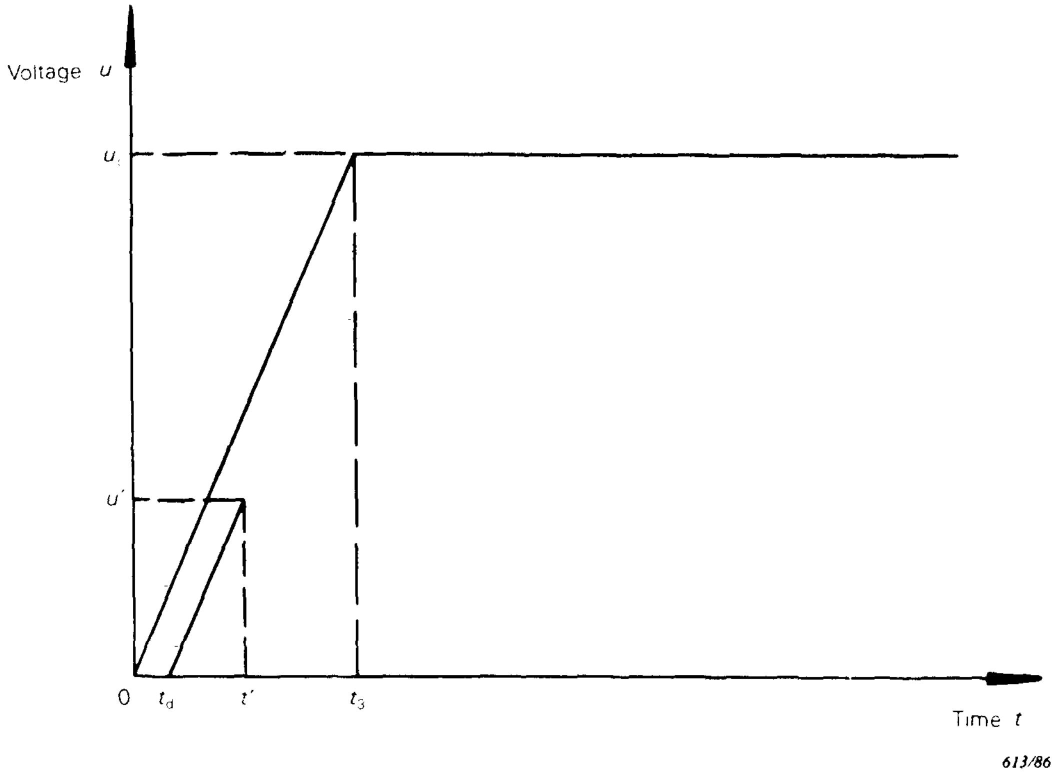
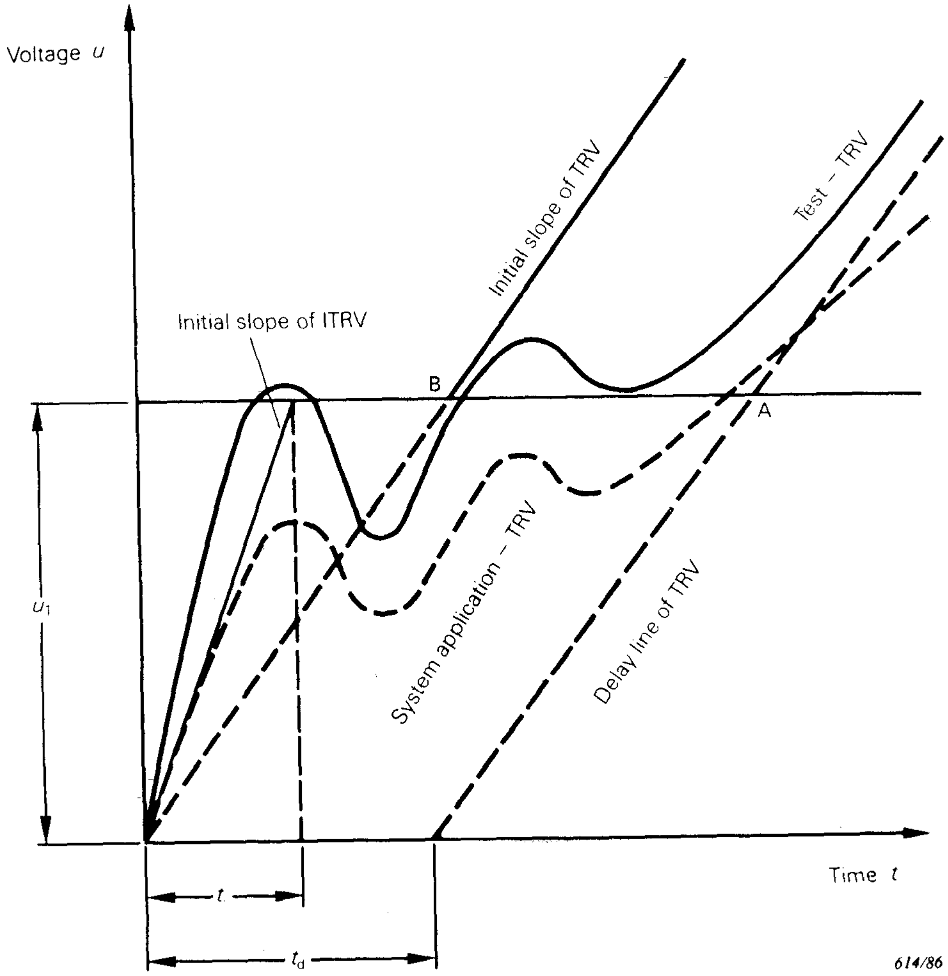


FIG. 11. — Representation of a specified TRV by a two-parameter reference line and a delay line.

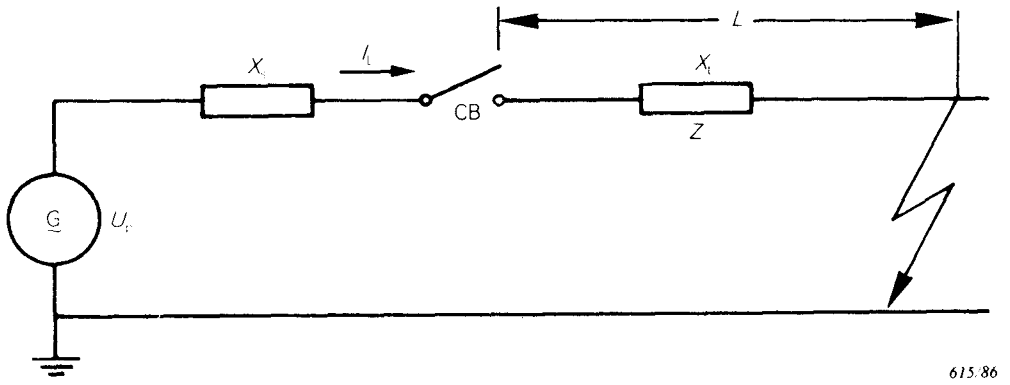


Note. — Slight displacement of TRV at t = O has been neglected.

A = intersection of ITRV envelope with TRV delay line

B = intersection of ITRV envelope with TRV envelope

FIG. 12. — Representation of ITRV and its relationship to the TRV.



G = source of power

U_p = voltage, phase-to-earth value : $U/\sqrt{3}$

I_l = short-line fault current

CB = circuit-breaker

X_s = reactance on source side

X_L = reactance on line side

Z = surge impedance of line

L = length of line to fault

FIG. 13. — Short-line fault circuit.

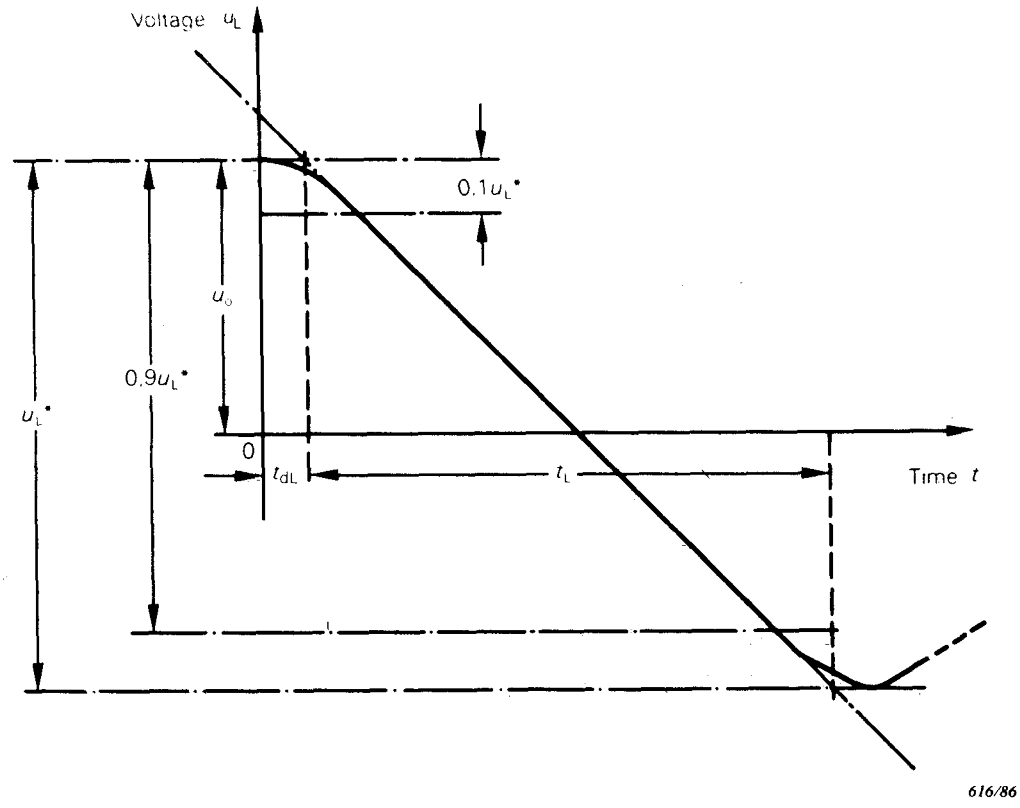


FIG. 14. — Example of a line-side transient voltage with time delay and rounded crest showing construction to derive the values u_L*, t_L and t_{dL}.

CHAPTER II: TESTS, SELECTION, ORDERS AND INSTALLATION

6. Type tests

Clause 6 of IEC Publication 694 is applicable with the following additions:

The type tests also include:

- mechanical and environmental tests, including mechanical operation test at ambient air temperature, low and high temperature tests, humidity test, test to prove operation under severe ice conditions and static terminal load test (see Sub-clause 6.101);
- short-circuit current making and breaking tests including terminal fault tests, short-line fault test, and also out-of-phase test (see Sub-clauses 6.103 to 6.110);
- capacitive current switching tests, including line-charging, cable-charging, single capacitor bank and back-to-back capacitor bank tests (see Sub-clause 6.111);
- magnetizing and small inductive current switching tests (see Sub-clause 6.112).

In principle, the individual type tests shall be made on a circuit-breaker in a new and clean condition, and the various type tests may be made at different times and at different locations.

Where tests are made on a circuit-breaker whose report of type tests has already been accepted, the responsibility of the manufacturer is limited by the specified values and not by the result obtained during the type tests previously made.

Details relating to records and reports of type tests for making, breaking and short-time current performance are given in Appendix CC.

6.1 *Dielectric tests*

6.1.1 *Ambient air conditions during tests*

Sub-clause 6.1.1 of IEC Publication 694 is applicable.

6.1.2 *Wet test procedure*

Sub-clause 6.1.2 of IEC Publication 694 is applicable with the following addition:

Note. — For dead tank circuit-breakers, see Note 1 of Sub-clause 6.1.7.

6.1.3 *Condition of circuit-breaker during dielectric tests*

Sub-clause 6.1.3 of IEC Publication 694 is applicable.

6.1.4 *Application of test voltage and test conditions*

Sub-clause 6.1.4 of IEC Publication 694 is applicable.

6.1.5 *Test voltages*

Sub-clause 6.1.5 of IEC Publication 694 is applicable.

6.1.6 *Lightning and switching impulse voltage tests*

Sub-clause 6.1.6 of IEC Publication 694 is applicable with the following addition:

a) Lightning impulse voltage tests

For rated voltages up to 245 kV and when the lower rated lightning impulse withstand voltages are chosen according to Sub-clause 4.2, a higher test voltage when testing the insulation across the open breaker may be required.

In these cases:

- for rated voltages from 100 kV to 245 kV, the test voltage shall be one of the rated lightning impulse withstand voltages according to Sub-clause 4.2 corresponding to the rated voltage of the circuit-breaker, subject to agreement between manufacturer and user;
- for rated voltages up to and including 72.5 kV, the test voltage shall be subject to agreement between manufacturer and user.

Subject to the manufacturer's approval, for circuit-breakers of rated voltage greater than or equal to 300 kV, tests with the circuit-breaker open may be performed avoiding the use of the power-frequency voltage source. In this case, two test series shall be performed:

- the first test series consists of the application, to each terminal in turn, of 15 consecutive impulses at a voltage equal to the sum of the rated lightning impulse withstand voltage U_w and the value $0.7\ U\sqrt{2}\ /\sqrt{3}$ (peak value), the opposite terminal being earthed. The other terminals, the terminal to which the voltage is applied and the base, may be insulated in such a way as to prevent disruptive discharges to earth;
- the second test series consists of the application, to each terminal in turn, of 15 consecutive impulses at the rated withstand voltage U_w. The other terminals and the base shall be earthed.

In general, this test is deemed to be more severe than that following the specified test procedure.

Note. — For rated voltages above 420 kV, this test procedure may not be appropriate. For these voltages other test methods are under consideration by IEC Technical Committee No. 42: High-voltage Testing Techniques.

b) Switching impulse voltage tests

For outdoor circuit-breakers dry tests shall be performed using voltage of positive polarity only.

With the circuit-breaker closed, the test voltage equal to the rated withstand voltage to earth shall be applied for each test condition of Table VIII of Sub-clause 6.1.4 in IEC Publication 694.

With the circuit-breaker open, two test series shall be performed:

- the first test series with a test voltage equal to the rated withstand voltage to earth for each test condition of Table VIII of IEC Publication 694;
- the second test series with a test procedure depending upon the intended application of the circuit-breaker, see Sub-clause 4.2.3.

For circuit-breakers intended for standard applications, the second test series is performed with a test voltage equal to the rated withstand voltage across the open circuit-breaker (IEC Publication 694, Sub-clause 4.2.3, Table IV, column (5)) for each test condition of Table VIII of IEC Publication 694.

Since in this case the applied voltage may be higher than the rated withstand voltage to earth, it is admissible to insulate the terminal to which the voltage is applied, the terminals of the other poles and the base in order to prevent disruptive discharges to earth.

As an alternative, for circuit-breakers intended for special applications, the second test series shall be performed with test voltages according to column (6) of Table IV in IEC Publication 694. For each test condition of Table X of Sub-clause 6.1.4 in IEC Publication 694, one terminal shall be energized with switching impulse voltage and the opposite terminal with power frequency voltage.

Subject to the manufacturer's approval this test can be performed avoiding the use of the power-frequency voltage source.

This test series consists of the application, to each terminal in turn, of impulses at a voltage equal to the sum of the switching impulse voltage and the value $U\sqrt{2} / \sqrt{3}$ (peak value), from column (6) of Table IV in IEC Publication 694, the opposite terminal being earthed. The other terminals, the terminal to which the voltage is applied and the base, may be insulated in such a way as to prevent disruptive discharges to earth.

In general, this test is deemed to be more severe than that following the specified test procedure.

Note. — For rated voltages above 420 kV, this test procedure may not be appropriate. For these voltages other test methods are under consideration by IEC Technical Committee No. 42.

6.1.7 *Power-frequency voltage tests*

Sub-clause 6.1.7 of IEC Publication 694 is applicable with the following addition:

a) For circuit-breakers having a rated voltage lower than 300 kV

If during a wet test a disruptive discharge on external self-restoring insulation occurs, this test shall be repeated in the same test condition and the circuit-breaker shall be considered to have passed this test successfully if no further disruptive discharge occurs.

Note. — In the case of dead tank circuit-breakers, when the bushings have been previously tested according to the relevant IEC Publication, tests under wet conditions can be omitted.

b) For circuit-breakers having a rated voltage 300 kV and above

With the circuit-breaker open, for each test condition (see Table IX of Sub-clause 6.1.4 in IEC Publication 694), the test voltage shall be applied simultaneously to the two terminals of each pole, using two different voltage sources in out-of-phase conditions, in order to obtain across the open breaker a voltage equal to 2.5 $U/\sqrt{3}$. Neither of the two voltage values applied to one terminal shall be higher than U. Total voltage values across the open breaker are given in Table IV of IEC Publication 694.

With the circuit-breaker open, subject to agreement with the manufacturer, tests may be performed using one single voltage source. In this case, a voltage equal to 2.5 $U/\sqrt{3}$ shall be applied for 1 min to each terminal of each pole in turn the opposite terminal and all normally live parts of other poles being earthed.

For this test it is admissible to insulate the base of the circuit-breaker from earth.

This test is more severe than that following the specified test procedure.

Note. — For special applications, the test voltage value of 2.5 $U/\sqrt{3}$, when testing the insulation across the open circuit-breaker, may be insufficient. In such cases higher test values may be used, subject to agreement between manufacturer and user.

6.1.8 *Artificial pollution tests*

Sub-clause 6.1.8 of IEC Publication 694 is applicable with the following addition:

Notes 1. — Appropriate tests for checking the open breaker insulation are under consideration.

2. — To obviate the necessity of erecting large circuit-breakers for test purposes alone, in the case of circuit-breakers of modular construction one single module may be tested. In this case, however, the test severity is different from that of the test of the complete pole.

6.1.9 *Partial discharge tests*

Sub-clause 6.1.9 of IEC Publication 694 is applicable with the following addition:

No partial discharge tests are required to be performed on the complete circuit-breaker. However, in the case of circuit-breakers using components for which a relevant IEC Publication exists including partial discharge measurements (e.g. bushings, see IEC Publication 137: Bushings for Alternating Voltages Above 1 000 V), evidence shall be produced by the manufacturer showing that those components have passed the partial discharge tests as laid down in the relevant IEC Publication.

6.1.10 *Tests on auxiliary and control circuits*

Sub-clause 6.1.10 of IEC Publication 694 is applicable.

6.2 *Radio interference voltage (r.i.v.) tests*

Radio interference voltage tests shall be performed by agreement between manufacturer and user. Sub-clause 6.2 of IEC Publication 694 is applicable with the following addition:

Tests may be performed on one pole of the circuit-breaker in both closed and open positions.

6.3 *Temperature-rise tests*

6.3.1 *Conditions of the circuit-breaker to be tested*

Sub-clause 6.3.1 of IEC Publication 694 is applicable.

6.3.2 *Arrangement of the equipment*

Sub-clause 6.3.2 of IEC Publication 694 is applicable with the following additions:

For a circuit-breaker not fitted with series connected accessories, the test shall be made with the rated normal current of the circuit-breaker.

For a circuit-breaker fitted with series connected accessories having a range of rated normal currents, the following tests shall be made:

a) a test of the circuit-breaker fitted with the series connected accessory having a rated normal current equal to that of the circuit-breaker, and made at the rated normal current of the circuit-breaker;

b) a series of tests of the circuit-breaker fitted with the intended accessories, and made with currents equal to the rated normal current of each accessory.

Note. — If the accessories can be removed from the circuit-breaker, and if it is evident that the temperature rise of the circuit-breaker and of the accessories do not appreciably influence each other, Test *b)* above may be replaced by a series of tests on the accessories alone.

6.3.3 *Measurement of the temperature and the temperature rise*

Sub-clause 6.3.3 of IEC Publication 694 is applicable.

6.3.4 *Ambient air temperature*

Sub-clause 6.3.4 of IEC Publication 694 is applicable.

6.3.5 *Temperature-rise tests of the auxiliary equipment*

Sub-clause 6.3.5 of IEC Publication 694 is applicable.

6.3.6 *Interpretation of the temperature-rise tests*

Sub-clause 6.3.6 of IEC Publication 694 is applicable.

6.4 *Measurement of the resistance of the main circuit*

Sub-clause 6.4 of IEC Publication 694 is applicable.

6.5 *Short-time withstand current and peak withstand current tests*

Sub-clause 6.5 of IEC Publication 694 is applicable.

6.5.1 *Arrangement of the circuit-breaker and of the test circuit*

Sub-clause 6.5.1 of IEC Publication 694 is applicable with the following addition:

If the circuit-breaker is fitted with direct over-current releases, these shall be arranged for test with the coil of the minimum operating current set to operate at the maximum current and maximum time delay; the coil shall be connected to the source side of the test circuit. If the circuit-breaker can be used without direct over-current releases, it shall also be tested without it.

6.5.2 *Test current and duration*

Sub-clause 6.5.2 of IEC Publication 694 is applicable with the following addition:

For circuit-breakers fitted with direct over-current releases, the rated operating sequence confined to opening operations only shall be performed. The average of the r.m.s. values of the a.c. components of the breaking current in all phases and operations shall be considered as the r.m.s. value of the short-time current except that where the test is made at rated voltage, prospective current values may be used.

6.5.3 *Behaviour of circuit-breaker during test*

Sub-clause 6.5.3 of IEC Publication 694 is applicable.

6.5.4 *Conditions of circuit-breaker after test*

Sub-clause 6.5.4 of IEC Publication 694 is applicable with the following addition:

The condition of circuit-breakers fitted with direct over-current releases shall comply with Sub-clause 6.102.8.

6.101 *Mechanical and environmental tests*

6.101.1 *Miscellaneous provisions for mechanical and environmental tests*

6.101.1.1 *Component tests*

When testing of a complete circuit-breaker is not practicable, component tests may be accepted as type tests. The manufacturer should determine the components which are suitable for testing.

Components are separate functional sub-assemblies which can be operated independently of the complete circuit-breaker (e.g. pole, breaking unit, operating mechanism).

When component tests are made the manufacturer shall prove that the mechanical stress on the component during the tests is not less than the mechanical stress applied to the same component when the complete circuit-breaker is tested. Component tests shall cover all different types of components of the complete circuit-breaker, provided that the particular test is applicable to the component. The conditions for the type tests shall be derived from the normal or special service conditions and rated characteristics of the circuit-breaker.

Parts of auxiliary and control equipment which have been manufactured in accordance with relevant standards shall comply with these standards. The proper function of such parts in connection with the function of the other parts of the circuit-breaker shall be verified.

6.101.1.2 *Characteristics and settings of the circuit-breaker to be recorded before and after the tests*

Before and after the tests the following operating characteristics or settings shall be recorded or evaluated if applicable:

a) closing time;

b) opening time;

c) time spread between units of one pole;

d) time spread between poles (if multipole-tested);

e) recharging time of the operating device;

f) consumption of the control circuit;

g) consumption of the tripping devices, possible recording of the current of the releases;

h) duration of opening and closing command impulse;

i) tightness (see Appendix EE);

j) gas densities or pressures;

k) resistance of the main circuit;

l) other important characteristics or settings as specified by the manufacturer.

And, if the design of the circuit-breaker permits, such measurements as:

m) time-travel chart;

n) closing speed;

o) opening speed.

The above operating characteristics shall be recorded at:

- rated supply voltage and rated operating pressure;
- maximum supply voltage and maximum operating pressure;
- minimum supply voltage and minimum operating pressure;
- minimum supply voltage and maximum operating pressure.

6.101.1.3 *Condition of the circuit-breaker during and after the tests*

During and after the tests, the circuit-breaker shall be in such a condition that it is capable of operating normally, carrying its rated normal current, making and breaking its rated short-circuit current and withstanding the voltage values according to its rated insulation level.

In general, these requirements are deemed to be fulfilled if:

- during the tests, the circuit-breaker operates on command and does not operate without command;
- during and after the tests, the characteristics measured according to Sub-clause 6.101.1.2 are within the tolerances given by the manufacturer;
- during and after the tests, all parts, including contacts, do not show undue wear;
- after the tests, coated contacts are such that a layer of coating material remains at the contact area. If this is not the case the contacts shall be regarded as bare and the test requirements are fulfilled only if the temperature-rise of the contacts during temperature-rise test (according to Sub-clause 6.3) does not exceed the value permitted for bare contacts;
- during and after the tests, any distortion of mechanical parts is not such that it adversely affects the operation of the circuit-breaker or prevents the proper fitting of any replacement part.

6.101.1.4 *Condition of the auxiliary and control equipment during and after the tests*

During and after the tests, the following conditions for the auxiliary and control equipment shall be fulfilled:

- during the tests, care should be taken to prevent undue heating;
- during the tests, a set of contacts (both make and break auxiliary contacts) shall be arranged to switch the current of the circuits to be controlled (see Sub-clause 5.4);
- during and after the tests, the auxiliary and control equipment shall fulfill its functions;
- during and after the tests, capability of the auxiliary circuits of the auxiliary switches and of the control equipment shall not be impaired. In case of doubt, the tests according to Sub-clause 6.1.10 of IEC Publication 694 shall be performed;
- during and after the tests, the contact resistance of the auxiliary switches shall not be affected adversely. The temperature rise when carrying the rated current shall not exceed the specified values (see Table V of IEC Publication 694).

6.101.2 *Mechanical operation test at ambient air temperature*

6.101.2.1 *General*

The mechanical operation test shall be made at the ambient air temperature of the test location. The ambient air temperature should be recorded in the test report. Auxiliary equipment forming part of the operating devices shall be included.

The mechanical operation test shall consist of 2 000 operating cycles.

Except for circuit-breakers fitted with over-current releases the test shall be made without voltage on or current in the main circuit.

For circuit-breakers fitted with over-current releases approximately 10% of the operating cycles shall be performed with the opening device energized by the current in the main circuit. The current shall be the minimum current necessary to operate the over-current release. For these tests, the current through over-current releases may be supplied from a suitable low-voltage source.

During the test, lubrication is allowed in accordance with the manufacturer's instructions, but no mechanical adjustment or other kind of maintenance is allowed.

For special service requirements and/or for circuit-breakers to be used with high frequency of operations, the testing procedure and the number of operating cycles shall be agreed between manufacturer and user. In the case of tests with a number of operating cycles greater than 2 000, it is permissible to perform adjustments and maintenance in accordance with the manufacturer's instructions.

6.101.2.2 *Condition of the circuit-breaker before the test*

The circuit-breaker for test shall be mounted on its own support and its operating mechanism shall be operated in the specified manner. It shall be tested according to its type as follows:

A multi-pole circuit-breaker actuated by a single operating device and/or with all poles mounted on a common frame shall be tested as a complete unit.

A multi-pole circuit-breaker in which each pole or even each column is actuated by a separate operating device should be tested preferably as a complete multi-pole circuit-breaker, but for convenience, or owing to limitation of the dimensions of the test bay, one single-pole unit of the circuit-breaker may be tested, provided that it is equivalent to, or not in a more favourable condition than, the complete multi-pole circuit-breaker over the range of tests, for example in respect of:

- closing speed;
- opening speed;
- power and strength of closing and opening mechanism;
- rigidity of structure.

6.101.2.3 *Description of the test*

The circuit-breaker shall be tested in accordance with Table XII.

TABLE XII

Operating sequence	Control voltage and operating pressure	Number of operating sequences	
		Circuit-breakers for auto-reclosing	Circuit-breakers not for auto-reclosing
$C - t_a - O - t_a$	Minimum Rated Maximum	500 500 500	500 500 500
$O - t - CO - t_a - C - t_a$	Rated	250	–
$CO - t_a$	Rated	–	500

where:

O = opening
C = closing
CO = a closing operation followed immediately (i.e., without any intentional time-delay) by an opening operation
t_a = time between two operations which is necessary to restore the initial conditions and/or to prevent undue heating of parts of the circuit-breaker (this time can be different according to the type of operation)
t = 0.3 s for circuit-breakers intended for rapid auto-reclosing, if not otherwise specified.

6.101.3 *Low and high temperature tests*

6.101.3.1 *General*

The low and high temperature tests shall be made only upon agreement between manufacturer and user. The two tests need not be performed in succession, and the order in which they are made is arbitrary. For class −5 °C indoor circuit-breakers, no low temperature test is required.

For single enclosure circuit-breakers or multi-enclosure circuit-breakers with common operating device, three-pole tests shall be made. For multi-enclosure circuit-breakers with independent poles, testing of one complete pole is permitted.

Owing to limitations of the test facilities, multi-enclosure type circuit-breakers may be tested using one or more of the following alternatives provided that the circuit-breaker in its testing arrangement is not in a more favourable condition than normal condition for mechanical operation (see Sub-clause 6.101.2.2):

a) reduced length of phase-to-earth insulation;

b) reduced pole spacing;

c) reduced number of modules.

If heat sources are required they shall be in operation.

Liquid or gas supplies for circuit-breaker operation are to be at the test air temperature unless the circuit-breaker design requires a heat source for these supplies.

No maintenance, replacement of parts, lubrication or readjustment of the circuit-breaker is permissible during the tests.

Note. – In order to determine the material temperature characteristics, ageing, etc., tests of longer duration than those specified in the following sub-clauses may be necessary.

As an alternative approach to the methods in this standard, a manufacturer may establish compliance with performance requirements for an established circuit-breaker family by documenting satisfactory circuit-breaker field experience in at least one location with ambient air temperatures frequently at or above the specified maximum ambient air temperature of 40 °C, and at least one location with satisfactory field experience in specified minimum ambient air temperature of −25 °C or −40 °C depending on the class of the circuit-breaker (see Clause 2 of IEC Publication 694).

6.101.3.2 *Measurement of ambient air temperature*

The ambient air temperature of the test environment shall be measured at half the height of the circuit-breaker and at a distance of 1 m from the circuit-breaker.

The maximum temperature deviation over the height of the circuit-breaker shall not exceed 5 K.

6.101.3.3 *Low temperature test*

The diagram of the test sequences and identification of the application points for the tests specified are given in Figure 15a, page 230.

If the low temperature test is performed immediately after the high temperature test, the low temperature test can proceed after completion of Item *u)* of the high temperature test. In this case Items *a)* and *b)* are omitted.

a) The test circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.

b) Characteristics and settings of the circuit-breaker shall be recorded in accordance with Sub-clause 6.101.1.2 and at an ambient air temperature of 20 ± 5 °C (T_A). The tightness test (if applicable) shall be performed with the circuit-breaker in the closed position.

c) With the circuit-breaker in the closed position, the air temperature shall be decreased to the appropriate minimum ambient air temperature (T_L), according to the class of the circuit-breaker. Values of T_L may be −25 °C, or −40 °C, as appropriate. The circuit-breaker shall be kept in the closed position for 24 h after the ambient air temperature stabilizes at T_L.

d) During the 24 h period with the circuit-breaker in the closed position at temperature T_L, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed three times the specified permissible value F_p (see Appendix EE).

e) After 24 h at temperature T_L, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The opening time and the closing time shall be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible.

f) The low temperature behaviour of the circuit-breaker and its alarms and lock-out systems shall be verified by disconnecting the supply of heating devices for 2 h. The time interval between the instant of disconnection of heating devices and the occurrence of alarms, lock-out or opening without order should be recorded (if applicable). At the end of the 2 h period, an opening order, at rated values of supply voltage and operating pressure, shall be given. If the circuit-breaker does not open, the heating devices shall be reconnected and the time interval until the circuit-breaker opens on order be noted.

g) The circuit-breaker shall be left in the open position for 24 h.

h) During the 24 h period with the circuit-breaker in the open position at temperature T_L, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed three times the specified permissible value F_p (see Appendix EE).

i) At the end of 24 h, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at temperature T_L. At least a 3 min interval shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible.

Following the first closing operation (C) and the first opening operation (O) three CO operating cycles (no intentional time delay) shall be performed. The additional operations shall be made by performing $C-t_a-O-t_a$ operating sequences (t_a is defined in Sub-clause 6.101.2.3).

j) After completing the 50 opening and 50 closing operations, the air temperature shall be increased to ambient air temperature T_A at a rate of change of approximately 10 K per hour.

During the temperature transition period the circuit-breaker shall be subjected to alternate $C-t_a-O-t_a-C$ and $O-t_a-C-t_a-O$ operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in open and closed positions for 30 min periods between the operating sequences.

k) After the circuit-breaker has stabilized thermally at ambient air temperature T_A, a recheck shall be made of the circuit-breaker settings, operating characteristics and tightness as in Items *a)* and *b)* for comparison with the initial characteristics.

6.101.3.4 *High temperature test*

The diagram of the test sequence and identification of the application points for the tests specified are given in Figure 15b, page 230.

If the high temperature test is performed immediately after the low temperature test, the high temperature test can proceed after completion of Item *k)* of the low temperature test. In this case, Items *l)* and *m)* are omitted.

l) The test circuit-breaker shall be adjusted in accordance with the manufacturer's instructions.

m) Characteristics and settings of the circuit-breaker shall be recorded in accordance with Sub-clause 6.101.1.2 and at an ambient air temperature of 20 ± 5 °C (T_A). The tightness test (if applicable) shall be performed with the circuit-breaker in the closed position.

n) With the circuit-breaker closed, the air temperature shall be increased to 40 °C, and the circuit-breaker kept in the closed position for 24 h after the ambient air temperature stabilizes at 40 °C.

Note. — If the influence of solar radiation is to be considered, it is necessary to simulate the natural conditions of the radiation (e.g. the intensity and direction of the radiation). See IEC Publication 68-2-5: Basic Environmental Testing Procedures, Part 2: Tests, Test Sa: Simulated Solar Radiation at Ground Level.

Attention is drawn to the fact that an increase in ambient temperature of the test room does not simulate this radiation effect.

o) During the 24 h period with the circuit-breaker in the closed position at the temperature of 40 °C, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed three times the specified permissible value F_p (see Appendix EE).

p) After 24 h at the temperature of 40 °C, the circuit-breaker shall be opened and closed at rated values of supply voltage and operating pressure. The opening time and the closing time shall be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

q) The breaker shall be opened and left open for 24 h at the temperature of 40 °C.

r) During the 24 h period with the circuit-breaker in the open position at the temperature of 40 °C, a tightness test shall be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the circuit-breaker is restored to the ambient air temperature T_A and is thermally stable. The increased temporary leakage rate shall not exceed three times the specified permissible value F_p (see Appendix EE).

s) At the end of 24 h, 50 closing and 50 opening operations shall be made at rated values of supply voltage and operating pressure with the circuit-breaker at the temperature of 40 °C. At least a 3 min interval shall be allowed for each cycle or sequence. The first closing and opening operation shall be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

Following the first closing operation (C) and the first opening operation (O) three CO operation cycles (no intentional time delay) shall be performed. The additional operations shall be made by performing $C - t_a - O - t_a$ operating sequences (t_a is defined in Sub-clause 6.101.2.3).

t) After completing the 50 opening and 50 closing operations, the air temperature shall be decreased to ambient air temperature T_A, at a rate of change of approximately 10 K per hour.

During the temperature transition period, the circuit-breaker shall be subjected to alternate $C-t_a-O-t_a-C$ and $O-t_a-C-t_a-O$ operating sequences at rated values of supply voltage and operating pressure. The alternate operating sequences should be made at 30 min intervals so that the circuit-breaker will be in the open and closed positions for 30 min periods between the operating sequences.

u) After the circuit-breaker has stabilized thermally at ambient air temperature T_A, a recheck shall be made of the circuit-breaker settings, operating characteristics and tightness as in Items *l)* and *m)* for comparison with the initial characteristics.

6.101.4 *Humidity test*

6.101.4.1 *General*

The humidity test shall be performed by agreement between manufacturer and user and is limited to circuit-breaker components which may be affected by humidity.

The test procedure described in Sub-clause 6.101.4.2 is applicable to components with a thermal time constant of about 10 min.

Note. — The test for components having higher thermal time constant is under consideration.

6.101.4.2 *Test procedure*

The circuit-breaker components shall be arranged in a test chamber containing circulating air and in which the temperature and humidity conditions are as follows:

- the temperature of the room undergoes cyclic variations from 25 ± 3 °C to 40 ± 2 °C according to Figure 16, page 231;
- the relative humidity within the room is constantly above 95% while the temperature is raised and during the period when the temperature is held at 40 °C.

Note. — In order to obtain these conditions, steam should be injected directly into the room or heated water should be atomized; the rise from 25 °C to 40 °C may be obtained with the provision of heat coming from the steam or atomized water or, if necessary, by additional heaters.

No value of relative humidity is specified during the drop in temperature, however, the humidity shall be above 80% during the period when the temperature is maintained at 25 °C.

The air shall be circulated in order to obtain uniform distribution of the humidity in the room.

The water used to create the humidity shall be such that the water collected in the room has a resistivity equal to or greater than 100 Ω m and contains neither salt (NaCl) nor corrosive element.

Note. — If the facilities of the test chamber permit, the times t_1 and t_3 may be reduced, but then the times t_2 and t_4 should be increased so that $t_1 + t_2 + t_3 + t_4$ remains constant.

The number of cycles shall be 350.

After the test, the operating characteristics of the circuit-breaker components shall not be affected. The auxiliary and control circuits shall withstand a power frequency voltage of 1 500 V for 1 min. The degree of corrosion, if any, should be indicated in the test report.

6.101.5 *Test to prove the operation under severe ice conditions*

The test under severe ice conditions is applicable only to outdoor circuit-breakers having moving external parts and for which a class of 10 mm or 20 mm of ice thickness is specified. The test shall be performed under the conditions described in IEC Publication 129: Alternating Current Disconnectors and Earthing Switches.

6.101.6 *Guide for static terminal load test*

6.101.6.1 *General*

The static terminal load test is applicable only to outdoor circuit-breakers having rated voltages of 52 kV and above.

The static terminal load test is made only upon agreement between manufacturer and user, and is performed to demonstrate that the circuit-breaker operates correctly when loaded by stresses resulting from ice, wind and connected conductors.

Ice coating and wind pressure on the circuit-breaker shall be in accordance with Sub-clause 2.1.2 of IEC Publication 694.

Some examples of forces due to flexible and tubular connected conductors (not including wind or ice load on the circuit-breaker itself) are given as a guide in Table XIII.

TABLE XIII

Rated voltage range (kV)	Rated current range (A)	Static horizontal force F_{th}		Static vertical force (vertical axis-upward and downward) F_{tv} (N)
		Longitudinal F_{thA} (N)	Transversal F_{thB} (N)	
52-72.5	800-1 250	500	400	500
52-72.5	1 600-2 500	750	500	750
100-170	1 250-2 000	1 000	750	750
100-170	2 500-4 000	1 250	750	1 000
245	1 600-3 150	1 250	1 000	1 250
420	2 000-4 000	1 750	1 250	1 500

The tensile force due to the connected conductors is assumed to act at the outermost end of the circuit-breaker terminal.

For simultaneous action of ice,wind and connected conductors, the resultant terminal loads, F_{shA}, F_{shB} and F_{sv} respectively (see Figure 17, page 233) are defined as rated static terminal loads.

If the manufacturer by calculations can prove that the circuit-breaker can withstand the stresses, tests need not be performed.

6.101.6.2 *Tests*

The tests shall be made at the ambient air temperature of the test room.

