# IEC/PAS 62271-109

**Edition 1.0**
2002-07

# High-voltage switchgear and controlgear –

# Part 109: Alternating-current series capacitor by-pass switches



PUBLICLY AVAILABLE SPECIFICATION

INTERNATIONAL ELECTROTECHNICAL COMMISSION

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## Part 109: Alternating-current series capacitor by-pass switches

## FOREWORD

A PAS is a technical specification not fulfilling the requirements for a standard, but made available to the public.

IEC-PAS 62271-109 has been processed by subcommittee 17A: High-voltage switchgear and controlgear, of IEC technical committee 17: Switchgear and controlgear.

The text of this PAS is based on the following document:

This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document:

| Draft PAS | Report on voting |
|---|---|
| 17A/631/PAS | 17A/637/RVD |

Following publication of this PAS, the technical committee or subcommittee concerned will investigate the possibility of transforming the PAS into an International Standard.

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.

**New numbering**

In accordance with the decision taken at the joint SC 17A/SC 17C meeting in Frankfurt (item 20.7 of 17A/535/RM) a common numbering system will be established of the standards falling under the responsibility of SC 17A and SC 17C. IEC 62271 (with the main title of *High-voltage switchgear and controlgear*) is the basis of the common standard.

Numbering of the standards will apply the following principle:

a) Common standards prepared by SC 17A and SC 17C will start with IEC 62271-001;

b) Standards of SC 17A will start with IEC 62271-100;

c) Standards of SC 17C will start with number IEC 62271-200;

d) Guides prepared by SC 17A and SC 17C will start with number IEC 62271-300.

The following Table provides an overview of the relationship between the old and new numbering:

## Common numbering of standards falling under the responsibility of subcommittees 17A and 17C

| IEC 62271 | HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR | |
|---|---|---|
| **Part** | **Original title** | **Old IEC number, if any** |
| 1 | Common specifications | IEC 60694<br>IEC 60516 |
| | | |
| 100 | High-voltage alternating current circuit-breakers | IEC 60056 |
| 101 | Synthetic testing of high-voltage alternating current circuit-breakers | IEC 60427 |
| 102 | High-voltage alternating current disconnectors and earthing switches | IEC 60129 |
| 103 | High-voltage switches for rated voltages above 1 kV and less than 52 kV | IEC 60265-1 |
| 104 | High-voltage switches for rated voltages of 52 kV and above | IEC 60265-2 |
| 105 | High voltage alternating current switch-fuse combinations | IEC 60420 |
| 106 | High-voltage alternating current contactors and contactor based motor-starters | IEC 60470 |
| 107 | Alternating current switchgear-fuse combinations | New |
| 108 | Switchgear having combined functions | New |
| | | |
| 200 | Metal enclosed switchgear and controlgear for rated voltages up to and including 38 kV | IEC 60298 |
| 201 | Insulation-enclosed switchgear and controlgear for rated voltages up to and including 52 kV | IEC 60466 |
| 202 | High-voltage/low voltage prefabricated substations | IEC 61330 |
| 203 | Gas-insulated metal enclosed switchgear for rated voltages above 52 kV | IEC 60517<br>IEC 61259 |
| 204 | High-voltage gas-insulated transmission lines for rated voltages of 72,5 kV and above | IEC 61640 |
| | | |
| 300 | Guide for seismic qualification | IEC 61166 |
| 301 | Guide for inductive load switching | IEC 61233 |
| 302 | Guide for short-circuit and switching test procedures for metal-enclosed and dead tank circuit-breakers switches | IEC 61633 |
| 303 | Use and handling of sulphur hexafluoride ($SF_6$) in high-voltage switchgear and controlgear | IEC 61634 |
| 304 | Additional requirements for enclosed switchgear and controlgear from 1 kV to 72,5 kV to be used in severe climatic conditions | IEC 60932 |
| 305 | Cable connections for gas-insulated metal-enclosed switchgear for rated voltages above 52 kV | IEC 60859 |
| 306 | Direct connection between power transformers and gas-insulated metal-enclosed switchgear for rated voltages above 52 kV | IEC 61639 |
| 307 | The use of electronic and associated technologies in auxiliary equipment of switchgear and controlgear | IEC 62063 |
| 308 | Guide for asymmetrical short-circuit breaking test duty T100a | New |
| 309 | Electrical endurance testing for circuit-breakers rated 72,5 kV and above | New |

# HIGH-VOLTAGE SWITCHGEAR AND CONTROLGEAR –

# Part 109: Alternating-current series capacitor by-pass switches

## 1 General

### 1.1 Scope

This Publicly Available Specification is applicable to a.c. series capacitor by-pass switches designed for outdoor installation and for operation at frequencies of 50 Hz and 60 Hz on systems having voltages above 1 000 V.

It is only applicable to by-pass switches for use in three-phase systems.

This specification is also applicable to the operating devices of by-pass switches and to their auxiliary equipment.

This specification does not cover vacuum by-pass switches.

### 1.2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this Publicly Available Specification. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this Publicly Available Specification are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 60050(151):1978, *International Electrotechnical Vocabulary – Chapter 151: Electrical and magnetic devices*

IEC 60050(441):1984, *International Electrotechnical Vocabulary – Chapter 441: Switchgear, controlgear and fuses*

IEC 60050(436):1990, *International Electrotechnical Vocabulary – Chapter 436: Power capacitors*

IEC 60050(601):1985, *International Electrotechnical Vocabulary – Chapter 601: Generation, transmission and distribution of electricity – General*

IEC 60050(604):1987, *International Electrotechnical Vocabulary – Chapter 604: Generation, transmission and distribution of electricity – Operation*

IEC 60059:1999, *IEC standard current ratings*

IEC 60060: all parts, *High-voltage test techniques*

IEC 60099-4:2002, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*

IEC 60129:1984, *Alternating current disconnectors and earthing switches*

IEC 60137:1995, *Bushings for alternating voltages above 1 000 V*

IEC 60143-1:1992, *Series capacitors for power systems – Part 1: General – Performance, testing and rating – Safety requirements – Guide for installation*

IEC 60143-2:1994, *Series capacitors for power systems – Part 2: Protective equipment for series capacitor banks*

IEC 60255-3:1989, *Electrical relays – Part 3: Single output energizing quantity measuring relays with dependent or independent time*

IEC 60296:1982, *Specification for unused mineral insulating oils for transformers and switchgear*

IEC 60376:1971, *Specification and acceptance of new sulphur hexafluoride*

IEC 60427:1989, *Synthetic testing of high-voltage alternating current circuit-breakers*

IEC 60480:1974, *Guide to the checking of sulphur hexafluoride ($SF_6$) taken from electrical equipment*

IEC 60529:1989, *Degrees of protection provided by enclosures (IP code)*

IEC 60694:1996, *Common specifications for high-voltage switchgear and controlgear standards*

IEC 61633:1995, *High-voltage alternating current circuit-breakers – Guide for short-circuit and switching test procedures for metal-enclosed and dead tank circuit-breakers*

IEC 61634:1995, *High-voltage switchgear and controlgear – Use and handling of sulphur hexafluoride ($SF_6$) in high-voltage switchgear and controlgear*

IEC 62271-100:2001, *High-voltage switchgear and controlgear – Part 100: High-voltage alternating current circuit-breakers*

## 2 Normal and special service conditions

Clause 2 of IEC 60694 is applicable.

## 3 Definitions

For the purpose of this Publicly Available Specification, the definitions of IEC 60050(151), IEC 60050(436), IEC 60050(441), IEC 60050(604), IEC 60143-1, IEC 60143-2 and IEC 60694 apply. Some of them are recalled here for ease of reference.

Additional definitions are classified so as to be aligned with the classification used in IEC 60050(441).

### 3.1 General terms

**3.1.101**
**switchgear and controlgear**
[IEV 441-11-01]

**3.1.102**
**outdoor switchgear and controlgear**
[IEV 441-11-05]

**3.1.103**
**short-circuit current**
[IEV 441-11-07]

**3.1.104**
**ambient air temperature**
[IEV 441-11-13]

**3.1.105**
**temperature rise (of a part of a by-pass switch)**
difference between the temperature of the part and the ambient air temperature

**3.1.106**
**overvoltage (in a system)**
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

[IEV 604-03-09, modified]

**3.1.107**
**unit test**
test made on a by-passing or insertion unit or group of units at the by-pass making current or the insertion current, specified for the test on the complete pole of a by-pass switch and at the appropriate fraction of the applied voltage, or the transient recovery voltage, specified for the test on the complete pole of the by-pass switch

**3.1.108**
**external insulation**
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.
[IEV 604-03-02, modified]

**3.1.109**
**internal insulation**
internal solid, liquid or gaseous parts of the insulation of equipment, which are protected from the effects of atmospheric and other external conditions
[IEV 604-03-03]

**3.1.110**
**self-restoring insulation**
insulation which completely recovers its insulating properties after a disruptive discharge

[IEV 604-03-04]

**3.1.111**
**non-self restoring insulation**
insulation which loses its insulating properties, or does not recover them completely, after a disruptive discharge
[IEV 604-03-05]

**3.1.112**
**disruptive discharge**
phenomenon 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

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

NOTE 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).

NOTE 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.

**3.1.112**
**restrike performance**
expected probability of restrike during insertion current test duty as demonstrated by specified type test

NOTE Specific numeric probabilities cannot be applied throughout a by-pass switch service life.

### 3.2 Assemblies

No particular definitions.

### 3.3 Parts of assemblies

No particular definitions.

### 3.4 Switching devices

**3.4.101**
**switching device**
[IEV 441-14-01]

**3.4.102**
**mechanical switching device**
[IEV 441-14-02]

**3.4.103**
**by-pass switch**
switching device used in parallel with a series capacitor and its overvoltage protector to shunt line current of a specified level for a specified time, or continuously. Besides by-passing the capacitor, this device normally has the capability to insert the capacitor into a circuit that carries a specified level of current

**3.4.104**
**by-pass switch class BP1**
by-pass switch used as the non-primary device for by-passing the capacitor. This class of by-pass switch is used in conjunction with a fast by-passing device such as a spark gap (see Figure 2 of IEC 60143-2)

**3.4.105**
**by-pass switch class BP2**
by-pass switch used as the primary by-passing device

**3.4.106**
**by-pass switch class M1**
by-pass switch with normal mechanical endurance (mechanically type tested for 2 000 operating sequences) not falling into the category of class M2 as defined in 3.4.107

**3.4.107**
**by-pass switch class M2**
frequently operated by-pass switch for special service requirements and designed so as to require only limited maintenance as demonstrated by specific type tests (by-pass switch with extended mechanical endurance, mechanically type tested for 10 000 operating sequences). This type of by-pass switch is normally used on multi-segmented capacitors where the control of the capacitor impedance is a frequent duty

NOTE A combination of the different classes of by-pass switches with regard to application and mechanical endurance is possible. For the designation of these by-pass switches the notation of the different classes are combined following an alphabetical order, for example BP1-M2.

### 3.5 Parts of by-pass switches

**3.5.101**
**pole**
[IEV 441-15-01]

**3.5.102**
**main circuit**
[IEV 441-15-02]

**3.5.103**
**control circuit**
[IEV 441-15-03]

**3.5.104**
**auxiliary circuit**
[IEV 441-15-04]

**3.5.105**
**contact**
[IEV 441-15-05]

**3.5.106**
**contact piece**
[IEV 441-15-06]

**3.5.107**
**main contact**
[IEV 441-15-07]

**3.5.108**
**arcing contact**
[IEV 441-15-08]

**3.5.109**
**control contact**
[IEV 441-15-09]

**3.5.110**
**auxiliary contact**
[IEV 441-15-10]

**3.5.111**
**auxiliary switch**
[IEV 441-15-11]

**3.5.112**
**“a” contact;**
**make contact**
[IEV 441-15-12]

**3.5.113**
**“b” contact;**
**break contact**
[IEV 441-15-13]

**3.5.114**
**sliding contact**
[IEV 441-15-15]

**3.5.115**
**rolling contact**
[IEV 441-15-16]

**3.5.116**
**release**
[IEV 441-15-17]

**3.5.117**
**arc control device**
[IEV 441-15-18]

**3.5.118**
**position indicating device**
[IEV 441-15-25]

**3.5.119**
**connection (bolted or equivalent)**
two or more conductors designed to ensure permanent circuit continuity when forced together by means of screws, bolts or the equivalent

**3.5.120**
**terminal**
component provided for the connection of a device to external conductors
[IEV 151-01-03]

**3.5.121**
**by-pass (or insertion) unit**
part of a by-pass switch which in itself acts as a by-pass switch and which, in series with one or more identical and simultaneously operated by-pass or insertion units, forms the complete by-pass switch

NOTE 1 By-pass units and insertion units are normally combined but may be separated. Each unit may have several contacts.

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

**3.5.122**
**module**
assembly which generally comprises by-pass or insertion units, post-insulators and mechanical parts and which is mechanically and electrically connected to other identical assemblies to form a pole of a by-pass switch

**3.5.123**
**enclosure**
part of switchgear and controlgear providing a specified degree of protection (see IEC 60529) of equipment against external influences and a specified degree of protection against approach to or contact with live parts and against contact with moving parts
[IEV 441-13-01, modified]

## 3.6 Operation

**3.6.101**
**operation**
[IEV 441-16-01]

**3.6.102**
**operating cycle**
[IEV 441-16-02]

**3.6.103**
**operating sequence**
[IEV 441-16-03]

**3.6.104**
**closing operation**
[IEV 441-16-08]

**3.6.105**
**opening operation**
[IEV 441-16-09]

**3.6.106**
**auto-reopening**
the operating sequence of a by-pass switch whereby, following its closing, it opens automatically after a predetermined time

**3.6.107**
**positive opening operation**
[IEV 441-16-11]

**3.6.108**
**positively driven operation**
[IEV 441-16-12]

**3.6.109**
**dependent power operation**
[IEV 441-16-14]

**3.6.110**
**stored energy operation**
operation by means of energy stored in the mechanism itself prior to the switching operation and sufficient to complete the specified operating sequence under predetermined conditions

**3.6.112**
**independent manual operation**
a stored energy operation where the energy originates from manual power, stored and released in one continuous operation, such that the speed and force of the operation are independent of the action of the operator
[IEV 441-16-16]

**3.6.113**
**closed position**
[IEV 441-16-22]

**3.6.114**
**open position**
[IEV 441-16-23]

**3.6.115**
**shunt release**
[IEV 441-16-41]

**3.6.116**
**anti-pumping device**
device that prevents the reopening after a open-close operation as long as the device initiating opening is maintained in the position for opening

**3.6.118**
**interlocking device**
[IEV 441-16-49]

**3.6.119**
**by-pass switch with lock-out preventing opening**
by-pass switch in which none of the moving contacts can insert the capacitor if the opening command is initiated while the conditions which should cause the closing operation remain established

### 3.7 Characteristic quantities

Figures 1 to 3 illustrate some definitions of this subclause.

Time quantities, see definitions 3.7.120 to 3.7.130, are expressed in milliseconds or in cycles. When expressed in cycles, the power frequency should be stated in brackets.

**3.7.101**
**rated value**
quantity value assigned, generally by a manufacturer, for a specified operating condition of component, device or equipment
[IEV 151-04-03]

**3.7.102**
**prospective current (of a circuit and with respect to a switching device or a fuse)**
[IEV 441-17-01]

**3.7.103**
**prospective peak current**
peak value of the first current loop of the prospective current during the transient period following initiation

NOTE The definition assumes that the current is made by an ideal by-pass switch, 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 instantaneous voltage across the capacitor prior to by-passing.

**3.7.104**
**peak current**
peak value of the first current loop during the transient period following initiation

**3.7.105**
**(peak) by-pass current**
peak value of the first current loop in a pole of a by-pass switch during the transient period following the initiation of current during a by-passing operation

NOTE 1 The peak value may differ from one pole to another and from one operation to another as it depends on the instantaneous capacitor voltage prior to by-passing.

NOTE 2 Where, for a three-phase circuit, a single value of (peak) by-passing current is referred to, this is, unless otherwise stated, the highest value in any phase.

**3.7.106**
**by-pass insertion current**
steady state root-mean-square current that flows through the by-pass switch immediately prior to opening

**3.7.107**
**insertion capacity**
value of prospective current that a by-pass switch is capable of inserting at stated voltage under prescribed conditions of use and behaviour

**3.7.108**
**by-passing capacity**
value of prospective current that a by-pass switch is capable of by-passing at a stated voltage under prescribed conditions of use and behaviour

**3.7.109**
**short-circuit making capacity**
[IEV 441-17-10]

**3.7.110**
**short-time withstand current**
[IEV 441-17-17]

**3.7.111**
**peak withstand current**
[IEV 441-17-18]

**3.7.112**
**applied voltage**
[IEV 441-17-24]

**3.7.113**
**recovery voltage**
[IEV 441-17-25]

**3.7.114**
**power frequency recovery voltage**
[IEV 441-17-27]

**3.7.115**
**peak arc voltage**
[IEV 441-17-30]

**3.7.116**
**clearance**
[IEV 441-17-31]

**3.7.117**
**clearance between poles**
[IEV 441-17-32]

**3.7.118**
**clearance to earth**
[IEV 441-17-33]

**3.7.119**
**clearance between open contacts**
[IEV 441-17-34]

**3.7.120**
**opening time**
opening time of a by-pass switch defined according to the tripping method as stated below and with any time delay device forming an integral part of the by-pass switch adjusted to its minimum setting.

For a by-pass switch tripped by any form of auxiliary power, the opening time is the interval of time between the instant of energising the opening release, the by-pass switch being in the closed position, and the instant when the arcing contacts have separated in all poles

NOTE 1 For by-pass switches with more than one insertion 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.

NOTE 2 The opening time includes the operating time of any auxiliary equipment necessary to open the by-pass switch and forming an integral part of the by-pass switch.

**3.7.121**
**arcing time (of a multipole switching device)**
interval of time between the instant of the first initiation of an arc and the instant of final arc extinction in all poles
[IEV 441-17-38]

**3.7.122**
**insertion time**
interval of time between the beginning of the opening time of a by-pass switch and the end of the arcing time

**3.7.123**
**closing time**
interval of time between energising the closing circuit, the by-pass switch 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 by-pass switch and forming an integral part of the by-pass switch.