The tests should be made preferably on at least one complete pole of the circuit-breaker. If the manufacturer can prove that there is no interaction between different columns in the pole, it is sufficient to test only one column. For circuit-breakers which are symmetrical about the pole unit vertical centreline, only one terminal need be tested with the rated static terminal load. For circuit-breakers which are not symmetrical, each terminal shall be tested.

Tests shall be made separately, firstly with a horizontal force, F_{shA}, applied in longitudinal axis of the terminal (direction A in Figure 18, page 235), secondly with a horizontal force, F_{shB}, applied in two directions successively at 90° from the longitudinal axis of the terminals (directions B_1 and B_2 in Figure 18) and thirdly, with a vertical force, F_{sv}, applied in two directions successively (directions C_1 and C_2 in Figure 18). To avoid the need to apply a special force representing the force of wind acting at the circuit-breaker's centre of application of pressure, this wind load may be applied at the terminal (see Figure 17) and reduced in magnitude in proportion to the longer lever arm (the bending moment at the lowest part of the circuit-breaker should be the same).

Two operating cycles shall be performed for each of the specified five terminal load tests.

6.102 *Miscellaneous provisions for making and breaking tests*

The following sub-clauses are applicable to all making and breaking tests unless otherwise specified in the relevant clauses.

6.102.1 *General*

Circuit-breakers intended to be used with all three poles operating together shall be capable of making and breaking all short-circuit currents, symmetrical and asymmetrical, up to and including the rated short-circuit breaking currents: this is deemed to be proved if the circuit-breakers make and break the specified three phase symmetrical and asymmetrical currents between 10% (or such lower currents as specified in Sub-clause 6.107.2 if Sub-clause 6.107.1 is applicable) and 100% of the rated short-circuit breaking current at rated voltage.

In addition circuit-breakers intended to be used in an earthed neutral system or for single-pole operation shall make and break single-phase short-circuit currents between 10% (or such lower currents as specified in Sub-clause 6.107.2 if Sub-clause 6.107.1 is applicable) and 100% of the rated short-circuit breaking current at phase to earth voltage ($U/\sqrt{3}$).

For a three-pole circuit-breaker, all short-circuit making and breaking requirements, three-phase or single-phase if required, can be proved with a three-pole circuit-breaker with all poles operating together.

Three-phase making and breaking requirements should preferably be proved in three-phase circuits.

If the tests are carried out in a laboratory, the applied voltage, current, transient and power frequency recovery voltages may all be obtained from a single power source (direct tests) or from several sources where all of the current, or a major portion of it, is obtained from one source, and the transient recovery voltage is obtained wholly or in part from one or more separate sources (synthetic tests).

If due to limitations of the testing facilities the short-circuit performance of the circuit-breaker cannot be proved in the above way, several methods employing either direct or synthetic test methods may be used either singly or in combination depending on the circuit-breaker type:

a) single-pole testing;

b) unit-testing;

c) multi-part testing.

6.102.1.1 *Single-pole testing*

According to this method, a single-pole of a three-pole circuit-breaker is tested single-phase applying to the pole the same current and substantially the same power frequency voltage which would be impressed upon the most highly stressed pole during three-phase making and breaking by the complete three-pole circuit-breaker under corresponding conditions. See Sub-clause 6.102.3.1.

6.102.1.2 *Unit testing*

Certain circuit-breakers are constructed by assembling identical breaking or making units in series, the voltage distribution between the units of each pole often being improved by the use of parallel impedances.

This type of design enables the breaking or making performance of a circuit-breaker to be tested by carrying out tests in accordance with Sub-clause 6.102.3.2 on one or more units.

6.102.1.3 *Multi-part testing*

If all TRV requirements for the given test duty cannot be met simultaneously, the test may be carried out in two or more parts in succession for instance as illustrated in Figure 27, page 243. See Sub-clause 6.102.3.3.

Note. — For circuit-breakers equipped with closing resistors or low ohmic opening resistors other special procedures may be used.

6.102.2 *Arrangement of circuit-breaker for tests*

The circuit-breaker for test shall be mounted complete on its own support or on an equivalent support. A circuit-breaker supplied as an integral part of an enclosed unit shall be assembled in its own supporting structure and enclosure complete with any disconnecting features, with vent outlets forming part of the unit and, where practicable, with main connections and busbars. Its operating devices shall be operated in the manner specified and in particular, if it is electrically, pneumatically or hydraulically operated, it shall be operated at the minimum voltage or pressure at commencement of the operating sequence, specified in Sub-clauses 4.8, 4.10 and 5.7, unless otherwise specified in the relevant clauses. It shall be shown that the circuit-breaker will operate satisfactorily under the above conditions at no-load as specified in Sub-clause 6.102.5. Gas-blast circuit-breakers shall be tested at the minimum pressures of the compressed gas for interruption corresponding to the series of operations to be performed, as specified in Sub-clause 5.103, unless otherwise specified in the relevant clauses.

Note. — Current chopping may be more pronounced at maximum operating pressure and/or maximum gas pressure/density.

The circuit-breaker shall be tested according to its type as follows:

a) Single-enclosure type

A three-pole circuit-breaker having all its arcing contacts supported within a common enclosure shall be tested as a complete three-pole circuit-breaker in three-phase circuits even in the case of line to ground fault conditions.

The reasons are:

- possibility of flash-over between poles or to earth due to the influence of exhaust gases;
- possible differences in the conditions of the extinguishing medium (pressures, temperatures, pollution levels, etc.);

- possible influence between phases due to electro-dynamical forces in the case of a three-phase fault;
- possible different stresses on the operating mechanism.

b) Multi-enclosure type

A three-pole circuit-breaker consisting of three independent single-pole switching devices can be tested single-phase according to Sub-clause 6.102.1.1 provided that the pole spread is in accordance with the requirements of Sub-clause 5.101.

A three-pole circuit-breaker not having completely independent switching devices shall be tested preferably as a complete three-pole circuit-breaker, but for convenience, or owing to limitation of available testing facilities, one single-pole of the circuit-breaker may be tested, provided that it is equivalent to, or not in a more favourable condition than, the complete three-pole circuit-breaker over the range of tests in respect of:

- speed of make;
- speed of break;
- availability of arc-extinguishing medium;
- power and strength of closing and opening devices;
- rigidity of structure.

6.102.2.1 *Circuit-breakers with over-current releases*

Circuit-breakers fitted with direct over-current releases shall, subject to the provisions of Sub-clause 6.103.4, be arranged for Test-duties Nos. 1 to 5 (Sub-clause 6.106) as specified below and the over-current release coils shall be connected to the live side of the test circuit:

With the coil of the maximum rated operating current set to operate at the maximum current and maximum time-delay for Test-duties Nos. 1, 2, 3 and 4, and at the minimum current and minimum time-delay for Test-duty No. 5.

Note. — When the above time-delay is too great for convenient oscillographic recording it shall be permissible to use a smaller time-delay setting or to render the time-delay device inoperative for Test duties Nos. 1 and 2 only.

6.102.3 *General considerations concerning testing methods*

6.102.3.1 *Single-pole testing of three-pole circuit-breakers*

In those cases where the circuit-breaker design permits single-pole testing to simulate three-phase conditions and the circuit-breaker is equipped with one operating mechanism for all poles a complete three-pole assembly shall be supplied for the tests.

The contact travel characteristics (speed and stroke) of the complete circuit-breaker shall be recorded in a suitable test reproducing the maximum stresses the mechanism has to cope with in actual short-circuit conditions at the rated short-circuit breaking current and at the highest available voltage but not higher than the value corresponding to the rated voltage.

Single-pole tests on such a circuit-breaker, at the rated short-circuit breaking current, then have to be carried out with the contact travel characteristics recorded during the above test, within a tolerance of ±10% in both speed and contact gap at any instant during the opening stroke between the instant of contact separation and the instant corresponding to maximum arc duration. At lower currents, the contact velocities may be different.

Note. — To achieve the correct travel characteristics, it may be necessary to make adjustments of operating energy, moving masses, etc.

Special attention should be paid to the emission of arc products. If it is considered that such emission would, for example, be likely to impair the insulation distance to adjacent poles, then this shall be checked, using earthed metallic screens (see Sub-clause 6.102.7).

6.102.3.2 *Unit testing*

When a testing laboratory is not equipped to test a complete three-pole circuit-breaker or a single pole of a circuit-breaker, tests on one or more units may be carried out depending on the type of the circuit-breaker.

The requirements of Sub-clause 6.102.2 and 6.102.3.1 also apply for unit-testing.

Since therefore at least a complete pole assembly has to be made available for tests on one or more units the test-results relate only to the specific pole considered.

Circuit-breakers consisting of units or assemblies of units which are separately operated may be tested as units or assemblies of units respectively as long as the supply of the operating medium is not more favourable than for the complete circuit-breaker.

If the interrupting unit is applied for different voltage ratings of circuit-breakers, the possibility of regarding only the most onerous test conditions for a specific voltage rating may be subject to agreement between manufacturer and user.

When carrying out unit tests it is essential that the units are identical and that the static voltage distribution for the type of test under consideration (terminal faults, short-line fault, out of phase, etc.) is known.

6.102.3.2.1 *Identical nature of the units*

The units of the circuit-breaker shall be identical in their shape, in their dimension and in their operating conditions; only the devices for controlling the voltage distribution among units may be different. In particular, the following conditions shall be fulfilled:

a) Operation of contacts

The opening, in breaking tests, or the closing, in making tests, of the contacts of one pole shall be such that the time interval between the opening or closing of the contacts of the unit which is first to operate and the contacts of the unit which is last to operate is not more than 1/8 cycle of rated frequency. Rated operating pressures and voltages shall be used to determine this time interval (see Sub-clause 5.101).

b) Supply of the arc-extinguishing medium

For a circuit-breaker using a supply of arc-extinguishing medium from a source external to the units, the supply to each unit shall for all practical purposes be independent of the supply to the other units, and the arrangement of the supply pipes shall be such as to ensure that all units are fed essentially together and in an identical manner.

c) Condition of the arc-extinguishing medium

The design of the circuit-breaker and its units shall be such that during the breaking or making operations, the condition of the medium in which the arc is created (e.g. temperature, pressure, rate of flow, etc.) in each unit is for all practical purposes not influenced by the operation of the other units.

In particular, neither the supply of extinguishing medium to the unit or units under test nor the ease of exhaust of products from the arc shall be increased owing to the absence of arcing in the other units normally in series with the unit or units under test.

Ionized gases or vapours which may be present in the exhaust should be so discharged that they cannot cause malfunctioning of adjacent units in the same or other phases, or failure of the circuit-breaker as a whole by flash-over either partially or totally through the exhaust gases.

6.102.3.2.2 *Voltage distribution*

The test voltage is determined by analyzing the voltage distribution between the units of the pole.

The voltage distribution between units of a pole as affected by the influence of earth shall be determined for the relevant test conditions laid down for tests on one pole; for terminal fault conditions see Items *c)* and *d)* of Sub-clause 6.103.3 and Figures 21a, 21b, 22a and 22b, pages 238 and 239, for short-line fault conditions Sub-clause 6.109.3 and for out-of-phase conditions Sub-clause 6.110.2 and Figures 29, 30 and 31, pages 246 and 247. Where the units are not symmetrically arranged, the voltage distribution shall be determined also with reverse connections.

If the circuit-breaker is fitted with parallel resistors, the voltage distribution shall be calculated or measured statically at the equivalent frequency involved in the TRV.

Note 1. — The equivalent frequency is deemed to be equal to $1/(3\,t_1)$ in the case of four parameters or to $1/(2\,t_3)$ in the case of two parameters (see Figures 23 and 24, page 241).

For short-line fault unit tests, the voltage distribution shall be calculated or measured statically on the basis of a voltage on the line side at the fundamental frequency of the line oscillation and a voltage on the source side at the equivalent frequency of the TRV for terminal faults, the common point of the two voltages being at earth potential.

If only capacitors are used, the voltage distribution may be calculated or measured at power frequency.

The manufacturing tolerances for resistors and capacitors shall be taken into account. The manufacturer shall state the value of these tolerances.

Notes 2. — It may be taken into account that the voltage distribution may be more favourable during the out-of-phase breaking tests than during the terminal or short-line fault tests. This applies also when in exceptional cases tests have to be performed under the conditions of unearthed faults in earthed neutral systems.

3. — The influence of pollution is not considered in determining the voltage distribution. In some cases, pollution may affect this voltage distribution.

6.102.3.2.3 *Requirements for unit testing*

All unit testing shall be performed on the maximum number of units in series compatible with the capabilities of the testing laboratory, at the specified making and breaking currents.

When testing a single unit, the test voltage shall be the voltage of the most highly stressed unit of the complete pole of the circuit-breaker determined in accordance with Sub-clause 6.102.3.2.2. For short-line fault conditions, the unit referred to is that most highly stressed at the specified time of the first peak of the line side transient voltage.

When testing a group of units, the voltage appearing at the terminals of the most highly stressed unit of the group shall be equal to the voltage of the most highly stressed unit of the pole, both determined in accordance with Sub-clause 6.102.3.2.2.

During unit testing, the insulation to earth is not stressed with the full voltage occurring during a breaking operation of the complete circuit-breaker. For certain types of circuit-breakers, such as circuit-breakers in metal enclosures, it is therefore necessary to prove that the insulation to earth is capable of withstanding this full voltage after interruption of the rated short-circuit current with maximum arcing time in all units. The influence of exhaust gases should also be taken into account.

Notes 1. — A test may be carried out with full current flowing through all the units of a pole and by applying simultaneously a voltage from a separate source to the enclosure.

2. — Higher recovery voltages are applicable at currents lower than the rated breaking value and it may be necessary to check the behaviour of the circuit-breaker under these conditions also.

6.102.3.3 *Multi-part testing*

In the first part the initial portion of the TRV shall not cross the straight line defining the delay time and shall meet the specified reference line up to the voltage u_1 and the time t_1.

In the second part, the voltage u_c and the time t_2 shall be attained (see Figure 27, page 243).

If by those tests the area below the specified reference line is not sufficiently covered a third test is necessary with a TRV peak value intermediate between u_1 and u_c and a time intermediate between t_1 and t_2.

If the arcing times on separate tests forming part of one multipart test are significantly different, measured from the same point-on-wave of the contact separation, it is necessary for the validity of the test that the shorter arcing times are prolonged in order to obtain the longest arcing time in all tests.

6.102.4 *Synthetic tests*

A synthetic test is defined as a test in which all of the current, or a major portion of it, is obtained from one source (power-frequency current circuit) and in which the transient recovery voltage is obtained wholly or in part from one or more separate sources (voltage circuits), this voltage corresponding to the rated voltage of the tested circuit-breaker. The voltage of the power-frequency current source may be a fraction of that of the voltage circuit.

The requirements to be met when using synthetic test methods employing either current injection or voltage injection methods are stated in IEC Publication 427: Report on Synthetic Testing of High-voltage Alternating Current Circuit-Breakers.

Note. — Synthetic test methods for short-circuit testing other than current injection or voltage injection methods and synthetic test methods for load current testing are under consideration.

6.102.5 *No-load operations before tests*

Before commencing making and breaking tests, no-load operations shall be made and details of the operating characteristics of the circuit-breaker, such as speed of travel, closing time and opening time, shall be recorded.

For a circuit-breaker fitted with a making current release, it shall be shown that this does not operate on no-load.

For electrically operated circuit-breakers, operations shall be made with the closing solenoid energized at 105%, 100% and 85% of the rated supply voltage of the closing device and with the shunt opening release energized at 110%, 100% and 85% in the case of a.c., and 110%, 100% and 70% in the case of d.c. of the rated supply voltage.

For pneumatic or hydraulic operating devices, the operations shall be made under the following conditions with reference to the minimum, rated and maximum pressure specified in Sub-clauses 5.5 and 5.6:

a) minimum pressure with the shunt opening releases energized at 85% in case of a.c., 70% in case of d.c. and with the shunt closing releases energized at 85% of the rated supply voltage.

b) rated pressure with the shunt releases energized at the rated supply voltage,

c) maximum pressure with the shunt releases energized at 110% of the rated supply voltage,

d) maximum pressure with the shunt opening releases energized at 85% in case of a.c., 70% in case of d.c. and with the shunt closing releases energized at 85% of the rated supply voltage.

For spring-operated circuit-breakers, operations shall be made with the shunt closing releases energized at 110%, 100% and 85% of the rated supply voltage and with the shunt opening releases energized at 110%, 100% and 85% in case of a.c., and 110%, 100% and 70% in case of d.c. of the rated supply voltage.

6.102.6 *Alternative closing mechanisms*

If the circuit-breaker is designed for use with alternative closing mechanisms, a separate series of short-circuit test-duties shall be made for each type of mechanism, unless it can be shown that the change of mechanism does not affect the performance of the common portion, particularly with regard to the opening characteristics of the circuit-breaker.

If this can be satisfactorily shown, only a single complete series of short-circuit test-duties is required using one of the alternative mechanisms, but any short-circuit test-duty which includes making operations (see Sub-clause 6.106.4) shall be repeated with all other alternative mechanisms.

6.102.7 *Behaviour of circuit-breaker during tests*

During making and breaking tests, the circuit-breaker shall neither show signs of excessive distress nor endanger the operator. From oil circuit-breakers, there shall be no outward emission of flame, and the gases produced, together with the oil carried with the gases, shall be conducted from the circuit-breaker and directed away from all live conductors and locations where persons may be present.

For other types of circuit-breakers, if there is appreciable emission of flame or metallic particles, it may be required that the short-circuit tests shall be made with metallic screens placed in the vicinity of the live parts and separated from them by a safety clearance distance which the manufacturer shall specify.

The screens shall be insulated from earth but connected thereto by a suitable device to indicate any significant leakage current to earth.

There shall be no indication of significant leakage currents to the circuit-breaker earthed structure, or screens when fitted, during the tests. In case of doubt, the earthed parts, etc., should be connected to earth through a fuse consisting of a copper wire of 0.1 mm diameter and 5 cm long. No significant leakage is assumed to have occurred if this fuse wire is intact after the test.

In certain circumstances, it may be necessary to maintain a permanent electrical connection between the frame of the circuit-breaker and earth. In such cases it is permissible to earth the frame through the primary winding of a suitable transformer having a 1:1 ratio, with the fuse connected across the secondary winding of the transformer and with the secondary terminals protected by a spark gap.

Overvoltages produced during line-charging, cable-charging, capacitor bank and small inductive current breaking tests shall not exceed the maximum permissible switching overvoltages specified by the manufacturer (see Sub-clauses 4.107 to 4.110 and 4.112). External flashover shall not occur.

6.102.8 *Condition of circuit-breaker after tests*

6.102.8.1 *General*

The circuit-breaker may be inspected after any test-duty. Its mechanical parts and insulators shall be in practically the same condition as before the test-duty.

6.102.8.2 *Condition after a short-circuit test-duty*

After each short-circuit test-duty, the circuit-breaker shall be capable of making and breaking its rated normal current at the rated voltage, although its short-circuit making and breaking performance may be impaired.

The main contacts shall be in such a condition, in particular with regard to burning, contact area, pressure and freedom of movement, that they are capable of carrying the rated normal current of the circuit-breaker without their temperature rise exceeding by more than 10 K the values specified for them in Table V of Sub-clause 4.4.2 in IEC Publication 694. In case of doubt, it may be necessary to perform an additional temperature rise test. Experience shows that an increase of the voltage drop across the circuit-breaker cannot alone be considered as reliable evidence of an increase in temperature rise.

Contacts shall be considered as "silver-faced" only if there is still a layer of silver at the contact points after any of the short-circuit test-duties; otherwise they shall be treated as "not silver-faced" (see IEC Publication 694, Table V, Note 5).

6.102.8.3 *Condition after a short-circuit test series*

In order to check the operation of the circuit-breaker after test, no-load closing and opening operations shall be made at the completion of the entire series of short-circuit tests. These shall be compared with the corresponding operations made in accordance with Sub-clause 6.102.5 and shall show no significant change. The circuit-breaker shall close and latch satisfactorily.

After the completion of the entire series of short-circuit test-duties, local burning of the lining of oil circuit-breaker enclosures may be expected, and provided this does not render the lining incapable of performing its function, such damage is permissible. This does not apply to linings, tubes, barriers, etc., which form part of the main insulation of the circuit-breaker.

Slight distortion of non-metallic interphase barriers and tank linings may be permitted on oil circuit-breakers, provided such distortion does not interfere with the normal opening and closing of the circuit-breaker.

If, for reasons other than the behaviour of the tested circuit-breaker, it becomes necessary to perform a greater number of short-circuit test-duties than are required by this standard, and if the enclosure lining is so damaged that the manufacturer considers it desirable to change it before completing the entire series of test-duties, a statement of changes and necessary explanation shall be included in the test report.

Damage to main insulation (i.e. that which is subject to electrical stress under normal operating conditions with the circuit-breaker either open or closed) such that the insulation of the circuit-breaker is impaired shall disqualify the circuit-breaker. Damage to shields fitted for bushings or arc control devices shall not invalidate the performance provided the shields remain substantially intact and are capable of continuing to perform their function. Damage to surfaces of insulation along which creepage may occur under normal voltage, either to earth, between poles or across the break, invalidates the performance.

No criterion of oil deterioration can be given, as this will depend upon the particular circuit-breaker tested.

6.102.8.4 *Condition after a test series other than a short-circuit test series*

The circuit-breaker shall, after performing the line-charging, cable-charging, capacitor bank and small inductive current breaking test series specified in Sub-clauses 6.111.8 and 6.112, before reconditioning, be capable of operating satisfactorily at any making and breaking current up to its rated short-circuit making and breaking current.

In addition the circuit-breaker shall be capable of carrying its rated normal current with a temperature rise not in excess of the temperature rise permitted by Table V of Sub-clause 4.4.2 in IEC Publication 694.

There shall be no evidence of internal puncture, flashover or tracking of insulating materials, except that moderate wear of the parts of arc control devices exposed to the arc is permissible.

Note. — Verification of compliance with the above requirements is necessary only in case of doubt.

6.102.8.5 *Reconditioning after a short-circuit test-duty and other test series*

It is understood that after performing a short-circuit test-duty or other test series it may be necessary to carry out maintenance work on the circuit-breaker in order to restore it to the original conditions specified by the manufacturer. For example, the following may be necessary:

a) repair or replacement of the arcing contacts and any other renewable parts recommended by the manufacturer;

b) renewal or filtration of the oil, or of any other extinguishing medium, and the addition of any quantity of the medium necessary to restore its normal level or density;

c) removal of deposit caused by the decomposition of the extinguishing medium from internal insulation.

6.102.9 *Circuit-breakers with short arcing times*

It is recognized that, when breaking tests are made on circuit-breakers having short arcing times, there may be great variation in actual severity of tests with the same circuit setting due to the point on the current wave at which contact separation occurs. For this reason, the testing procedure for circuit-breakers with arcing times (to the extinction of the main arc for circuit-breakers with switching resistors) not exceeding one cycle for the first pole to clear is given below under Items (A) and (B).

The tests under Items (A)2) and (B)2) consist of three valid operations independent of the rated operating sequence. After the number of operations provided for in accordance with the rated operating sequence the circuit-breaker may be reconditioned in accordance with Sub-clause 6.102.8.5.

(A) *Three-phase tests*

1) Test-duties Nos. 1, 2, 3, 4, 4b (Sub-clauses 6.106.1 to 6.106.4)

For these test-duties, the setting of the control of the tripping impulse shall be advanced by approximately 40 electrical degrees between each opening operation.

2) Test-duty No. 5 (Sub-clause 6.106.5)

Since the severity of the tests for this duty can vary widely depending on the moment of contact separation a procedure has been developed in order to arrive at realistic stresses on the circuit-breaker under test. The intention is to arrive at a series of three valid tests. The initiation of the short-circuit changes 60 electrical degrees between tests in order to transfer the required d.c. component at the moment of contact separation from phase to phase.

Furthermore it is the intention to have at least once during the test series a first phase to clear condition in the phase with the required d.c. component in order to comply with the TRV requirements. This test is valid if in this phase the current is interrupted after arcing during a full major loop or the greatest possible part thereof. Since some circuit-breakers will not clear after a major loop, a test is still valid if arcing goes on during a subsequent minor loop. However, if the circuit-breaker clears in the phase with the required d.c. component after a foreshortened major loop or after a minor loop without arcing during a preceding major loop or the greatest possible part thereof, the test shall be considered invalid.

The procedure is as follows:

For the first valid operation the initiation of short-circuit and the setting of the control of the tripping impulse shall be such that:

a) the required d.c. component at contact separation is obtained in one phase;

b) arc extinction occurs in the same phase after a major loop (or the greatest possible part of that loop) in case of the first phase to clear or after a major extended loop (or the greatest possible part of that loop) in case of one of the last phases to clear.

For the second operation, the initiation of short-circuit shall be advanced by 60 electrical degrees.

If the first operation was a first phase to clear after a major loop, the setting of the control of the tripping impulse shall be advanced by approximately 130 electrical degrees with respect to the first valid test. In other cases, provided that the first test is valid, this shall be approximately 25 electrical degrees.

For the third operation, the procedure for the second operation may be repeated, i.e. the initiation of short-circuit shall be advanced by 60 electrical degrees with respect to the second test.

If the second operation was a first phase to clear after a major loop, the setting of the control of the tripping impulse shall be advanced by approximately 130 electrical degrees with respect to the second valid test. In other cases, provided that the second test is valid, this shall be approximately 25 electrical degrees.

(B) *Single-phase tests*

1) Test-duties Nos. 1, 2, 3, 4, 4b and short-line fault tests (Sub-clauses 6.106.1 to 6.106.4 and 6.109.5).

To achieve the first valid breaking operation, contact separation shall be advanced relative to one current zero such that any further advance would result in clearance at that current zero. It may be necessary to make more than one test to achieve this.

For the second breaking operation, the setting of the control of the tripping impulse shall be advanced by approximately 60 electrical degrees from that of the first valid breaking operation.

If during the second breaking operation arc extinction occurs at the first current zero, then the third breaking operation shall be made with the same setting of the control of the tripping impulse as the first valid breaking operation. If during the second breaking operation arc extinction does not occur at the first current zero, then the third breaking operation shall be made with the setting of the control of the tripping impulse advanced by approximately 60 electrical degrees from that of the second breaking operation.

2) Test duty No. 5 (Sub-clause 6.106.5)

A first valid operation shall be established in such a way that arc extinction occurs at the end of the major loop. Contact separation shall occur in or even before the preceding minor loop. It may be necessary to make more than one test to achieve this valid test.

Relative to this moment of contact separation a second breaking operation shall be made with the setting of the control of the tripping impulse advanced by approximately 60 electrical degrees. This second operation is valid only if arc extinction occurs after the minor loop. If arc extinction does not occur at the end of the minor loop, then the first operation is invalid.

A third operation shall be made with the setting of the control of the tripping impulse retarded by approximately 60 electrical degrees with respect to the first valid operation.

3) Out-of-phase test duties (Sub-clause 6.110.4)

For test duty No. 1 the second breaking operation shall be made with the setting of the control of the tripping impulse 60 electrical degrees retarded with respect to the first operation. If the interruption occurs in the same current zero as in the first operation, then a third test with the setting of the control of the tripping impulse further retarded by 60 electrical degrees shall be made.

For test duty No. 2 the setting of the control of the tripping impulse of the two breaking operations shall be 60 electrical degrees apart.

For direct tests the above mentioned procedure may lead to more than one loop of arcing. In order to perform synthetic tests on the same basis the arcing of the tested circuit-breaker shall be prolonged through the necessary number of zeros of power-frequency current by means of forced reignition.

6.103 *Test circuits for short circuit making and breaking tests*

6.103.1 *Power factor*

The power factor in each phase shall be determined in accordance with one of the methods described in Appendix DD.

The power factor of a polyphase circuit shall be taken as the average of the power factors in each phase.

During the tests, this average value shall not exceed 0.15.

The power factor of any phase shall not vary from the average by more than 25% of the average.

6.103.2 *Frequency*

Circuit-breakers shall be tested at rated frequency with a tolerance of ±10%.

However, for convenience of testing, some deviations from the above tolerance are allowable; for example, when circuit-breakers rated at 50 Hz are tested at 60 Hz and vice versa, care should be exercized in the interpretation of the results, taking into account all significant facts such as the type of the circuit-breaker and the type of test performed.

Note. — In some cases, the rated characteristics of a circuit-breaker may be different for use at 60 Hz and for use at 50 Hz.

6.103.3 *Earthing of test circuit*

The connections to earth of the test circuit for short-circuit making and breaking tests shall be in accordance with the following requirements and shall in all cases be indicated in the diagram of the test circuit included in the test report (see Appendix CC, Sub-clause 2.4, Item *g)*).

a) For three-phase tests of a three-pole circuit-breaker, first-pole-to-clear factor 1.5:

The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply isolated and the short-circuit point earthed as shown in Figure 19a, page 236, or vice versa as shown in Figure 19b, page 236, if the test can be made only in the latter way.

These test circuits give a first-pole-to-clear factor of 1.5.

In accordance with Figure 19a, the neutral of the supply source may be earthed through a resistor, the resistance of which is as high as possible and, expressed in ohms, in no case less than $U/10$, where U is the numerical value in volts of the voltage between lines of the test circuit.

When a test circuit according to Figure 19b is used, it is recognized that in case of an earth fault at one terminal of the test circuit-breaker, the resulting earth current could be dangerous. It is consequently permitted to connect the supply neutral to earth through an appropriate impedance.

b) For three-phase tests of a three-pole circuit-breaker, first-pole-to-clear factor 1.3:

The circuit-breaker (with its structure earthed as in service) shall be connected in a test circuit having the neutral point of the supply connected to earth by an appropriate impedance and the short-circuit point earthed as shown in Figure 20a, page 237, or vice versa as shown in Figure 20b, page 237, if the test can be made only in the latter way.

The impedance in the neutral connection shall be selected appropriate to a first-pole-to-clear factor of 1.3.

c) For single-phase tests of a single pole of a three-pole circuit-breaker, first-pole-to-clear factor 1.5,

– intended for universal use irrespective of the earthing condition of the system neutral:

The test circuit and the circuit-breaker structure shall be connected as in Figure 21a, page 238, so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first pole to clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 19a.

For convenience of the test station, subject to agreement of the user, the test circuit can be used with an intermediate point of the supply earthed, the voltage distribution preferably being as shown in Figure 21b, page 238.

– intended for use on systems with earthed neutral subject to unearthed faults:

The test circuit and the circuit-breaker structure shall be connected as in Figure 21b so that the voltage conditions between live parts and the structure after arc extinction are the same as those which would exist in the first pole to clear of a three-pole circuit-breaker if tested in the test circuit shown in 19b.

For convenience of the test station, subject to agreement of the manufacturer, the test circuit shown in Figure 21a can be used.

d) For single-phase tests of a single pole of a three-pole circuit-breaker, first-pole-to-clear factor 1.3:

The test circuit and the circuit-breaker structure shall be connected as in Figure 22a, page 239, so that the voltage conditions between live parts and the structure after extinction are approximately the same as those that would exist in the first pole to clear of a three-pole circuit-breaker if tested in the test circuit shown in Figure 20a, page 237.

For convenience of the test station, subject to agreement of the user, the test circuit can be used with an intermediate point of the supply earthed, the voltage distribution preferably being as shown in Figure 22b, page 239.

e) For single-phase tests of a single-pole circuit-breaker:

The test circuit and the circuit-breaker structure shall be connected so that the voltage conditions between live parts and earth within the circuit-breaker after arc extinction reproduce the service voltage conditions. The connections used shall be indicated in the test report.

6.103.4 *Connection of test circuit to circuit-breaker*

Where the physical arrangement of one side of the circuit-breaker differs from that of the other side, the live side of the test circuit shall be connected for test to that side of the circuit-breaker, connection with which gives the more severe conditions with respect to voltage to earth, unless the circuit-breaker is especially designed for feeding from one side only.

In case of doubt, the Test-duties Nos. 1 and 2 (Sub-clause 6.106) shall be made with opposite connections, and likewise Test-duties Nos. 4 and 5. If Test-duty No. 5 is omitted, Test-duty No. 4 shall be made with each of the two connections.

6.104 *Short-circuit test quantities*

Where a tolerance is not specified, type tests shall be carried out at values not less severe than the specified values; the upper limits are subject to the consent of the manufacturer.

6.104.1 *Applied voltage before short-circuit making tests*

For the short-circuit making tests of Sub-clause 6.106.4 the applied voltage shall be as follows:

a) For three-phase tests on a three-pole circuit-breaker, the average value of the applied voltages shall not be less than the rated voltage U divided by $\sqrt{3}$ and shall not exceed this value by more than 10% without the consent of the manufacturer.

The differences betwen the average value and the applied voltages of each pole shall not exceed 5%.

b) For single-phase tests on a three-pole circuit-breaker, the applied voltage shall not be less than the phase-to-earth value $U/\sqrt{3}$ and shall not exceed this value by more than 10% without the consent of the manufacturer.

Note. — With the manufacturer's consent it is permissible, for convenience of testing, to apply a voltage equal to the product of the phase-to-earth voltage and the first-pole-to-clear factor (1.3 or 1.5) of the circuit-breaker.

Where the circuit-breaker can be arranged for a single-pole reclosing operation and the maximum time difference between the contacts touching in a subsequent three-pole closing operation exceeds one half cycle of rated frequency (compare Sub-clause 5.101, Note 2) the applied voltage shall be the product of the phase-to-earth voltage and the first-pole-to-clear factor (1.3 or 1.5) of the circuit-breaker.

c) For a single-pole circuit-breaker, the applied voltage shall not be less than the rated voltage and shall not exceed this value by more than 10% without the consent of the manufacturer.

6.104.2 *Short-circuit (peak) making current*

When the short-circuit making current does not attain 100% of the rated short-circuit making current in both tests for which this value is specified in Sub-clause 6.106.4, these tests are still valid if the short-circuit making current attains 100% in one test and 90% in the other test.

Where a circuit-breaker exhibits pre-arcing to such an extent that the rated short-circuit making current is not attained during the first close-open operation of Test-duty No. 4 and even after adjustment of the timing, the rated short-circuit making current is not achieved during the second close-open operation, testing stations shall adopt the following procedure. The procedure shall be applied only in the case of single-phase testing since during three-phase tests the requirements outlined in Items *a)* and *b)* below are considered to be adequately demonstrated during the normal Test-duty No. 4.

As the amount of pre-arcing is directly dependent on the applied voltage it is likely that in the majority of cases Test-duty No. 4 is undertaken as Test-duties Nos. 4a and 4b in order to avoid undue stressing of the circuit-breaker. In such cases Test-duty No. 4a given in Sub-clause 6.106.4.1 shall be carried out as $O-t-CO-t'-CO$ with prospective rated short-circuit making current at phase-to-earth voltage and with the short-circuit breaking current as close as is possible to the rated short-circuit breaking current.

When the circuit-breaker exhibits pre-arcing, two cases have to be considered:

a) when the required short-circuit making currents are not attained in the two close-open tests due to pre-arcing, evidence shall be produced that the short-circuit making currents attained are representative of conditions the circuit-breaker is required to meet;

b) when the circuit-breaker exhibits appreciable pre-arcing, a special close-open test has to be performed to prove that the circuit-breaker can withstand the stresses present when pre-arcing is such that a symmetrical current is initiated.

In either of the above cases additional tests are required and since it is extremely difficult to differentiate between the two cases the same test procedure has been established for both. The procedure aims to demonstrate that:

c) the maximum possible short-circuit making current has been attained;

d) the circuit-breaker can close and open against a symmetrical current as a result of pre-arcing commencing at a peak of the applied voltage.

Condition of Item *c)* is likely to be met when a closing operation is made with a reconditioned circuit-breaker. Condition of Item *d)* can only be met after one or more opening operations have been performed. Therefore, if during Test-duty No. 4 or 4a either Item *a)* or *b)* is apparent the test-duty shall be completed and then the circuit-breaker shall be reconditioned after which the following additional tests shall be made: $CO-t'-CO$, where the first closing operation shall aim to demonstrate condition of Item *c)* and the second close-open operation shall demonstrate condition of Item *d)*. The second CO-test may be deleted, if the conditions according to Item *d)* have already been met during the normal Test-duty No. 4 or 4a.

The tests shall be performed at phase-to-earth voltage and the prospective short-circuit making current shall be at least equal to the rated short-circuit making current and the short-circuit breaking current shall be as near as is possible to the rated short-circuit breaking current.

6.104.3 *Short-circuit breaking current*

The short-circuit current broken by a circuit-breaker shall be measured at the instant of contact separation in accordance with Figure 8, page 98, and shall be stated in terms of two values as specified below:

a) the average of the r.m.s. values of the a.c. components in all phases;

b) the percentage value of the maximum d.c. component in any phase.

The r.m.s. value of the a.c. component in any phase shall not vary from the average by more than 10% of the average.

Although the short-circuit breaking current is measured at the instant corresponding to contact separation, the breaking performance of the circuit-breaker is determined among other factors by the current which is finally broken in the last loop of arcing. The decrement of the a.c. component of the short-circuit current is therefore very important, particularly when testing those circuit-breakers which arc for several loops of current. To obviate an easement of duty, the decrement of the a.c. component of the short-circuit current should be such that at a time corresponding to the final extinction of the main arc in the last pole to clear, the a.c. component of the prospective current is not less than 90% of the appropriate value for the test-duty.

If the characteristics of the circuit-breaker are such that it reduces the short-circuit current value below the prospective breaking current, or if the oscillogram is such that the current wave envelope cannot be drawn successfully, the average prospective short-circuit breaking current in all phases shall be deemed to be the short-circuit breaking current and shall be measured from the oscillogram of prospective current at a time corresponding to the instant of contact separation.

The instant of contact separation can be determined according to the experience of the testing station and the type of apparatus under test by various methods, for instance, by recording the contact travel during the test, by recording the arc voltage or by a test on the circuit-breaker at no-load.

In a synthetic test-circuit, there may be some additional distortion of the current, depending upon the ratio of the arc voltage to the voltage of the power-frequency current circuit. In order to comply with the requirements given above in that case also, a procedure for determining the correct short-circuit breaking current as given in IEC Publication 427 applies.

6.104.4 *D.C. component of short-circuit breaking current*

For circuit-breakers which operate in opening times preventing the control of the d.c. component, e.g. circuit-breakers fitted with direct over-current releases when in a condition for test as set out in Sub-clause 6.102.2, the d.c. component may be greater than that specified for Test-duties Nos. 1 to 4 of Sub-clause 6.106.

Circuit-breakers shall be considered to have satisfied Test-duty No. 5, even if the percentage d.c. component in one opening operation is less than the specified value, provided that the average of the percentage d.c. components of the opening operations of the test-duty exceeds the specified percentage d.c. component.

6.104.5 *Transient recovery voltage (TRV) for terminal fault tests*

6.104.5.1 *General*

The prospective TRV of the test circuits shall be determined by such a method as will produce and measure the TRV-wave without significantly influencing it, and shall be measured at the terminals to which the circuit-breaker will be connected with all necessary test-measuring devices, such as voltage dividers, included. Suitable methods are described in Appendix GG (see also Sub-clause 6.104.6).