**3.7.124**
**by-pass time**
interval of time between energising the closing circuit, the by-pass switch being in the open position, and the instant when the current begins to flow in the first pole

NOTE 1 The by-pass time includes the operating time of any auxiliary equipment necessary to close the by-pass switch and forming an integral part of the by-pass switch.

NOTE 2 The by-pass time may vary, e.g. due to the variation of the pre-arcing time.

**3.7.125**
**pre-arcing time**
interval of time between the initiation of current flow in the first pole during a by-passing operation and the instant when the contacts touch in all poles for three-phase conditions and the instant when the contacts touch in the arcing pole for single-phase conditions

NOTE The pre-arcing time depends on the instantaneous value of the applied voltage during a specific by-passing operation and therefore may vary considerably.

**3.7.126**
**open-close time**
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 by-passing operation

NOTE Unless otherwise stated, it is assumed that the closing release incorporated in the by-pass switch is energised at the instant when the contacts have separated in all poles during opening. This represents the minimum open-close time.

**3.7.127**
**dead time (during auto-reclosing)**
interval of time between final arc extinction in all poles in the insertion operation and the first re-establishment of current in any pole in the subsequent by-passing operation

NOTE The dead time may vary, e.g. due to the variation of the pre-arcing time.

**3.7.128**
**by-pass insertion time**
interval of time between the initiation of current flow in the first pole during a by-passing operation and the end of the arcing time during the subsequent insertion operation

NOTE 1 The by-pass insertion time may vary due to the variation of the pre-arcing and arcing times.

NOTE 2 The by-pass insertion time should be compatible with system requirements.

**3.7.129**
**minimum trip duration**
minimum time the auxiliary power is applied to the opening release to ensure complete opening of the by-pass switch

**3.7.130**
**minimum close duration**
minimum time the auxiliary power is applied to the closing device to ensure complete closing of the by-pass switch

**3.7.131**
**re-ignition (of an a.c. mechanical switching device)**
[IEV 441-17-45]

**3.7.132**
**restrike (of an a.c. mechanical switching device)**
[IEV 441-17-46]

**3.7.133**
**normal current**
current which the main circuit of a by-pass switch is capable of carrying continuously under specified conditions of use and behaviour

**3.7.134**
**insulation level**
for a by-pass switch, a characteristic defined by values indicating the insulation withstand voltages to earth and/or across the by-pass units

**3.7.135**
**power frequency withstand voltage**
r.m.s. value of sinusoidal power frequency voltage that the by-pass switch can withstand during tests made under specified conditions and for a specified time
[IEV 604-03-40, modified]

**3.7.136**
**impulse withstand voltage**
peak value of the standard impulse voltage wave which the insulation of the by-pass switch 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".

**3.7.137**
**minimum functional pressure for operation**
pressure, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa, which may be expressed in relative or absolute terms, at which and above which rated characteristics of a by-pass switch are maintained and at which a replenishment of the operating device becomes necessary

NOTE This pressure is often designated as interlocking pressure (refer to 3.6.4.6 of IEC 60694).

**3.7.138**
**minimum functional pressure for by-passing, insertion and insulation**
pressure for by-passing, insertion and for insulation, referred to the standard atmospheric air conditions of +20 °C and 101,3 kPa, which may be expressed in relative or absolute terms, at which and above which rated characteristics of a by-pass switch are maintained and at which a replenishment of the by-passing, insertion and/or insulating fluid becomes necessary

NOTE 1 See also 3.6.4.5 of IEC 60694.

NOTE 2 For by-pass switches with a sealed pressure system (also termed sealed-for-life), the minimum functional pressure for by-passing and insertion is the one at which the rated characteristics of the by-pass switch are maintained taking into account the pressure drop at the end of the expected operating life.

## 3.8 Definitions related to series capacitor banks

**3.8.1**
**capacitor**
the word “capacitor” is used when it is not necessary to lay particular stress upon the different meanings of the word capacitor unit, segment or phase bank

**3.8.2**
**overvoltage protector (of a series capacitor)**
quick-acting device that limits the instantaneous voltage across the capacitor to a permissible value when that value would otherwise be exceeded as a result of a circuit fault or other abnormal network conditions
[IEV 436-03-14, modified]

**3.8.3**
**rated capacitance (of a capacitor)** $C_N$
capacitance value for which the capacitor has been designed
[IEV 436-01-12, modified]

**3.8.4**
**rated current (of a capacitor)** $I_N$
r.m.s. value of the alternating current for which the capacitor has been designed
[IEV 436-01-13, modified]

**3.8.5**
**rated voltage (of a capacitor)** $U_N$
r.m.s. value of the voltage between the terminals, derived from rated capacitance, rated current and rated frequency
[IEV 436-01-15, modified]

**3.8.6**
**limiting voltage** ($U_{LIM}$)
maximum instantaneous voltage occurring between capacitor terminals immediately before or during operation of the overvoltage protector, divided by √2

**3.8.7**
**series capacitor phase bank (or phase bank)**
assembly of capacitor units connected in one phase so as to act together, the protection system(s) for these capacitors, etc.

**3.8.8**
**segment (of a series capacitor)**
where the phase bank is divided into several series-connected parts of which each part contains its own assembly of capacitor units and protection system(s) each such complete part is called segment

**3.8.9**
**series capacitor bank (or bank)**
three-phase banks operated in common
[IEV 436-01-06, modified]

**3.8.10**
**bank protection**
general term for all protective equipment for a capacitor bank, or part thereof

**3.8.11**
**by-pass current**
steady-state r.m.s. current flowing through the by-pass switch in parallel with the capacitor

**3.8.12**
**by-pass fault current**
current flowing through the by-passed series capacitor bank caused by a fault on the line

**3.8.13**
**by-pass gap (protective gap)**
gap, or system of gaps, to protect either the capacitor (type K) against overvoltage or the non-linear resistor (type M) against overload by carrying load or fault current around the protected parts for a specified time (see Figure 2 of IEC 60143-2)

**3.8.14**
**by-pass interlocking device**
device that requires all three poles of the by-pass device to be in the same open or closed position

**3.8.15**
**current-limiting damping equipment**
reactor or a reactor with a parallel connected resistor to limit the current magnitude and frequency and to provide a sufficient damping of the discharge of the capacitors upon operation of the by-pass gap or the by-pass switch

**3.8.16**
**insertion**
opening of the series capacitor by-pass switch to insert the series capacitor in series with the transmission line

**3.8.17**
**insertion current**
r.m.s. current that flows through the series capacitor after the by-pass switch has opened. This current may be at the specified continuous or overload current magnitudes

**3.8.18**
**insertion voltage**
peak voltage appearing across the series capacitor upon transfer of the by-pass current with the opening of the by-pass switch

**3.8.19**
**main gap**
that part of the protective spark gap intended to carry the fault current during a specified time, comprising two or more heavy-duty electrodes

**3.8.20**
**module (capacitor switching step)**
three-phase function unit consisting of one capacitor segment (possibly several) per phase with provision for interlocked operation of the single-phase by-pass switches

**3.8.21**
**non-linear resistor (varistor)**
device to act as overvoltage protection of the capacitor consisting of resistors with a non-linear voltage-dependent resistance (normally metal-oxide varistors)

**3.8.22**
**protective level**
maximum instantaneous voltage appearing across the capacitor immediately before or during operation of the by-pass gap (gap-scheme) or at a specified instantaneous current through the varistor (varistor-scheme). In practice, the protective level is equal to $U_{LIM} \times \sqrt{2}$

**3.8.23**
**reinsertion**
restoration of load current to the series capacitor from the by-pass path

**3.8.24**
**reinsertion current**
transient current, power frequency current, or both, flowing through the series capacitor after the opening of the by-pass path

**3.8.25**
**reinsertion voltage**
transient voltage, power frequency voltage, or both, appearing across the series capacitor after the opening of the by-pass path

**3.8.26**
**temporary overvoltage**
temporary power-frequency voltage higher than the continuous rated voltage of the series capacitor

### 3.9 Index of definitions

## 4 Ratings

The characteristics of a by-pass switch, including its operating devices and auxiliary equipment, that should be used to determine the ratings are the following:

*Rated characteristics to be given for all by-pass switches*

a) rated voltage to earth and across the by-pass unit;
b) rated insulation level to earth and across the by-pass unit;
c) rated frequency;
d) rated normal current;
e) rated short-time withstand current;
f) rated peak withstand current;
g) rated duration of short-circuit;
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 and/or of hydraulic supply for operation, insertion, by-passing and insulation, as applicable;
k) rated by-pass making current;
l) rated by-pass insertion current;
m) rated reinsertion voltage (peak value)
n) rated operating sequence;
o) rated time quantities.

The rated characteristics of the by-pass switch are referred to the rated operating sequence.

### 4.1 Rated voltage ($U_r$)

Subclause 4.1 of IEC 60694 is applicable with the following addition.

#### 4.1.101 Rated voltage to earth ($U_{re}$)

Subclause 4.1 of IEC 60694 is applicable.

#### 4.1.102 Rated voltage across the by-pass switch ($U_{rp}$)

The voltage applied across the by-pass switch should be determined by multiplying the impedance of the series capacitor bank or segment ($X_N=1/\omega C_N$) by its rated current ($I_N$). The rated voltage (phase-to-phase) assigned to the by-pass switch should be calculated from the applied voltage (multiplied by $\sqrt{3}$) and adjusted to the next higher standardized value given in 4.1 of IEC 60694.

For series capacitor banks having current overload capabilities, the rated voltage across the by-pass switch should be determined by using the maximum specified overload current.

### 4.2 Rated insulation level

Subclause 4.2 of IEC 60694 is applicable with the following addition.

#### 4.2.101 Rated insulation level to earth

The standard values of rated withstand voltages to earth are given in tables 1a, 1b, 2a and 2b of IEC 60694.

### 4.2.102 Rated insulation level across the by-pass switch

The standard values of rated insulation voltages across the by-pass switch are given in tables 1a, 1b, 2a and 2b of IEC 60694 for the corresponding rated voltage across the by-pass switch. The rated lightning impulse level should be at least 1,3 times the protective level of the parallel spark-gap or parallel varistor whichever is lower.

NOTE A minimum margin of 1,3 over the protective level of the varistor or the parallel spark gap has been specified as it is specified for the impulse voltage withstand capability of surge arrestor housings (see IEC 60099-4).

### 4.3 Rated frequency ($f_r$)

Subclause 4.3 of IEC 60694 is applicable with the following addition:

The standard values for the rated frequency of high voltage by-pass switches are 50 Hz and 60 Hz.

### 4.4 Rated normal current ($I_r$) and temperature rise

Subclause 4.4 of IEC 60694 is applicable.

### 4.5 Rated short-time withstand current ($I_k$)

Subclause 4.5 of IEC 60694 is applicable.

### 4.6 Rated peak withstand current ($I_p$)

Subclause 4.6 of IEC 60694 is applicable.

### 4.7 Rated duration of short circuit ($t_k$)

Subclause 4.7 of IEC 60694 is applicable.

### 4.8 Rated supply voltage of closing and opening devices and of auxiliary and control circuits ($U_a$)

Subclause 4.8 of IEC 60694 is applicable.

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

Subclause 4.9 of IEC 60694 is applicable.

### 4.10 Rated pressures of compressed gas supply for insulation, operation and/or by-passing and insertion

Subclause 4.10 of IEC 60694 is applicable.

### 4.101 Rated operating sequence

The rated characteristics of the by-pass switch are referred to the rated operating sequence.

C - $t$ - OC - $t'$ - OC

Unless otherwise specified:

- $t$ = 0,2 s for by-pass switches intended for rapid auto-reopening (dead time);
- $t'$ = 3 min.

NOTE 1 Instead of $t'$ = 3 min., other values: $t'$ = 15 s and $t'$ = 1 min are also used for by-pass switches intended for rapid auto-reopening.

NOTE 2 Other operating sequences may be specified depending upon system requirements. One example is C -$t$ – OC - $t$- OC - $t'$ – OC

where

C represents a closing operation;

OC represents an opening operation followed immediately (that is, without any intentional delay) by a closing operation;

$t$ and $t'$ are time intervals between successive operations;

$t$ and $t'$ should always be expressed in minutes or in seconds.

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

### 4.102 Rated by-pass making current ($I_{BP}$)

The rated by-pass making current is the peak value of the current that the by-pass switch should be capable of making when the capacitor bank is precharged to the limiting voltage of the overvoltage protector ($U_{LIM}\times\sqrt{2}$) and with a frequency of the by-pass current corresponding to the actual capacitance of the capacitor bank with its associated inductance of the damping circuit. The effective damping of the by-pass discharge current can be taken into consideration.

NOTE The by-pass making performance is covered when the product of the required peak by-pass making current times the required frequency of the by-pass current ($I_{BP}\times f_{BP}$) is equal to or lower than the product of those values used in the relevant test.

### 4.103 Rated by-pass insertion current ($I_{INS}$)

The rated by-pass insertion current is the r.m.s value of the power frequency current that the by-pass switch should be capable of transferring from the by-pass circuit path to the main series capacitor path under the rated reinsertion voltage.

NOTE The rated by-pass insertion current should be taken from the R10 series and the rated by-pass insertion current may be equal to or lower than the rated normal current of the by-pass switch.

### 4.104 Rated reinsertion voltage ($U_{INS}$)

The rated reinsertion voltage is the peak value of the transient recovery voltage that the by-pass switch should be capable of withstanding, without restrike, during the transfer of the rated by-pass insertion current.

In general, the transient reinsertion voltage should be equal to $U_{LIM}\times\sqrt{2}$ to take into account all emergency overload conditions and power swings that could result in transient insertion voltages up to the protective level of the overvoltage protector.

Several transient reinsertion voltage waveshapes can be obtained in service. In order to cover several cases, this specification recommends a "1-cos" waveshape having a time-to-peak of 4,1 ms. Other waveshapes may be required and should be specified to the manufacturer at the time of enquiry.

NOTE 1 No specific recommended values can be given for the transient reinsertion voltage, since this value is depending of the series capacitor design parameters (capacitive impedance, rated normal current of the capacitor bank, protective level of the overvoltage protector, etc...).

NOTE 2 To cover 50 Hz and 60 Hz application with one single test-duty, the transient recovery voltage has been defined with a time-to-peak of 4,1 ms.

NOTE 3 System simulations showed that to cover the effect of the undertone frequency which is dependent of the compensation factor and the transient recovery voltage peak shift caused by power swing during insertion, the transient recovery voltage frequency has to be higher than the system power frequency. The envelope of the specified transient recovery voltage should cover most of the practical cases. Different transient recovery voltage waveshapes may be specified if required and justified by systems studies.

### 4.105 Rated time quantities

Refer to Figures 1, 2, and 3.

Rated values should be assigned to the following time quantities:

– opening time (no-load);
– maximum closing time (no-load);
– maximum open-close time (no-load);

Rated time quantities are based on

– rated supply voltages of closing and opening devices and of auxiliary and control circuits (see 4.8);
– rated supply frequency of closing and opening devices and of auxiliary circuits (see 4.9);
– rated pressures of compressed gas supply for operation, for insulation and/or by-passing and insertion, as applicable (see 4.10);
– rated pressure of hydraulic supply for operation;
– an ambient air temperature of 20 °C ± 5 °C.

NOTE 1 Usually it is not practical to assign a rated value of by-pass making time or of by-pass-insertion time due to the variation of the arcing time and the pre-arcing time.

NOTE 2 The maximum closing time and the maximum open-close time should be given for the minimum supply voltages, maximum pressure of compressed gas supply for operation, for insulation and/or by-passing and insertion, as applicable (see 4.10) and minimum pressure of hydraulic supply for operation.

### 4.106 Number of mechanical operations

A by-pass switch should be able to perform the following number of operating sequences taking into account the programme of maintenance specified by the manufacturer:

| | |
|---|---|
| Standard by-pass switch (normal mechanical endurance) **class M1** | 2 000 operating sequences |
| By-pass switch for special service requirements (extended mechanical endurance) **class M2** | 10 000 operating sequences |

### 4.107 Classification of by-pass switches as a function of application

By-pass switches classified as "BP1" are intended to be used in conjunction with a fast by-passing device such as by-pass spark-gaps acting as the primary protection of the overvoltage protector. This type of by-pass switch should be able to make frequent by-pass currents from a capacitor bank precharged to the rated voltage (peak value). This type of by-pass switch should also be capable to make, in rare occasion, by-pass fault currents from a capacitor bank precharged to the protective level of the overvoltage protector ($U_{LIM}\times\sqrt{2}$).

By-pass switches classified as "BP2" are intended to be used as the primary protection for the overvoltage protector. This type of by-pass switch should be capable to make frequent by-pass fault currents from a capacitor bank precharged to the protective level of the overvoltage protector ($U_{LIM}\times\sqrt{2}$).

## 5 Design and construction

### 5.1 Requirements for liquids in by-pass switches

Subclause 5.1 of IEC 60694 is applicable.

### 5.2 Requirements for gases in by-pass switches

Subclause 5.2 of IEC 60694 is applicable.

### 5.3 Earthing of by-pass switches

Subclause 5.3 of IEC 60694 is applicable.

### 5.4 Auxiliary equipment

Subclause 5.4 of IEC 60694 is applicable with the following additions:

– where shunt opening and closing releases are used, appropriate measures should be taken in order to avoid damage on the releases when permanent orders for closing or opening are applied. For example, those measures may be the use of series control contacts arranged so that when the by-pass switch is closed, the close release control contact ("b" contact or break contact) is open and the open release control contact ("a" contact or make contact) is closed, and when the by-pass switch is open, the open release control contact is open and the close release control contact is closed;

NOTE 1 Systems other than contacts are possible and may be used.

– for shunt closing releases the protective measures for the shunt closing releases (the “b” contact) as mentioned in the first indent above should open no sooner than the minimum close duration (3.7.130) provided by the by-pass switch and no later than the rated closing time;

NOTE 2 If the current of the shunt closing release is interrupted by the control contact, the closing command should be positively longer than the rated closing time.