For three-phase circuits, the TRV refers to the first pole to clear, i.e. the voltage across one open pole with the other two poles closed, with the appropriate test circuit arranged as specified in Sub-clause 6.103.3.

The prospective TRV for the test is represented by its envelope drawn as shown in Appendix FF and by its initial portion.

The TRV specified for the test is represented by a reference line, a delay line and initial transient recovery voltage (ITRV) envelope in the same manner as the rated TRV in accordance with Sub-clause 4.102.2 and Figures 10, 11 and 12, pages 99, 100 and 101.

The prospective transient recovery voltage wave of the test circuit shall comply with the following two requirements:

– *Requirement a)*

Its envelope shall at no time be below the specified reference line.

Note. – It is stressed that the extent by which the envelope may exceed the specified reference line requires the consent of the manufacturer (see Sub-clause 6.104); this is of particular importance in the case of two-parameter envelopes when four-parameter reference lines are specified, and in the case of four-parameter envelopes when two-parameter reference lines are specified.

– *Requirement b)*

Its initial portion shall reach the specified ITRV peak value u_i at a time not exceeding t_i. Thereafter, it shall not cross the specified delay line of the TRV.

These requirements are illustrated in Figures 12 and 23 to 27, pages 101, 241 to 243.

6.104.5.2 *Test-duties Nos. 4 and 5*

The specific reference lines, delay lines and ITRV are given by the standard values in Tables IIA, IIB, IIC, IID, IIE and III.

With reference to ITRV, if a test is made with a TRV including an oscillatory initial part passing through the point (u_i, t_i) and the horizontal line between A and B of Figure 12, it is assumed that the effect on the circuit-breaker is similar to that of any ITRV defined by (u_i, t_i), the horizontal line from (u_i, t_i) to B and the initial slope of the TRV.

Owing to limitations of the testing station, it may not be feasible to comply with the requirement of Item *b)* of Sub-clause 6.104.5.1 with respect to the time delay t_d as specified in Tables IIA, IIB, IIC, IID or IIE. Where short-line fault duties are also to be performed any such deficiency of the TRV of the supply circuit shall be compensated by an increase of the voltage excursion to the first peak of the line-side voltage (see Sub-clause 6.109.3, Item *a)*). The time delay of the supply circuit shall be as small as possible, but shall in any case not exceed the delay line limit values given in Tables XIVA, XIVB, XIVC, XIVD or XIVE.

Where short-line fault duties are also to be performed, it may be convenient to combine the ITRV and SLF requirements in the line side circuit. When the ITRV is combined with the transient voltage of a short line having a time delay t_{dL} as specified in Table V, the total stress is for practical considerations equal to the stress of a short line without time delay. Therefore, the ITRV requirements for test duties 4 and 5 are considered to be covered when the short-line fault duties are performed using a short line without time delay t_{dL} (see also Sub-clause 6.109.3, Item *c)*).

TABLE XIVA

Standard limit values of delay lines of prospective transient recovery voltage for Test-duties Nos. 4 and 5 where short-line fault tests are also made

Rated voltage Series I — First-pole-to-clear factor 1.5

Rated voltage U (kV)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)
52	20	30	64
72.5	25	41	80

$t_d = 0.15\ t_3$.

TABLE XIVB

Standard limit values of delay lines of prospective transient recovery voltage for Test-duties Nos. 4 and 5 where short-line fault tests are also made

Rated voltage Series II — First-pole-to-clear factor 1.5

Under consideration.

TABLE XIVC

Standard limit values of delay lines of prospective transient recovery voltage for Test-duties Nos. 4 and 5 where short-line fault tests are also made Rated voltages 100 kV to 170 kV — First-pole-to-clear 1.3

Rated voltage U (kV)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)
100	8	53	34
123	10	65	42
145	12	77	50
170	14	90	59

$t_d = 0.15\ t_1$.

TABLE XIVD

Standard limit values of delay lines of prospective transient recovery voltage for Test-duties Nos. 4 and 5 where short-line fault tests are also made Rated voltages 100 kV to 170 kV — First-pole-to-clear factor 1.5

Rated voltage U (kV)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)
100	9	61	40
123	11	75	49
145	13	89	58
170	16	104	68

$t_d = 0.15\ t_1$.

TABLE XIVE

Standard limit values of delay lines of prospective transient recovery voltage for Test-duties Nos. 4 and 5 where short-line fault tests are also made

Rated voltages 245 kV and above — First-pole-to-clear factor 1.3

Rated voltage U (kV)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)
245	20	130	85
300	24	159	103
362	29	192	125
420	33	223	145
525	42	279	181
765	61	406	264

$t_d = 0.15\ t_1$.

6.104.5.3 *Test-duty No. 3*

For rated voltages up to and including 72.5 kV, two-parameter reference lines are used. The specified standard values are given in Tables XVA and XVB.

For rated voltages of 100 kV and above, four-parameter reference lines are used. The specified standard values are given in Tables XVC, XVD and XVE. The values of t_d and t' without brackets are the lower limits which should not be reduced and the values in brackets are the upper limits which should not be exceeded during tests.

TABLE XVA

Standard values of prospective transient recovery voltage for Test-duty No. 3

Rated voltage Series I

Representation by two parameters — First-pole-to-clear factor 1.5

Rated voltage U (kV)	TRV peak value u_c (kV)	Time t_3 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_c/t_3 (kV/μ/s)
3.6	6.6	17	3	2.2	9	0.39
7.2	13	22	4	4.4	12	0.60
12	22	26	5	7.3	14	0.85
17.5	32	31	6	11	17	1.04
24	44	38	8	15	20	1.16
36	66	46	9	22	25	1.44
52	96	57	11	32	30	1.68
72.5	133	72	14	44	38	1.85

$u_c = 1.5 \cdot 1.5 \sqrt{\frac{2}{3}}\, U$; $t_d = 0.2\ t_3$; $u' = \frac{1}{3} u_c$.

TABLE XVB

Standard values of prospective transient recovery voltage for Test-duty No. 3

Rated voltages Series II

Representation by two parameters — First-pole-to-clear factor 1.5

Under consideration.

TABLE XVC

Standard values of prospective transient recovery voltage for Test-duty No. 3

Rated voltages 100 kV to 170 kV

Representation by four parameters — First-pole-to-clear factor 1.3

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
100	106	35	159	158	2 (9)	53	20 (27)	3.0
123	131	44	196	198	2 (11)	65	24 (33)	3.0
145	154	51	231	230	2 (13)	77	28 (38)	3.0
170	180	60	271	270	2 (15)	90	32 (45)	3.0

$u_1 = 1.3 \sqrt{\frac{2}{3}} U$; $t_2 = 4.5\, t_1$; $u_c = 1.5\, u_1$; $t_d = 2$ μs or $0.25\, t_1$; $u' = \frac{1}{2} u_1$.

TABLE XVD

Standard values of prospective transient recovery voltage for Test-duty No. 3

Rated voltages 100 kV to 170 kV

Representation by four parameters — First-pole-to-clear factor 1.5

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
100	122	41	184	185	2 (10)	61	22 (31)	3.0
123	150	50	226	225	2 (13)	75	27 (38)	3.0
145	178	59	266	266	2 (15)	89	32 (44)	3.0
170	208	69	312	311	2 (17)	104	37 (52)	3.0

$u_1 = 1.5 \sqrt{\frac{2}{3}} U$; $t_2 = 4.5\, t_1$; $u_c = 1.5\, u_1$; $t_d = 2$ μs or $0.25\, t_1$; $u' = \frac{1}{2} u_1$.

TABLE XVE

Standard values of prospective transient recovery voltage for Test-duty No. 3
Rated voltages 245 kV and above
Representation by four parameters — First-pole-to-clear factor 1.3

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
245	260	87	390	392	2 (22)	130	45 (65)	3.0
300	318	106	478	477	2 (27)	159	55 (80)	3.0
362	384	128	576	576	2 (32)	192	66 (96)	3.0
420	446	149	669	671	2 (37)	223	76 (111)	3.0
525	557	186	836	837	2 (46)	279	95 (139)	3.0
765	812	271	1 218	1 220	2 (68)	406	137 (203)	3.0

$u_1 = 1.3 \sqrt{\frac{2}{3}} U$; $t_2 = 4.5\, t_1$; $u_c = 1.5\, u_1$; $t_d = 2$ μs or $0.25\, t_1$; $u' = \frac{1}{2} u_1$.

6.104.5.4 *Test-duty No. 2*

For rated voltages up to and including 72.5 kV, two-parameter reference lines are used. The specified standard values are given in Tables XVIA and XVIB.

For rated voltages of 100 kV and above, four-parameter reference lines are used. The specified standard values are given in Table XVIC; the values of t_d and t' without brackets are the lower limits which should not be reduced, and the values in brackets are the upper limits which should not be exceeded during tests.

Note. — In view of the fact that the contribution of transformers to the short-circuit current is relatively larger at smaller values of short-circuit current, and even in earthed neutral systems of rated voltages 100 kV to 170 kV, a comparatively large number of transformers with unearthed neutral are in service, the TRV specified for Test-duties Nos. 2 and 1 are based on a first-pole-to-clear factor 1.5 for rated voltages 100 kV to 245 kV. The same applies for Test-duty No. 1 for rated voltages 300 kV and above.

TABLE XVIA

Standard values of prospective transient recovery voltage for
Test-duty No. 2
Rated voltages Series I
Representation by two parameters — First-pole-to-clear factor 1.5

Rated voltage U (kV)	TRV peak value u_c (kV)	Time t_3 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_c/t_3 (kV/μs)
3.6	6.6	9	2	2.2	5	0.77
7.2	13	11	2	4.4	6	1.20
12	22	13	3	7.3	7	1.70
17.5	32	15	3	11	8	2.14
24	44	19	4	15	10	2.32
36	66	23	5	22	12	2.88
52	96	28	6	32	15	3.41
72.5	133	36	7	44	19	3.70

$u_c = 1.5 \cdot 1.5 \sqrt{\frac{2}{3}} U$; $t_d = 0.2\, t_3$; $u' = \frac{1}{3} u_c$.

Note. — In testing stations, it may be difficult to meet the small values of time t_3. The shortest time which can be met should be used and the value stated in the test report.

Table XVIb

Standard values of prospective transient recovery voltage for Test-duty No. 2

Rated voltages Series II

Representation by two parameters — First-pole-to-clear factor 1.5

Under consideration.

Table XVIc

Standard values of prospective transient recovery voltage for Test-duty No. 2

Rated voltages 100 kV and above

Representation by four parameters — First-pole-to-clear factor 1.5 for rated voltages 100 kV to 245 kV and 1,3 for rated voltages 300 kV and above

Rated voltage U (kV)	First reference voltage u_1 (kV)	Time t_1 (μs)	TRV peak value u_c (kV)	Time t_2 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_1/t_1 (kV/μs)
100	122	24	184	180	5 (6)	61	17 (18)	5.0
123	151	30	226	225	5 (8)	75	20 (23)	5.0
145	178	36	266	270	5 (9)	89	23 (27)	5.0
170	208	42	312	315	5 (11)	104	26 (31)	5.0
245	300	60	450	450	5 (15)	150	35 (45)	5.0
300	318	64	478	480	5 (16)	159	37 (48)	5.0
362	384	77	576	578	5 (19)	192	43 (58)	5.0
420	446	89	669	668	5 (22)	223	50 (67)	5.0
525	557	111	836	833	5 (28)	279	61 (84)	5.0
765	812	162	1 218	1 215	5 (41)	406	86 (122)	5.0

U from 100 kV to 245 kV: $u_1 = 1.5 \sqrt{\frac{2}{3}} U$; $t_2 = 7.5\, t_1$; $u_c = 1.5\, u_1$.

$U \geqslant 300$ kV: $u_1 = 1.3 \sqrt{\frac{2}{3}} U$; $t_d = 5$ μs or $0.25\, t_1$; $u' = \frac{1}{2} u_1$.

6.104.5.5 *Test-duty No. 1*

For rated voltages below 100 kV, the TRV peak value shall correspond to the appropriate value specified for Test-duty No. 2 in Tables XVIa and XVIb. Owing to difficulties of meeting short times t_3 in testing stations at low currents, no values are specified. The shortest time which can be obtained should be used but not less than the values in Tables XVIa and XVIb.

For rated voltages 100 kV and above, a factor 0.9 is introduced to recognize that only 90% (approximately) of the circuit voltage appears across the transformer which is assumed to be supplying the total short-circuit current at this level.

Two-parameter reference lines are used for all rated voltages. The specified standard values are given in Table XVII. The time to peak is a function of the natural frequency of transformers.

TABLE XVII

Standard values of prospective transient recovery voltage for Test-duty No. 1

Rated voltages 100 kV and above

Representation by two parameters — First-pole-to-clear factor 1.5

Rated voltage U (kV)	TRV peak value u_c (kV)	Time t_3 (μs)	Time delay t_d (μs)	Voltage u' (kV)	Time t' (μs)	Rate of rise u_c/t_3 (kV/μs)
100	187	34	4	62	16	5.5
123	230	40	5	77	18	5.8
145	272	45	6	91	21	6.0
170	319	51	6	106	23	6.2
245	459	66	8	153	30	7.0
300	562	73	9	187	33	7.7
362	678	82	10	226	37	8.3
420	787	88	11	262	40	8.9
525	984	98	12	328	45	10.0
765	1 434	114	14	478	52	12.6

$u_c = 1.7 \cdot 1.5 \sqrt{\frac{2}{3}}\, U \cdot 0.9;\ u' = \frac{1}{3} u_c;\ t_d = 0.123\ t_3.$

Note. — In testing stations, it may be difficult to meet the small values of time t_3. The shortest time which can be met should be used and the values stated in the test report.

6.104.6 *Measurement of transient recovery voltage*

During a short-circuit test, the circuit-breaker characteristics such as arc voltage, post arc conductivity and presence of switching resistors (if any) will affect the transient recovery voltage. Thus the test transient recovery voltage will differ from the prospective TRV-wave of the test circuit upon which the performance requirements are based to a degree depending upon the characteristics of the circuit-breaker.

Unless the modifying effect of the circuit-breaker is not significant and the breaking current does not contain a significant d.c. component, records taken during tests should not be used for assessing the prospective transient recovery voltage characteristics of the circuit, and this should be done by other means, as described in Appendix GG.

It is, however, desirable to record the transient recovery voltage during test for the purpose of providing a check on the prospective test circuit characteristics.

6.104.7 *Power frequency recovery voltage*

The power frequency recovery voltage of the test circuit may be stated as a percentage of the power frequency recovery voltage specified below. It shall not be less than 95% of the specified value and shall be maintained for at least 0.1 s.

In order to obtain the required power frequency recovery voltage in a generator testing station, the testing generator may have its excitation temporarily increased during the short-circuit period.

Regarding synthetic test circuits, details and tolerances are given in IEC Publication 427.

For the basic short-circuit test duties of Sub-clause 6.106, the power frequency recovery voltage shall be as follows, subject to the 95% minimum stated above:

a) For three-phase tests on a three-pole circuit-breaker, the average value of the power frequency recovery voltages shall be equal to the rated voltage U of the circuit-breaker divided by $\sqrt{3}$.

The power frequency recovery voltage of any pole should not deviate by more than 20% from the average value at the end of the time for which it is maintained.

b) For single-phase tests on a three-pole circuit-breaker, the power frequency recovery voltage shall be equal to the product of the phase-to-earth value $U/\sqrt{3}$ and the first-pole-to-clear factor (1.3 or 1.5); the power frequency recovery voltage may be reduced to $U/\sqrt{3}$ after an interval of one cycle of rated frequency.

c) For a single-pole circuit-breaker, the power frequency recovery voltage shall be equal to the rated voltage U of the circuit-breaker.

The power frequency recovery voltage shall be measured between terminals of a pole in each phase of the test circuit. Its r.m.s. value shall be determined on the oscillogram within the time interval of one half cycle and one cycle of test frequency after final arc extinction, as indicated in Figure 28, page 245. The vertical distance (V_1, V_2 and V_3 respectively) between the peak of the second half-wave and the straight line drawn between the respective peaks of the preceding and succeeding half-waves shall be measured, and this, when divided by $2\sqrt{2}$ and multiplied by the appropriate calibration, gives the r.m.s. value of the power frequency recovery voltage recorded.

6.105 *Short-circuit test procedure*

6.105.1 *Time interval between tests*

The basic short-circuit tests and, if applicable, short-line fault tests consist of the series of test-duties specified in Sub-clauses 6.106 and 6.109. The operations and time intervals of the test-sequences are derived from the rated operating sequence of the circuit-breaker which is given in Sub-clause 4.104.

The time intervals between individual operations of a test-sequence shall be the time intervals of the rated operation sequence of the circuit-breaker subject to the following provision:

If, with the time intervals specified, it is difficult to comply with all test requirements, the time intervals for test shall be subject to agreement between manufacturer and user.

Occasionally, it may for other reasons be necessary to exceed the specified time interval, e.g. due to the more complicated procedure of synthetic testing, or it may be found necessary to make minor adjustments to control or measuring equipment or to excite or to synchronize large test-plant generators. In such cases, provided that the time interval does not exceed 10 min when the rated time interval is 3 min, the tests shall not be disqualified. The actual time interval between operations shall be indicated in the test report.

It is also possible that trouble may be experienced with the testing station equipment and an interval longer than 10 min may be required. Provided that such a delay is not due to faulty operation of the circuit-breaker and has no effect on its condition and operation, the resulting time interval is permissible if it does not occur more than once in any series of test-duties.

On the other hand, the time interval between tests shall not be shorter than 2 min when the rated time interval is 3 min. The actual time interval shall be recorded in this case to the nearest half-minute.

6.105.2 *Application of auxiliary power to the opening release — Breaking tests*

Auxiliary power shall whenever practicable be applied to the opening release after the initiation of the short-circuit, but when this is impracticable the power may be applied before the initiation of the short-circuit (with the limitation that contacts shall not start to move before the initiation of the short-circuit). It shall then be demonstrated, or test evidence produced, that the circuit-breaker can open satisfactorily at the specified short-circuit current without being pre-tripped. This evidence may be obtained by tests at a reduced voltage.

6.105.3 *Application of auxiliary power to the opening release — Make-break tests*

In a make-break test other than a test to Sub-clause 6.106.5 auxiliary power shall not be applied to the opening release before the circuit-breaker has reached the closed position. In the closing-opening operations of Test-duty No. 4, Sub-clause 6.106.4, the power shall not be applied until at least one half-cycle has elapsed from the instant of contact make. It is permissible to delay the circuit-breaker opening so that the permissible d.c. component is not exceeded.

6.105.4 *Latching on short-circuit*

Unless the circuit-breaker is fitted with a making current release, or equivalent device, it shall be proved that it latches satisfactorily without undue hesitation when there is negligible decrement of the a.c. component of the current during the closing period. If this cannot be proved by Test-duty No. 4, or the permissible alternatives, the test shall be repeated at reduced voltage using a test circuit which gives the rated short-circuit making current, with negligible decrement of the a.c. component.

It is sometimes difficult to establish whether or not a circuit-breaker has latched and at what instant of time latching occurred. For this reason, it is not possible to specify a test procedure to cover all cases and if necessary, the method employed to prove satisfactory latching shall be recorded in the test report.

6.105.5 *Invalid tests*

It may become necessary to perform a greater number of short-circuit tests than are required by this standard. In the event of an invalid test of a duty cycle the invalid part of the duty cycle may be repeated without reconditioning of the circuit-breaker. In case of a failure of the circuit-breaker during such additional tests, the circuit-breaker may be reconditioned and the complete duty cycle repeated.

Note. — In a rapid auto-reclosing duty cycle, the O − *t* − CO is also regarded as one part and an ensuing CO is regarded as one part.

6.106 *Basic short-circuit test-duties*

The basic short-circuit test series shall consist of the Test-duties Nos. 1 to 5 specified below.

The breaking current may depart from the specified values by not more than 20% of the specified values for Test-duties Nos. 1 and 2 and by not more than 10% for Test-duty No. 3.

The peak short-circuit current during the breaking-current tests of Test-duties Nos. 4, 4b and 5 shall not exceed 110% of the rated short-circuit making current of the circuit-breaker.

For convenience in testing, it is permissible to introduce a closing operation before any opening operation in Test-duties Nos. 1, 2, 3 and 5.

6.106.1 *Test-duty No. 1*

Test-duty No. 1 consists of the rated operating sequence confined to opening operations only, at 10% of the rated short-circuit breaking current with a d.c. component of less than 20% and a transient and power frequency recovery voltage as specified in Sub-clauses 6.104.5.5 and 6.104.7 (see also Tables XVIA, XVIB and XVII).

6.106.2 *Test-duty No. 2*

Test-duty No. 2 consists of the rated operating sequence confined to opening operations only, at 30% of the rated short-circuit breaking current with a d.c. component of less than 20% and a transient and power frequency recovery voltage as specified in Sub-clause 6.104.5.4 Tables XVIA, XVIB, XVIC and Sub-clause 6.104.7.

6.106.3 *Test-duty No. 3*

Test-duty No. 3 consists of the rated operating sequence confined to opening operations only, at 60% of the rated short-circuit breaking current with a d.c. component of less than 20% and a transient and power frequency recovery voltage as specified in Sub-clause 6.104.5.3 Tables XVA, XVB, XVC, XVD, XVE and Sub-clause 6.104.7.

6.106.4 *Test-duty No. 4*

Test-duty No. 4 consists of the rated operating sequence at 100% of the rated short-circuit breaking current taking account of Sub-clause 6.104.3, and with a transient and power frequency recovery voltage as specified in Tables IIA, IIB, IIC, IID, IIE, III and Sub-clause 6.104.7 and 100% of the rated short-circuit making current taking account of Sub-clause 6.104.2 and an applied voltage as specified in Sub-clause 6.104.1 (see also Tables XIVA, XIVB, XIVC, XIVD and XIVE).

For this test-duty, the percentage d.c. component shall not exceed 20% of the a.c. component.

When making single-phase tests on one pole of a three-pole circuit-breaker, or when the characteristics of the test plant are such that it is impossible to carry out Test-duty No. 4 within the specified limits of applied voltage in Sub-clause 6.104.1, making current in Sub-clause 6.104.2, breaking current in Sub-clause 6.104.3 and transient and power frequency recovery voltages in Sub-clauses 6.104.5.2 and 6.104.7 taking account also of Sub-clauses 6.105.3 and 6.105.4 the making and breaking tests in Test-duty No. 4 may be made separately as follows:

6.106.4.1 *Test-duty No. 4a, making tests*

$C-t'-C$ in case of a rated operating sequence $O-t-CO-t'-CO$;

$C-t''-C$ in case of a rated operating sequence $CO-t''-CO$ at 100% of the rated short-circuit making current and at an applied voltage as specified in Sub-clause 6.104.1.

6.106.4.2 *Test-duty No. 4b, breaking tests*

$O-t-O-t'-O$ in case of a rated operating sequence $O-t-CO-t'-CO$;

$O-t''-O$ in case of a rated operating sequence $CO-t''-CO$ at 100% of the rated short-circuit breaking current and with a transient and power frequency recovery voltage as specified in Sub-clauses 6.104.5.2 and 6.104.7.

However, when Test-duty No. 4 is made as Test-duties Nos. 4a and 4b, either Test-duty No. 4a shall be a full rated operating sequence with breaking current and transient and power frequency recovery voltage as close as possible to the values specified for Test-duty No. 4, or Test-duty No. 4b shall be a full rated operating sequence with making current and applied voltage as close as possible to the values specified for Test-duty No. 4.

It is permissible to restore the circuit-breaker to its initial condition as indicated in Sub-clause 6.102.8.5, between Test-duties Nos. 4a and 4b.

If it is possible to prove 100% of the rated short-circuit making current in a test-duty other than Test-duty No. 4, for example Test-duty No. 5, it is permissible to perform Test-duty No. 4b only in place of Test-duty No. 4.

6.106.5 *Test-duty No. 5*

Test-duty No. 5 shall be applied only to circuit-breakers having a time interval τ, determined in accordance with Sub-clause 4.101.2, of less than 80 ms.

Test-duty No. 5 consists of the rated operating sequence confined to opening operations only, at 100% of the rated short-circuit breaking current, with a percentage d.c. component equal to the appropriate rated value specified in Sub-clause 4.101, and transient and power frequency recovery voltages as specified in Sub-clauses 6.104.5.2 and 6.104.7 (see also Sub-clause 6.104.6). (For Table references see Sub-clause 6.106.4.)

However, for a circuit-breaker which is of such design that it may not reach its closed position when being closed against a short-circuit current, Test-duty No. 5 shall be made with the rated operating sequence.

For circuit-breakers intended to be used where it can be expected that the percentage of the d.c. component will be greater than that corresponding to Figure 9, page 99, as may occur in the vicinity of centres of generation, testing shall be subject to agreement between manufacturer and user, see note of Sub-clause 4.101.2 and Sub-clause 8.103.1.

6.107 *Critical current tests*

6.107.1 *Applicability*

These tests are short-circuit tests additional to the basic short-circuit test-duties covered by Sub-clause 6.106 and are applicable only to circuit-breakers which have a critical current of less than 10% of the rated short-circuit breaking current. It shall be assumed that this is the case if the average of the arcing times in Test-duty No. 1, Sub-clause 6.106.1, is significantly greater than that in Test-duty No. 2, Sub-clause 6.106.2.

6.107.2 *Test currents*

Where applicable, critical current tests shall be made at currents in the range of 4% to 6% and in the range of 2% to 3% of the rated short-circuit breaking current.

Note. — Tests for breaking small inductive currents are covered by Sub-clause 6.112.

6.107.3 *Critical current test-duties*

The critical current test-duties shall be as for Test-duty No. 1, Sub-clause 6.106.1, with the breaking currents specified in Sub-clause 6.107.2 and with the TRV provisions for Test-duty No. 1

modified by multiplying time t_3 in Sub-clause 6.104.5.4, Tables XVIA, XVIB and XVII, by the factor $\sqrt{10/X}$ where X is the test breaking current as a percentage of the rated short-circuit breaking current.

Note. – This adjustment is based on test circuit capacitances being the same for Test-duty No. 1 and the critical current test-duties.

6.108 *Single-phase short-circuit tests*

6.108.1 *Applicability*

Single-phase short-circuit tests are additional to the basic short-circuit test duties covered by Sub-clause 6.106 and are applicable only to three-pole circuit-breakers intended for use on an earthed neutral system, having the three poles in one enclosure, or three separately enclosed poles which are coupled mechanically and fitted with a common opening release. The tests are intended to show that the operation of the circuit-breaker is not adversely affected by the unbalanced forces produced.

6.108.2 *Test current and recovery voltage*

It shall be demonstrated, or evidence shall be produced, to show that the circuit-breaker is capable of breaking its rated short-circuit breaking current with a d.c. component not exceeding 20% of the a.c. component, with the current applied to one pole only, the transient recovery voltage meeting requirements of Items *a)* and *b)* of Sub-clause 6.104.5.1 with standard values derived from Tables IIA, IIB, IID and IIE, by dividing the voltages by the first-pole-to-clear factor indicated above the tables, the time coordinates remaining unchanged.

Where necessary, advantage may be taken of the provisions of Sub-clause 6.104.5.2 concerning test plant limitations. The specified value of the power frequency recovery voltage (Sub-clause 6.104.7) is the phase-to-earth value $U/\sqrt{3}$ of the rated voltage of the circuit-breaker.

6.108.3 *Test-duty*

The test-duty shall consist of a single breaking test, the current being applied as follows:

a) for circuit-breakers having three poles in one enclosure: through one outer pole;

b) for circuit-breakers having three separately enclosed poles which are mechanically coupled: through the pole which will give the maximum stress on the inter-pole coupling mechanism.

6.109 *Short-line fault tests*

6.109.1 *Applicability*

Short-line fault tests are short-circuit tests additional to the basic short-circuit test duties covered by Sub-clause 6.106 and are applicable only to three-pole circuit-breakers designed for direct connection to overhead transmission lines and having a rated voltage of 52 kV and above and a rated short-circuit breaking current exceeding 12.5 kA.

6.109.2 *Test current*

The test current shall take into account the source and line side impedances.

The source side impedance shall be that corresponding to approximately 100% rated short-circuit breaking current and the phase-to-earth value of the rated voltage. Two values of line side impedance are specified corresponding to a reduction of the a.c. component of the short-circuit breaking current to 90% and 75% respectively.

In a test, the line length represented on the load side of a circuit-breaker may differ from the length of line corresponding to currents equal to 90% and 75% of rated short-circuit breaking current. Deviations from these theoretical lengths of −20% for tests at 90% and of ±20% for tests at 75% are permitted; the tolerances of +5% and ±5% respectively on the current give margin for these deviations (see Sub-clause 6.109.5). For these tests, the percentage d.c. component at the instant of contact separation shall be less than 20%.

6.109.3 *Test circuit*

The test circuit shall be single-phase and consist of a supply circuit and a line side circuit.

The supply circuit shall, in terminal fault conditions, meet the following requirements:

a) The prospective transient recovery voltage of the supply circuit shall meet Requirement *a)* and in principle Requirement *b)* of Sub-clause 6.104.5.1 with the standard values given in Tables IVA, IVB and IVC. Owing to limitations of the testing station it may, as stated in Sub-clause 6.104.5.2, not be feasible to comply with the requirement of Item *b).*

Any such deficiency of transient recovery voltage of the supply circuit shall, in short-line fault tests, be compensated by an increase of the voltage excursion to the first peak of the line side voltage.

b) The specified value of the power frequency recovery voltage (Sub-clause 6.104.7) of the supply circuit is the phase-to-earth value $U/\sqrt{3}$ of the rated voltage.

The line side circuit shall meet the following requirement:

c) The prospective transient recovery voltage oscillation of the line side circuit shall have an approximately triangular wave form but may have a time delay and some rounding at the peaks as indicated in Table V and Figure 14, page 102. If it is impracticable to represent the ITRV on the source side, then the use of a line side voltage oscillation without time delay more or less compensates for the missing ITRV. The prospective transient recovery voltage of the test circuit shall comply with Sub-clause 6.109.4.

Note. — Whenever a deficiency on the source side is compensated by an enhancement of the line side voltage, as described above, it is essential that full consideration be given to the differing effects of the voltage distribution between the units under test.

Other characteristics of the supply and line side circuits shall be approximately in accordance with the rated characteristics for short-line faults given in Sub-clause 4.105 and with values derived from those and the test current (see Appendix AA).

It may be necessary to make certain adjustments, notably to the distribution of power-frequency impedance between supply and line side circuits in order to cater for any difference between rated peak factor and actual peak factor measured in the line side circuit, apart from any adjustments arising from the compensation provided for in Item *a)* above.

6.109.4 *Transient recovery voltage*

The prospective transient recovery voltage of the test circuit measured across the circuit-breaker is a combination of the source and line side components as shown in Figure AA1, page 256.

The time t_L of the first line side peak of the specified prospective transient recovery voltage and the value u_T of voltage at that time shall be determined from the rated characteristics for short-line faults given in Sub-clause 4.105 and the actual* test current, as shown in Appendix AA.

* Actual as distinct from the nominal (90% or 75%) value; the use of prospective short-circuit breaking current in accordance with Sub-clause 6.104.3 is not precluded.

The time t_L related to the first peak of the line side prospective TRV evaluated in accordance with Figure 14, page 102, shall not exceed the value determined from the rated characteristics for short-line faults. There may also be deviations from the standard transient recovery voltage after the line side voltage oscillation has ceased, due to adjusted distribution of the power frequency impedance of the test circuit provided for in Sub-clause 6.109.3.

Note. — The amount by which the time at which u_T is attained precedes t_L and the amount by which the first peak of the prospective TRV of the test circuit exceeds u_T are subject to the consent of the manufacturer.

The test report should show the specified transient recovery voltage appropriate to the rating of the circuit-breaker, and for comparative purposes the prospective transient recovery voltage of the test circuit used.

It is desirable to record the transient recovery voltage during test for the purpose of providing a check on the prospective test circuit characteristics, particularly with regard to the time t_L to the first peak.

6.109.5 *Test-duties*

The standard tests shall be a series of test-duties as specified below, each consisting of the rated operating sequence confined to opening operations only.

For convenience in testing, it is permissible to introduce a closing operation before an opening operation.

a) Test-duty No. L_{90}

At $(90\,^{+5}_{-0})$% of the rated short-circuit breaking current and the appropriate prospective transient recovery voltage.

b) Test-duty No. L_{75}

At (75 ± 5)% of the rated short-circuit breaking current and the appropriate prospective transient recovery voltage.

6.109.6 *Short-line fault tests with a test supply of limited power*

When the maximum short-circuit power available at a testing plant is not sufficient to make the short-line fault tests on a complete pole of a circuit-breaker, it may be possible to make unit tests, see Sub-clause 6.102.3.2.

By agreement between manufacturer and user, short-line fault tests may also be made at reduced power frequency voltage, the provisions of Items *a)* and *b)* of Sub-clause 6.109.3 being relaxed. These provisions shall be met as well as possible and, for the transient recovery voltage to Item *a)*, at least up to three times the specified time of the first line side peak. This method is used if the basic short-circuit tests in Sub-clause 6.106 have been satisfactory, it being assumed that the dielectric strength of the circuit-breaker near the peak value of transient recovery voltage is independent of stresses applied immediately after current zero. The test method may also be used in combination with unit tests. One set of tests is sufficient.

6.110 *Out-of-phase making and breaking tests*

6.110.1 *Applicability*

The tests specified in this sub-clause are required only if a rated out-of-phase breaking current has been specified for the circuit-breaker by the manufacturer.

Tests shall be made to determine the ability of a circuit-breaker to break and make currents during out-of-phase conditions.

6.110.2 *Test circuit*

The power factor of the test circuit shall not exceed 0.15.

For single-phase tests, the test circuit shall be so arranged that approximately one half of the applied voltage and of the recovery voltage is on each side of the circuit-breaker (see Figure 29, page 246).

If it is not practicable to use this circuit in the testing station, it is permissible with the agreement of the manufacturer to use two identical voltages separated in phase by 120 electrical degrees, instead of 180°, provided that the total voltage across the circuit-breaker is as stated in Sub-clause 6.110.3 (see Figure 30, page 246).

Tests, either single-phase or three-phase, with one terminal of the circuit-breaker earthed are permissible only with special agreement of the manufacturer (for single-phase tests, see Figure 31, page 247).

Three-phase tests with three terminals on one side of the circuit-breaker earthed or with the neutral of the supply earthed, are permissible only with special agreement of the manufacturer (see Figures 19a and b, page 236), especially for circuit-breakers intended to operate in systems other than earthed neutral systems.

6.110.3 *Test voltages*

For single-phase tests, both the applied voltage and the power frequency recovery voltage shall, as nearly as practicable, be equal to one of the following values:

a) $2.0/\sqrt{3}$ times the rated voltage for circuit-breakers intended to be used in earthed neutral systems;

b) $2.5/\sqrt{3}$ times the rated voltage for circuit-breakers intended to be used in systems other than earthed neutral systems.

For three-phase tests, the power-frequency recovery voltage of the first pole to clear shall have the appropriate value stated above for single phase tests.

The transient recovery voltage shall be in accordance with Sub-clause 4.106.

6.110.4 *Test-duties*

The test-duties to be made are indicated in Table XVIII.

TABLE XVIII

Test duties to demonstrate the out-of-phase rating

Test-duty	Operation or duty cycle	Breaking current in percent of the rated out-of-phase breaking current
1	O and O	20 to 40
2	O and CO	100 to 110

In the case of a power frequency voltage of $2.5/\sqrt{3}$ times the rated voltage as stated in Sub-clause 6.110.3 Test-duty No. 2 can alternatively be performed with two opening operations at $2.5/\sqrt{3}$ times the rated voltage and one close-open operation at $2.0/\sqrt{3}$ times the rated voltage.

The time interval between the tests in each test-duty shall be sufficient to permit the circuit-breaker to return to its initial condition.

For the opening operation of each test-duty, the d.c. component of the breaking current shall be less than 20% of the a.c. component.

For the close-open cycle of Test-duty No. 2, neither the making current nor the d.c. component of the breaking current is specified.

Notes 1. — For circuit-breakers fitted with closing resistors, the closing resistors may be tested separately subject to agreement between manufacturer and user.

2. — Test-duty No. 1 may be omitted for those circuit-breakers whose arcing characteristics are such that critical current tests according to Sub-clause 6.107.1 are not required.

6.111 *Capacitive current switching tests*

6.111.1 *Applicability*

Capacitive current switching tests are applicable to all circuit-breakers to which one or more of the following ratings have been assigned:

- rated line-charging breaking current;
- rated cable-charging breaking current;
- rated single-capacitor bank breaking current;
- rated back-to-back capacitor bank breaking current;
- rated capacitor bank inrush making current.

Line-charging current switching tests of circuit-breakers of rated voltages less than 72.5 kV and cable-charging current switching tests of circuit-breakers of rated voltages equal to or less than 24 kV are in general considered unnecessary.

Note. — The determination of overvoltages when closing onto unloaded long lines is not covered by this standard.

6.111.2 *General*

The tests can be made either as field tests or laboratory tests. For field tests, actual circuits are used with a supply system on the source side and a line, cable or capacitor bank on the load side.

The results of such tests, however, are only valid for circuit-breakers working in circuits identical to those during the tests. In laboratory tests the lines and cables are partly or fully replaced by artificial circuits with lumped elements of capacitors, reactors or resistors.

Laboratory tests for verification of the rated line or cable-charging breaking current are only valid if the circuit-breaker is restrike-free.

Single-phase tests of a three-pole circuit-breaker are only valid if the tested circuit-breaker is restrike-free and the requirements of Sub-clause 6.102.3.1 are fulfilled.

Unit tests are only valid where single-phase laboratory tests with capacitor banks are allowed and the requirements of Sub-clauses 6.102.3.1 and 6.102.3.2 are fulfilled.

If the circuit-breaker is not restrike-free and if limitations of the test plant preclude the use of three-phase tests, a single-phase test or laboratory circuits may be used upon agreement between manufacturer and user.

The test circuit frequency for tests shall be according to Sub-clause 6.103.2.

Notes 1. — For restrike-free circuit-breakers, tests at 60 Hz may be considered to prove the breaking characteristics at 50 Hz.

2. — For restrike-free circuit-breakers, tests at 50 Hz may be considered to prove the characteristics at 60 Hz provided that the voltage across the circuit-breaker is not less during the first 8.3 ms than it would be during a test at 60 Hz with the specified voltage. If restrikes occur after 8.3 ms, due to the instantaneous voltage being higher than it would be during a test at 60 Hz with the specified voltage, the test-duty should be repeated at 50 Hz with a test voltage as prescribed for the 60 Hz test and if no restrikes occur the circuit-breaker is considered to have passed the test.

3. — Where single-phase laboratory tests with capacitor banks are permitted, the specification of the circuits may be replaced by a specification of the recovery voltage.

4. — The laboratory test circuits representing lines and cables are not applicable for determining the magnitude of possible over-voltage when a restrike occurs. They are adapted to demonstrate the switching performance only.

5. — Synthetic test procedures for capacitive current switching are under consideration.

6.111.3 *Characteristics of supply circuits*

A three-phase supply circuit shall be used for three-phase tests and for single-phase field tests. A single-phase supply circuit shall be used for single-phase laboratory tests.

The capacitive current breaking tests shall be performed using two different supply circuits as specified in Sub-clauses 6.111.3.1 and 6.111.3.2.

6.111.3.1 *Supply circuit A*

Supply circuit A is a circuit having an impedance such that its short-circuit current does not exceed 10% of the rated short-circuit current of the circuit-breaker except that, if necessary, the impedance shall be reduced below the value given by this requirement so that the power frequency voltage variation caused by switching the capacitive current does not exceed 10%.

For line-charging, cable-charging or single capacitor bank current switching tests the prospective transient recovery voltage of the supply circuit shall be as close as possible to the transient recovery voltage specified for short-circuit Test-duty No. 2 in Sub-clause 6.104.5.4 but shall not exceed it. The requirements for time delay need not be taken into account.

For single phase laboratory tests, the values of the voltage parameters u_c and u', stated in Sub-clause 6.104.5.4, shall be multiplied by k/f_φ, where k is the factor stated in Items *a)* to *e)* of Sub-clause 6.111.7 and f_φ is the first-pole-to-clear factor quoted in Sub-clause 6.104.5.4.

For back-to-back capacitor bank breaking current tests, the capacitance of the supply circuit and the impedance between the capacitors on the supply and load sides shall be such as to give the rated capacitor bank inrush making current when testing with 100% of the rated back-to-back capacitor bank breaking current.

Note. — The impedance of supply circuit A for Test-duty No. 2 may accordingly differ from that for Test-duty No. 1.

6.111.3.2 *Supply circuit B*

Supply circuit B is a circuit having an impedance which is as low as possible, but not so low that its short-circuit current exceeds the rated short-circuit current of the circuit-breaker. The characteristics of the test circuit shall be such that the power frequency voltage variation when switching is as small as possible and is in any case less than 5% for Test-duty No. 4.

For line-charging, cable-charging or single capacitor bank current switching tests the prospective transient recovery voltage of the supply circuit shall be less severe than the transient recovery voltage specified for short-circuit Test-duty No. 4 in Sub-clause 6.104.5.2.

For single phase laboratory tests, the values of the voltage parameters stated in Sub-clauses 6.104.5.2 and 4.102.3 shall be multiplied by k/f_φ, where k is the factor stated in Items *a)* to *e)* of Sub-clause 6.111.7 and f_φ is the first-pole-to-clear factor quoted in Sub-clause 4.102.3.

For back-to-back capacitor bank breaking current tests, the capacitance of the supply circuit and the impedance between the capacitors on the supply and load sides shall be such as to give the rated capacitor bank inrush making current when testing with 100% of the rated back-to-back capacitor bank breaking current.

Notes 1. — If a circuit-breaker is intended to be used in a system with appreciable lengths of cable on the supply side, a supply circuit incorporating appropriate additional capacitance should be used.

2. — For back-to-back capacitor bank switching current tests with restrike-free circuit-breakers and where separate making tests are performed, a lower capacitance of the supply circuit may be chosen for the breaking tests. The capacitance should, however, not be so low that the prospective transient recovery voltage of the supply side exceeds that specified for short-circuit Test-duty No. 4 in Sub-clause 6.104.5.2.

6.111.4 *Earthing of the supply circuit*

For single-phase laboratory tests, either terminal of the single-phase supply circuit can be earthed. However, when it is necessary to ensure the correct voltage distribution between the units of the circuit-breaker another point of the supply circuit can be connected to earth.

For three-phase tests the earthing shall be as follows:

a) For capacitor bank current switching tests the neutral of the supply circuit shall be earthed. The zero sequence impedance shall be less than three times the positive sequence impedance of the supply side.

b) For line-charging and cable-charging current switching tests the earthing of the supply circuit shall, in principle, correspond to the earthing conditions in circuits for which the circuit-breaker is to be used:

- for three-phase tests of a circuit-breaker intended for use in earthed neutral systems, the neutral point of the supply circuit shall be earthed. The zero sequence impedance shall be less than three times the positive sequence impedance of the supply side;
- for three-phase tests of a circuit-breaker intended for use in isolated neutral and resonant earthed systems, the neutral point of the supply side shall be isolated or connected to earth through an arc suppression coil.

6.111.5 *Characteristics of the capacitive circuit to be switched*

The characteristics of the capacitive circuit shall, with all necessary measuring devices such as voltage dividers included, be such that the voltage decay does not exceed 10% at the end of an interval of 100 ms after final arc extinction. However, in the case of field tests the above requirement does not apply.

Note. — Since the voltage decay may be very much influenced by apparatus such as voltage transformers connected to the capacitive circuit, the measurement shall preferably be made with suitable voltage dividers.

6.111.5.1 *Line-charging current switching tests*

For circuit-breakers which are restrike-free, there are three possibilities:

a) Three-phase tests, where it is allowed to use parallel lines or to partly or fully replace the real three-phase line with concentrated capacitor banks. The resulting positive sequence capacitance shall be approximately twice the zero sequence capacitance.

b) Single-phase tests in a three-phase test circuit with two phases of the capacitive circuit connected directly to the three-phase supply circuit and one phase connected to the supply circuit through the circuit-breaker pole to be tested.

c) Single-phase laboratory tests, where it is allowed to replace partly or fully the real lines by concentrated capacitor banks and to use any parallel connection of the conductors in the individual phases with current return through earth or through a conductor.

When capacitors are used to simulate overhead lines a non-inductive resistor of maximum 10% of the capacitive impedance may be inserted in series with the capacitors. Higher values may unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (e.g. LR) may be used instead of the resistor provided that the current and voltage conditions at the instant of breaking and the recovery voltage do not differ significantly from the specified values. (The characteristics of the alternative impedance are under consideration.)

Tests on circuit-breakers which are not restrike-free should be the subject of agreement between manufacturer and user (see Sub-clause 6.111.2). Suitable test circuits are under consideration.

Note. — A short cable may be used in series with an overhead line for the tests provided the cable-charging current is less than 20% of the overhead line charging current.

6.111.5.2 *Cable-charging current switching tests*

Capacitors may be used to simulate screened and belted cables. For three-phase tests representing three-core belted cables the positive sequence capacitance shall be approximately twice the zero sequence capacitance.

When capacitors are used to simulate cables a non-inductive resistor of maximum 10% of the capacitive impedance may be inserted in series with the capacitors. Higher values may unduly influence the recovery voltage. If, with this resistor connected, the peak inrush current is still unacceptably high, then an alternative impedance (e.g. LR) may be used instead of the resistor provided that the current and voltage conditions at the instant of breaking and the recovery voltage do not differ significantly from the specified values. (The characteristics of the alternative impedance are under consideration.)

Note. — A short overhead line may be used in series with a cable for the tests provided the line charging current does not exceed 1% of the cable charging current.

6.111.5.3 *Capacitor bank current switching tests*

The neutral of the capacitor shall be isolated except that, for rated voltages exceeding 72.5 kV, the earthing conditions of the test capacitor shall be the same as for the capacitor when in service if the circuit-breaker is intended for use in earthed neutral systems.

6.111.6 *Waveform of the current*

The waveform of the current to be broken should, as nearly as possible, be sinusoidal. This condition is considered to be complied with if the ratio of the r.m.s. value of the current to the r.m.s. value of the fundamental component does not exceed 1.2.

The current to be broken shall not go through zero more than once per half cycle of power frequency.

6.111.7 *Test voltage*

For three-phase tests and for single-phase tests with the capacitive circuit to be switched according to the arrangement in Item *b)* of Sub-clause 6.111.5.1, the test voltage measured between the phases at the circuit-breaker location immediately prior to opening shall, as nearly as possible, be equal to the rated voltage U of the circuit-breaker.

For single-phase laboratory tests, the test voltage measured at the circuit-breaker location immediately before the opening shall, as nearly as possible, be equal to the product of $U/\sqrt{3}$ and the following factor:

a) 1.0
for tests corresponding to normal service in earthed neutral systems without significant mutual influence of adjacent phases of the capacitive circuit, typically capacitor banks with earthed neutral and screened cables;

b) 1.2
for tests on belted cables and for line-charging current switching tests according to Item *c)* of Sub-clause 6.111.5.1 corresponding to normal service conditions in earthed neutral systems;

c) 1.4
for tests corresponding to:
— breaking during normal service conditions in systems other than earthed neutral systems;

— breaking of capacitor banks with isolated neutral.

d) 1.4
for tests corresponding to breaking in the presence of single or two-phase earth faults in earthed neutral systems;

e) 1.7
for tests corresponding to breaking in systems other than earthed neutral systems in the presence of single or two-phase earth faults.

For unit tests the test voltage shall be chosen to correspond to the most stressed unit of the pole of the circuit-breaker.

The power frequency test voltage and the d.c. voltage resulting from the trapped charge on the capacitive circuit shall be maintained for a period of 0.3 s after breaking.

Notes 1. — Shorter discharge time constants of the capacitive circuit than stated in Sub-clause 6.111.5 may be used provided that the behaviour of the circuit-breaker under d.c. voltage is checked by alternative means.

2. — When the non-simultaneity of contact separation in the different poles of the circuit-breaker exceeds 1/6th of a cycle of the rated frequency, it is recommended according to agreement between the manufacturer and the user to raise further the voltage factor or to make only three-phase tests.

6.111.8 *Test duties*

6.111.8.1 *Test conditions corresponding to normal service conditions*

The capacitive current switching tests shall consist of four test-duties as specified in Table XIX.

TABLE XIX

Test-duty	Supply circuit	Test current as percentage of the rated capacitive breaking current
1	A	20 to 40
2	A	Not less than 100
3	B	20 to 40
4	B	Not less than 100

The number of tests for each test-duty shall be:

— 10 tests for three-phase tests;

— 12 tests for single-phase tests with the contact separation distributed at intervals of approximately 30 electrical degrees.

For line- and cable-charging current switching tests the last two tests of Test-duties Nos. 2 and 4 shall be make-break tests.

For capacitor bank current switching tests all tests in Test-duties Nos. 2 and 4 shall be make-break tests. The closing shall occur within 15 electrical degrees of the peak value of applied voltage (on one phase for three-phase tests). The making current shall in Test-duty No. 4 be equal to the rated capacitor bank inrush making current as given in Sub-clause 4.111 for circuit breakers with a rated back-to-back capacitor bank breaking current.

Due to limitations of the test plant it may not be possible to comply with the requirements of the inrush current in Test-duty No. 4 for the back-to-back capacitor bank current switching tests. For restrike-free circuit-breakers it is then allowed to make an alternative test procedure where in Test-duty No. 4 the requirements are met as best as possible and where a separate making test series is performed. This test series should comprise ten making operations with a making current equal to the rated back-to-back capacitor bank inrush making current. The test voltage shall be the same as for Test-duty No. 4 and the closing shall occur within 15 electrical degrees of the peak value (on one phase for three-phase tests).

For the break and make-break tests the contacts of the circuit-breaker shall not be separated until the transient currents have subsided.

No appreciable charge shall remain on the capacitive circuits before the making operations.

Breaking tests may alternatively be performed with a recovery voltage, according to Table XX and Figure 32, page 247.

TABLE XX

Test-duties	Recovery voltage value of Figure 32 in relation to the peak value of the test voltage		Time for Figure 32		
	U_c	U_1	t_1	t_2 (μs)	
				50 Hz	60 Hz
1 and 2	≥ 1.95	≤ 0.14	$\geq t_1$ or t_3 in Sub-clause 6.104.5.4	≤ 8.7	≤ 7.3
3 and 4	≥ 2.0	≤ 0.01	$\geq t_1$ or t_3 in Sub-clause 4.102.3	≤ 8.7	≤ 7.3

6.111.8.2 *Test conditions corresponding to breaking in the presence of earth faults*

a) Overhead lines and cables

Tests corresponding to breaking of overhead line and cable charging currents in the presence of earth faults should be made upon agreement between manufacturer and user.

Single-phase laboratory tests shall be made with a test voltage as given in Sub-clause 6.111.7 and a capacitive current equal to:

- 1.25 times the rated capacitive breaking current in earthed neutral systems;
- 1.7 times the rated capacitive breaking current in systems other than earthed neutral systems.

b) Single capacitor banks

Tests are not necessary for capacitor banks in earthed neutral systems.

Switching earthed neutral capacitor banks on systems other than earthed neutral systems can result in higher stresses. As this is not a normal system condition, the tests are subject to agreement between manufacturer and user.

6.111.9 *Test results*

The overvoltages to earth shall be measured on supply and capacitive circuit side.

The circuit-breakers shall have successfully passed the tests if the following conditions are fulfilled:

a) the behaviour of the circuit-breaker during making and breaking the capacitive currents in all prescribed test-duties fulfills the conditions given in Sub-clause 6.102.7;

b) no restrikes occur during the tests or, where three-phase tests on restriking circuit-breakers are made, the maximum measured breaking overvoltages for each test-duty shall not exceed the maximum permissible switching overvoltages specified by the manufacturer. External flashover shall not occur;

c) the condition of the circuit-breaker after the test series corresponds to the condition in Sub-clause 6.102.8.4.

6.112 *Small inductive current switching tests*

6.112.1 *Transformer magnetizing current for circuit-breakers with rated voltages of 100 kV and above*

Experience indicates that when interrupting magnetizing currents of unloaded transformers under steady state conditions and at voltages not exceeding their rated voltage the over-voltages are small. Tests are therefore not specified to simulate this switching condition.

Switching of the inrush magnetizing current of an unloaded transformer is not a normal service condition and no tests are specified.

6.112.2 *Transformer magnetizing current for circuit-breakers with rated voltages below 100 kV*

Generally tests are not required but in cases of doubt they should be made on the system under actual service conditions. If this is not possible, three-phase tests may be made in a laboratory using the actual transformer to be switched in service.

In either case, the source circuit should have as low a capacitance as possible subject to the rated TRV not being exceeded. Any means of voltage limiting to be used in service may be connected for the tests.

6.112.3 *Transformer with a tertiary winding loaded with reactors*

This shall be considered a special case and agreement reached between manufacturer and user.

6.112.4 *Shunt reactors*

A test circuit is under consideration.

6.112.5 *High voltage motors*

A test circuit is under consideration.

7. Routine tests

Clause 7 of IEC Publication 694 is applicable with the following addition:

The routine tests also comprise mechanical operating tests in accordance with Sub-clause 7.101.

7.1 *Power frequency voltage withstand dry tests on the main circuit*

Sub-clause 7.1 of IEC Publication 694 is applicable with the following addition:

In the case of circuit-breakers constructed by assembling identical breaking and making units in series, the test voltage to be applied across each single unit, when open, shall be the higher fraction of the total withstand voltage resulting from actual power-frequency voltage distribution with the circuit-breaker fully open and one terminal earthed.

With reference to Figure 1 of IEC Publication 694 which shows a diagram of a three-pole circuit-breaker, the test voltage shall be applied, according to Table XXI:

TABLE XXI

Test condition No.	Circuit-breaker	Voltage applied to	Earth connected to
1*	Closed	AaCc	BbF
2*	Closed	Bb	AaCcF
3	Open	ABC	abcF
4	Open	abc	ABCF

7.2 *Voltage withstand tests on control and auxiliary circuits*

Sub-clause 7.2 of IEC Publication 694 is applicable.

7.3 *Measurement of the resistance of the main circuit*

Sub-clause 7.3 of IEC Publication 694 is applicable.

7.101 *Mechanical operating tests*

Mechanical operating tests shall include:

a) at specified maximum supply voltage and pressure (if applicable):

1) five closing operations,
2) five opening operations.

b) At specified minimum supply voltage and pressure (if applicable):

1) five closing operations,
2) five opening operations.

* If the insulation between poles is air at atmospheric pressure, test conditions Nos. 1 and 2 may be combined, the test voltage being applied between all parts of the main circuit connected together and the base.

c) At rated supply voltage and pressure (if applicable):

1) five close-open operating cycles with the tripping mechanism energized by the closing of the main contacts,
2) moreover, for circuit-breakers intended for rapid auto-reclosing (see Sub-clause 4.104), five open-close sequences $O-t-C$ where t shall be not more than the time interval specified for the rated operating sequence.

Mechanical operating tests should preferably be made on the complete circuit-breaker. However, when circuit-breakers are assembled and shipped as separate units, routine tests may be performed on components according to Sub-clause 6.101.1.1. Operating mechanisms and control cubicles shall be tested together with the circuit-breaker or with an appropriate dummy load.

Routine tests on the complete circuit-breaker may be made on site.

At all required operating sequences shall be performed:

- measurement of operating times;
- measurement of fluid consumption (if applicable).

If the design of the circuit-breaker permits such measurements, the time-travel diagram should be recorded. Mechanically stressed auxiliary equipment shall function correctly during and after the tests.

After completion of the required operating sequences the following tests and inspections shall be performed (if applicable):

- connections shall be checked;
- the control and/or auxiliary switches shall correctly indicate the open and closed positions of the circuit-breaker;
- all auxiliary equipment shall operate correctly at the limits of supply voltages and/or quenching and operating pressures.

Furthermore the following tests and inspections shall be made (if applicable):

- tightness tests;
- measurement of the resistance of heaters (if fitted) and of the control coils;
- inspections of the wiring of the control, heater and auxiliary equipment circuits and checking of the number of auxiliary contacts, in accordance with the order specification;
- inspection of control cubicle (electrical, mechanical, pneumatic and hydraulic systems);
- output capacity measurement for the compressor;
- functional performance of pressure relief valve;
- operation of electrical, mechanical, pneumatic or hydraulic interlocks and signalling devices;
- operation of anti-pumping device;
- general performance of equipment within the required tolerance of the supply voltage;
- inspection of earthing terminals of the circuit-breaker.

For circuit-breakers fitted with over-current releases, the releases shall be set at the minimum calibration mark on the scale of current settings.

It shall be shown that the over-current releases correctly initiate the opening of the circuit-breaker with the current through the main circuit not exceeding 110% of the value set on the scale of current settings.

The current through over-current releases may for these tests be supplied from a suitable low-voltage source.

For circuit-breakers fitted with under-voltage opening releases, it shall be shown that the circuit-breaker opens and can be closed when voltages within the specified limits are applied to the releases (see Sub-clause 5.7.4 of IEC Publication 694).

If adjustments are required during the mechanical operating tests, the complete test sequence shall be repeated following the adjustments.

7.102 *Design and visual checks*

The circuit-breaker shall be checked to verify its compliance with the order specification.

In particular, the following items shall be checked:

- the language and data on the nameplates;
- identification of any auxiliary equipment;
- the colour and quality of paint and corrosion protection of metallic surfaces;
- the values of the resistors and capacitors (if applicable) connected to the main circuit.

8. Guide to the selection of circuit-breakers for service

8.101 *General*

A circuit-breaker suitable for a given duty in service is best selected by considering the individual rated values required by load conditions and fault conditions.

Co-ordinated values of rated characteristics for circuit-breakers are given in Tables XA to XC. It is desirable that the rated values of a circuit-breaker are chosen from these tables according to the characteristics of the system as well as to its anticipated developments.

The complete list of rated characteristics is given in Clause 4. The following individual ratings are dealt with in this clause:

- rated voltage . . . . Sub-clause 8.102.1
- rated insulation level . . . . Sub-clause 8.102.2
- rated frequency . . . . Sub-clause 8.102.3
- rated normal current . . . . Sub-clause 8.102.4
- rated short-circuit breaking current . . . . Sub-clause 8.103.1
- rated transient recovery voltage for terminal faults . . . . Sub-clause 8.103.2
- rated out-of-phase breaking current . . . . Sub-clause 8.103.3
- rated short-circuit making current . . . . Sub-clause 8.103.4
- rated operating sequence . . . . Sub-clause 8.103.5
- rated duration of short-circuit . . . . Sub-clause 8.103.6

For rated characteristics not dealt with in this clause reference should, if applicable, be made to Clause 4 as follows:

- rated short-time withstand current . . . . Sub-clause 4.5
- rated peak withstand current . . . . Sub-clause 4.6
- rated supply voltage of closing and opening devices and of auxiliary circuits . . . . Sub-clause 4.8
- rated supply frequency of closing and opening devices and of auxiliary circuits . . . . Sub-clause 4.9
- rated pressures of compressed gas supply for operation and for interruption . . . . Sub-clause 4.10
- rated characteristics for short-line faults . . . . Sub-clause 4.105
- rated line-charging breaking current . . . . Sub-clause 4.107
- rated cable-charging breaking current . . . . Sub-clause 4.108
- rated single capacitor bank breaking current . . . . Sub-clause 4.109
- rated back-to-back capacitor bank breaking current . . . . Sub-clause 4.110
- rated capacitor bank inrush making . . . . Sub-clause 4.111
- rated small inductive breaking current . . . . Sub-clause 4.112

Other parameters to be considered when selecting a circuit-breaker are for example:

- local atmospheric and climatic conditions . . . . Sub-clause 8.102.5
- use at high altitudes . . . . Sub-clause 8.102.6
- opening time . . . . Sub-clause 8.103.1
- frequency of operation . . . . Sub-clause 6.101.2.1

The duty imposed by the fault conditions with which a circuit-breaker is required to deal should be determined by calculating the fault currents at the place where the circuit-breaker is to be located in the system, in accordance with some recognized method of calculation.

When selecting a circuit-breaker, due allowance should be made for the likely future development of the system as a whole, so that the circuit-breaker may be suitable not merely for immediate needs but also for the requirements of the future.

Circuit-breakers which have satisfactorily completed type tests for a combination of rated values (i.e. voltage, normal current, making and/or breaking current) are suitable for any lower rated values (with the exception of rated frequency) without further testing. Some switching conditions, such as switching of high voltage motors, for which tests are not yet specified, may require caution to be exercised with regard to switching overvoltage if a circuit-breaker is used at a rated voltage lower than that at which the tests were made.

Note. — Some fault conditions such as evolving faults and some service conditions such as switching of arc furnaces, are not dealt with in this standard and should therefore be considered as special conditions for which agreement should be reached between manufacturer and user.

The same is applicable to circuit-breakers used for any operation leading to a power-frequency recovery voltage higher than that corresponding to the rated voltage of the circuit-breaker, which may be the case at certain points of the system and, in particular, at the end of long lines. In this particular case, the value of current to be interrupted at the highest voltage which may occur across the terminals of the circuit-breaker when opening should be subject to a similar agreement.

8.102 *Selection of rated values for service conditions*

8.102.1 *Selection of rated voltage*

The rated voltage of the circuit-breaker should be chosen so as to be at least equal to the highest voltage of the system at the point where the circuit-breaker is to be installed.

The rated voltage of a circuit-breaker should be selected from the standard values given in Sub-clause 4.1 of IEC Publication 694.

In selecting the rated voltage the corresponding insulation levels specified in Sub-clause 4.2 should also be taken into account (see also Sub-clause 8.102.2).

Preferred combinations of rated voltage, rated short-circuit current and rated normal current are given in Tables XA, XB and XC.

8.102.2 *Insulation co-ordination*

The rated insulation level of a circuit-breaker should be selected according to Sub-Clause 4.2. The values in these tables apply to both indoor and outdoor circuit-breakers. It should be specified in the enquiry whether the circuit-breaker is to be of indoor or outdoor type.

The insulation co-ordination in an electrical system serves to minimize damage to the electrical equipment due to overvoltages and tends to confine flashovers (when these cannot be economically avoided) to points where they will cause no damage.

Precautions should be taken to limit the overvoltages on the terminals of the circuit-breaker to stated values below the insulation level (see IEC Publication 71-2: Insulation Co-ordination, Part 2: Application Guide).

Where a circuit-breaker is required for a position necessitating a higher insulation level, this should be specified in the enquiry (see Sub-clause 9.101).

For circuit-breakers intended for use in synchronizing operation when a substantial switching surge may simultaneously occur, see Sub-clause 4.2.3.

8.102.3 *Rated frequency*

The manufacturer should be consulted if a circuit-breaker is to be used at any frequency other than its rated frequency (see Sub-clause 4.3 of IEC Publication 694).

8.102.4 *Selection of rated normal current*

The rated normal current of a circuit-breaker should be selected from the standard values given in Sub-clause 4.4. Preferred combinations of rated normal current, rated voltage and short-circuit current are given in Tables XA, XB and XC.

It should be noted that circuit-breakers have no specified continuous over-current capability. When selecting a circuit-breaker therefore, the rated normal current should be such as to make it suitable for any load current that may occur in service. Where intermittent over-currents are expected to be frequent and severe, the manufacturer should be consulted.

Note. — It is understood that the rated normal current is the current that a circuit-breaker can carry continuously except for uncommon conditions of use. Such conditions may be met for generator circuit-breakers which may be in the closed position for a very long time at a current near the rated normal current without being operated, and in a high ambient temperature.

8.102.5 *Local atmospheric and climatic conditions*

The normal atmospheric and climatic conditions for circuit-breakers are given in Clause 2.

A distinction is made between classes "minus 5 indoor", "minus 25 indoor", "minus 25 outdoor" and "minus 40 outdoor" circuit-breakers, these being suitable for differing minimum ambient air temperatures. Where "minus 25 indoor" or "minus 40 outdoor" class is required, it is necessary to state it clearly. The manufacturer should be consulted if a circuit-breaker is to be located where the ambient air temperature may fall below −25 °C for an indoor circuit-breaker, and below −40 °C for an outdoor circuit-breaker, or where the temperature may exceed 40 °C (or if the 24-hour average value exceeds 35 °C).

For outdoor circuit-breakers, the atmospheric conditions in certain areas are unfavourable on account of smoke, chemical fumes, salt-laden spray and the like. Where such adverse conditions are known to exist, special consideration should be given to the design of those parts of the circuit-breaker, especially the insulators, normally exposed to the atmosphere.

The performance of an insulator in such atmospheres also depends on the frequency of washing or cleaning operations and on the frequency of natural washing by rain. Since the performance of an insulator under such conditions is dependent on so many factors, it is not possible to give precise definitions of normal and heavily polluted atmospheres. Experience in the area where the insulator is to be used is the best guide.

The manufacturer should be consulted when the circuit-breaker is to be located where the wind pressure exceeds 700 Pa.

Three different classes of circuit-breakers are specified with regard to ice-coating. These classes correspond to an ice-coating not exceeding 1 mm, 10 mm and 20 mm. If a circuit-breaker is to be located where an ice-coating exceeding 20 mm is expected, agreement should be reached between manufacturer and user as to the ability of the circuit-breaker to perform correctly under such conditions.

Agreement should also be reached between manufacturer and user in cases where earth tremors can be expected.

For indoor installation, the humidity conditions are under consideration, but guide-lines are given in Sub-clause 2.1.1 of IEC Publication 694.

For indoor circuit-breakers the manufacturer should be consulted for any special service conditions, for example when chemical fumes, aggressive atmosphere, salt laden spray, etc., are present.

8.102.6 *Use at high altitudes*

The normal service conditions specified in Clause 2 of IEC Publication 694 provide for circuit-breakers intended for use at altitudes not exceeding 1 000 m.

For installation at altitudes above 1 000 m the manufacturer should be consulted.

8.103 *Selection of rated values for fault conditions*

8.103.1 *Selection of rated short-circuit breaking current*

As stated in Sub-clause 4.101, the rated short-circuit breaking current is expressed by two values:

a) the r.m.s. value of its a.c. component;

b) its percentage d.c. component.

The percentage d.c. component varies with time from the incidence of the short-circuit. When the circuit-breaker meets the standard requirements stated in Sub-clause 4.101.2, the percentage d.c. component the circuit-breaker can deal with is not less than the value given in Figure 9, page 99, at the end of the time interval corresponding to the shortest possible opening time of the circuit-breaker plus, for a circuit-breaker to be tripped solely by a form of auxiliary power, a minimum relay time of one half cycle of rated frequency. Figure 9, page 99, is based on a constant a.c. component and on a short-circuit power factor of 0.07 for 50 Hz.

When the location of the installation is sufficiently remote electrically from rotating machines, the decrement of the a.c. component is negligible and it is only necessary to verify that the short-circuit power factor is not less than 0.07 and the minimum time delay of the protective equipment is not less than one half cycle of rated frequency. In these conditions it is sufficient that the selected circuit-breaker has a rated short-circuit breaking current not less than the r.m.s. value of the short-circuit current at the point where the circuit-breaker is to be installed.

The basic short-circuit test duties, see Sub-clause 6.106, together with the critical current tests, see Sub-clause 6.107, and where applicable, short-line fault tests, see Sub-Clause 6.109, have been chosen to prove the circuit-breaker for all values of current up to the rated short-circuit breaking current. Therefore, for situations where the prospective short-circuit current is lower, it is not necessary to perform a short-circuit test series based on a lower rated short-circuit breaking current.

In some cases the percentage d.c. component may be higher than the standard values given in Figure 9. For instance, when circuit-breakers are in the vicinity of centres of generation, the a.c. component may decrease more quickly than in the normal case. The short-circuit current may then not have a current zero for a number of cycles. In such circumstances the duty of the circuit-breaker can be eased, for example, by delaying its opening, or by connecting an additional damping device with another circuit-breaker and opening the circuit-breakers in sequence. If the standard values of percentage d.c. component cannot be adhered to, the required percentage should be specified in the enquiry and testing should be subject to agreement between manufacturer and user; in this relation attention is drawn to Item *b)* of Sub-clause 8.103.2.

The rated short-circuit breaking current should be selected from the standard values given in Sub-clause 4.101.1. Preferred combinations of rated short-circuit current, rated voltage and rated normal current are given in Tables XA, XB and XC.

8.103.2 *Selection of rated transient recovery voltage (TRV) for terminal faults, first-pole-to-clear factor and rated characteristics for short-line faults*

The prospective transient recovery voltage (TRV), of the system should not exceed the reference line representing the rated transient recovery voltage specified for the circuit-breaker; it should cross the specified delay line close to zero voltage but should not recross it later (see Sub-clause 4.102.2). Standard values relating to the rated short-circuit breaking current are given in Sub-clause 4.102.3, and standard values relating to short-circuit breaking currents below the rated short-circuit breaking current are specified in Sub-clause 6.104.5.

Note. — The transient recovery voltages which appear when breaking the highest short-circuit currents are not necessarily more severe than those which appear in other cases. For example, the rate-of-rise of transient recovery voltage may be higher when breaking smaller short-circuit currents.

The standard values given for rated voltages below 100 kV are applicable to a first-pole-to-clear factor 1.5. For rated voltages 100 kV to 170 kV a choice between first-pole-to-clear factors 1.3 and 1.5 is provided. For rated voltages above 170 kV the standard values are applicable to a first-pole-to-clear factor 1.3 (see also the note in Sub-clause 6.104.5.4).

The factor 1.3 is based on a system with earthed neutral where three-phase faults not involving earth are considered highly improbable. For applications in isolated neutral and resonant earthed systems, the first-pole-to-clear factor 1.5 should be used. For applications in systems with earthed neutral in cases where the probability of three-phase faults not involving earth cannot be disregarded, and for applications in systems other than earthed neutral systems, a first-pole-to-clear factor of 1.5 may be necessary.

Generally it will not be necessary to consider alternative transient recovery voltages as the standard values specified cover the majority of practical cases.

More severe conditions may occur in some cases, for instance:

a) In the case of a short-circuit immediately after a transformer without any appreciable additional capacitance between the transformer and the circuit-breaker, both the peak voltage and rate-of-rise of transient recovery voltage may exceed the values specified in this standard.

Note. — Care should also be taken when selecting a circuit-breaker for the primary side for a transformer which may have to interrupt a short-circuit on the secondary side.

b) In the case of a short-circuit on circuit-breakers in the vicinity of centres of generation, the rate-of-rise of transient recovery voltage may exceed the values specified in this standard.

In such cases it may be necessary for special TRV characteristics to be agreed between manufacturer and user.

When circuit-breakers are required for installations necessitating the assignment of rated characteristics for short-line faults, the line on which they are to be used should have a surge impedance and peak-factor not greater than and a time delay not less than the standard values of rated line characteristic given in Table V. However, if this should not be the case, it is still possible that a standard circuit-breaker is suitable, especially if the short-circuit current of the system is less than the rated short-circuit breaking current of the circuit-breaker. This can be established by calculating the prospective TRV for short-line faults from the rated characteristics by the method given in appendix AA and comparison with the prospective TRV derived from the actual characteristics of the system.

If special characteristics for short-line faults are required, they should be agreed between manufacturer and user.

8.103.3 *Selection of out-of-phase characteristics*

The requirements of this standard cater for the great majority of applications of circuit-breakers intended for switching during out-of-phase conditions. Several circumstances would have to be combined to produce a severity in excess of those covered by the tests of the standard and, as switching during out-of-phase conditions is rare, it would be uneconomical to design circuit-breakers for the most extreme conditions.

The actual system conditions should be considered when frequent out-of-phase switching is expected or where excessive stresses are probable, which could be the case for generator circuit-breakers, for example.

A special circuit-breaker, or one rated at a higher voltage, may sometimes be required. As an alternative solution, the severity of out-of-phase switching duty is reduced in several systems by using relays with coordinated impedance sensitive elements to control the tripping instant, so that interruption will occur either substantially after or substantially before the instant the phase angle reaches 180°.

A higher rate of rise may occur when one circuit-breaker terminal is transformer-connected. Circuit-breakers tested in accordance with this standard are considered to comply with this higher rate-of-rise requirement provided they have satisfied Test-duty No. 2 of the basic short-circuit test series.

8.103.4 *Selection of rated short-circuit making current*

As stated in Sub-clause 4.103, the rated short-circuit making current shall correspond to the rated voltage and shall be, unless otherwise stated, 2.5 times (i.e. approximately 1.8 $\sqrt{2}$ times) the a.c. component of the rated short-circuit breaking current of the circuit-breaker.

The selected circuit-breaker should have a rated short-circuit making current not less than the highest peak value of the short-circuit currents expected at the application point.

In some cases, for example when induction motors are electrically close, the maximum peak value of the fault current may be more than 2.5 times the a.c. component of the short-circuit current. In such cases, a special design should be avoided and a standard circuit-breaker having a suitable rated short-circuit making current should be selected.

8.103.5 *Operating sequence in service*

The rated operating sequence of a circuit-breaker should be one of the operating sequences given in Sub-clause 4.104. Unless otherwise specified, the values of the time intervals given in Sub-clause 4.104 apply and the rated operating sequences provided for are:

a) O − 3 min − CO − 3 min − CO;

b) CO − 15 s − CO;

c) O − 0.3 s − CO − 3 min − CO (for circuit-breakers intended for rapid auto-reclosing).

Note. — Instead of 3 min, other time intervals, namely 15 s (for rated voltages less than or equal to 52 kV) and 1 min are also used for circuit-breakers intended for rapid auto-reclosing. The interval to be chosen depends in principle upon system requirements such as continuity of service.

If the short-circuit current the circuit-breaker is capable of breaking on auto-reclosing is less than the rated short-circuit breaking current, this should be specified by the manufacturer.

When the operating sequence in service is more severe than is provided for in this standard, this should be specified by the user in his enquiry and/or order, so that the manufacturer may modify the rating of the circuit-breaker appropriately. Examples of circuit-breakers for special duty are those used for controlling arc furnaces, electrode boilers and, in certain cases, rectifier plants. Single-pole operation of a multi-pole circuit-breaker, for example with a view to single-phase making and breaking, is also a special duty.

8.103.6 *Selection of rated duration of short-circuit (for circuit-breakers not fitted with direct over-current releases)*

The standard value of rated duration of short-circuit (Sub-clause 4.7 of IEC Publication 694) is 1 s.

If, however, a higher duration is necessary, the value of 3 s should be selected as rated value.

For short-circuit durations greater than the rated duration, the relation between current and time, unless otherwise stated by the manufacturer, is in accordance with the formula:

I^2t = constant.

9. Information to be given with enquiries, tenders and orders

9.101 *Information to be given with enquiries and orders*

When enquiring for or ordering a circuit-breaker, the following particulars should be supplied by the enquirer:

(A) Particulars of systems, i.e. nominal and highest voltages, frequency, number of phases, and details of neutral earthing.

(B) Service conditions including minimum and maximum ambient air temperatures, the latter, if greater than the normal value; altitude if over 1 000 m; and any special conditions likely to exist or arise, for example unusual exposure to water vapour, moisture, fumes, explosive gases, excessive dust, or salt air (see Sub-clauses 8.102.5 and 8.102.6).

(C) Characteristics of circuit-breaker.

The following information should be given:

a) number of poles;

b) class: indoor or outdoor;

c) rated voltage . . . . Sub-clause 8.102.1

d) rated insulation level where a choice exists between different insulation levels corresponding to a given rated voltage, or, if other than standard, the desired insulation level . . . . Sub-clause 8.102.2

e) rated frequency . . . . Sub-clause 8.102.3

f) rated normal current . . . . Sub-clause 8.102.4

g) if applicable, rated line-charging breaking current . . . . Sub-clause 4.107

h) if applicable, rated cable-charging breaking current . . . . Sub-clause 4.108

i) if applicable, rated single capacitor bank breaking current . . . . Sub-clause 4.109

j) if applicable, rated back-to-back capacitor bank breaking current . . . . Sub-clause 4.110

k) if applicable, rated capacitor bank inrush making current . . . . Sub-clause 4.111

l) if applicable, rated small inductive breaking current . . . . Sub-clause 4.112

m) rated short-circuit breaking current . . . . Sub-clause 8.103.1

n) first-pole-to-clear factor . . . . Sub-clause 8.103.2

o) if other than standard, desired transient recovery voltage for terminal faults . . . . Sub-clause 8.103.2

p) if other than standard, desired characteristics for short-line faults . . . . Sub-clause 8.103.2

q) if other than standard, desired short-circuit making current . . . . Sub-clause 8.103.4

r) rated operating sequence . . . . Sub-clause 8.103.5

s) if other than standard, desired duration of short-circuit . . . . Sub-clause 8.103.6

t) if applicable, rated out-of-phase breaking current . . . . Sub-clause 4.106

u) break-time . . . . Sub-clause 4.113.1

v) the type tests specified under special request (artificial pollution and radio interference) . . . . Sub-clauses 6.1.8 and 6.2

w) the frequency of operation . . . . Sub-clause 6.101.2.1

(D) Characteristics of the operating mechanism of circuit-breaker and associated equipment, in particular:

a) method of operation, whether manual or power;

b) number and type of spare auxiliary switches;

c) rated supply voltage and rated supply frequency.

(E) Requirements concerning the use of compressed air and requirements for design and tests of pressure vessels.

Note. – The enquirer should give information of any special conditions not included above that might influence the tender or order (see also the note in Sub-clause 8.101).