– for shunt opening releases the protecting measures for the shunt opening releases (the “a” contact) as mentioned in the first indent above should open no sooner than the minimum trip duration (3.7.129) required by the by-pass switch and no later than 20 ms after separation of the main contacts;

– for short open-close time requirements the protective measures for the shunt closing releases (the “b” contact) as mentioned in the first indent above should close no sooner than when the “a” contact has opened;

– where auxiliary switches are used as position indicators, they should indicate the end position of the by-pass switch at rest, open or closed. The signalling should be sustained;

– connections should withstand the stresses imposed by the by-pass switch, especially those due to mechanical forces during operations;

– all auxiliary equipment including the wiring should be adequately protected against rain and humidity;

– where special items of control equipment are used, they should operate within the limits specified for supply voltages of auxiliary and control circuits, interrupting and/or insulating and operating media, and be able to switch the loads which are stated by the by-pass switch manufacturer;

– special items of auxiliary equipment such as liquid indicators, pressure indicators, relief valves, filling and draining equipment, heating and interlock contacts should operate within the limits specified for supply voltages of auxiliary and control circuits and/or within the limits of use of interrupting and/or insulating and operating media;

– the power consumption of heaters at rated voltage should be within the tolerance of ± 10 % of the value stated by the manufacturer;

– where anti-pumping devices are part of the by-pass switch control scheme, they should act on each control circuit, if more than one is installed;

– where a control scheme of pole discrepancy is part of the by-pass switch, the position of the poles should be supervised, open or closed. The closing of one pole should initiate closure of the remaining poles. Each by-pass switch should be similarly interlocked for the opening operation.

### 5.5 Dependent power operation

Subclause 5.5 of IEC 60694 is applicable with the following addition:

– a by-pass switch arranged for dependent power opening with external energy supply should also be capable of closing immediately following an opening operation.

### 5.6 Stored energy operation

Subclause 5.6 of IEC 60694 is applicable with the following addition to the first paragraph.

A by-pass switch arranged for stored energy operation should also be capable of closing immediately following an opening operation.

### 5.7 Independent manual operation

Subclause 5.7 of IEC 60694 is not applicable for by-pass switches.

### 5.8 Operation of releases

Subclause 5.8 of IEC 60694 is applicable with the following additions:

#### 5.8.101 Multiple releases

If a by-pass switch is fitted with more than one release for the same function, a defect in one release should not disturb the function in the others. Releases used for the same function should be physically separated, i.e. magnetically decoupled.

#### 5.8.102 Operation limits of releases

For shunt opening releases the minimum trip duration and for shunt closing releases the minimum command duration at rated supply voltage should not be less than 2 ms.

The minimum supply voltage for operation of shunt releases should not be less than 20 % of the rated supply voltage.

#### 5.8.103 Power consumption of releases

The power consumption of shunt closing or opening releases of a three-pole by-pass switch should not exceed 1 200 VA. For certain by-pass switch designs higher values may be necessary.

### 5.9 Low- and high-pressure interlocking devices

Subclause 5.9 of IEC 60694 is replaced by the following:

All by-pass switches having an energy storage in gas receivers or hydraulic accumulators (see 5.6.1 of IEC 60694) and all by-pass switches except sealed pressure devices, using compressed gas for by-passing and insertion (see 5.103) should be fitted with a low-pressure interlocking device, and can also be fitted with a high-pressure interlocking device, set to operate at, or within, the appropriate limits of pressure stated by the manufacturer.

### 5.10 Nameplates

Subclause 5.10 of IEC 60694 is applicable with the following additions: the nameplates of a by-pass switch and its operating devices should be marked in accordance with Table 1.

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

Releases should bear the appropriate data.

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

**Table 1 – Nameplate information**

| | Abbrevi-ation | Unit | By-pass switch | Operating device | Condition: Marking only required if |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| Manufacturer | | | X | X | |
| Type designation and serial number | | | X | X | |
| Rated voltage to earth | $U_{re}$ | kV | X | | |
| Rated voltage across by-pass switch | $U_{rp}$ | kV | X | | |
| Rated lightning impulse withstand voltage to earth | $U_{pe}$ | kV | X | | |
| Rated lightning impulse withstand voltage across by-pass switch | $U_{pp}$ | kV | X | | |
| Rated switching impulse withstand voltage to earth | $U_{se}$ | kV | y | | Rated voltage 300 kV and above |
| Rated switching impulse withstand voltage across by-pass switch | $U_{sp}$ | kV | y | | Rated voltage 300 kV and above |
| Rated frequency | $f_r$ | Hz | y | | Rating is not applicable at both 50 Hz and 60 Hz |
| Rated normal current | $I_r$ | A | X | | |
| Rated duration of short circuit | $t_k$ | s | y | | Different from 1 s |
| Rated short-time withstand current | $I_k$ | kA | X | | |
| Rated peak withstand current | $I_p$ | kA | | | |
| Rated by-pass making current | $I_{BP}$ | kA | | | |
| By-pass making current frequency | $f_{BP}$ | kHz | | | |
| Rated by-pass insertion current | $I_{INS}$ | A | | | |
| Rated reinsertion voltage | $U_{INS}$ | kV | | | |
| Rated filling pressure for operation | $p_{rm}$ | MPa | | (X) | |
| Rated filling pressure for by-passing and insertion | $p_{re}$ | MPa | (X) | | |
| Rated supply voltage of closing and opening devices | $U_{op}$ | 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 by-pass switches) | $M$ | kg | y | y | More than 300 kg |
| Mass of fluid for by-passing and insertion | $m$ | kg | y | | If gas or oil by-pass switches |
| Rated operating sequence | | | X | | |
| Year of manufacture | | | X | | |
| Temperature class | | | y | y | Different from –25 °C outdoor |
| Classification | | | y | | If different from BP1 and M1 |
| Relevant standard with date of issue | | | X | X | |

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 in column 1 are used, the word “rated“ need not appear.

### 5.11 Interlocking devices

Subclause 5.11 of IEC 60694 is applicable.

See also 5.4.

### 5.12 Position indication

Subclause 5.12 of IEC 60694 is applicable.

### 5.13 Degrees of protection by enclosures

Subclause 5.13 of IEC 60694 is applicable.

### 5.14 Creepage distances

Subclause 5.14 of IEC 60694 is applicable.

### 5.15 Gas and vacuum tightness

Subclause 5.15 of IEC 60694 is applicable.

### 5.16 Liquid tightness

Subclause 5.16 of IEC 60694 is applicable.

### 5.17 Flammability

Subclause 5.17 of IEC 60694 is applicable.

### 5.18 Electromagnetic compatibility

Subclause 5.18 of IEC 60694 is applicable.

### 5.101 Requirements for simultaneity within a pole

If one pole consists of more than one by-pass unit connected in series, the maximum difference between the instants of contact separation or contact touch within these series connected units should not exceed one eighth of a cycle of rated frequency.

### 5.102 General requirement for operation

A by-pass switch, including its operating devices, should be capable of completing its rated operating sequence (4.101) in accordance with the relevant provisions of 5.5 to 5.9 and 5.103 for the whole range of ambient temperatures within its temperature class as defined in Clause 2 of IEC 60694.

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

By-pass switches provided with heaters should be designed to permit a closing operation at the minimum ambient temperature defined by the temperature class when the heaters are not operational for a minimum time of 2 h.

### 5.103 Pressure limits of fluids for operation

The manufacturer should state the maximum and minimum pressures of the fluid for operation at which the by-pass switch is capable of performing according to its ratings and at which the appropriate low- and high-pressure interlocking devices should be set (see 5.9). The

manufacturer should state the minimum functional pressure for operation, by-passing and insertion (see 3.7.137 and 3.7.138).

The manufacturer may specify pressure limits at which the by-pass switch is capable of each of the following performances:

a) making its rated by-pass making current, i.e. a "C" operation;

b) reinserting its rated by-pass insertion current immediately followed by making its rated by-pass making current, i.e. a "OC" operating cycle;

c) for by-pass switches intended for rapid auto-reinsertion; making its rated by-pass making current followed after a time interval $t$ of the rated operating sequence (4.101) by reinserting its rated by-pass insertion current, immediately followed again by making its rated by-pass making current, i.e. an "C - $t$ - OC" operating sequence.

The by-pass switches should be provided with energy storage of sufficient capacity for satisfactory performance of the appropriate operations at the corresponding minimum pressures stated.

### 5.104 Vent outlets

Vent outlets are devices that allow a deliberate release of pressure in a by-pass switch during operation.

NOTE This is applicable to air, air-blast and oil by-pass switches.

Vent outlets of by-pass switches should 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 necessary safety distance should be stated by the manufacturer.

The construction should 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 by-pass switch or its auxiliary equipment.

## 6 Type tests

Clause 6 of IEC 60694 is applicable with the following additions:

The type tests for by-pass switches are listed in Table 2.

All type tests should be carried out using the number of test samples specified in 6.1.1 of IEC 60694 and in 6.102.2.

For the type tests, the tolerances on test quantities are given in Annex A.