9.102 **Information to be given with tenders**

When the enquirer requests technical particulars of a circuit-breaker, the following information (those which are applicable) should be given by the manufacturer, with the descriptive matter and drawings:

(A) *Rated values and characteristics:*

a) number of poles;

b) class: indoor or outdoor, temperature, ice-coating . . . . Sub-clause 8.102.5

c) rated voltage . . . . Sub-clause 8.102.1

d) rated insulation level . . . . Sub-clause 8.102.2

e) rated frequency . . . . Sub-clause 8.102.3

f) rated normal current . . . . Sub-clause 8.102.4

g) rated line-charging breaking current . . . . Sub-clause 4.107

h) rated cable-charging breaking current . . . . Sub-clause 4.108

i) rated single capacitor bank breaking current . . . . Sub-clause 4.109

j) rated back-to-back capacitor bank breaking current . . . . Sub-clause 4.110

k) rated capacitor bank inrush making current . . . . Sub-clause 4.111

l) rated small inductive breaking current . . . . Sub-clause 4.112

m) rated short-circuit breaking current . . . . Sub-clause 8.103.1

n) first-pole-to-clear factor . . . . Sub-clause 8.103.2

o) rated transient recovery voltage for terminal faults . . . . Sub-clause 8.103.2

p) rated characteristics for short-line faults . . . . Sub-clause 8.103.2

q) rated short-circuit making current . . . . Sub-clause 8.103.4

r) rated operating sequence . . . . Sub-clause 8.103.5

s) rated duration of short-circuit . . . . Sub-clause 8.103.6

t) rated out-of-phase breaking current . . . . Sub-clause 4.106

u) rated opening time, rated break time and rated closing time . . . . Sub-clause 4.113

v) the type tests specified under special request (artificial pollution and radio interference) . . . . Sub-clauses 6.1.8 and 6.2

(B) *Type tests*

Certificate or report on request.

(C) *Constructional features:*

a) For oil circuit-breakers: mass of complete circuit-breaker without oil; mass of oil; recommendations regarding oil quality; number of tanks.

b) For air-blast circuit-breakers: mass of complete circuit-breaker; rated supply pressure of air for interruption and limits between which the circuit-breaker operates correctly; the capacity of the local air receiver; quantity of free air for one opening operation and for one closing operation followed immediately by one opening operation. For circuit-breakers intended for rapid auto-reclosing, the quantity of free air should be given also for one opening operation followed by one closing operation and immediately followed by one opening operation.

For other gas circuit-breakers: mass of complete circuit-breaker; rated supply pressure of gas for interruption and limits between which the circuit-breaker operates correctly; the total volume of the gas per pole at a pressure of 0.1 MPa (1 bar); tightness characteristics of the circuit-breaker.

c) Number of units in series per pole.

d) Minimum clearances in air:
- between poles;
- to earth;
- the safety boundaries during a breaking operation, for circuit-breakers with an external exhaust for ionised gases or flame.

e) Any special arrangements (heating and cooling) to maintain the rated characteristics of the circuit-breaker at the required extreme temperatures of the ambient air.

(D) *Operating mechanism of circuit-breaker and associated equipment:*

a) type of closing mechanism;

b) whether the circuit-breaker is suitable for trip-free or fixed trip operation and whether it is provided with a lock-out device preventing closing;

c) rated supply voltage and/or pressure of closing mechanism, pressure limits if different from the standard values;

d) current required at rated supply voltage to close the circuit-breaker;

e) quantity of free air required to close the circuit-breaker at rated supply pressure;

f) rated supply voltage of shunt opening release;

g) current required at rated supply voltage for shunt opening release;

h) number and type of spare auxiliary switches;

i) current required at rated supply voltage by other auxiliaries;

j) setting of high and low pressure interlocking devices.

(E) *Overall dimensions and other information*

The manufacturer should give the necessary information as regards the overall dimensions of the circuit-breaker and details necessary for the design of the foundation.

General information regarding maintenance of the circuit-breaker and its connections should be given.

10. Rules for transport, storage, erection and maintenance

Clause 10 of IEC Publication 694 is applicable.

10.1 *Conditions during transport, storage and erection*

Sub-clause 10.1 of IEC Publication 694 is applicable.

10.2 *Erection*

Sub-clauses 10.2.1 to 10.2.4 of IEC Publication 694 are applicable, with the following addition:

10.2.101 *Guide for commissioning tests*

After a circuit-breaker has been erected and all connections have been completed, commissioning tests should be performed. The purpose of such tests is to check that transport and storage have not damaged the circuit-breaker. In addition, when a large part of the assembly and/or of the adjustment is performed on site, the tests allow checking of the quality of the work and of functional characteristics depending on it.

Repetition of tests already performed in the factory should be avoided.

Depending on the relative amount of site assembly and on agreement between manufacturer and user, the commissioning tests can be:

- performed by the manufacturer;
- performed by the user, in accordance with the manufacturer's instructions (types of tests to perform and acceptable limits for the results).

The results of the tests should be recorded in a test report.

Depending on the type of the circuit-breaker, the type of the control device, the service conditions, the amount of information desired and technical and economic aspects, the manufacturer and the user should choose the tests to be performed.

An example of a commissioning test programme is given in Appendix HH.

Note. — When for any reason all or parts of the routine tests are not performed in the factory they should be performed on site (see IEC Publication 694, Clause 7). Such a routine test programme should be combined with the commissioning test programme.

10.3 *Maintenance*

Sub-clause 10.3 of IEC Publication 694 is applicable with the following addition:

The manufacturer should, further, give information regarding the overhaul of circuit-breakers following:

a) short-circuit operations;

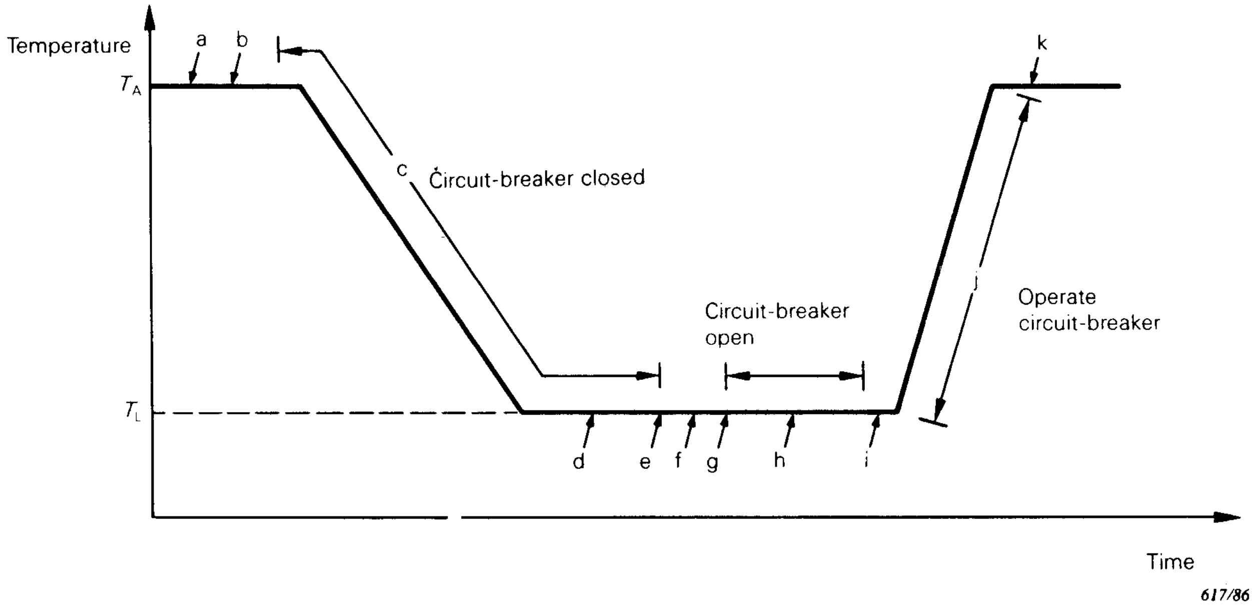
b) operations in normal service.

This information should include the number of operations according to Items *a)* and *b)* after which the circuit-breaker is to be overhauled.

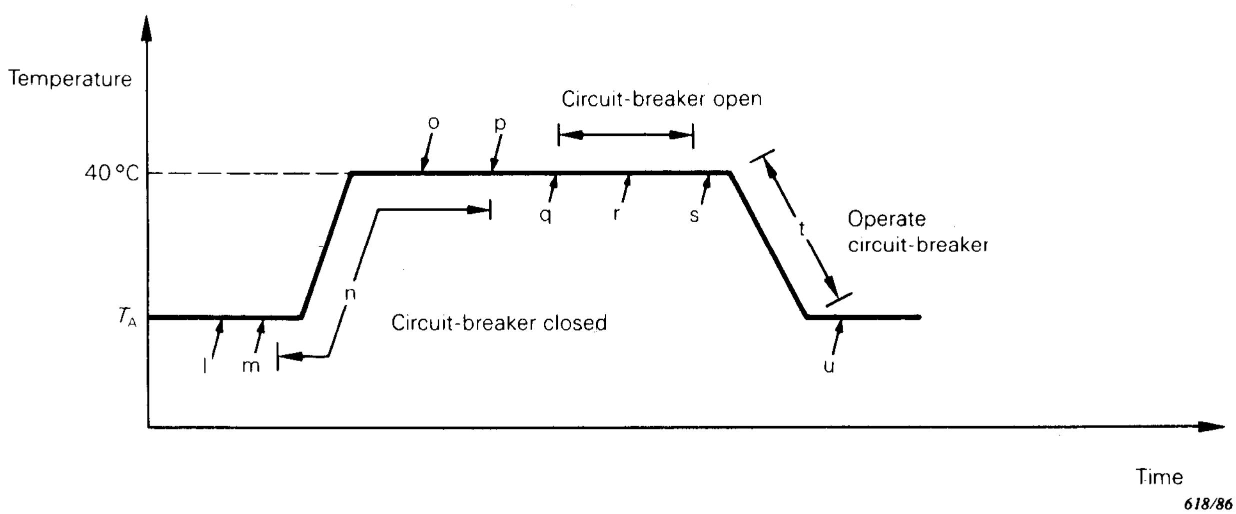
Sub-clauses 10.3.1 to 10.3.11 of IEC Publication 694 are applicable.

10.3.101 *Resistors and capacitors*

Checking of resistors and capacitors. Allowed variations of the values should be given.



a) Low temperature test



b) High temperature test

Note. — Letters a to u identify application points of tests specified in Sub-clauses 6.101.3.3 and 6.101.3.4.

FIG. 15. — Test sequences for low and high temperature tests.

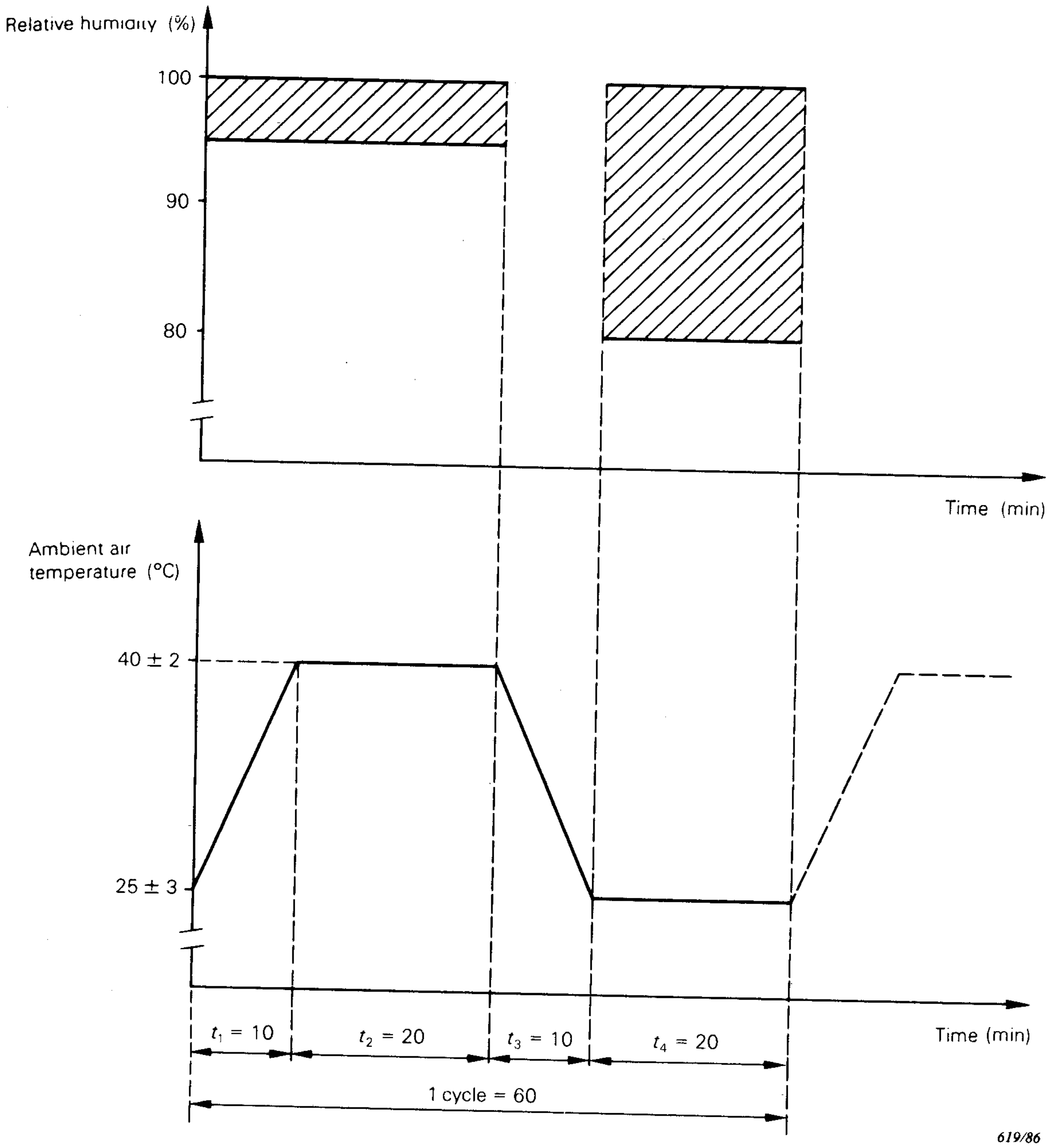
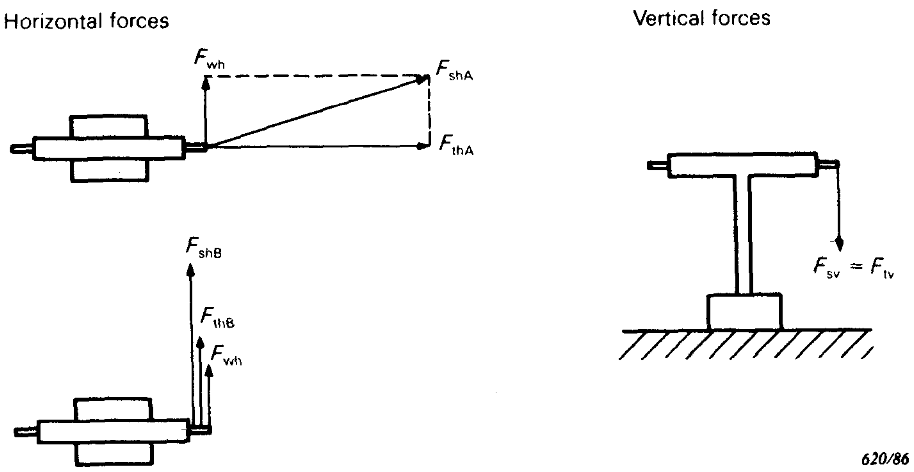


FIG. 16. — Humidity test.



F_{thA} = tensile horizontal force due to connected conductors (direction A)
F_{thB} = tensile horizontal force due to connected conductors (direction B)
F_{tv} = tensile vertical force due to connected conductors (direction C)
F_{wh} = horizontal force on circuit-breaker due to wind pressure on ice-coated circuit-breaker
F_{shA}, F_{shB}, F_{sv} = rated static terminal load (resultant forces)

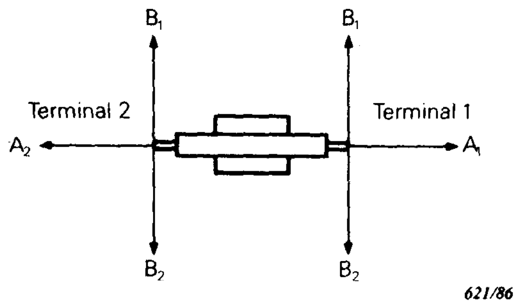
Note. — Refer to Figure 18, page 235, for directions A, B and C.

FIG. 17. — Static terminal load forces.

	Horizontal	Vertical	Remark
Forces due to dead weight, wind and ice on connected conductor	F_{thA}, F_{thB}	F_{tv}	According to Table XIII
Forces due to wind and ice on circuit-breaker*	F_{wh}	O	Calculated by manufacturer
Resultant force	F_{shA}, F_{shB}	F_{sv}	

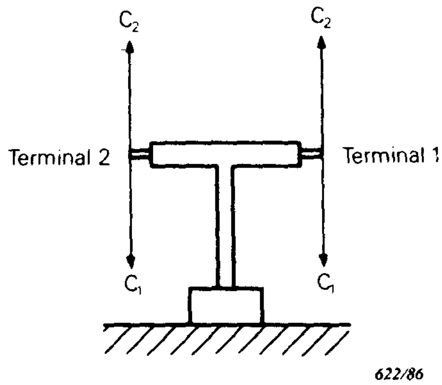
* The horizontal force on the circuit-breaker, due to wind, may be moved from the centre of pressure to the terminal and reduced in magnitude in proportion to the longer lever arm. (The bending moment at the lowest part of the circuit-breaker should be the same.)

Horizontal forces



Force directions: A_1, B_1, B_2 for Terminal 1
Force directions: A_2, B_1, B_2 for Terminal 2
Horizontal test forces: F_{shA} and F_{shB} (see Figure 17, page 233)

Vertical forces



Force directions: C_1, C_2 for Terminal 1
Force directions: C_1, C_2 for Terminal 2
Vertical test force (both directions): F_{sv} (see Figure 17)

Note. — For circuit-breakers which are symmetrical about the pole unit vertical centreline, only one terminal needs to be tested.

FIG. 18. — Directions for static terminal load tests.

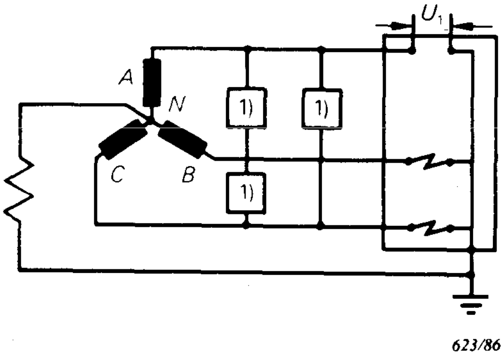


FIG. 19a. — Preferred circuit.

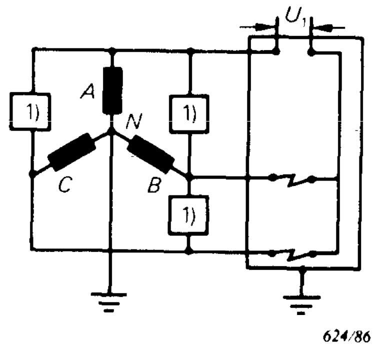


FIG. 19b. — Alternative circuit.

[1] The squares represent combinations of capacitances and resistances.

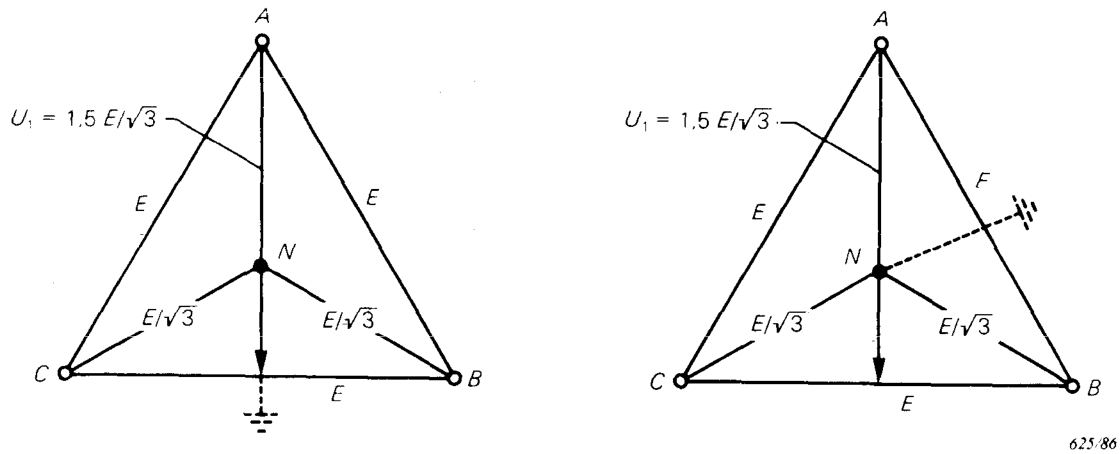


FIG. 19. — Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1.5.

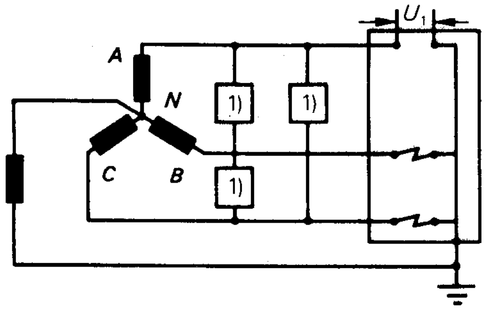


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FIG. 20a. — Preferred circuit.

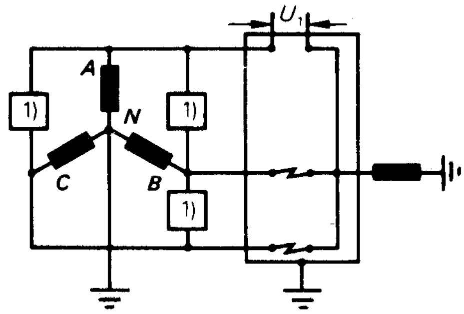

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FIG. 20b. — Alternative circuit.

[1)] The squares represent combinations of capacitances and resistances.

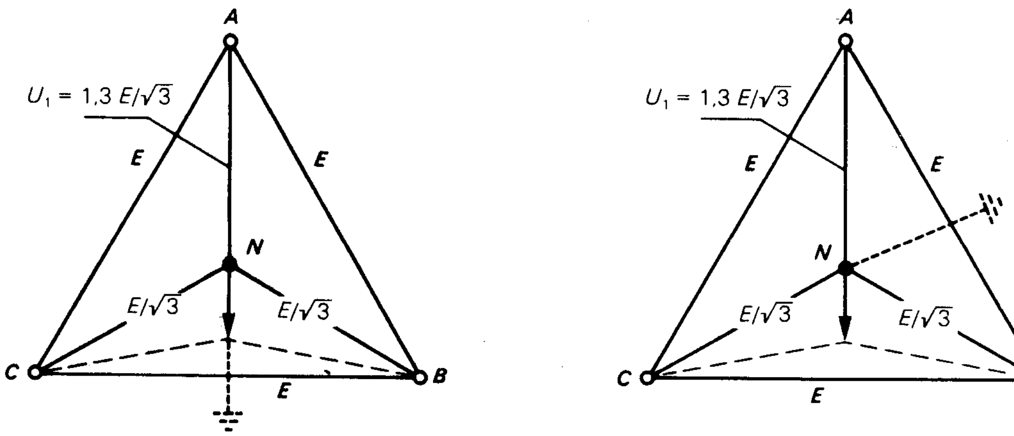

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FIG. 20. — Earthing of test circuits for three-phase short-circuit tests, first-pole-to-clear factor 1.3.

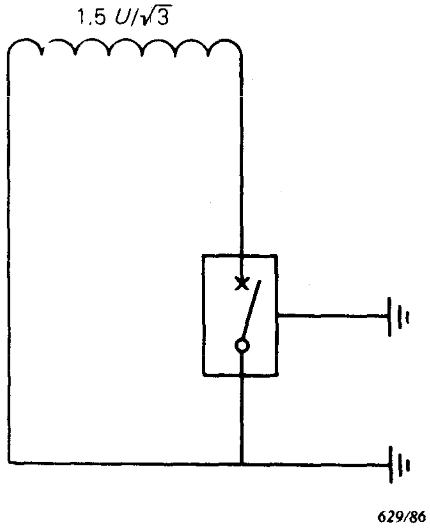


FIGURE 21a

Preferred circuit for circuit-breaker intended for universal use irrespective of the earthing condition of the system neutral; alternative test circuit for circuit-breaker intended for use in earthed neutral systems (subject to agreement of the manufacturer).

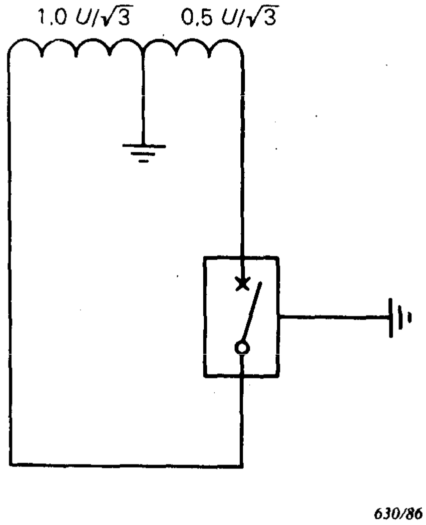


FIGURE 21b

Preferred circuit for circuit-breaker intended for use in earthed neutral systems; alternative circuit for circuit-breaker intended for universal use irrespective of the earthing condition of the system neutral (subject to agreement of the user).

FIG. 21. — Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1.5.

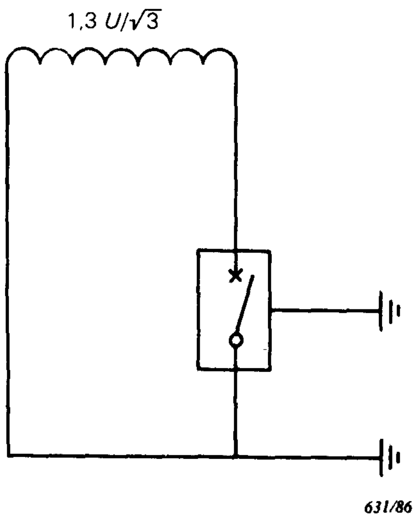


FIG. 22a. — Preferred circuit.

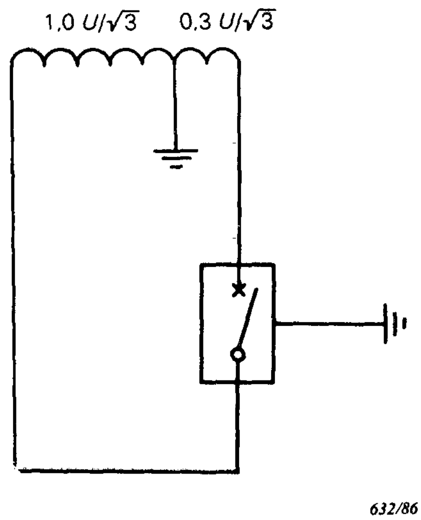


FIG. 22b. — Alternative circuit
(Subject to agreement of the user).

FIG. 22. — Earthing of test circuits for single-phase short-circuit tests, first-pole-to-clear factor 1.3.

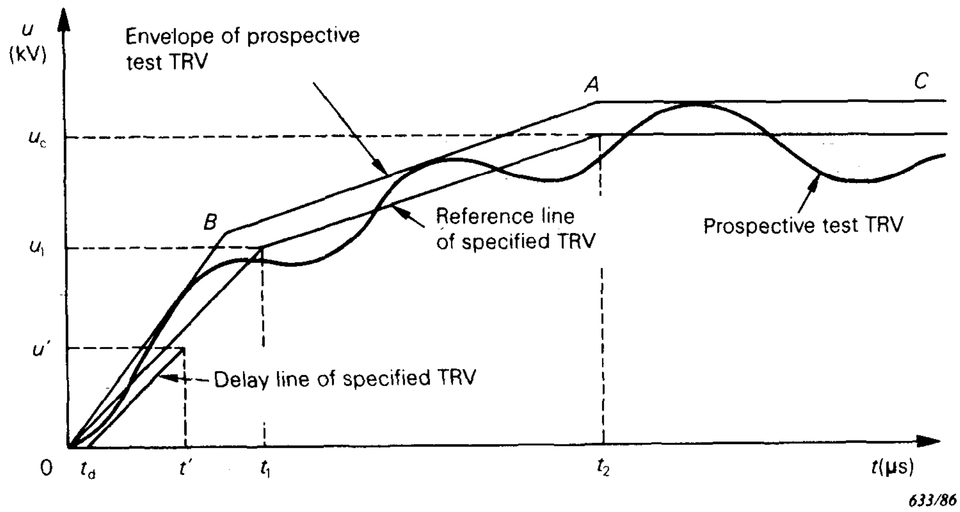


FIG. 23. — Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with four-parameter reference line.

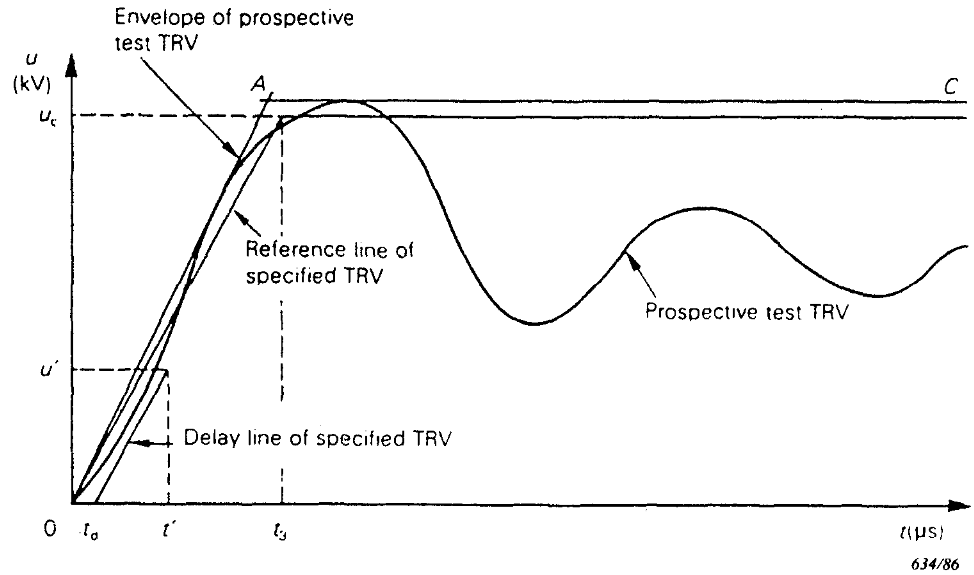


FIG. 24. — Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with two-parameter reference line.

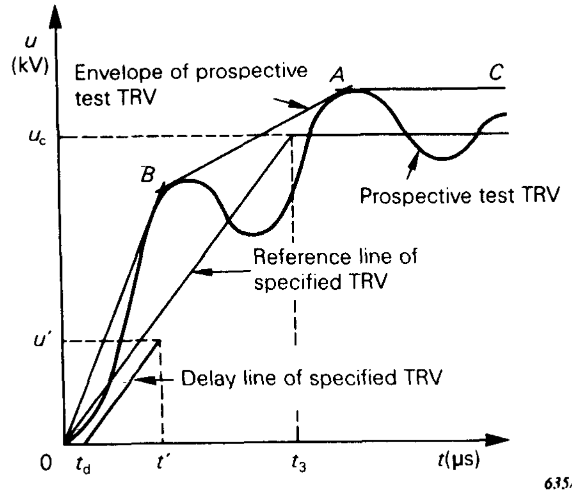


FIG. 25. — Example of prospective test TRV with four-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with two-parameter reference line.

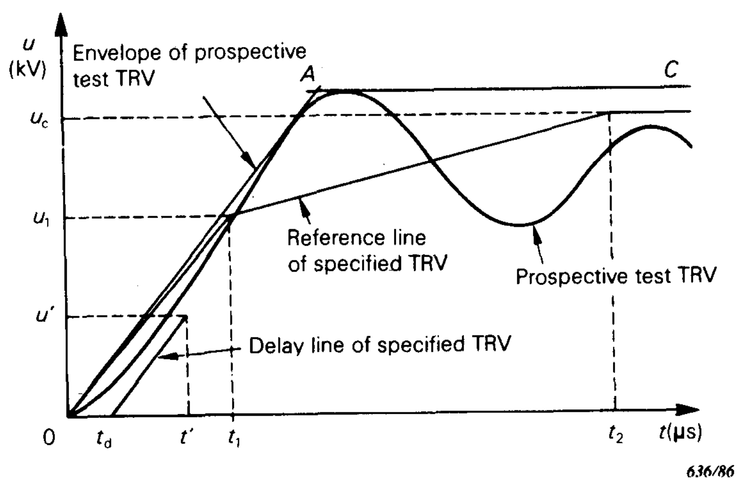


FIG. 26. — Example of prospective test TRV with two-parameter envelope which satisfies the conditions to be met during type test: case of specified TRV with four-parameter reference line.

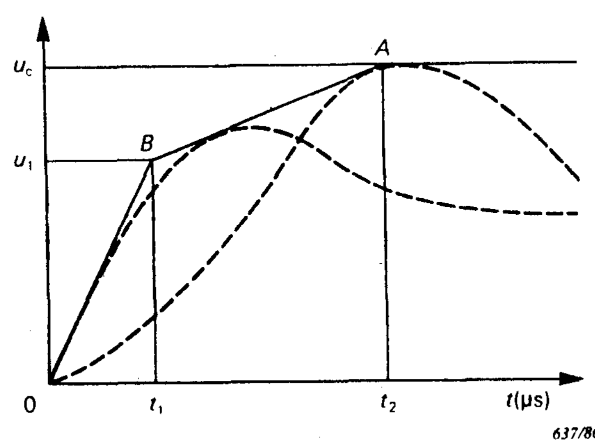
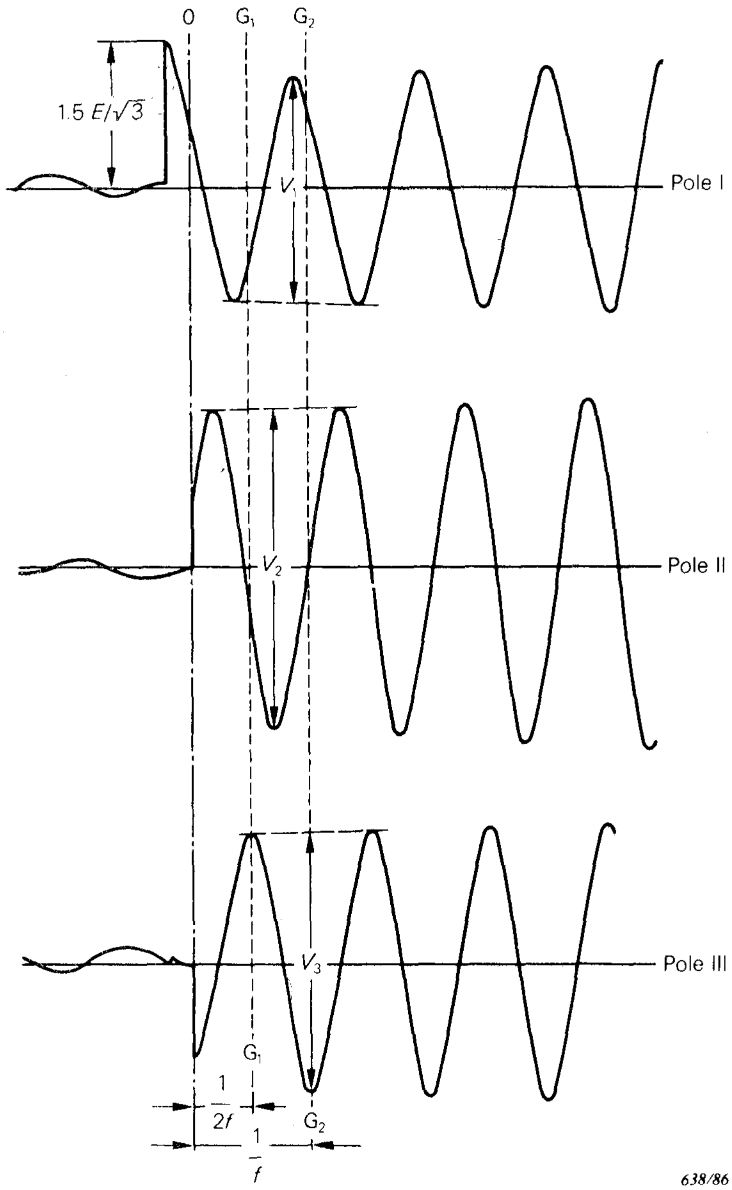


FIG. 27. — Example of two prospective test TRV-waves and their combined envelope in two-part tests.



Pole I = first pole to clear

OO = instant of final arc-extinction on all phases

G_1G_1 = instant $\frac{1}{2f}$ from OO

G_2G_2 = instant $\frac{1}{f}$ from OO

f = test frequency

$\frac{V_1}{2\sqrt{2}}$ = value of power frequency recovery voltage of Pole I

$\frac{V_2}{2\sqrt{2}}$ = value of power frequency recovery voltage of Pole II

$\frac{V_3}{2\sqrt{2}}$ = value of power frequency recovery voltage of Pole III

In Pole III a voltage peak occurs exactly at instant G_1G_1. In such event measurement is made at later instant G_2G_2.

Average value of the power frequency recovery voltages of Poles I, II and III

$$= \frac{\frac{V_1}{2\sqrt{2}} + \frac{V_2}{2\sqrt{2}} + \frac{V_3}{2\sqrt{2}}}{3}$$

The example illustrates three voltages obtained during a test upon a three-pole circuit breaker in a three-phase test circuit having one of its neutral points insulated, see Figure 19a or 19b, thus producing momentarily in the first pole to clear a 50% increase in the recovery voltage, as shown in Pole I.

FIG. 28. — Determination of power frequency recovery voltage.

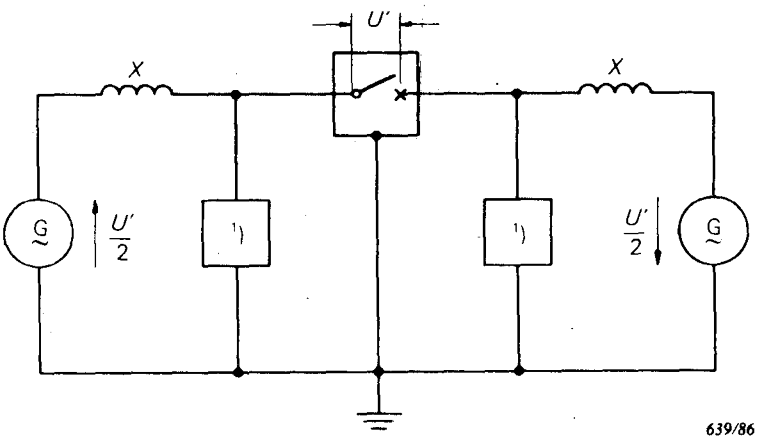


FIG. 29. — Test circuit for single-phase out-of-phase tests.