The individual type tests should, in principle, be performed on a by-pass switch in a new and clean condition. In case of by-pass switches using $SF_6$ for insulation, by-passing and insertion and/or operation, the quality of the gas should at least comply with the acceptance levels of IEC 60480.

The responsibility of the manufacturer is limited to the declared rated values and not to those values achieved during the type tests.

The uncertainty of each measurement by oscillograph or equivalent equipment (for example transient recorder), including associated equipment, of the quantities that determine the ratings (for example by-pass current, applied voltage and transient recovery voltage) should be within ±5 % (equal to a coverage factor of 2,0).

NOTE For the meaning of coverage factor, there is referred to ISO Guide to the expression of uncertainty in measurement (see Bibliography).

**Table 2 – Type tests**

| Mandatory type tests | Subclauses |
|---|---|
| Dielectric tests | 6.2 |
| Radio interference voltage tests | 6.3 |
| Measurement of the resistance of the main circuit | 6.4 |
| Temperature-rise tests | 6.5 |
| Short-time withstand current and peak withstand current tests | 6.6 |
| Tightness tests | 6.8 |
| EMC tests | 6.9 |
| Mechanical operation test at ambient air temperature | 6.101.2 |
| By-pass making current tests | 6.105 |
| Insertion current tests | 6.106 |
| **Mandatory type tests, where applicable** | **Subclauses** |
| Verification of the degree of protection | 6.7 |
| Extended mechanical endurance tests on by-pass switches for special service conditions * | 6.101.2.4 |
| Low and high temperature tests | 6.101.3 |
| Static terminal load tests | 6.101.6 |
| Test to prove operation under severe ice conditions * | 6.101.5 |
| NOTE Where the test is marked by *, an additional test sample is allowed. | |

## 6.1 General

### 6.1.1 Grouping of tests

Subclause 6.1.1 of IEC 60694 is applicable.

### 6.1.2 Information for identification of specimens

Subclause 6.1.2 of IEC 60694 is applicable.

### 6.1.3 Information to be included in type test reports

Subclause 6.1.3 of IEC 60694 is applicable with the following addition:

Further details relating to records and reports of type tests for by-pass current making and insertion tests are given in Annex B.

## 6.2 Dielectric tests

### 6.2.1 Ambient air conditions during tests

Subclause 6.2.1 of IEC 60694 is applicable.

### 6.2.2 Wet test procedure

Subclause 6.2.2 of IEC 60694 is applicable with the following note:

NOTE In the case of dead tank by-pass switches, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

### 6.2.3 Condition of by-pass switch during dielectric tests

Subclause 6.2.3 of IEC 60694 is applicable.

### 6.2.4 Criteria to pass the test

Subclause 6.2.4 of IEC 60694 is applicable with the following addition:

The by-pass switch has passed the impulse tests if the following conditions are fulfilled:

a) the number of disruptive discharges should not exceed two for each series of 15 impulses;

b) no disruptive discharges on non-self-restoring insulation should occur.

This is verified by at least five impulses without disruptive discharge following that impulse out of the series of 15 impulses, which caused the last disruptive discharge. If this impulse is one of the last five out of the series of 15 impulses, additional impulses should be applied.

If disruptive discharges occur and, for any reason, evidence cannot be given during testing that the disruptive discharges were on self-restoring insulation, after the completion of the dielectric tests the by-pass switch should be dismantled and inspected. If punctures of non-self-restoring insulation are observed, the by-pass switch has failed the test.

NOTE The determination of the location of the observed disruptive discharges should be carried out by the laboratory using sufficient detection means, for example, photographs, video recordings, internal inspection, etc.

### 6.2.5 Application of test voltage and test conditions

Subclause 6.2.5 of IEC 60694 is applicable.

### 6.2.6 Tests of by-pass switches of $U_{re} \leq 245$ kV or $U_{rp} \leq 245$ kV

Subclause 6.2.6 of IEC 60694 is applicable.

#### 6.2.6.1 Power-frequency voltage tests

Subclause 6.2.6.1 of IEC 60694 is applicable with the following note:

NOTE In the case of dead tank by-pass switches, when the bushings have been previously tested according to the relevant IEC standard, tests under wet conditions can be omitted.

#### 6.2.6.2 Lightning impulse voltage test

Subclause 6.2.6.2 of IEC 60694 is applicable.

### 6.2.7 Tests of by-pass switches of $U_{re} > 245$ kV or $U_{rp} > 245$ kV

Subclause 6.2.7 of IEC 60694 is applicable.

#### 6.2.7.1 Power-frequency voltage tests

Subclause 6.2.7.1 of IEC 60694 is applicable with the following addition:

The test procedure following the alternative method is more severe than the test procedure following the preferred method.

#### 6.2.7.2 Switching impulse voltage tests

Subclause 6.2.7.2 of IEC 60694 is applicable with the following addition:

The dry tests should be performed using voltage of positive polarity only. With the by-pass switch closed, the test voltage equal to the rated withstand voltage to earth should be applied for each test condition of Table 9 of IEC 60694.

With the by-pass switch open, the test voltage equal to the rated withstand voltage across the open by-pass switch should be applied for each test condition of Table 9 of IEC 60694.

#### 6.2.7.3 Lightning impulse voltage tests

Subclause 6.2.7.3 of IEC 60694 is applicable with the following addition:

With the by-pass switch closed, the test voltage equal to the rated withstand voltage to earth should be applied for each test condition of Table 9 of IEC 60694.

With the by-pass switch open, the test voltage equal to the rated withstand voltage across the open by-pass switch should be applied for each test condition of Table 9 of IEC 60694.

### 6.2.8 Artificial pollution tests

Subclause 6.2.8 of IEC 60694 is applicable.

### 6.2.9 Partial discharge tests

Subclause 6.2.9 of IEC 60694 is applicable with the following addition:

Partial discharge tests are not normally required to be performed on the complete by-pass switch. However, in the case of by-pass switches using components for which a relevant IEC standard exists, and if this relevant standard requires partial discharge measurements (for example, bushings, see IEC 60137), evidence should be produced by the manufacturer showing that those components have passed the partial discharge tests as laid down in the relevant IEC standard.

### 6.2.10 Tests on auxiliary and control circuits

Subclause 6.2.10 of IEC 60694 is applicable.

### 6.2.11 Voltage test as a condition check

Subclause 6.2.11 of IEC 60694 is applicable with the following addition:

Where after by-pass and insertion tests (see 6.102.9) or where after mechanical or environmental tests (see 6.101.1.4) a voltage test is performed as a condition check, the following conditions should apply:

NOTE Generally the insulation across the pole and to earth cannot be verified simultaneously since the insulation levels across pole are different from the insulation levels to earth. Additional condition check test may be necessary.

For by-pass switches with an asymmetrical current path, the connections should be reversed. The complete tests should be carried out once for each arrangement of the connections.

– By-pass switches with $U_{re} \leq 72{,}5$ kV or $U_{rp} \leq 72{,}5$ kV

  A 1 min power-frequency voltage test should be performed. The test voltage should be 80 % of the value in Table 1a, column (2) of IEC 60694.

– By-pass switches with $72{,}5 \text{ kV} < U_{re} \leq 245$ kV or $72{,}5 \text{ kV} < U_{rp} \leq 245$ kV

  An impulse voltage test should be performed. The crest value of the impulse voltage should be 60 % of the highest relevant value in Table 1a, column (4) of IEC 60694.

– By-pass switches with $300 \text{ kV} \leq U_{re} \leq 420$ kV or $300 \text{ kV} \leq U_{rp} \leq 420$ kV

An impulse voltage test should be performed. The crest value of the impulse voltage should be 80 % of the rated switching impulse withstand voltage given in Table 2a of IEC 60694. The rated switching impulse withstand voltage should be taken from column (4). The reference value for the condition check should be taken from the same column.

– By-pass switches with 550 kV ≤ $U_{re}$ ≤ 800 kV or 550 kV ≤ $U_{rp}$ ≤ 800 kV

An impulse voltage test should be performed. The crest value of the impulse voltage should be 90 % of the rated switching impulse withstand voltage given in Table 2a of IEC 60694. The rated switching impulse withstand voltage should be taken from column (4) of this Table. The reference value for the condition check should be taken from the same column.

Where an impulse voltage test should be carried out, five impulses of each polarity should be applied across the switching device and to earth (if required). The by-pass switch should be considered to have passed the test if no disruptive discharge occurs.

For the impulse voltage test, the synthetic testing equipment of the power laboratory may be applied. The waveshape of the impulse voltage should be either a standard switching impulse or a waveshape according to the TRV specified for terminal fault T10 (see IEC 62271-100). For the test with the waveshape according to T10, timing tolerances of –10 % and +200 % on time $t_3$ are permitted.

NOTE 1 Comparative tests have shown that there are almost no differences in the behaviour of circuit-breakers, both in new and in worn conditions, when testing is performed with standard switching impulses or with TRV impulses with a waveshape in accordance with terminal fault T10, respectively.

NOTE 2 If the tests are performed using the TRV impulse with a T10 waveshape, equivalence is maintained to the standard switching impulse if the following rules are applied:

– the damping of the TRV should be such that the second peak of the TRV oscillation is not higher than 80 % of the first one;

– about 2,5 ms after the peak the actual value of the recovery voltage should be in the range of 50 % of the peak value.

### 6.3 Radio interference voltage (r.i.v.) tests

Subclause 6.3 of IEC 60694 is applicable with the following addition:

Tests may be performed on one pole of the by-pass switch in closed position only. During the tests the by-pass switch should be equipped with all accessories such as grading capacitors, corona rings, HV connectors, etc., which may influence the radio interference voltage performance.

NOTE If the by-pass switch forms an integral part of the series capacitor platform and r.i.v. tests have been performed on the platform, the r.i.v. test on the by-pass switch is considered to be covered.

### 6.4 Measurement of the resistance of the main circuit

Subclause 6.4 of IEC 60694 is applicable.

### 6.5 Temperature-rise tests

#### 6.5.1 Conditions of the by-pass switch to be tested

Subclause 6.5.1 of IEC 60694 is applicable.

#### 6.5.2 Arrangement of the equipment

Subclause 6.5.2 of IEC 60694 is applicable.

#### 6.5.3 Measurement of the temperature and the temperature rise

Subclause 6.5.3 of IEC 60694 is applicable.

### 6.5.4 Ambient air temperature

Subclause 6.5.4 of IEC 60694 is applicable.

### 6.5.5 Temperature-rise tests of the auxiliary and control equipment

Subclause 6.5.5 of IEC 60694 is applicable.

### 6.5.6 Interpretation of the temperature-rise tests

Subclause 6.5.6 of IEC 60694 is applicable.

## 6.6 Short-time withstand current and peak withstand current tests

Subclause 6.6 of IEC 60694 is applicable.

### 6.6.1 Arrangement of the by-pass switch and of the test circuit

Subclause 6.6.1 of IEC 60694 is applicable.

### 6.6.2 Test current and duration

Subclause 6.6.2 of IEC 60694 is applicable.

### 6.6.3 Behaviour of the by-pass switch during test

Subclause 6.6.3 of IEC 60694 is applicable.

### 6.6.4 Conditions of the by-pass switch after test

Subclause 6.6.4 of IEC 60694 is applicable.

## 6.7 Verification of the degree of protection

### 6.7.1 Verification of the IP coding

Subclause 6.7.1 of IEC 60694 is applicable to all parts of by-pass switches that are accessible in normal service.

### 6.7.2 Mechanical impact test

Subclause 6.7.2 of IEC 60694 is applicable.

## 6.8 Tightness tests

Subclause 6.8 of IEC 60694 is applicable.

## 6.9 Electromagnetic compatibility (EMC) tests

Subclause 6.9 of IEC 60694 is applicable.

## 6.101 Mechanical and environmental tests

### 6.101.1 Miscellaneous provisions for mechanical and environmental tests

#### 6.101.1.1 Reference mechanical travel characteristics

At the beginning of the type tests, the mechanical travel characteristics of the by-pass switch should be established, for example, by recording no-load travel curves. These curves will serve as the reference mechanical travel characteristics. The purpose of these reference

mechanical travel characteristics is to characterise the mechanical behaviour of the by-pass switch. Similar tests are required before and/or after other tests including mechanical, environmental, by-pass making and insertion tests and at the time of routine testing and commissioning tests, if applicable.

The following operating characteristics should be recorded:

– mechanical travel characteristics for opening and closing operation;
– the sensor used for the record of the mechanical travel characteristics should be mounted at a suitable location making it possible to provide the mechanical travel characteristics at best, either directly or indirectly. The location should be stated in the test report. The mechanical travel characteristics curve may be recorded continuously or discretely. In the latter case, at least 20 discrete values should be given for the complete stroke;
– closing time;
– opening time.

The reference mechanical travel characteristics should be produced during a no-load test made with the operating sequence C - $t$ - OC at rated supply voltage of operating devices and of auxiliary and control circuits, rated functional pressure for operation and, for convenience of testing, at the minimum functional pressure for by-passing and insertion. The reference no-load test may be taken from any appropriate no-load test being part of an individual type test.

The reference mechanical travel characteristics should be used to confirm that the different test samples used during the mechanical, by-pass and insertion type tests behave mechanically in a similar way. All test samples used for mechanical, by-pass and insertion type tests should have a mechanical travel characteristic within the following described envelopes. When, due to variable measuring methods at different laboratories, a direct comparison between the envelopes cannot be made, the manufacturer should be able to show evidence that the envelopes correspond.

The reference mechanical travel characteristics should be used for determining the limits of the allowable deviations over or under this reference curve. From this reference curve, two envelope curves should be drawn from the instant of contact separation to the end of the contact travel for opening and from start of the contact travel to the instant of contact touch for closing. The distance of the two envelopes from the original course should be ±5 % of the total stroke as shown in Figure 7b. In case of by-pass switches with a total stroke of 20 mm or less the distance of the two envelopes from the original course should be ±2 mm. It is recognised that for some designs of by-pass switches these methods are inappropriate. In such cases, the manufacturer should justify the method and limits used.

The series of Figures 7a through 7d are for illustrative purposes and only illustrate the opening operation. They are idealised, and do not show the variation in profile caused by the friction effect of the contacts or the end of travel damping. In particular, it is important to note that the effects of damping are not shown in these diagrams. The oscillations produced at the end of travel are dependent upon the efficiency of the damping of the drive system. The shape of these oscillations may be a deliberate function of the design or be caused by poor design, manufacture, assembly or adjustment. Therefore, it is important that any variations in the curve at the end of the stroke, which are outside the tolerance margin given by the envelope, are fully explained and understood before they are rejected or accepted as showing equivalence with the reference curves. In general, all curves should fall within the envelopes for acceptance.

The envelopes can be moved in the vertical direction until one of the curves covers the reference curve. This gives maximum tolerances over the reference mechanical travel characteristics of –0 %, +10 % and –10 %, +0 %, respectively as shown in Figures 7c and 7d. The displacement of the envelope can be used only once for the complete procedure in order to get a maximum total deviation from the reference characteristic of 10 %.

The opening time and the closing time recorded in the reference no-load test should be used as reference closing and reference opening time. The allowable deviations from these reference times correspond to the tolerances given by the manufacturer, but should not exceed ±10 %, when performed at rated control voltage.

#### 6.101.1.2 Component tests

When testing of a complete by-pass switch is not practicable, component tests may be accepted as type tests. The manufacturer should determine the components that are suitable for testing.

Components are separate functional sub-assemblies that can be operated independently of the complete by-pass switch (for example, pole, by-pass unit, operating mechanism).

When component tests are made, the manufacturer should prove that the mechanical and environmental stresses on the component during the tests are not less than those applied to the same component when the complete by-pass switch is tested. Component tests should cover all different types of components of the complete by-pass switch, provided that the particular test is applicable to the component. The conditions for the component type tests should be the same as those which could be employed for the complete by-pass switch.

Parts of auxiliary and control equipment that have been manufactured in accordance with relevant standards should comply with these standards. The proper function of such parts in connection with the function of the other parts of the by-pass switch should be verified.

#### 6.101.1.3 Characteristics and settings of the by-pass switch to be recorded before and after the tests

Before and after the tests, the following operating characteristics or settings should be recorded and evaluated:

a) closing time;
b) opening time;
c) time spread between units of one pole;
d) time spread between poles (if multi-pole 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, if applicable;
j) gas densities or pressures, if applicable;
k) resistance of the main circuit;
l) time-travel chart;
m) other important characteristics or settings as specified by the manufacturer.

The above operating characteristics should be recorded at

– rated supply voltage and rated filling pressure for operation;
– maximum supply voltage and maximum filling pressure for operation;
– maximum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and minimum functional pressure for operation;
– minimum supply voltage and maximum filling pressure for operation.

#### 6.101.1.4 Condition of the by-pass switch during and after the tests

During and after the tests, the by-pass switch should be in such a condition that it is capable of operating normally, carrying its rated normal current, by-passing its rated by-pass making current and inserting its rated insertion current and withstanding the voltage values according to its rated insulation levels.

In general, these requirements are fulfilled if

– during the tests, the by-pass switch operates on command and does not operate without command;

– after the tests, the characteristics measured according to 6.101.1.3 are within the tolerances given by the manufacturer;

– 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 should be regarded as bare and the test requirements are fulfilled only if the temperature rise of the contacts during the temperature-rise test (according to 6.5) 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 by-pass switch or prevents the proper fitting of any replacement part;

– after the tests the insulating properties of the by-pass switch in the open position should be in essentially the same condition as before the tests. Visual inspection of the by-pass switch after the tests is usually sufficient for verification of the insulating properties. In the case of by-pass switches with sealed-for-life by-pass units, a voltage test as a condition check in accordance with 6.2.11 may be necessary.

#### 6.101.1.5 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 should 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) should be arranged to switch the current of the circuits to be controlled (see 5.4);

– during and after the tests, the auxiliary and control equipment should fulfil its functions;

– during and after the tests, capability of the auxiliary circuits of the auxiliary switches and of the control equipment should not be impaired. In case of doubt, the tests according to 6.2.10 of IEC 60694 should be performed;

– during and after the tests, the contact resistance of the auxiliary switches should not be affected adversely. The temperature rise when carrying the rated current should not exceed the specified values (see Table 3 of IEC 60694).