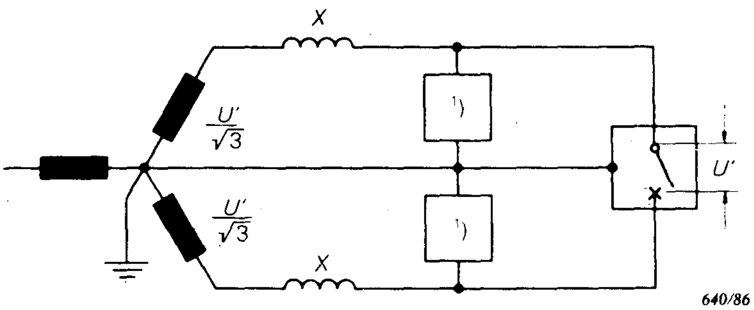


FIG. 30. — Test circuit for out-of-phase tests using two voltages separated by 120 electrical degrees.

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1) The squares represent combinations of capacitances and resistances.

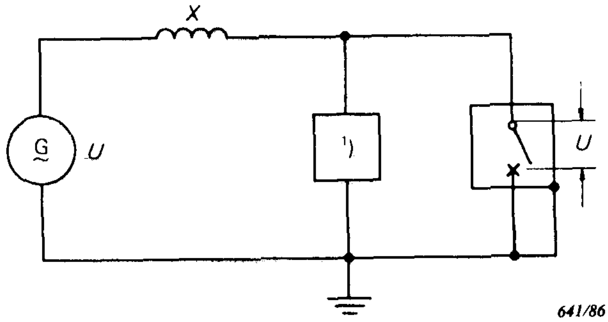


FIG. 31. — Test circuit for out-of-phase tests with one terminal of the circuit-breaker earthed (subject to agreement of the manufacturer).

1) The square represents combinations of capacitances and resistances.

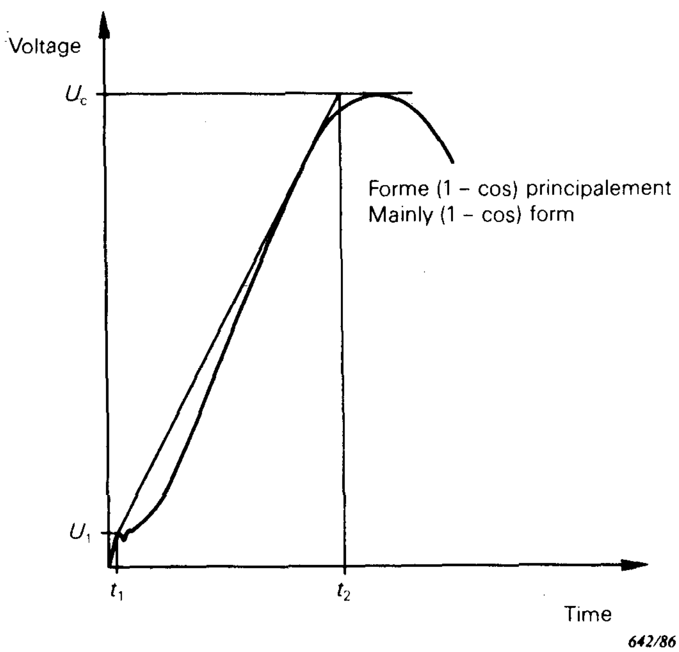


FIG. 32. — Prospective recovery voltage for capacitive current breaking tests.

CHAPTER III: APPENDICES

APPENDIX AA

CALCULATION OF TRANSIENT RECOVERY VOLTAGES FOR SHORT-LINE FAULTS FROM RATED CHARACTERISTICS

AA1. Basic approach

For rating and testing purposes, it has been decided to consider only a short-line fault occurring from one phase to earth in a system having the neutral earthed, the severity of this being sufficient to cover other cases, except in special circumstances where the system parameters may be more severe than the standard values.

The simplified single-phase circuit can be represented as in Figure 13, page 102.

During the short-circuit, the voltage will be:

$$U_p = U/\sqrt{3} \tag{1}$$

U is the rated voltage of the circuit-breaker.

This voltage drives the current I_L through the circuit consisting of reactances X_s and X_L in series. The r.m.s. value of the voltage drop on the source side will be:

$$U_s = I_L X_s \tag{2}$$

and along the line

$$U_L = I_L X_L \tag{3}$$

When the current is broken the instantaneous voltage to earth on the line side terminal of the circuit-breaker will be the initial voltage:

$$u_o = U_L \sqrt{2} \tag{4}$$

This initial voltage will return to zero by a series of travelling waves reflected back and forth along the line between the circuit-breaker and the fault, producing a transcient voltage on the line side in the form of a damped saw-tooth oscillation* as shown by u_L in Figure AA1, page 256. The voltage to earth on the source side terminal of the circuit-breaker will also be u_o at the instant of breaking. It will rise to a peak value u_m depending upon the transient recovery voltage on the source side as shown by u_s in figure AA1, the crest value U_m of the power frequency voltage to earth on the source side (after the ending of transient phenomena) becoming:

$$U_m = U_p \sqrt{2} = U \sqrt{\tfrac{2}{3}} \tag{5}$$

The resulting specified transient recovery voltage for short-line faults appearing across the circuit-breaker is the difference between the source and the line side transient voltages as shown by $u_s - u_L$ in Figure AA1.

---

* In practice the saw-tooth waveform is in some degree modified by a time delay due to lumped capacitances present at the terminals of the circuit-breaker (capacitances of voltage transformers, current transformers, etc.); also the top of the oscillation is slightly rounded.

AA2. Initial voltage to earth

The ratio between the voltage u_o at the instant of breaking and the crest value U_m of the driving voltage is dependent only on the reduction in current due to the reactance of the line, and is independent of rated voltage, rated short-circuit breaking current and the line constants, hence:

$$u_o/U_m = 1 - I_L/I \tag{6}$$

where:

I = rated short-circuit breaking current
I_L = short-line fault breaking current

This relation is shown in Table AA1 for the standard ratios of short-line fault currents; for other ratios it can be taken from Figure AA2, page 257.

TABLE AA1.

Initial voltage to earth and peak value of transient recovery voltage for short-line faults

I_L/I	u_o/U_m	u_m/U_m
0.90	0.10	1.36
0.75	0.25	1.30

AA3. Transient voltage on line side

The line-side characteristics have been standardized as shown in Table V.

The excursion u_L^* of the line-side transient voltage u_L from the initial value u_o is obtained by multiplying the value u_o by the appropriate peak factor k:

$$u_L^* = k\,u_o \tag{7}$$

The time t_L to the first peak value u_L^* is obtained from the rate-of-rise du_L/dt of transient voltage u_L on the line-side after breaking the line current $i = I_L\sqrt{2}\,\sin(2\,\pi\,\text{ft})$ at current zero by:

$$t_L = u_L^*/sI_L \tag{8}$$

where:

$$-sI_L = du_L/dt = -2\,\pi f Z I_L \sqrt{2} \tag{9}$$

s = RRRV factor
Z = surge impedance of the line
f = rated frequency

The rated line characteristics Z, k and s are given in Table V.

The transient voltage will fall to zero by a damped saw-tooth oscillation the exact waveform of which depends upon the characteristics of the actual line. This is shown as an example by the dotted lines in Figure AA1, page 256.

Note. — The approximate length of line corresponding to a given short-line fault can be obtained by the formula:

$$L = \frac{ct_L}{2} \tag{10}$$

where c is the speed of the travelling wave propagation assumed to be equal to:

$$c = 0.3 \text{ km}/\mu\text{s} \tag{11}$$

AA4. Transient voltage on source side

The course of the source-side transient voltage from the initial value u_o to the peak value u_m can be derived from Tables IV. The times t_1, t_2, t_3 and t_d given there can be used directly. The voltage u_1 in Table IVc equalling the power-frequency crest voltage U_m is not affected, but the TRV peak value u_c must be scaled down to the value u_m such that

$$u_m/U_m = 1 + 0.4\ I_L/I \tag{12}$$

as given in Table AA1 and Figure AA2, page 257.

The values given in Tables IV correspond to the limit case of $I_L/I = 1.0$:

$$u_c/U_m = 1.4 \tag{13}$$

The peak value u_m of the source-side transient voltage is also that of the resulting transient recovery voltage for short-line faults provided the voltage oscillation on the line has fallen to zero by the time t_2 (or t_3), as is generally the case.

In service, the source-side transient voltage will commence to rise as a curve having as a boundary the delay line (see Sub-clause 4.102.2). The most important part of the resulting transient recovery voltage for short-line faults is up to the first peak value $u_L{}^*$ of the transient voltage on the line side which is reached by the time t_L. For the calculation of the source-side contribution $u_s{}^*$ at the time t_L, negligible error is introduced by ignoring the curvature, the voltage being deemed to follow the straight delay line running parallel to the reference line with time delay t_d, compare Figures 10 and 11, pages 99 and 100.

AA5. Example of calculation

Circuit-breaker ratings:

$$U = 245\ \text{kV};\ I = 31.5\ \text{kA};\ f = 50\ \text{Hz}$$

Short-line fault current considered:

$$I_L = 0.75\ I = 23.6\ \text{kA}$$

Power-frequency crest voltage to earth (from equation (5) or u_1 in Table IVc):

$$U_m = 245\ \sqrt{\frac{2}{3}} = 200\ \text{kV}$$

Initial voltage u_o to earth (from equation (6) or u_o/U_m in Table AA1):

$$u_o = 0.25 \cdot 200 = 50\ \text{kV}$$

First excursion of line-side transient voltage (from equation (7) and Table V):

$$u_L{}^* = 1.6 \cdot 50 = 80\ \text{kV}$$

Time t_L to the first peak value of the transient voltage on the line side (from equation (8) and Table V):

$$t_L = \frac{80}{0.2 \cdot 23.6} = \frac{80}{4.72} = 16.95\ \mu\text{s}$$

Length L of line to fault (from equation (10)):

$$L = \frac{0.3 \cdot 16.95}{2} = 2.54\ \text{km}$$

From the above data, and with $t_{dL} = 0.5\ \mu s$ (see Table V), the initial line-side transient voltage can be constructed. The time to the first peak is $t_L + t_{dL}$. See Figure AA1.

The times t_1, t_2 and t_d for the source-side transient voltage can be obtained from Table IVc:

$$t_1 = 100\ \mu s; \quad t_2 = 300\ \mu s; \quad t_d = 2\ \mu s$$

Rate-of-rise of source-side transient voltage:

$$\frac{200 - 50}{100} = 1.5\ kV/\mu s$$

Voltage contribution from the source-side at time $t_L + t_{dL}$:

$$u_s^* = (t_L + t_{dL} - t_d)\ 1.5 = (16.95 + 0.5 - 2)\ 1.5 = 23.2\ kV$$

(if $t_L < t_d$ the source-side contribution is only ITRV).

ITRV contribution of the source-side (from Table III):

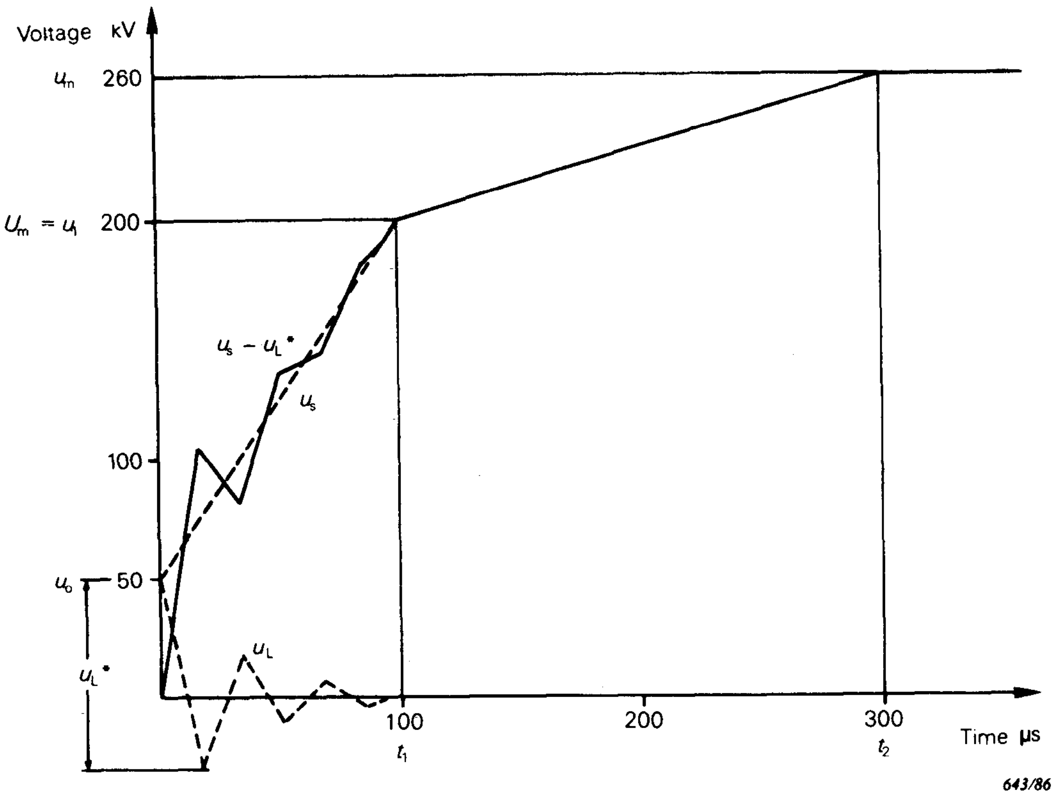
$$t_i = 0.6\ \mu s; \quad u_i = 0.069 \cdot 23.6 = 1.63\ kV$$

Peak value u_m of the source-side transient voltage (from equation (12) or Table AA1):

$$u_m = 1.30 \cdot 200 = 260\ kV$$

From the above data, the source-side transient voltage can be constructed and thus the resulting prospective transient recovery voltage $u_s - u_L$ appearing across the circuit-breaker terminals can be evaluated as shown in Figure AA1. The value u_T at the time $t_L + t_{dL}$ is:

$$u_T = u_L^* + u_s^* = 103.2\ kV$$



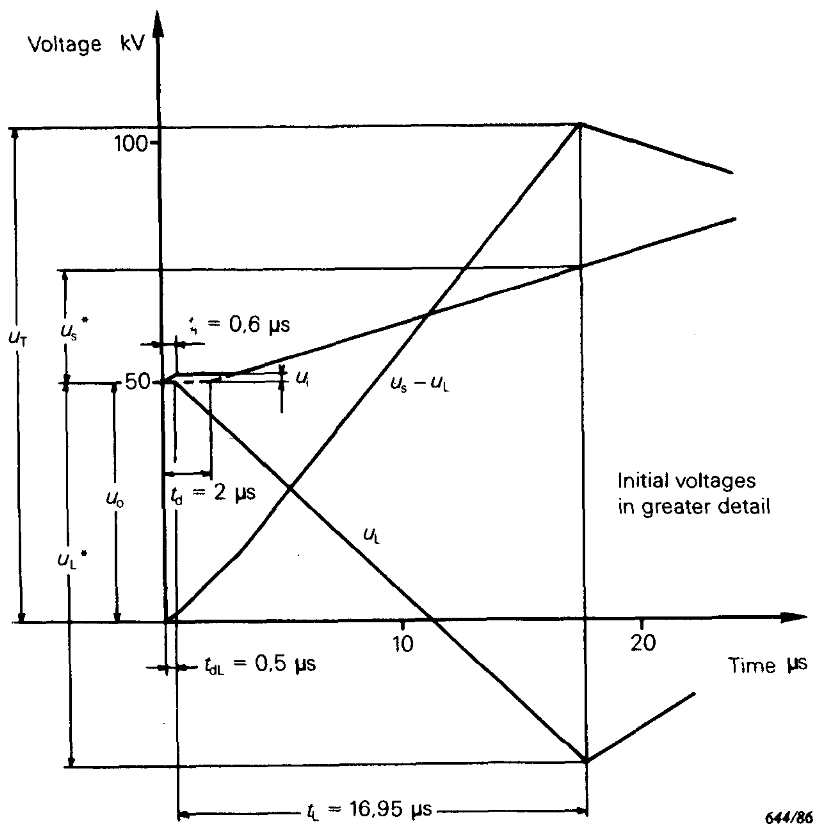


FIG. AA1. — Construction of TRV for short-line fault.

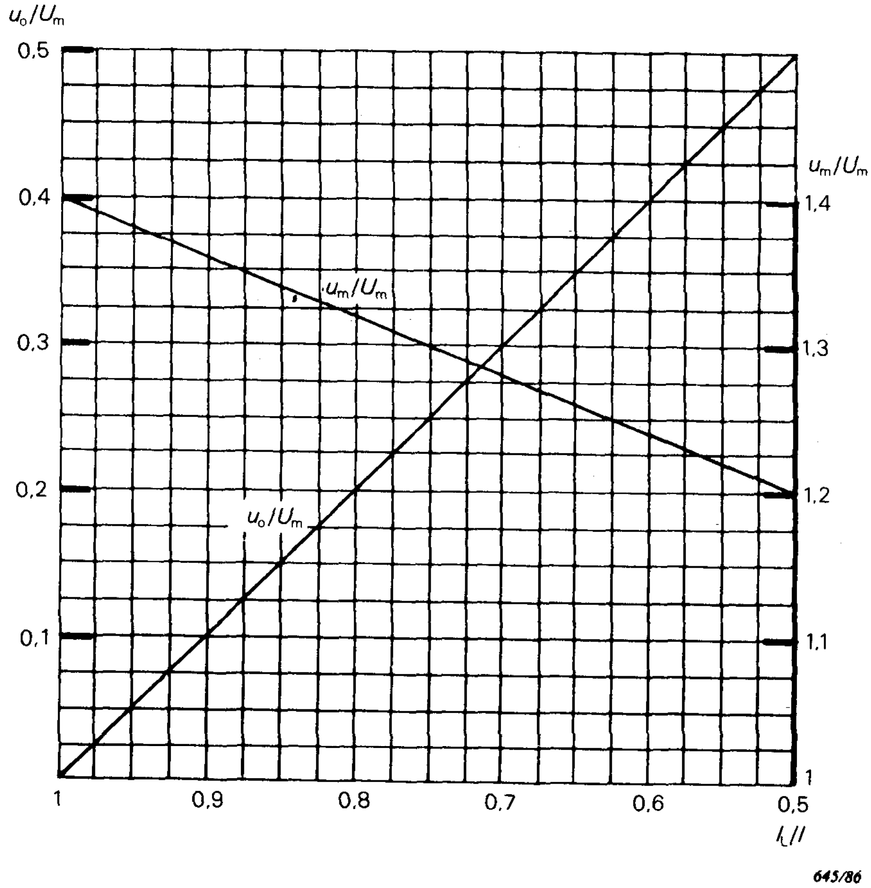


FIG. AA2. — Relation of u_o/U_m and u_m/U_m as a function of I_L/I.

APPENDIX BB

CAPACITOR BANK INRUSH CURRENTS

The energizing of a capacitor bank by closing a circuit-breaker produces an inrush current which is a function of the applied voltage, the capacitances of the circuit, the values and location of the inductances in the circuit, the charges on the capacitors at the time the circuit is closed and the damping of the switching transients. Calculations of inrush current are usually made on the assumption that the capacitor bank has no initial charge and that the circuit is closed at a time which produces the maximum inrush current.

When closing onto a pre-charged capacitor bank, the inrush current can be higher than when closing onto an uncharged capacitor bank. An estimate of the factor by which the current may be increased can be obtained from:

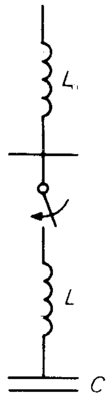
$$\frac{\text{Voltage change on pre-charged bank while being energized}}{\text{Voltage change on uncharged bank while being energized.}}$$

It should be noted that restriking circuit-breakers can also impose hazardous stresses on capacitors.

The inrush curent can be calculated knowing the network impedances. Figure BB1, page 261, shows the three different cases of connection of a capacitor bank when zero, one and n banks respectively are already connected to the busbar.

Normally the simplified calculations in Figures BB1b) and c) are acceptable.

When two or more capacitor banks are connected close to each other and the inductances between them are small, it may be necessary both from capacitor and circuit-breaker point of view to reduce the inrush current by inserting impedances in series with the capacitors.

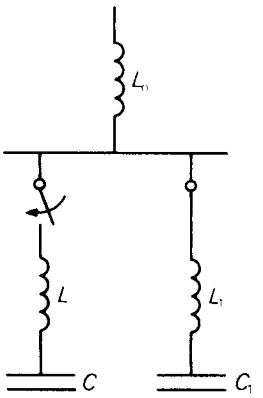


a) Connection of a single bank

$$\hat{i} = U\sqrt{\frac{2}{3}\,\frac{C}{L_0 + L}} \approx U\sqrt{\frac{2}{3}\,\frac{C}{L_0}}$$

$$L_0 \gg L$$

$$f = \frac{1}{2\pi\sqrt{C\,(L_0 + L)}} \approx \frac{1}{2\pi\sqrt{C\,L_0}}$$

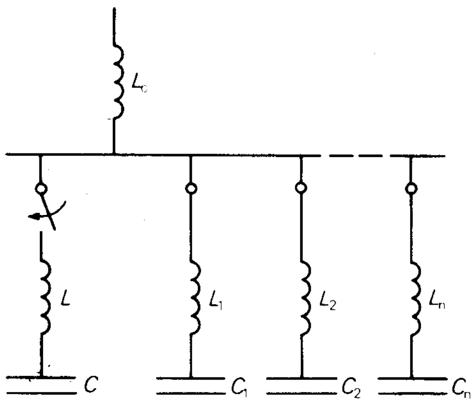


b) Connection when one bank is already connected

$$\hat{i} = U\sqrt{\frac{2}{3}\,\frac{C_1 C}{(C_1 + C)}\cdot\frac{1}{(L_1 + L)}}$$

$$f = \frac{1}{2\pi\sqrt{\dfrac{C_1 C}{(C_1 + C)}\cdot(L_1 + L)}}$$

$$S = \frac{U}{L_1 + L}\sqrt{\frac{2}{3}}$$



c) Connection when *n* banks are already connected

$$L' = \frac{1}{\dfrac{1}{L_1} + \dfrac{1}{L_2} + \cdots \dfrac{1}{L_n}}$$

$$C' = C_1 + C_2 + \cdots C_n$$

L' and C' substitute L_1 and C_1 in Figure BB1b. The calculation is correct if $L_1C_1 = L_2C_2 = \ldots L_nC_n$ and is an approximation in other cases.

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U = system voltage
$\hat{i}$ = inrush current peak
f = inrush current frequency
S = inrush current rate-of-rise

L_0 = source inductance
L = inductance in series with switched capacitor bank

C = capacitance of switched capacitor bank (equivalent star value)
$L_1, L_2 \ldots L_n$ = inductances in series with capacitor banks on source side
$C_1, C_2 \ldots C_n$ = bank capacitances (equivalent star values) on source side

FIG. BB1. — Capacitor bank inrush currents.

APPENDIX CC

RECORDS AND REPORTS OF TYPE TESTS FOR MAKING, BREAKING AND SHORT-TIME CURRENT PERFORMANCE

CC1. Information and results to be recorded

All relevant information and results of making, breaking and short-time current tests shall be included in the type-test report.

Oscillographic records in accordance with Clause CC2 shall be made of all short-circuit operations and included in the type-test report.

The accuracy of each measurement by oscillograph, including associated equipment, of the quantities which determine the ratings (e.g. short-circuit current, applied voltage and recovery voltage) shall be within $\pm 5\%$.

Photographs should be taken to illustrate the condition of the circuit-breaker before and after the series of tests.

The type-test report shall include a statement of the performance of the circuit-breaker during each test-duty and of the condition of the circuit-breaker after each test-duty, in so far as an examination is made, and at the end of the series of test-duties. The statement shall include the following particulars:

a) condition of circuit-breaker giving details of any replacements or adjustments made and condition of contacts, arc control devices, oil (including any quantity lost), statement of any damage to arc shields, enclosures, insulators and bushings;

b) description of performance during test-duty, including observations regarding emission of oil, gas or flame.

CC2. Information to be included in reports

CC2.1 General

a) date of tests;

b) reference of report number;

c) test numbers;

d) oscillogram numbers.

CC2.2 *Apparatus tested*

a) type or list number;

b) description (by the manufacturer), including number of poles;

c) manufacturer;

d) photograph numbers;

e) drawing numbers.

CC2.3 *Rating assigned by manufacturer*

a) voltage, in kilovolts;

b) normal current, in amperes;

c) frequency, in hertz;

d) short-circuit breaking current:

i) r.m.s. value of the a.c. component of current, in kiloamperes,

ii) percentage d.c. component;

e) minimum opening time, in milliseconds;

f) transient recovery voltage: peak value, in kilovolts, and rate-of-rise, in kilovolts per micro-second;

g) short-line fault surge impedance, in ohms, and peak factor;

h) short-circuit (peak) making current, in kiloamperes;

i) out-of-phase breaking-current, in kiloamperes;

j) duration of short-circuit, in seconds;

k) operating sequence;

l) line-charging breaking current, in amperes;

m) cable-charging breaking current, in amperes;

n) capacitor bank breaking (and making) current, in amperes;

o) small inductive breaking current, in amperes;

p) supply voltages, in volts:

i) closing device

ii) opening device

q) operating gas pressure range, in megapascals (or bars).

CC2.4 *Test conditions (for each series of tests)*

a) number of poles;

b) power factor;

c) frequency, in hertz;

d) generator neutral (earthed or isolated);

e) transformer neutral (earthed or isolated);

f) short-circuit point or load side neutral (earthed or isolated);

g) diagram of test circuit including connection(s) to earth.

CC2.5 *Short-circuit breaking and making tests*

a) operating sequence and time intervals;

b) applied voltage, in kilovolts;

c) making current (peak value), in kiloamperes;

d) breaking current:

i) r.m.s. value of a.c. component in kiloamperes for each phase and average,

ii) percentage d.c. component;

e) power frequency recovery voltage, in kilovolts;

f) prospective transient recovery voltage;

i) compliance with requirement *a)* of Sub-clause 6.104.5.1; voltage and time co-ordinates may be quoted;

ii) compliance with requirement *b)* of Sub-clause 6.104.5.1;

g) arcing time, in milliseconds;

h) opening time, in milliseconds;

j) break time, in milliseconds.

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.

k) physical behaviour:

i) emission of flame, gas, oil, etc.,

ii) behaviour, conditions and remarks.

CC2.6 *Short-time current test*

a) current

i) r.m.s. value, in kiloamperes,

ii) peak value, in kiloamperes;

b) duration, in seconds;

c) physical behaviour.

CC2.7 *No-load operation*

a) before making and breaking tests (see Sub-clause 6.102.5);

b) after making and breaking tests (see Sub-clause 6.102.8.3)

CC2.8 *Out-of-phase making and breaking tests*

a) breaking current in each phase, in kiloamperes;

b) voltage across each phase, in kilovolts;

c) gas pressure before tests (when applicable), in megapascals (or bars);

d) break-time, in milliseconds;

e) resistor current in each phase (when applicable), in amperes.

CC2.9 *Capacitive current switching tests*

a) test voltage, in kilovolts;

b) breaking current in each phase, in amperes;

c) peak values of the voltage between each phase and earth, in kilovolts:

i) supply side of circuit-breaker;

ii) 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) behaviour of circuit-breaker during test;

j) condition of circuit-breaker after test.

CC2.10 *Oscillographic and other records*

Oscillograms shall record the whole of the operation. The following quantities shall be recorded. Certain of these quantities may be recorded separately from the oscillograms, and several oscillographs with different time scales may be necessary.

a) applied voltage;

b) current in each pole;

c) recovery voltage (voltages on supply and load side of circuit-breaker for charging current tests);

d) current in closing coil;

e) current in opening coil;

f) suitable timing scale;

g) travel of moving contacts (if practicable).

All cases in which the requirements of this standard are not strictly complied with and all deviations shall be explicitly mentioned at the beginning of the test report.

APPENDIX DD

DETERMINATION OF SHORT-CIRCUIT POWER FACTOR

There is no method by which the short-circuit power factor can be determined with precision, but, for the purpose of the present standard the determination of the power factor in each phase of the test-circuit may be made with sufficient accuracy by whichever of the three following methods is the more appropriate.

DD1. Method I — Calculation from circuit constants

The power factor may be calculated as the cosine of an angle φ where φ = arc tan X/R, X and R being respectively the reactance and resistance of the test-circuit while the short-circuit exists.

Owing to the transitory nature of the phenomenon, no accurate method can be given for determining X and R, but for compliance with these rules the values may be determined by the following method:

R is measured in the test-circuit with direct current; if the circuit includes a transformer, the resistance R_1 of the primary circuit and the resistance R_2 of the secondary circuit are measured separately and the required value R is then given by the formula:

$$R = R_2 + R_1 N^2$$

in which N is the ratio of transformation of the transformer.

X is then obtained from the formula:

$$X = \sqrt{\left(\frac{E}{I}\right)^2 - R^2}$$

the ratio $\frac{E}{I}$ (circuit impedance) being obtained from the oscillogram as indicated in Figure DD1, page 273.

DD2. Method II — Determination from d.c. component

The angle φ may be determined from the curve of the d.c. component of an asymmetrical current wave between the incidence of short-circuit and the instant of contact separation as follows:

DD2.1 The formula for the d.c. component is:

$$i_d = I_{do}\, e^{-Rt/L}$$

where:

i_d = value of the d.c. component at any instant

I_{do} = initial value of the d.c. component

L/R = time constant of the circuit, in seconds

t = time interval, in seconds, between i_d and I_{do}

e = base of Napierian logarithms

The time constant L/R can be ascertained from the above formula as follows:

a) measure the value of I_{do} at the instant of short-circuit and the value of i_d at any other time t before contact separation;

b) determine the value of $e^{-Rt/L}$ by dividing i_d by I_{do};

c) from values of e^{-x} determine the value of $-x$ corresponding to the ratio i_d/I_{do};

d) the value x then represents Rt/L, from which L/R can be determined.

DD2.2 Determine the angle φ from:

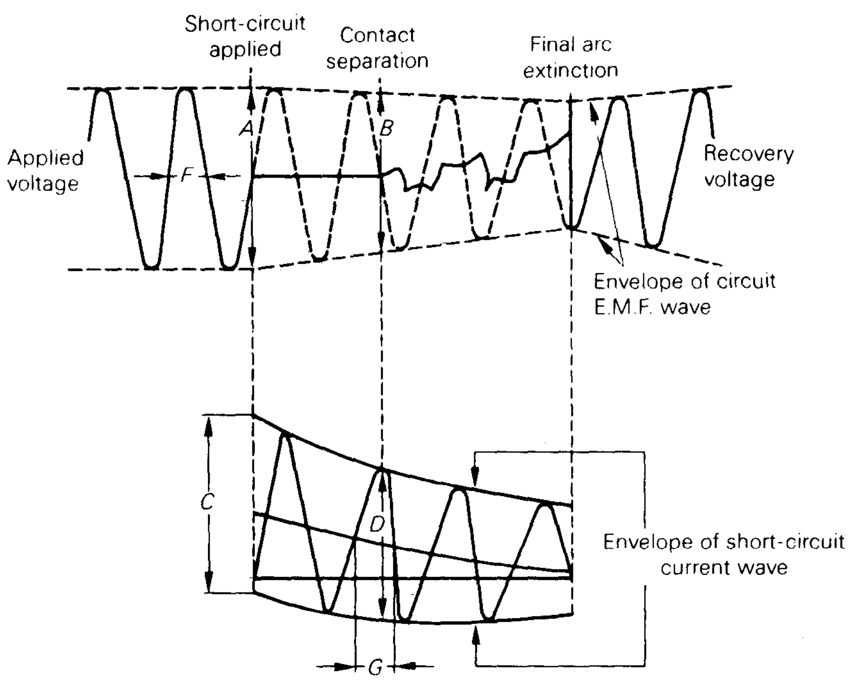
$$\varphi = \arctan \omega L/R$$

where ω is 2π times the actual frequency.

DD3. Method III — Determination with pilot generator

When a pilot generator is used on the same shaft as the test generator the voltage of the pilot generator on the oscillogram may be compared in phase first with the voltage of the test generator and then with the current of the test generator.

The difference between the phase angles between pilot generator voltage and main generator voltage on the one hand, and pilot generator voltage and test generator current on the other hand gives the phase angle between the voltage and current of the test generator, from which the power factor can be determined.



$$\text{Circuit impedance} = \frac{E}{I} = \frac{B}{D} = \frac{A}{C} \times \frac{F}{G}$$

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where:

E = circuit E.M.F. at contact separation = $\dfrac{B}{2\sqrt{2}}$

I = breaking current = $\dfrac{D}{2\sqrt{2}}$

A = twice the peak value of the applied voltage

C = twice the peak value of the a.c. component of the current wave at the beginning of the short-circuit

F = duration, in seconds, of one half-cycle of the applied voltage wave

G = duration, in seconds, of one-half-cycle of the current wave at the instant of contact separation

FIG. DD1. — Determination of circuit impedance for calculation of power factor in accordance with Method I of Appendix DD.

APPENDIX EE

TIGHTNESS SPECIFICATIONS AND TESTS

EE1. **Gas tightness**

EE1.1 *Scope and object*

This clause applies to high-voltage indoor or outdoor circuit-breakers which use gas, other than air at atmospheric pressure, as interrupting, insulating or operating medium, or vacuum. Its purpose is to define characteristics and test procedures relative to gas tightness.

Note. — The methods of leak detection described in IEC Publication 68-2-17: Basic Environmental Test Procedures, Part 2: Tests — Test Q: Sealing, can be applied to small components only and therefore cannot be used for testing high-voltage equipment.

EE1.2 *Definitions*

EE1.2.1 *Controlled pressure system (for gas)*

An assembly which is automatically refilled from an external or internal gas source.

Note. — Examples of controlled pressure systems are air-blast circuit-breakers, SF_6 double pressure circuit-breakers (internal tightness) or pneumatic operating mechanisms.

EE1.2.2 *Closed pressure system (for gas)*

An assembly which is refilled only periodically by manual connection to an external gas source.

Note. — Examples of closed pressure systems are SF_6 single or double pressure circuit-breakers (external tightness).

EE1.2.3 *Sealed pressure system*

An assembly for which no further processing is required during its expected operating life.

Notes 1. — Examples of sealed pressure systems are vacuum circuit-breakers or some SF_6 circuit-breakers.

2\. — Sealed pressure systems are completely assembled and tested in the factory.

EE1.2.4 *Rated filling pressure,* P_r (or density D_r)

The pressure referred to 20 °C (or density) to which the assembly is either manually or automatically filled.

EE1.2.5 *Minimum pressure,* P_m (or density D_m)

The pressure (or density) at which either manual or automatic refilling is necessary in order to maintain the rated performance of the assembly.

EE1.2.6 *Absolute leakage rate,* F

The amount of gas escaped by time unit, expressed in bar · cm³/s.

EE1.2.7 *Permissible leakage rate,* F_p

The maximum permissible leakage rate specified by the manufacturer for a complete circuit-breaker or, by using the tightness coordination chart TC, for an arrangement of sub-assemblies or for components.

EE1.2.8 *Relative leakage rate, F_{rel}*

The absolute leakage rate related to the total amount of gas in the system at rated filling pressure (or density). It is expressed in percent per year or per day.

EE1.2.9 *Time between refillings, T*

The time elapsed between two refillings performed either manually or automatically to compensate the leakage rate *F*.

EE1.2.10 *Number of refillings per day, N*

The number of refillings to compensate the leakage rate *F*.

This value is applicable to controlled pressure systems.

EE1.2.11 *Pressure drop, ΔP*

The drop of pressure in a given time caused by the leakage rate *F*, without refilling.

EE1.2.12 *Tightness coordination chart, TC*

A survey document supplied by the manufacturer, used when testing sub-assemblies or components to demonstrate the relationship between the tightness of the complete circuit-breaker and that of sub-assemblies and/or components.

EE1.2.13 *Cumulative leakage measurement*

A measurement which takes into account all the leaks from a given assembly to determine leakage rate.

EE1.2.14 *Sniffing*

The action of slowly moving a leakmeter sensing probe around an assembly to locate a leak.

EE1.3 *Specifications for gas tightness*

EE1.3.1 *Controlled pressure systems*

The tightness of controlled pressure systems is specified by the number of refilling operations per day (*N*) or by the pressure drop per day (ΔP).

The permissible values shall be given by the manufacturer.

EE1.3.2 *Closed pressure systems*

The tightness of closed pressure systems is specified by two quantities:

- relative leakage rate F_{rel};

  preferred values are 1% and 3% per year;
- time between refillings *T* ;

  preferred values are 3 and 10 years.

EE1.3.3 *Sealed pressure systems*

The tightness of sealed pressure systems is specified by their expected operating life. Preferred values are 10, 20 and 30 years.

EE1.4 *Tests*

The purpose of tightness tests is to demonstrate that the total system leakage *F* does not exceed the specified value F_p.

If possible, the test should be performed on a complete circuit breaker at P_r (or D_r). If it is not convenient, the tests may be performed on sub-assemblies or components. In these cases, the permissible leakage rate of the tested objects in relation to the leakage rate of the total circuit-breaker shall be shown by the tightness coordination chart TC. The possible leakages between sub-assemblies are also to be taken into account (see Figure EE1, page 287).

The test shall be performed both with the circuit-breaker in the closed and open positions, unless the leakage rate is independent of the position of the circuit-breaker or tested sub-assembly.

In general, only cumulative leakage measurements allow calculation of leakage rates.

The type test report should include such information as:

- a description of object under test, including its internal volume and the nature of the filling gas;
- whether the circuit-breaker was in the closed or open position (if applicable);
- the pressures and temperatures recorded at the beginning and end of the test and the number of refillings;
- the cut in and cut off pressure settings of the pressure (or density) control or monitoring device;
- an indication of the calibration of the meters,
- the results of the measurements,
- if applicable, the test gas and the conversion factor to assess the results.

EE1.4.1 *Tests of controlled or closed pressure systems*

EE1.4.1.1 *Type tests*

The tightness test shall be performed during the mechanical operation test and the low and high temperature tests (see Sub-clauses 6.101.2 and 6.101.3).

An increased leakage rate at extreme temperatures and/or during operations is acceptable, provided that this rate resets to the initial value after the temperature is returned to normal ambient air temperature, is thermally stable, and/or after the operations are performed. The increased temporary leakage rate shall not exceed 3 times the specified permissible value F_p.

a) Controlled pressure systems

The relative leakage rate F_{rel} shall be checked by measuring the pressure drop ΔP over a period t sufficient to determine it. A correction should be made to take into account the variation of ambient air temperature. During this period the refilling device shall be inoperative.

$$F_{rel} = \frac{\Delta P}{P_r} \cdot \frac{24}{t} \times 100 \text{ (\% per day)}$$

$$N = \frac{\Delta P}{P_r - P_m} \cdot \frac{24}{t}$$

t = test time (hours).

Note. — In order to maintain the linearity of the formula, ΔP should be of the same order of magnitude as $P_r - P_m$.

Alternatively, the number of refilling operations per day may be measured directly.

b) Closed pressure systems

Any method (examples are given in Figure EE2, page 289) may be used to measure the leakage rate F, which is used in combination with the tightness coordination chart to calculate:

- the relative rate F_{rel};
- the time betwen refillings T.

Due to the comparatively small leakage rates of these systems, pressure drop measurements are not applicable.

If the test object is filled with a test gas different to the gas used in service and/or at a test pressure different to the normal operating pressure, corrective factors defined by the manufacturer shall be used for calculations.

Since metering difficulties occur during low and high temperature tests, the procedure used may be:

- to perform the tightness test at ambient temperature before and after the low and high temperature tests to determine if there has been a change;
- to record the pressure (or the density) before and after the low and high temperature tests.

Note. — Leakage rate measurements in practice may have an inaccuracy of ±50%.

EE1.4.1.2 *Routine tests*

Routine tests shall be performed at normal ambient air temperature with the circuit-breaker filled at the pressure (or density) corresponding to the manufacturer's test practice. Sniffing may be used under controlled conditions.

a) Controlled pressure systems

The test procedure corresponds to Item *a*) of Sub-clause EE1.4.1.1.

b) Closed pressure systems

The tests may be performed in accordance with Item *b*) of Sub-clause EE1.4.1.1, at several stages of the manufacturing process on components or sub-assemblies according to the tightness coordination chart TC.

EE1.4.2 *Tests of sealed pressure systems*

EE1.4.2.1 *Type tests*

a) SF_6 circuit-breakers

SF_6 circuit-breakers shall be tested according to Item *b*) of Sub-clause EE1.4.1.1.

b) Vacuum circuit-breakers

Vacuum circuit-breaker tubes shall be tested by the electromagnetic method. A magnetic field is applied between the open contacts of the circuit-breaker tube, to which a step voltage impulse of maximum 100 ms duration is then applied, the internal vacuum being evaluated by the current magnitude.

The following procedure shall be applied:

- The maximum pressure of the vacuum at which the circuit-breaker still maintains its rated characteristics shall be given by the manufacturer.
- The relationship between the vacuum pressure level and the electrical parameters shall be calibrated for each type of circuit-breaker tube. This can be done by applying the electromagnetic method simultaneously with a conventional vacuum measurement before sealing a sample unit. The accuracy of the evaluation shall be established by repeating the tests.

- The vacuum pressure level shall be measured twice without operation of the circuit-breaker tube, with a time interval such that the rate of vacuum variation can be properly assessed.

  This rate shall be such that the vacuum pressure level will not reach the maximum acceptable threshold during the expected operating life. The minimum time interval depends on the size of the vacuum circuit-breaker tube and the sensitivity of the testing method.

Note. — Generally, a time interval of four weeks is considered acceptable.

EE.1.4.2.2 *Routine tests*

a) SF_6 circuit-breakers

Sealed SF_6 circuit-breakers shall be tested according to Item *b*) of Sub-clause EE 1.4.1.2.

b) Vacuum circuit-breakers

Each tube shall be identified by its serial number. It shall be tested by its manufacturer according to Item *b*) of Sub-clause EE 1.4.2.1. The test results shall be documented and, if asked for, certified.

After assembly of the circuit-breaker the vacuum level of tubes shall be tested by a significant routine dielectric test over the open contacts.

The dielectric test is to be carried out after the mechanical routine test. The test voltage shall be given by the manufacturer.

EE2. **Liquid tightness**

EE2.1 *Scope and object*

This clause applies to high-voltage indoor or outdoor circuit-breakers which use liquids as insulating, interrupting or control media with or without permanent pressure. Its purpose is to define characteristics and test procedures relative to liquid tightness.

EE2.2 *Definitions*

EE2.2.1 *Controlled pressure system (for liquid)*

An assembly which is automatically refilled with liquid.

EE2.2.2 *Closed pressure system (for liquid)*

An assembly which is manually refilled only periodically with liquid.

EE2.3 *Specifications for liquid tightness*

EE2.3.1 *Controlled pressure systems*

The tightness of controlled pressure systems is specified by the number of refillings per day N or by the pressure drop ΔP without refilling.

The permissible values are given by the manufacturer.

EE2.3.2 *Closed pressure systems*

The tightness of closed pressure systems for liquids pressurized or not shall be specified by the manufacturer.

EE2.3.3 *Tightness level*

For tightness levels, distinction shall be made between internal and external tightness.

EE2.3.3.1 *Total tightness*

No liquid loss can be detected.

EE2.3.3.2 *Relative tightness*

Slight loss is acceptable under the following conditions:

- the leakage rate shall be less than the permissible leakage rate;
- the leakage rate shall not increase with time or number of operations of the circuit-breaker;
- the liquid leakage shall cause no malfunction of the circuit-breaker, nor cause any injury to operators in the normal course of their duty.

EE2.4 *Tests*

EE2.4.1 *Type tests*

The circuit-breaker shall be as in service conditions with all its accessories and its normal fluid, mounted as close as possible as in service (framework, fixing).

The tightness test shall be performed during the mechanical operation test and the low and high temperature tests (see Sub-clauses 6.101.2 and 6.101.3).

An increased leakage rate at extreme temperatures and/or during operations is acceptable provided that this rate resets to the initial value, after the temperature is returned to normal ambient air temperature, is thermally stable, and/or after the operations are performed. The increased temporary leakage rate shall not impair the safe operation of the circuit-breaker.

The circuit-breaker shall be observed over a period sufficient to determine a possible leak or the pressure drop ΔP. In this case, the calculations given in Item *a*) of Sub-clause EE1.4.1.1 are valid.

Note. – Using different liquids than in service or gas for the test is possible but requires justification by the manufacturer.

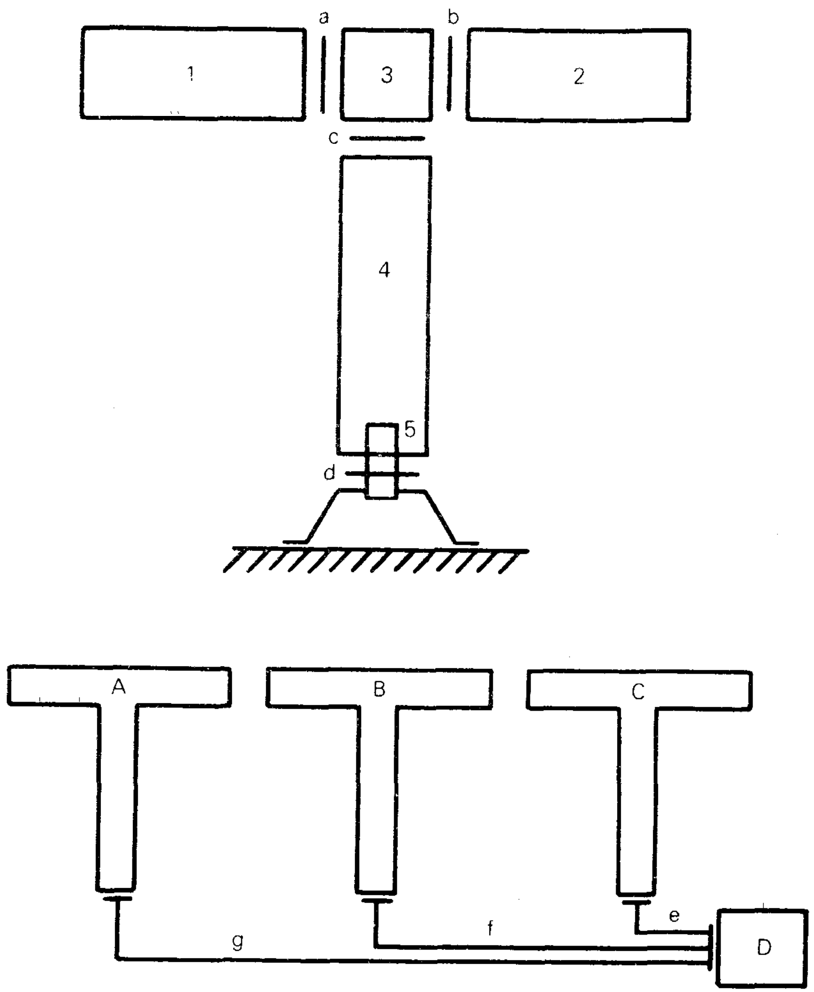
The test report should include such information as:

- a general description of the object under test,
- the number of operations performed and the time elapsed from the initial filling,
- the nature and pressure(s) of the liquid,
- the ambient air temperature during the test,
- the results with the circuit-breaker in closed and in open positions (where applicable).

EE2.4.2 *Routine tests*

Routine tests shall be performed at normal temperature with the complete assembled circuit-breaker. Testing of sub-assemblies is also permissible. In this case, a final check shall be performed at site.

The test methods correspond to those of the type tests (Sub-clause EE2.4.1).



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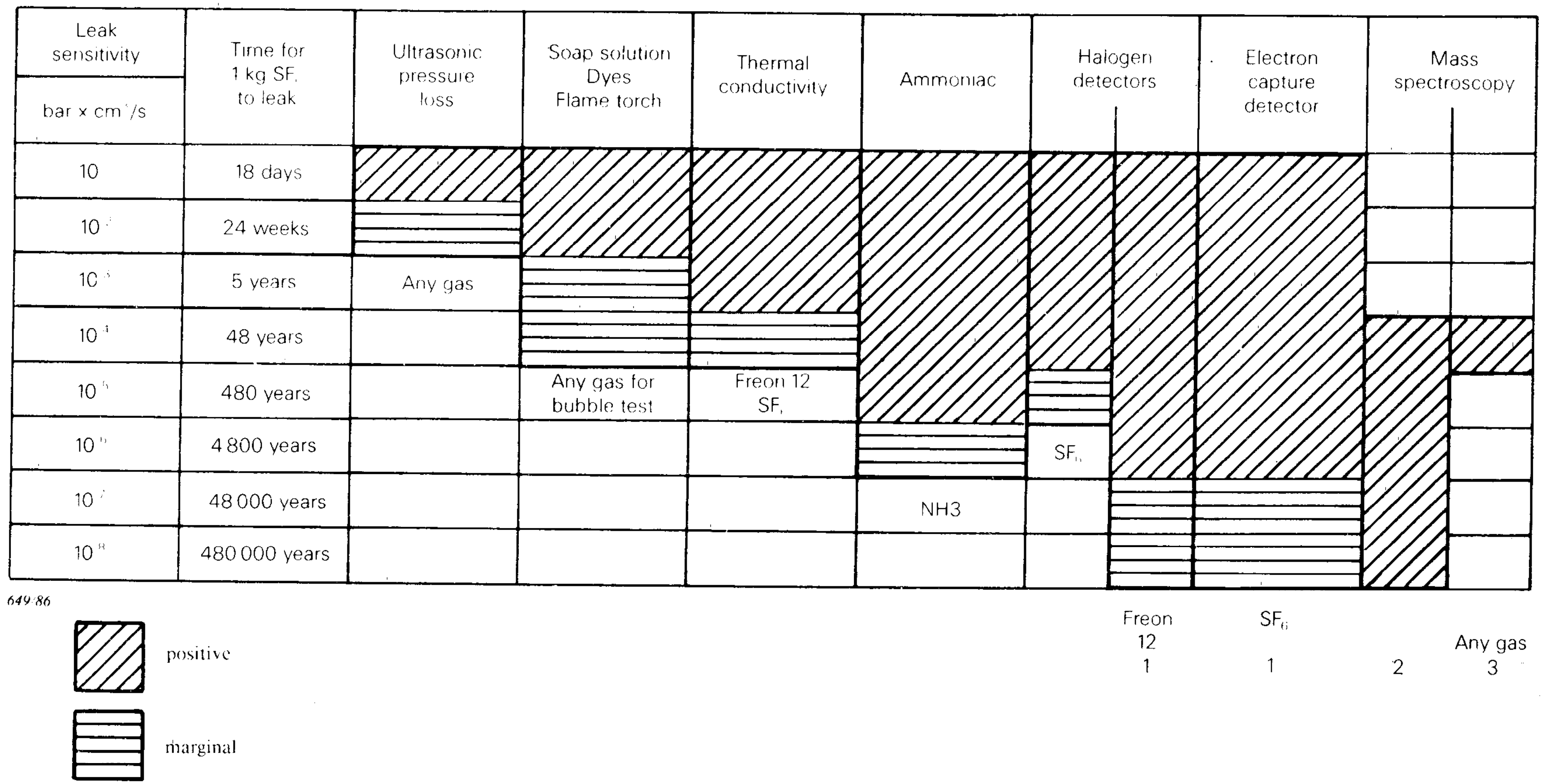
Rated filling pressure P_r: 6 bar (gauge)
Minimum pressure P_m: 5.65 bar (gauge)
Total internal volume: 256 dm^3

Leakage rates per pole		Permissable leakage rate 10^{-6} bar · cm^3/s
Pole subassemblies for tightness tests		
Interrupter unit	(1)	60
Interrupter unit	(2)	60
Gear housing	(3)	20
Porcelain column	(4)	2
Operating rod/drive	(5)	20
Sealings between subassemblies		
O-ring	(a)	2
O-ring	(b)	2
O-ring	(c)	2
O-ring	(d)	2
Leakage rate/pole		170
Leakage rate of complete circuit-breaker		
Pole A		170
Pole B		170
Pole C		170
Control cubicle (including valves, gauges, monitoring devices)	D	60
Piping	(e)	2
Piping	(f)	2
Piping	(g)	2
Complete circuit-breaker		576

$$F_{rel} = \frac{576.10^{-6} \cdot 60 \cdot 60 \cdot 24 \cdot 365}{(6+1) \cdot 256 \cdot 10^3} \cdot 100 = 1.0\% \text{ per year}$$

$$T = \frac{(6-5.65) \cdot 256 \cdot 10^3}{576 \cdot 10^{-6} \cdot 60 \cdot 60 \cdot 24 \cdot 365} = 5 \text{ years}$$

FIG. EE1. — Example for a tightness coordination chart TC.
Three-pole circuit-breaker (SF_6 single pressure).



Notes 1. — Sniffing in good conditions. By integrated leakage measurement, better sensitivity can be achieved.

2. — In integrated leakage measurement.

3. — By sniffing.

FIG. EE2. — Comparison of leak detection methods.

APPENDIX FF

METHOD OF DRAWING THE ENVELOPE OF THE PROSPECTIVE TRANSIENT RECOVERY VOLTAGE OF A CIRCUIT AND DETERMINING THE REPRESENTATIVE PARAMETERS

FF1. Introduction

A transient recovery voltage wave may assume different forms, both oscillatory and non-oscillatory.

The wave may be defined by means of an envelope made up of three consecutive line segments; when the wave approaches that of a damped oscillation at one single frequency, the enveloppe resolves itself into two consecutive line segments. In all cases, the envelope should reflect as closely as possible the actual shape of the transient recovery voltage. The method described here enables this aim to be achieved in the majority of practical cases with sufficient approximation.

Note. — Nevertheless, some cases may arise where the proposed construction would lead to parameters quite obviously more severe than would be justified by the transient recovery voltage curve. Such cases should be dealt with as exceptions and should therefore form the subject of an agreement between the manufacturer and user or the test laboratory.

FF2. Drawing the envelope

The following method is used for constructing the line segments forming the envelope of the prospective transient recovery voltage curve:

FF2.1 *The first line segment* passes through the origin O, is tangential to the curve and does not cut the curve (see Figures FF1 to FF3, segment OB, pages 294 and 295, and Figure FF4, segment OA, page 295).

In the case of curves whose initial portion is concave towards the left, the point of contact is often in the vicinity of the first peak (see figures FF1 and FF2, segment OB).

If the concavity is towards the right, as in the case of an exponential, the point of contact is near the origin (see Figure FF3, segment OB).

FF2.2 *The second line segment* is a horizontal line tangential to the curve at its highest peak (see Figures FF1 to FF4 segment AC).

FF2.3 *The third line segment* is tangential to the curve at one or more points situated between the first two points of contact, and does not cut the curve.

There are three possible cases of drawing this latter line segment:

FF2.3.1 One single line segment can be drawn touching the curve at two points (or possibly at more than two points).

In this case, it forms part of the envelope (see Figure FF1, segment BA).

The four-parameter envelope O, B, A, C, is then obtained.

FF2.3.2 Several segments can be drawn which touch the curve at two points (or possibly at more than two points) without cutting it:

In this case, the segment to be used for the envelope is that which touches the curve at one point only, situated so that the areas on either side of this point between the curve and the envelope are approximately equal (see Figure FF2, segment BA).

The four-parameter envelope O, B, A, C is then obtained.

FF2.3.3 No segment can be drawn touching the curve at more than one point without cutting it:

In this case, the following distinction should be made:

a) The point of contact of the first line segment and the highest peak are comparatively far apart from each other. This is typically the case for an exponential curve or a curve approximating to an exponential.

In this case, the line segment shall be tangential to the curve at a point such that the areas on either side of this point between the curve and the envelope are approximately equal, as in case FF2.3.2 (see Figure FF3, segment BA).

The four-parameter envelope O, B, A, C is then obtained.

b) The point of contact of the first line segment and the highest peak are comparatively close to each other. This is the case for a curve representing a damped oscillation of single frequency or a curve of similar shape.

In this case a third line segment is not drawn, and representation by two parameters, corresponding to the first two line segments, is adopted (see Figure FF4).

The two-parameter envelope O, A, C is then obtained.

FF3. **Determination of parameters**

The representative parameters are, by definition, the co-ordinates of the points of intersection of the line segments constituting the envelope.

When the envelope is composed of three line segments, the four parameters u_1, t_1, u_c and t_2 shown in Figures FF1, FF2 and FF3 can be obtained as co-ordinates of the points of intersection B and A.

When the envelope is composed of two line segments only, the two parameters u_c and t_3, shown in Figure FF4 can be obtained as co-ordinates of the point of intersection A.

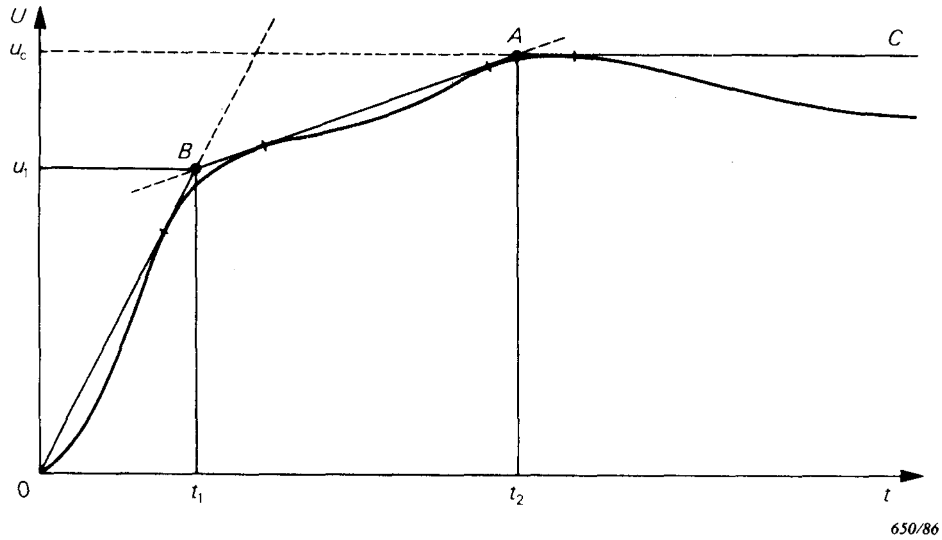


FIG. FF1. — Representation by *four parameters* of a prospective transient recovery voltage of a circuit. Case of Sub-clause FF2.3.1 of Appendix FF.

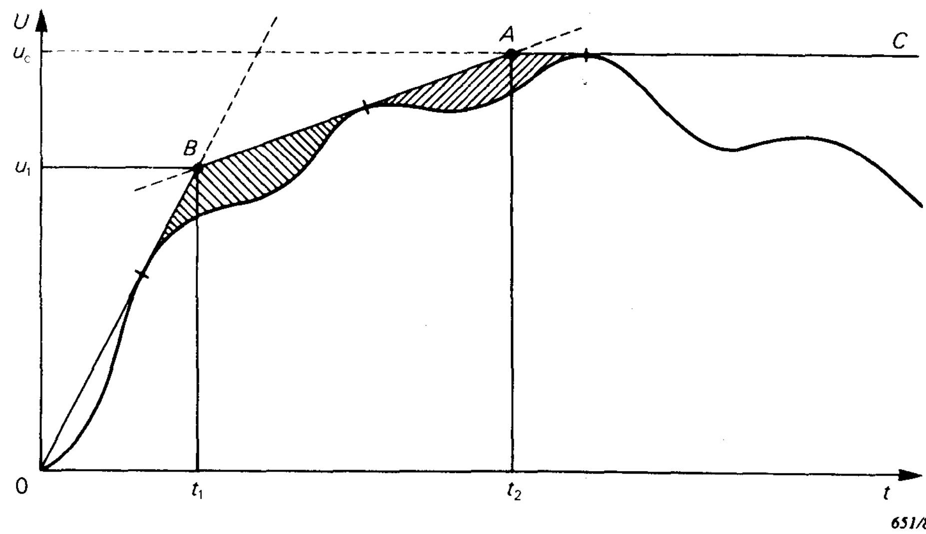


FIG. FF2. — Representation by *four parameters* of a prospective transient recovery voltage of a circuit. Case of Sub-clause FF2.3.2 of Appendix FF.

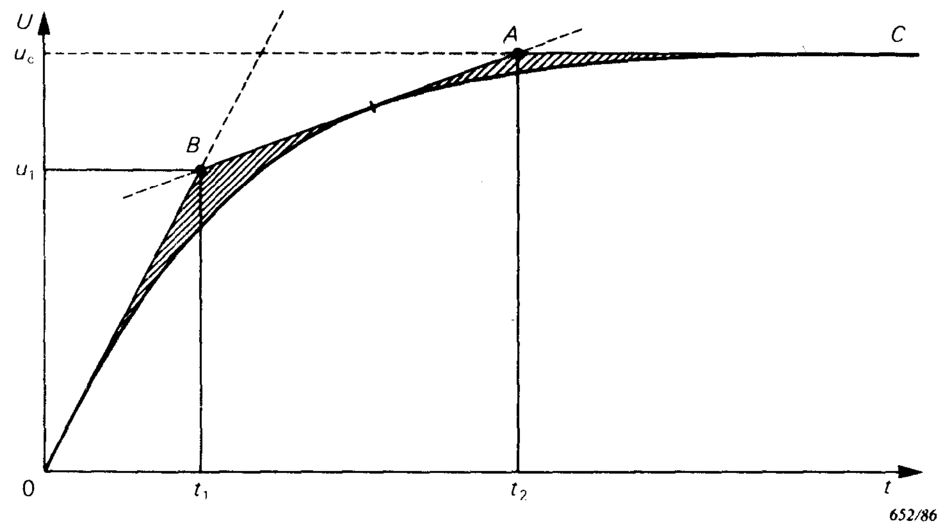


FIG. FF3. — Representation by *four parameters* of a prospective transient recovery voltage of a circuit. Case of Sub-clause FF2.3.3 *a)* of Appendix FF.

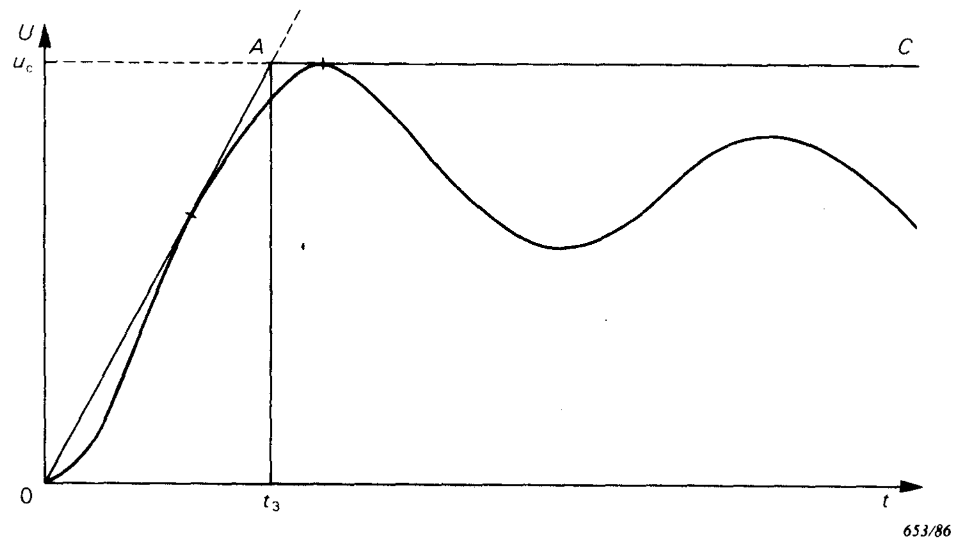


FIG. FF4. — Representation by *two parameters* of a prospective transient recovery voltage of a circuit. Case of Sub-clause 2.3.3 *b)* of Appendix FF.

APPENDIX GG

METHODS OF DETERMINING PROSPECTIVE TRANSIENT RECOVERY VOLTAGE WAVES

GG1. Introduction

The waveforms of the transient recovery voltage (TRV) resulting from the breaking of short-circuit currents depend on two main factors, namely: those dependent on the circuit characteristics (inductance, capacitance, resistance, surge impedance, etc.), and those arising from the circuit-breaker characteristics (arc voltage, post-arc conductivity, capacitors and switching resistors, etc).

Methods are recommended for determining the waveform of the TRV as produced solely by the circuit characteristics, this being the "prospective TRV"

Since any measuring device will have some effect upon the waveform of the prospective TRV, suitable precautions, and possibly corrections, are necessary.

Methods are available for the evaluation of the prospective TRV of both short-circuit test-plant circuits and power systems, and the recommended methods are enumerated and briefly described, taking into account the TRV characteristics which are now specified for rating and testing.

Experience on testing-plants and also on systems has shown that following the breaking of a short-circuit current, not only is a single or multi frequency oscillation superimposed on the power-frequency voltage wave, but exponential components of substantial size and duration are also present. The latter have time constants which are dependent upon the characteristics of the components of the circuit, for example generators, transformers, lines, etc. These exponential components have the effect of depressing the peak value of the TRV and the rate-of-rise to below those which would have occurred if the oscillatory components alone had been superimposed on the power-frequency voltage. This is shown in Figure GG1, page 314, and any method used for measurement should take this effect into account.

Measurements have shown that the inductance of the various circuit components varies with frequency, owing to the screening effects of eddy currents within the conductors, the earth and the magnetic circuits. Together with other factors tending to reduce instantaneous voltages, this introduces a time constant varying from hundreds of microseconds for some generators down to tens of microseconds for transformers, the exact values depending upon the design of the particular equipment and the frequency of the components of the TRV. In some cases this can result in a depression of the peak value of the TRV by as much as 25%.

It is therefore important that these factors are taken into account when assessing the prospective TRV of either a test-plant or system, and guidance is given in connection with the recommended methods.

Irrespective of the method used, the actual values measured in the test plant for the prospective TRV shall be in accordance with the values specified in this standard.

Where the time t_2 of the crest of the TRV exceeds, say, 1 250 μs, then in addition to the effects described above, the instantaneous power-frequency voltage will, in any case, have decreased by more than 6% at 50 Hz and more than 10% at 60 Hz. Consequently, this further effect shall be taken into consideration when using methods of determining the prospective TRV which involve a power-frequency recovery voltage, or where calculations are made using circuit constants.

The instantaneous value of the power-frequency component immediately following current zero is also dependent upon the short-circuit power factor and upon the percentage d.c. component of the last half cycle of current, and may thus be less than the full crest value. For symmetrical currents and short-circuit power factors of 0.15 or less, the reduction is not more than 1.5%, and so is of little importance on test-plant circuits; it may be of significance at higher power factors which may occur in service.

For the rated TRV for terminal faults (see Sub-clause 4.102), a time delay has been introduced to allow for the influence of local capacitance on the source side of the circuit-breaker. Corresponding time delays have also been specified for the relevant test-circuits (see Sub-clause 6.104.5), and the method used for measuring the TRV should be capable of resolving these time delays.

For some circuit-breakers the rated characteristics for short-line faults are also specified (see Sub-clause 4.105), and during short-line fault tests the corresponding resulting TRV has been specified. Local capacitance between the circuit-breaker and the line will also produce a time-delay in the line side TRV component. During testing, it is desirable to measure and record the line side time delay and the method used should be suitable for evaluating this.

GG2. General summary of the recommended methods

The basic methods for determining the prospective TRV waveforms are classified as follows:

- Group 1 — Direct short-circuit breaking;
- Group 2 — Power-frequency current injection;
- Group 3 — Capacitance current injection;
- Group 4 — Model networks;
- Group 5 — Calculation from circuit parameters;
- Group 6 — No-load switching of test circuits including transformers.

Groups 1 to 6 are suitable for short-circuit test-plants.

Groups 1, 4 and 5 are recommended for power systems.

Groups 2 and 3 can be used for portions of power systems.

When using Groups 1, 2, 3, 4 or 6, the voltage recording circuits should be carefully checked to ensure that the overall calibration is constant over the range of TRV frequencies to be recorded, and that time deflections are linear. The oscillograph and any voltage divider should then be calibrated against a known voltage. Where cathode-ray oscillographs with a sweep time base are used, the deflection/time scale should be accurately known, and preferably this should be linear to avoid replotting for comparative purposes, etc.

GG3. Detailed consideration of the recommended methods

GG3.1 *Group 1 — Direct short-circuit breaking*

This method involves the breaking of an actual short-circuit current, established by means of a solid metallic connection in the system under investigation and recording the resultant TRV by an oscillograph. Ideally, the current broken should be symmetrical, or allowance made for the change in di/dt if there is appreciable asymmetry. With this method, it is essential to allow for the influence of the circuit-breaker. The most important characteristics in this respect are: arc-voltage and post-arc conductivity.

Due to the voltage of the arc, the voltage across the circuit-breaker contacts may not be zero at the instant of current interruption, and hence the TRV does not rise from zero voltage but from the value of the arc-voltage at current zero. The TRV thus begins below the voltage zero axis and then crosses the latter (see Figure GG3, page 315).

As a result, the peak voltage is higher than in the case of an ideal circuit-breaker (zero arc voltage) (see Figure GG2, page 314). A similar but more pronounced effect results from interruption at a markedly premature current zero (current chopping) which may occur if the current is small (see Figure GG4, page 315). Furthermore, if the prospective TRV comprises several oscillatory components, current chopping may produce a waveform which is markedly different from that which would be obtained with an "ideal" circuit-breaker.

Thus a circuit-breaker with a low arc-voltage immediately before current zero and which does not exhibit current chopping is the most suitable for use with direct short-circuit breaking.

The influence of the arc-voltage may be compensated for as shown in Figure GG6, page 316, provided that the peak value of the arc-voltage is not more than 10% of the peak value of the TRV.

In principle, compensation for the arc-voltage is only suitable for TRV having a single-frequency transient component; nevertheless it may also be used as a good approximation for multi-frequency transients if the amplitude of the main oscillatory component is predominant.

The post-arc current, i.e., the current flowing through the arc-gap during the rise of the TRV, can influence the waveform of the latter by damping, thus reducing its rate-of-rise and peak value (see Figure GG5, page 315). A similar effect results from the use of resistors in parallel with the interrupting chambers of the circuit-breaker.

It follows, therefore, that in addition to the requirements relating to low arc voltage and absence of current chopping, any circuit-breaker used for the direct short-circuit breaking method should not be fitted with shunt resistors and should not exhibit significant post-arc conductivity.

Particularly where the test plant can be operated at a suitably reduced excitation, vacuum interrupters can often be used as nearly "ideal" circuit-breakers. However, it should be ascertained that any device used does not exhibit significant current chopping in the particular circuit under investigation.

The characteristics of circuit-breakers used for direct short-circuit breaking can sometimes be appropriately improved, for example by timing the instant of contact separation to produce a short arc duration and low arc voltage.

With this method, an actual short-circuit current is broken in the circuit under investigation and the recorded TRV will take into account, more or less, the effects contributing to depression of the recovery voltage. For this reason the direct short-circuit breaking method can be—depending upon the characteristics of the circuit-breaker—the most suitable means of obtaining an assessment of the prospective TRV, and is frequently used as the basis for checking other methods. However, the direct short-circuit breaking method is less suited for measuring time delays, particularly the time delay of the line-side TRV, in the case of short-line fault.

GG3.2 *Group 2 — Power-frequency current injection*

In general, this method is only used with the circuit de-energized, although schemes for making measurements whilst the circuit is live are being developed. This method is therefore mainly of use in test-plants, or where part of a system can be analysed whilst de-energized. It therefore does not take into account corona or magnetic saturation phenomena.

The basis of this method is the injection of a relatively small current into the circuit and the recording of the response of the circuit when the current is switched off by an ideal switching device, i.e. a device having negligible arc voltage and post-arc current.

A suitable source of injected current is a single-phase transformer operated from the local low-voltage mains, the secondary giving for example a range of currents and voltages between 2 A at 200 V and 300 A at 25 V. This range will cover the impedances of the majority of the circuits which have to be assessed. A schematic diagram as an example of the application of this method is shown in Figure GG7, page 317, together with details of the components. Figure GG8, page 318, shows the sequence of operation of the scheme.

Care should be taken to ensure that the inherent capacitances of the supply and measuring devices do not influence the results.

The voltage response should be measured at the input terminals of the circuit and when applicable, one terminal of the circuit should be earthed. In those cases where the circuit is not earthed at one of its terminals, it is essential that the measuring and injection equipment are completely isolated from earth. This can be achieved by using an auxiliary generator insulated from earth and having negligible capacitance to earth.

The most convenient switching device for this scheme is a semiconductor diode. In general, semiconductor diodes with reverse recovering times not exceeding 100 ns have been found to be suitable. Longer times are acceptable where the TRV has a low equivalent natural frequency. To obtain the correct current-carrying capacity, several diodes may be operated in parallel.

Note. — The characteristics of diodes are dependent on a number of factors, for example the value of the current in the forward direction, the waveform and value of the reverse voltage, and the manufacturer's data which are dependent on the methods employed to determine the characteristics.

To achieve a symmetrical current wave, it may be necessary for the current to flow for a time of up to 20 cycles. During most of this time, the diodes will be by-passed by a switch which is opened at the end of this time thus allowing the current to pass through the diodes which will interrupt the current at the following current-zero.

The current injected and the voltage across the circuit under investigation should be recorded using a time base of suitable velocity, and in addition high-speed records of current and voltage at the current-zero should be taken. The TRV should be recorded by an oscillograph of suitable sensitivity giving not less than 30 mm deflection for the peak voltage, and with a time scale not less than 30 mm from zero to the peak of the TRV.

To assess the time delay accurately, it will be necessary to amplify the voltage and time scales for the initial part of the wave.

The lower speed record of the current will show whether the current was symmetrical when broken, and the high speed record will give the rate-of-change, di/dt, immediately before current-zero. It will also show whether or not there was any appreciable post-zero current to cause damping of the TRV, or appreciable suppression of the current likely to affect the TRV amplitude.

The TRV record will represent the natural transient oscillation of the circuit under investigation, and will take into account most of the factors causing voltage depression.

The values can be determined using a voltage calibration in terms of the full power of the circuit. Detailed explanations are given in Sub-clause GG 3.4.

GG3.3 *Group 3 — Capacitance current injection*

This method is similar to Group 2 except that the current through the circuit being considered is obtained from the discharge of a capacitor. Thus, the frequency of the injected current will depend upon the values of the capacitor and the inductance of the circuit.

As the frequency of the discharge current should be 1/8th of the equivalent natural frequency of the circuit, this means that the method is suitable for measuring the TRV of circuits containing components with high natural frequencies. It is particularly useful for measuring the characteristics of the components on the line side of short-line fault test circuits, the natural frequencies of which are very high, with correspondingly small time delays.

The schematic diagram of an example of a capacitance current injection circuit is shown in Figure GG9, page 319, together with details of the components. Figure GG10, page 320, shows the sequence of operation of the schema.

The same precautions and method of calibration are used as for Group 2, and these are detailed in Sub-clause GG3.4.

GG3.4 *Groups 2 and 3 — Methods of calibration*

From the measured value of the rate-of-change, di/dt, of the injected current immediately before zero, calculate the equivalent r.m.s. value of the injected current I_i.

$$I_i = \frac{\dfrac{di_i}{dt}}{2\pi f_i \sqrt{2}}$$

where f_i is the frequency of the injected current.

In this calculation, it is assumed that:

$$i_i = I_i \sqrt{2} \sin 2\pi f_i t \simeq I_i \sqrt{2} \cdot \pi f_i t$$

This is approximately valid when $t_2 < 1\,250$ µs (or when $t_2 < 1\,000$ µs on a 60 Hz basis).

On the basis of the above approximations, the following rule may be derived:

The frequency of the injected current should be $\leqslant$ 1/8th of the equivalent natural frequency of the circuit being measured. For cases where the coordinate t_2 of the prospective TRV is greater than 1 250 µs (1 000 µs for 60 Hz), the frequency of the injected current should equal the rated power frequency.

If the r.m.s. value of the maximum short-circuit current of the circuit is I_{sc} A, then the voltage calibration V_{sc}/mm for the TRV corresponding to I_{sc} will be:

$$V_{sc}/\text{mm} = V_i/\text{mm} \cdot \frac{I_{sc}}{I_i} \cdot \frac{f_{sc}}{f_i}$$

where f_{sc} is the frequency of the short-circuit current.

Subject to the provisions given above, concerning prospective TRV with long times t_2, for those cases where the deviation of the curve of the current from the sinusoidal, symmetrical form is too significant to be neglected, the following basic formula should be used:

$$V_{sc}/\text{mm} = V_i/\text{mm} \frac{\dfrac{di_{sc}}{dt} \quad i_{sc} \rightarrow 0}{\dfrac{di_i}{dt} \quad i_i \rightarrow 0}$$

where $(di_{sc}/dt)\ i_{sc} \rightarrow 0$ is the rate-of-change of the power frequency short-circuit current at current zero, with the current function:

$$i_{sc} = I_{sc} \sqrt{2} \sin 2 \pi f_{sc} \cdot t \simeq I_{sc} \sqrt{2} \cdot 2 \pi f_{sc} t$$

This formula will apply particularly to the method of capacitance current injection where the current will be of a slightly damped oscillatory form.

To determine the calibration for short-line fault tests, the following method is suitable:

From the high-speed recording measure:

du_i/dt = RRRV of the TRV at zero of the injected current

u_i = first voltage peak of the injected current

di_i/dt = rate-of-change of the injected current at its zero

The value of the surge impedance Z is then obtained by calculation:

$$Z = \frac{du_i/dt}{di_i/dt}$$

GG3.5 *Group 4 — Model networks*

In this method, a model network is assembled from units which shall be true representations of the components of the full-scale circuit. It is usually necessary to imitate the components of the full-scale circuit which have distributed parameters by model units having lumped parameters. In addition, it is essential that the impedance (especially reactance and resistance) characteristics of the model units shall be, as near as possible, a true imitation of those characteristics of the full-scale components at frequencies up to at least that corresponding to the TRV under consideration.

The accuracy of this method depends upon having exact data for the parameters of the circuit to be imitated, and these are frequently difficult to obtain and to simulate on a small model component.

This applies particularly to parameters which vary with frequency, so that this method in general does not directly take into account the depression of the TRV, and tends to give values which are somewhat higher than those obtained with direct short-circuits on a full-scale system.

The method is mainly useful for investigating power systems since it does not require the system to be taken out of service, and will give useful guidance provided that its limitations are recognized.

GG3.6 *Group 5 — Calculation from circuit parameters*

When the data concerning the parameters of the components of the circuit are known, as for Group 4, it is often convenient to calculate the waveform of the TRV, particularly if the circuit is not too complex.

In general, the method does not take into account depression effects, although some allowance can be made for these if the relevant data for the circuit are available; similarly the decrement of the power-frequency component, for those TRV where the time t_2 exceeds 1 250 μs, can be taken into account.

The method is subject to the limitations of Group 4, plus the errors inherent in calculations unless experience has been gained in checking results with actual TRV obtained from tests using the techniques of Groups 1, 2, 3, or 6.

GG3.7 *Group 6 — No-load switching of test circuits including transformers*

This method consists of connecting the test transformer on the open circuit and recording, by oscillograms, the behaviour of the transient voltage at the open gap of the secondary circuit.

The method is very useful in those test stations where the short-circuit current is obtained by generators. However the circuit-breaker used for the switching shall have no shunt resistance, be free of any appreciable pre-striking and be located in close proximity to the circuit-breaker under test. Furthermore, this method has a limited application to those circuits producing single frequency TRV and does not reproduce the exponential component which is related to eddy currents.

GG4. **Comparison of the methods**

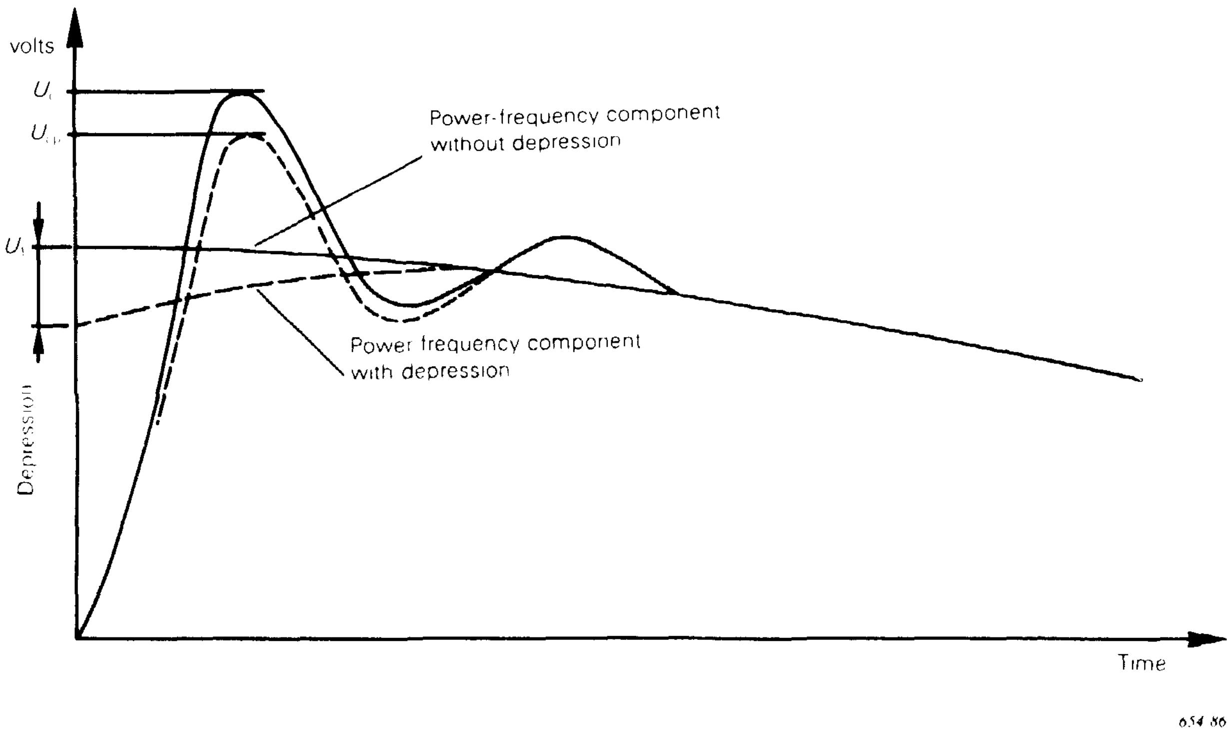
The various methods are listed in Table GGI, with their characteristics, advantages and disadvantages.

TABLE GGI

Methods for determination of prospective TRV

Method	Theoretical limitations	Practical limitations
1.1 Full scale tests with an ideal circuit-breaker	None. All phenomena are correctly represented	Non-existence of an ideal circuit-breaker to cover the full range of requirements
1.2 Power-frequency tests at full voltage with a limited current disturbance. (Either an ideal circuit-breaker test or a "close" test is feasible)	Does not account for non-linearities which may exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	Non-existence of an ideal circuit-breaker to cover the full range of requirements. Extraction of the TRV requires sophisticated measurement techniques: otherwise it is difficult to interpret results in the presence of a large power-frequency voltage component. For making tests, the most suitable current limiting device is a perfect inductance; otherwise an element of the test circuit may be used where it is available (e.g. resistor or capacitor). Elements used are likely to be bulky and expensive
1.3 Power-frequency tests at reduced voltage with an ideal circuit-breaker on an otherwise unmodified test circuit (i.e. low excitation tests)	Does not account for non-linearities which may exist in the test circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	Whilst ideal circuit-breakers to cover the whole range are not yet available, the selection of the ideal circuit-breaker to be used is limited. With circuits employing more than one generator, synchronization can be difficult to achieve. Excitation should be sufficiently high to avoid waveform distortion. Generally not possible in a network station
1.4 Full scale tests with a conventional circuit-breaker	Difficulty of separating the circuit-breaker effects from the TRV characteristics recorded during test	Choice of suitable circuit-breakers having a low arc-voltage producing negligible current distortion at current zero, negligible post-arc current and no shunt impedances. In cases where the above cannot be made, errors are introduced and there is the possibility of lack of uniformity between testing stations due to the use of circuit-breakers having different characteristics
2. Ideal circuit-breaker tests on a "dead" circuit with power frequency current injection	Does not account for non-linearities which may exist in the circuit, i.e. the absence of a linear relationship between current and voltage at a particular frequency (not to be confused with the effects of time-dependent circuit elements)	In a network-fed testing station, only applicable on "dead" circuit elements, for example short-line fault components, or where the impedance of the network is negligible compared with the remainder of the circuit impedance. Generators shall be at rest to avoid remanent voltages. Position of rotor may be important if there is a considerable difference between direct and quadrature reactances.

Method	Theoretical limitations	Practical limitations
		The reverse recovery time of switching diodes as used instead of an ideal circuit-breaker, capable of carrying the necessary injected power-frequency current, may affect the TRV where this contains high frequency components, for example in short-line fault test circuits. Interference from external sources induced in the "dead" circuit may affect the TRV where the measuring voltage is relatively small due to very low circuit reactance, for example as associated with short-line faults
3. Ideal circuit-breaker tests on a "dead" circuit with current injection at a frequency above power frequency	Does not account for non-linearities which may exist in the circuit. Does not give power frequency impedance directly. Gives correct waveform and values for the TRV of single and multi-frequency circuits from zero to the first maximum only, provided that the injection frequency is above power frequency and well below the frequency of the TRV. It is not possible to evaluate amplitude factor correctly	In a network-fed testing station, only applicable on "dead" circuit elements, e.g. short-line fault components, or where the impedance of the network is negligible compared with the remainder of the test circuit impedance. Generators shall be at rest to avoid remanent voltages. Position of rotor may be important if there is a considerable difference between phase and quadrature reactances
4. Model network tests (transient network analysers)	Precise information of non-linear and frequency-dependent characteristics of the network is not always available. Exact knowledge of circuit components and their stray parameters is necessary	Adequate representation of circuit components in the transient network analyser elements, including their non-linear and time-dependent characteristics, is necessary
5. Calculation from circuit parameters	Precise information on non-linear and frequency-dependent characteristics of the network is not always available. Exact knowledge of circuit components and their stray parameters is necessary	Where the network impedance is not negligible compared with the test station impedance, complete knowledge of the relevant momentary network conditions is necessary. Accurate or adequate representation of the circuit components, including their non-linear and time-line-dependent characteristics and particularly the stray parameters
6. No-load switching of testing transformers	Corrections necessary for power frequency voltage wavefront unless the transformers are energized at or near the peak of the voltage wave	Requires actual short-circuit test circuits. Applicable only for single-frequency circuits



U_c = peak value of specified TRV

U_{cp} = TRV measured with depression

U_1 = peak value of power frequency voltage without depression

FIG. GG1. — Effect of depression on the peak value of the TRV.

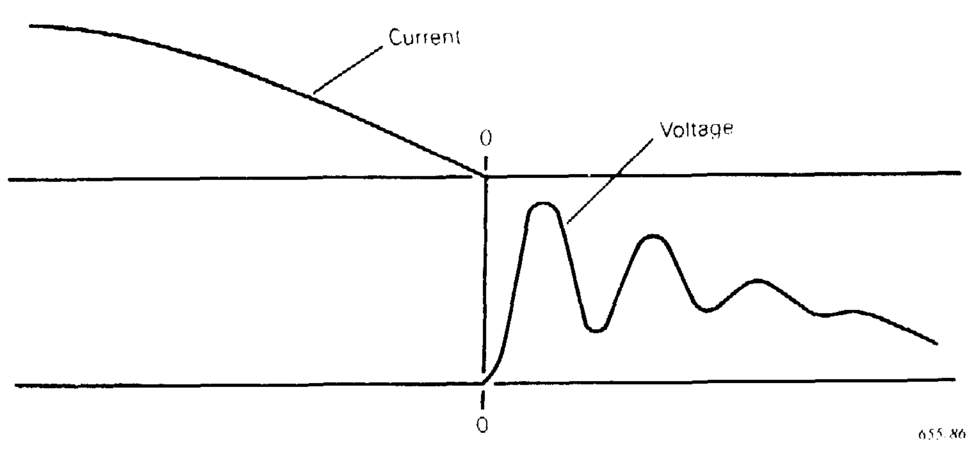


FIG. GG2. — TRV in case of ideal breaking.

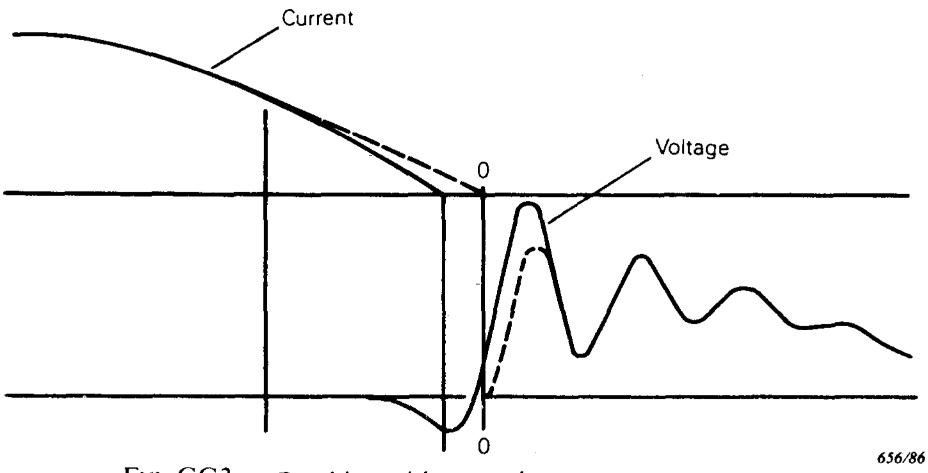


FIG. GG3. — Breaking with arc-voltage present.

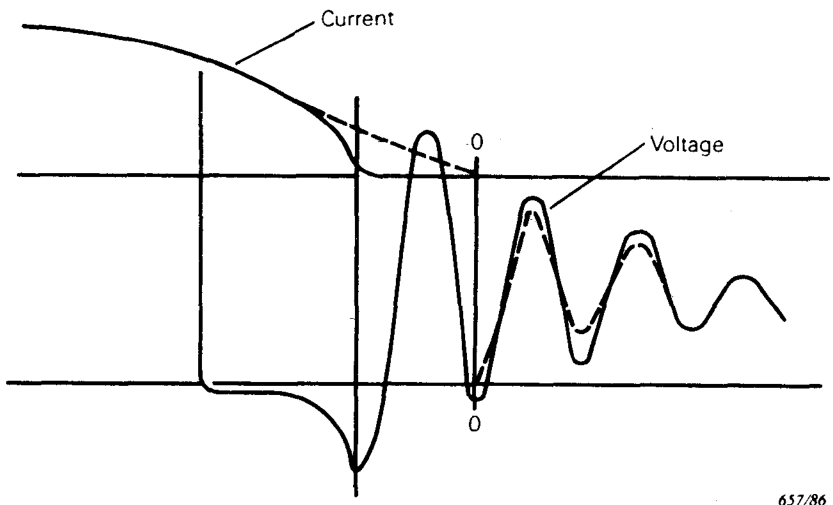


FIG. GG4. — Breaking with pronounced premature current-zero.

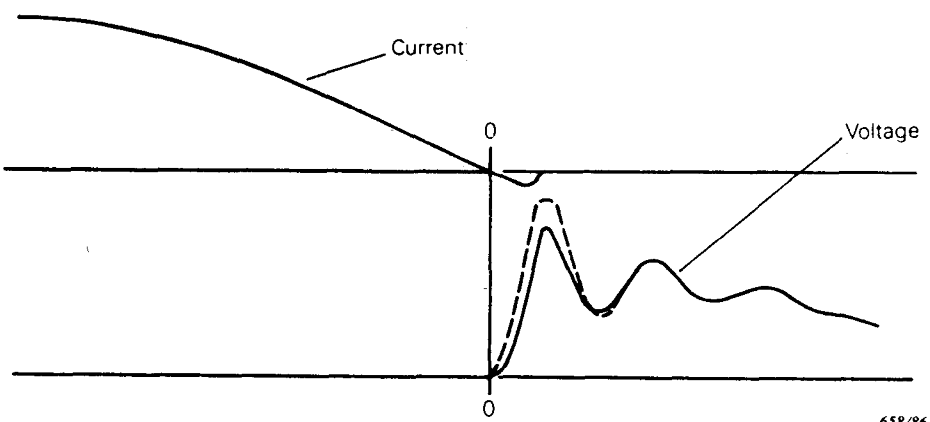
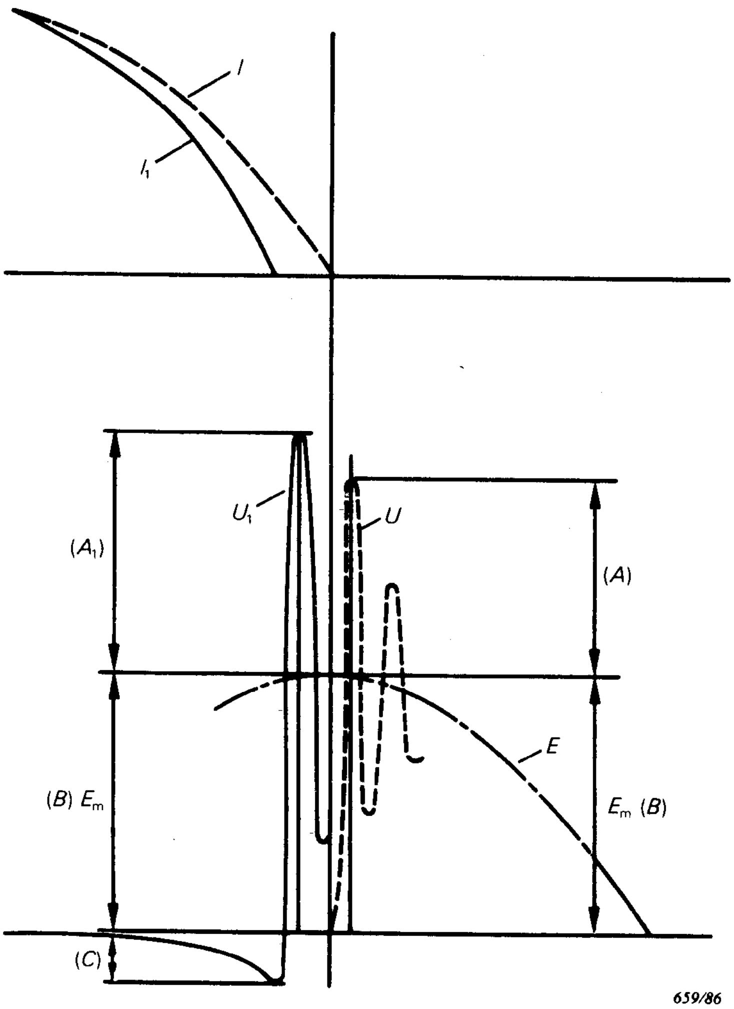


FIG. GG5. — Breaking with post-arc current.

Influence of the arc, of premature current-zero and of post-arc conductivity on the transient recovery voltage.
The chain-dotted lines in figures GG3 to GG5 represent the behaviour following ideal breaking.



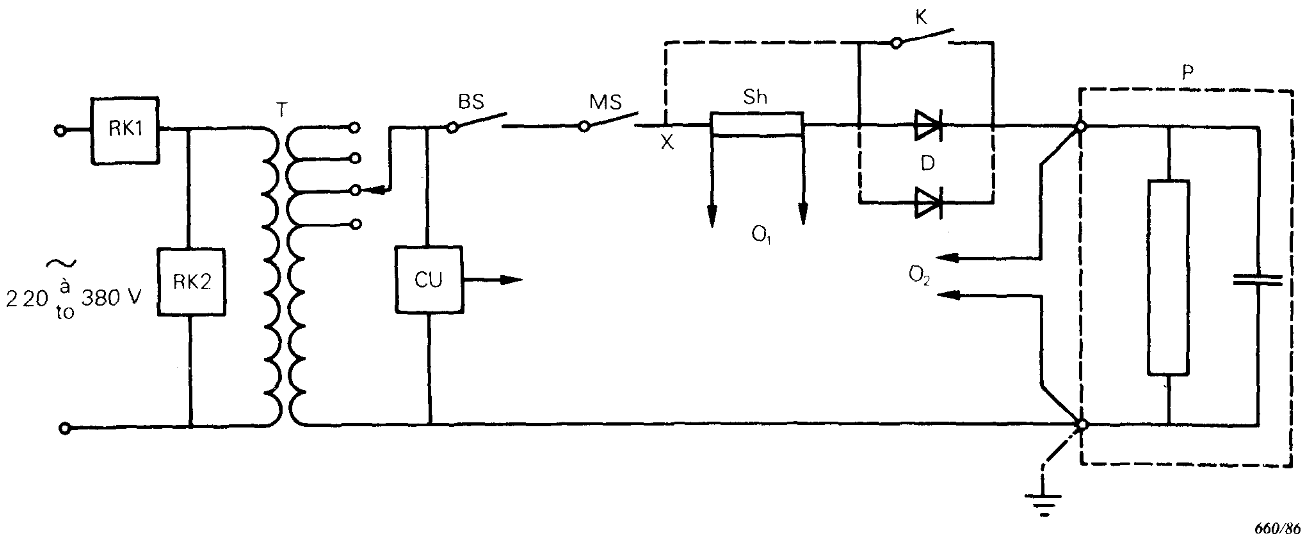
I_1, U_1 = current and voltage arising in test, respectively

I, U = prospective current and voltage, respectively, of system

E = power frequency recovery voltage

$A + B = A_1 \dfrac{B}{B + C} + B$ = peak value of transient recovery voltage

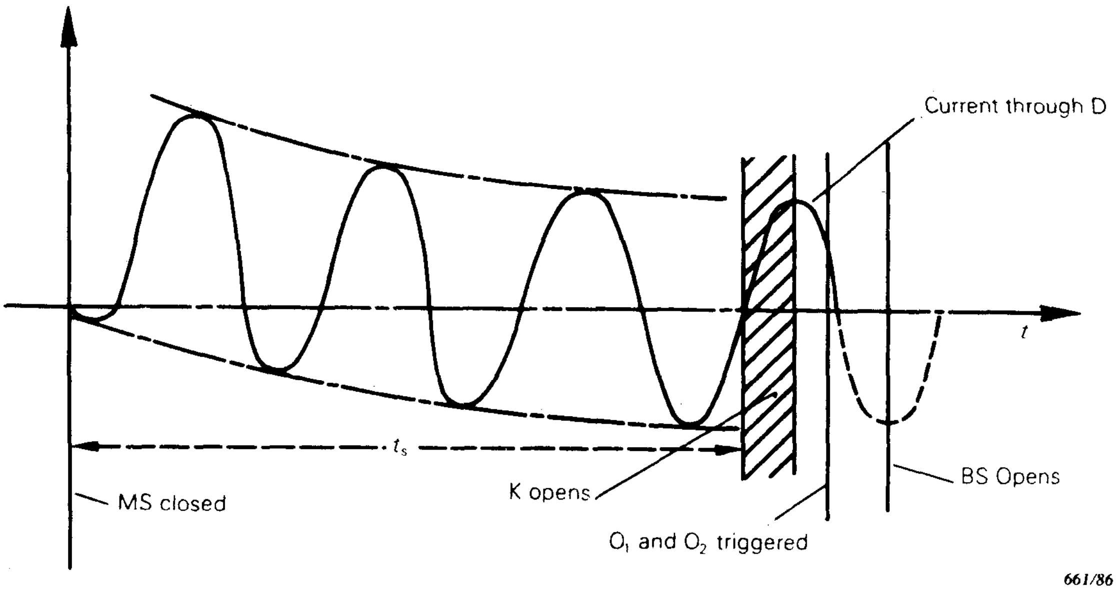
FIG. GG6. — Relationship between the values of current and TRV occurring in test and those prospective to the system.



RK1, RK2	=	where required, series and parallel resonant circuits for harmonic suppression purposes
T	=	transformer to isolate injection circuit from supply and to provide an adjustable output voltage
BS	=	back-up switch
MS	=	making switch
K	=	diode by-pass switch
X	=	alternative connection for K to permit use of a shunt having relatively low time-current rating
D	=	parallel connection of up to five fast silicon switching diodes
Sh	=	current measuring shunt
O_1	=	cathode-ray oscillograph, trace 1 recording magnitude and linearity of current for checking the diode operation
O_2	=	cathode-ray oscillograph, trace 2 recording the response of the circuit
P	=	circuit the prospective TRV of which is to be measured
CU	=	control unit to provide the sequence of operation given in Figure GG8

Note. — The measurement of the injected current may equally be made at earth potential.

FIG. GG7. — Schematic diagram of power-frequency current injection apparatus.



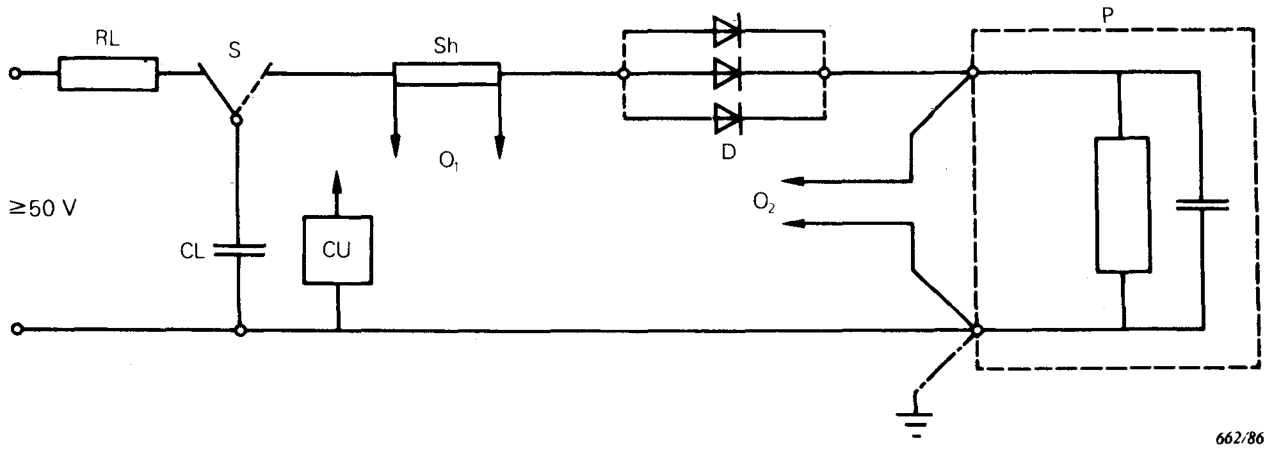
Quiescent state: BS and K closed, MS open.

t_s = duration of current flow prior to operation of switch K

Typical values lie between 10 and 20 cycles of injected current.

The main criterion is that the d.c. component of current, if any, shall have decayed to a value less than 20% of the a.c. component.

FIG. GG8. — Sequence of operation of power-frequency current injection apparatus.



RL = charging resistor

S = switching relay

CL = source capacitance

Note. — When the charged capacitance CL is connected to the circuit P via relay S an oscillatory current, of frequency f_1, flows. The value of CL should be adjusted so that:

a) $f_1 < \frac{f_c}{8}$ where f_c is the natural frequency of circuit P, $f_c = \frac{1}{2\ T_c/2}$

b) f_1 shall be such that the superimposed current oscillations will have disappeared before the instant of current zero.

Sh = current measuring shunt

O_1 = cathode-ray oscillograph, trace 1 recording magnitude and linearity of the current and checking the diode operation

O_2 = cathode-ray oscillograph, trace 2 recording the response of the circuit

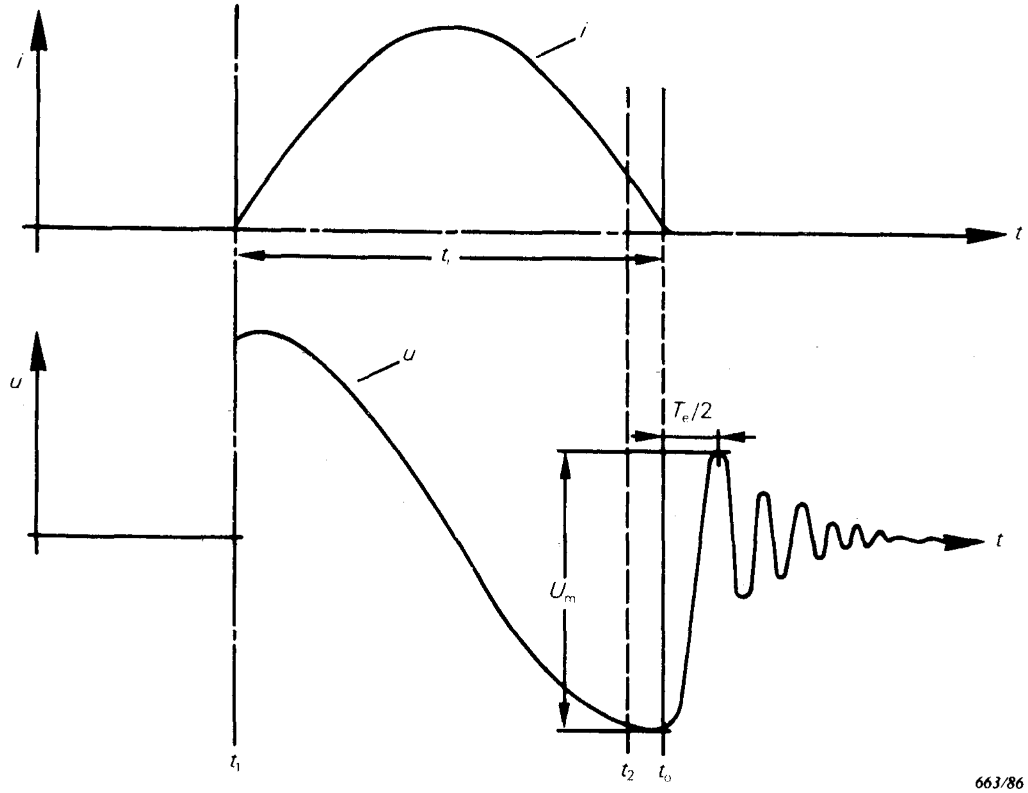
D = parallel connection of up to 100 fast silicon switching diodes

P = circuit the prospective TRV of which is to be measured

CU = control unit to provide the sequence of operation given in Figure GG10

Note. — The measurement of the injected current may equally be made at earth potential.

FIG. GG9. — Schematic diagram of capacitance injection apparatus.



t_1 = switching of S

t_2 = tripping of the cathode-ray oscillograph

u = voltage curve across the terminals of the circuit P

i = waveform of the injected current

U_m = maximum voltage stressing of the diodes

t_0 = time where current passes through zero (beginning of the TRV oscillation)

t_i = duration of current through diode D, $f_i = \frac{1}{2\,t_i}$

$\frac{T_e}{2}$ = duration of half-cycle of TRV

FIG. GG10. — Sequence of operation of capacitance-injection apparatus.

APPENDIX HH

EXAMPLE OF A COMMISSIONING TEST PROGRAMME

HH1. Checks after erection

HH1.1 *General checks*

- Assembly check as per manufacturer's drawings and instructions.
- Tightness check of circuit-breaker and its control devices.
- All piping, junctions.
- Tightening of terminal block connections.
- Painting and corrosion protection.
- Cleanliness.

HH1.2 *Checks of electrical circuits*

- Conformity to the wiring diagram.
- Signalling (position, alarms, lockouts, etc.).
- Heating and lighting.

HH1.3 *Checks of the insulation and/or extinguishing fluid(s)*

- Oil: type, dielectric strength (IEC Publication 296: Specification for Unused Mineral Insulating Oils for Transformers and Switchgear), level.
- SF_6: quality and humidity content (IEC Publication 376: Specification and Acceptance of New Sulphur Hexafluoride), filling pressure or density, except for sealed apparatus.
- Compressed air: quality (if applicable) and pressure.

HH2. Mechanical tests and measurements

HH2.1 *Measurements of characteristic operating fluid pressures (if applicable)*

HH2.1.1 *General*

The following measurements (list to be adapted as necessary) should be taken, in order to compare them with the values both recorded during routine tests and guaranteed by the manufacturer. These values may serve as a reference during later checks (maintenance) and will enable any drift in operating characteristics to be detected.

The measurements involve a check of the operation of the lockout or alarm devices (pressure-switches, relays, etc.).

HH2.1.2 *Measurements to be taken*

a) On a rise in pressure with the pumping device (pump, compressor, controlled valve, etc.) in service:

- reset of the opening lockout;
- reset of the closing lockout;

- reset of the auto-reclosing lockout (if applicable);
- disappearance of the low pressure alarm;
- cut-off of the pumping device;
- opening of the safety valve (if applicable).

Note. — The measurements may be combined with the measurements of the recharging time of the operating mechanism (see Sub-clause HH2.4.2).

b) On a drop in pressure with the pumping device switched off:

- closing of the safety valve (if applicable);
- starting of the pumping device;
- appearance of the low pressure alarm;
- lockout of the auto-reclosing (if applicable);
- lockout of the closing;
- lockout of the opening.

In the case of a hydraulic control, the pre-inflation pressure of the accumulators should be measured together with the ambient air temperature before the tests are performed.

HH2.2 *Measurement of consumption during operations (if applicable)*

With the pumping device switched off and the individual reservoir at the cut-in pressure of the pumping device, the consumptions during each of the following operations or sequences should be evaluated:

- O three-pole;
- C three-pole;
- O—0.3 s—CO three-pole (if applicable).

The steady-state pressure after each operation or sequence should be noted.

HH2.3 *Verification of the rated operating sequence*

The ability of the circuit-breaker to perform its specified rated operating sequence should be verified. The tests should be performed with the recharging device in service, with site supply voltage and, if applicable, starting with the cut-in pressure of the pumping device, as in Sub-clause HH2.2.

Note. — Site supply voltage is the voltage available at the actual circuit-breaker from the normal site supply.

HH2.4 *Measurement of time quantities*

HH2.4.1 *Characteristic time quantities of the circuit-breaker*

HH2.4.1.1 *Closing and opening times, time spread*

The following measurements should be made at maximum pressure (cutoff of pumping device) and at site supply voltage:

- closing time of each pole, time spread of the poles and when possible time spread of the breaking units or groups of units of each pole;
- opening time of each pole, time spread of the poles and when possible time spread of the breaking units or groups of units of each pole.

In the case of multiple trip coils all should be tested and the times recorded for each.

The instant at which the three-pole control relay, if any, is energized should also be recorded to enable calculation of the total time in three-pole operation (relay time plus closing or opening time).

When the circuit-breaker is provided with resistor closing or opening units, the resistor insertion times should be recorded.

HH2.4.1.2 *Operation of control and auxiliary contacts*

The timing of the operation of one of each kind (make and break) of control and auxiliary contacts should be determined in relation to the operation of the main contacts, on closing and on opening of the circuit-breaker.

HH2.4.2 *Recharging time of the operating mechanism*

HH2.4.2.1 *Fluid operated mechanism*

The operation time of the pumping device (pump, compressor, control valve, etc.) should be measured:

- between minimum and maximum pressure (cut in and cut off of the pumping device);
- during the following operations or sequence, starting each time with minimum pressure (cut in of the pumping device):
  - C three-pole;
  - O three-pole;
  - O−0.3 s−CO three-pole (if applicable).

HH2.4.2.2 *Spring operated mechanism*

The recharging time of the motor after a closing operation should be measured at the site supply voltage.

HH2.5 *Checks of certain specific operations*

HH2.5.1 *Auto-reclosing at the lockout pressure (if applicable)*

With the pumping device out of service, the control pressure should be lowered to the lockout value for auto-reclosing and an auto-reclosing operation be carried out (under site conditions it may be necessary to use a separate timing device to initiate reclosure). The test should be conducted at site supply voltage. The final pressure should be noted and it should be ensured that there is sufficient safety margin to the lockout pressure for opening, as a guard against pressure switch deviation and pressure transients.

In case of doubt, an alternative test to the one described above may be performed, starting with a lower pressure than the lockout pressure for auto-reclosing (short-circuited contact). It should then be verified that an opening operation is still possible.

HH2.5.2 *Closing at the lockout pressure (if applicable)*

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for closing and a closing operation be carried out. The test should be conducted at site supply voltage. The final pressure should be noted and it should be ensured that there is sufficient safety margin to the lockout pressure for opening.

In case of doubt, an alternative test to the one described above may be performed, starting with a lower pressure than the lockout pressure for closing (short-circuited contact). It should then be verified that an opening operation is still possible.

HH2.5.3 *Opening at the lockout pressure (if applicable)*

With the pumping device out of service, the control pressure should be lowered as far as the lockout value for opening and an opening operation be carried out. The test should be conducted at site supply voltage. The final pressure should be noted.

HH2.5.4 *Simulation of fault-making operation and check of anti-pumping device*

Measurement should be taken of the time during which the circuit-breaker remains closed on a CO-cycle with the trip circuit energized by the closing of the auxiliary contact.

The test also allows checking of the anti-pumping device operation and the absence of malfunction due to any mechanical, hydraulic or pneumatic reason, caused by the rapid application of the opening command.

The closing command should be maintained for 1 s to 2 s in order that the anti-pumping device can be checked for effective operation.

Note. — A simplified anti-pumping test may also be executed, using the local control. In this case, a closing command is applied and maintained, while a consecutive opening command is applied.

HH2.5.5 *Behaviour of the circuit-breaker on a closing command while an opening command is already present*

It should be verified that the circuit-breaker meets the technical specifications in the presence of a closing command when previously an opening command is applied and maintained.

HH2.5.6 *Application of an opening command on both releases simultaneously (if applicable)*

It may happen that both releases (normal and emergency) are energized simultaneously (or virtually simultaneously).

It should be ensured that the operations are not subject to any mechanical, hydraulic or pneumatic interference, particularly if the releases do not operate at the same level.

HH2.5.7 *Protection against pole discrepancy (if applicable)*

The protection against pole discrepancy should be checked by either of the following tests:

- with the circuit-breaker open, the closing release of one of the poles shall be energized and a check carried out to see that it closes and then opens;
- with the circuit-breaker closed, the opening release of one of the poles shall be energized and a check carried out to see that the other two poles open.

HH3. **Electrical tests and measurements**

HH3.1 *Dielectric tests*

The dielectric tests on the auxiliary circuits should normally be performed with reduced voltage, applied during 1 s, to avoid disconnection of parts of the circuits.

Normally no dielectric tests are performed on site on the main circuit.

Note. — When dielectric tests are performed on the main circuit, the shape and the level of the test voltage should be subject to agreement between manufacturer and user.

HH3.2 *Measurement of the resistance of the main circuit*

Measurement of the resistance of the main circuit need only be made if interrupting units have been assembled on site. The measurement should be made with direct current, and as far as possible in accordance with Sub-clause 7.3 of IEC Publication 694.

NATIONAL ANNEX

Users of this standard may find the following clarifications, elaborations of use in respect of the requirements in the clauses referred to herein :

Clause 2 — For more details on service conditions applicable to circuit-breakers in the Indian context, *also see* IS 9676:1980 Reference ambient temperature for electrical equipment.

Tables I, II, III, IV, V, VI, VII, VIII, IX, X, XIV, XV, XVI and XVII — For rated voltage values applicable to Indian conditions, reference is invited to IS 12360 : 1988 Voltage bonds for electrical installations including preferred voltages and frequency.

Clause 6.109.3 — For practical reasons, the conditions of the clause should be deemed to have been fulfilled if the time delay did not exceed 0.1 μ s for all rated voltages.

Clauses 6.104.5.2, 6.104.5.3 and 6.109.3 — Alternative standard values of prospective TRV for test duties 3, 4 and 5 through representation by 2-parameters are as given below :

STANDARD VALUES (ALTERNATIVE) OF PROSPECTIVE TRANSIENT RECOVERY VOLTAGE

Test-Duties No. 4 and 5 Rated Voltages 123 kV and Above Representation By 2-Parameters.

Rated Voltage	**First-Pole-To-Clear Factor 1.3**		**First-Pole-To-Clear Factor 1.5**	
U	TRV Peak Value U_c	Time Co-ordianate t_3	TRV Peak Value U_c	Time Co-ordinate t_3
(1)	(2)	(3)	(4)	(5)
kV	kV	μS	kV	μS
123	183	92	211	106
145	215	127	249	125
245	364	182	-	-
420	624	312	-	-

Test-Duties No. 3 Representation By 2-Parameters

Rated Voltage	**First-Pole-To-Clear Factor 1.3**		**First-Pole-To-Clear Factor 1.5**	
U	TRV Peak Value U_c	Time Co-ordianate t_3	TRV Peak Value U_c	TIme Co-ordinate t_3
(1)	(2)	(3)	(4)	(5)
kV	kV	μS	kV	μS
123	196	65	226	75
145	231	77	266	89
245	390	130	-	-
420	669	223	-	-

Clause 7.101 — Mechanical operating tests shall be done without current passing through the main circuit.