### 6.101.2 Mechanical operation test at ambient air temperature

#### 6.101.2.1 General

The mechanical operation test should 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 should be included.

The mechanical operation test should consist of 2 000 operating sequences .

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

### 6.101.2.2 Condition of the by-pass switch before the test

The by-pass switch for test should be mounted on its own support and its operating mechanism should be operated in the specified manner. It should be tested according to its type as follows:

A three-pole by-pass switch actuated by a single operating device and/or with all poles mounted on a common frame should be tested as a complete unit.

Tests should be conducted at the rated filling pressure for by-passing and insertion according to 6.101.1.3, item j).

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

– reference mechanical travel characteristics;
– power and strength of closing and opening mechanism;
– rigidity of structure.

### 6.101.2.3 Description of the test on class M1 by-pass switches

The by-pass switch should be tested in accordance with Table 3.

**Table 3 – Number of operating sequences**

| Operating sequence | Supply voltage and operating pressure | Number of operating sequences | |
|---|---|---|---|
| | | By-pass switches for auto-reopening | By-pass switches not for auto-reopening |
| O - $t_a$ – C – $t_a$ | Minimum | 500 | 500 |
| | Rated | 500 | 500 |
| | Maximum | 500 | 500 |
| C - $t$ - OC - $t_a$ – O - $t_a$ | Rated | 250 | - |
| OC – $t_a$ | Rated | - | 500 |

O = opening;

C = closing;

OC = an opening operation followed immediately (i.e., without any intentional time-delay) by a closing 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 by-pass switch (this time can be different according to the type of operation);

$t$ = 0,2 s for by-pass switches intended for rapid auto-reopening, if not otherwise specified.

### 6.101.2.4 Extended mechanical endurance tests on class M2 by-pass switches for special service requirements (multi-segmented series capacitor banks)

For special service requirements in the case of frequently operated by-pass switches (used in multi-segmented series capacitor banks), extended mechanical endurance tests may be carried out, as follows.

The tests should be made according to 6.101.1, 6.101.2.1, 6.101.2.2 and 6.101.2.3 with the following addition:

– the tests should consist of 10 000 operating sequences comprising five times the relevant test series specified in Table 3;

– between the test series specified, some maintenance, such as lubrication and mechanical adjustment, is allowed, and should be performed in accordance with the manufacturer's instructions. Change of contacts is not permitted;

– the programme of maintenance during the tests should be defined by the manufacturer before the tests and recorded in the test report.

#### 6.101.2.5 Acceptance criteria for the mechanical operation tests

The criteria given below apply for mechanical operation tests on class M1 and class M2 by-pass switches.

a) Before and after the total test programme, the following operations should be performed:

   – five open-close operations at the rated supply voltage of closing and opening devices and of auxiliary and control circuits and the rated pressure for operation;

   – five open-close operations at the minimum supply voltage of closing and opening devices and of auxiliary and control circuits and the minimum pressure for operation;

   – five open-close operations at the maximum supply voltage of closing and opening devices and of auxiliary and control circuits and the maximum pressure for operation.

   During these operations, the operating characteristics (see 6.101.1.3) should be recorded and evaluated. It is not necessary to publish all the oscillograms recorded. However, at least one oscillogram for each set of conditions given above should be included in the test report.

In addition, the following checks and measurements should be performed (see 10.2.102):

   – measurements of characteristic operating fluid pressures and consumption during operations, if applicable;

   – verification of the rated operating sequence;

   – checks of certain specific operations, if applicable.

   The variation between the mean values of each parameter measured before and after the extended mechanical endurance tests should be within the tolerances given by the manufacturer.

b) After each series of 2 000 operating sequences the operating characteristics a), b), c), d), e) and l) in 6.101.1.3 should be recorded.

c) After the total test programme the condition of the by-pass switch should be in accordance with 6.101.1.4.

#### 6.101.3 Low and high temperature tests

##### 6.101.3.1 General

The two tests need not be performed in succession, and the order in which they are made is arbitrary. For class –10 °C outdoor by-pass switches, no low temperature test is required.

For single enclosure by-pass switches or multi-enclosure by-pass switches with a common operating device, three-pole tests should be made. For multi-enclosure by-pass switches with independent poles, testing of one complete pole is permitted.

Owing to limitations of the test facilities, multi-enclosure type by-pass switches may be tested using one or more of the following alternatives provided that the by-pass switch in its testing arrangement is not in a more favourable condition than normal condition for mechanical operation (see 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 should be in operation.

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

No maintenance, replacement of parts, lubrication or readjustment of the by-pass switch 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 subclauses may be necessary.

As an alternative approach to the methods in this specification, a manufacturer may establish compliance with performance requirements for an established by-pass switch family by documenting satisfactory by-pass switch 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 depending on the class of the by-pass switch (see Clause 2 of IEC 60694).

#### 6.101.3.2 Measurement of ambient air temperature

The ambient air temperature of the immediate test environment should be measured at half the height of the by-pass switch and at a distance of 1 m from the by-pass switch.

The maximum temperature deviation over the height of the by-pass switch should 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 4a.

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 by-pass switch should be adjusted in accordance with the manufacturer's instructions.

b) Characteristics and settings of the by-pass switch should be recorded in accordance with 6.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C ($T_A$). The tightness test (if applicable) should be performed according to 6.8.

c) With the by-pass switch in the open position, the air temperature should be decreased to the appropriate, minimum ambient air temperature ($T_L$), according to the class of the by-pass switch as given in 2.1.1, 2.1.2 and 2.2.3 of IEC 60694. The by-pass switch should be kept in the open position for 24 h after the ambient air temperature stabilises at $T_L$.

d) During the 24 h period with the by-pass switch in the open position at temperature $T_L$, a tightness test should be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the by-pass switch is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate should not exceed the permissible temporary leakage rate of Table 12 of IEC 60694.

e) After 24 h at temperature $T_L$, the by-pass switch should be closed and opened at rated values of supply voltage and operating pressure. The closing time and the opening time

should be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible.

f) The low temperature behaviour of the by-pass switch and its alarms and lock-out systems should be verified by disconnecting the supply of all heating devices, including also the anti-condensation heating elements, for a duration $t_x$. During this interval, occurrence of the alarm is acceptable but lock-out is not. At the end of the interval $t_x$, a closing order, at rated values of supply voltage and operating pressure, should be given. The by-pass switch should then close. The closing time should be recorded (and the mechanical travel characteristics measured, if feasible) to allow assessment of the by-passing capability.

The manufacturer should state the value of $t_x$ (not less than 2 h) up to which the by-pass switch is still operable without auxiliary power to the heaters. In the absence of such a statement, the preferred value should be equal to 2 h.

g) The by-pass switch should be left in the closed position for 24 h.

h) During the 24 h period with the by-pass switch in the closed position at temperature $T_L$, a tightness test should be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the by-pass switch is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate should not exceed the permissible temporary leakage rate of Table 12 of IEC 60694.

i) At the end of the 24 h period, 50 opening and 50 closing operations should be made at rated values of supply voltage and operating pressure with the by-pass switch at temperature $T_L$. At least a 3 min interval should be allowed for each cycle or sequence. The first opening and closing operation should be recorded to establish low temperature operating characteristics. Contact velocity should be recorded if feasible. Following the first opening operation (O) and the first closing operation (C) three OC operating cycles (no intentional time delay) should be performed. The additional operations should be made by performing O - $t_a$ - C - $t_a$ operating sequences ($t_a$ is defined in Table 3).

j) After completing the 50 opening and 50 closing operations, the air temperature should 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 by-pass switch should be subjected to alternate O - $t_a$ - C - $t_a$ - O and C - $t_a$ - O - $t_a$ - C 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 by-pass switch will be in open and closed positions for 30 min periods between the operating sequences.

k) After the by-pass switch has stabilised thermally at ambient air temperature $T_A$, a recheck should be made of the by-pass switch settings, operating characteristics and tightness as in Items a) and b) for comparison with the initial characteristics.

The accumulated leakage during the complete low temperature test sequence from item b) to item j) should not be such that lock-out pressure is reached (reaching alarm pressure is allowed).

#### 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 4b.

If the high temperature test is performed immediately after the low temperature test, the high temperature test can proceed after completion of item j) of the low temperature test. In this case, items l) and m) below are omitted.

l) The test by-pass switch should be adjusted in accordance with the manufacturer's instructions.

m) Characteristics and settings of the by-pass switch should be recorded in accordance with 6.101.1.3 and at an ambient air temperature of 20 °C ± 5 °C ($T_A$). The tightness test (if applicable) should be performed according to 6.8.

n) With the by-pass switch in the open position, the air temperature should be increased to the appropriate, maximum ambient air temperature ($T_H$), according to the upper limit of ambient air temperature as given in 2.1.1, 2.1.2 and 2.2.3 of IEC 60694. The by-pass switch should be kept in the open position for 24 h after the ambient air temperature stabilises at $T_H$.

NOTE The influence of solar radiation is not considered.

o) During the 24 h period with the by-pass switch in the open position at the temperature $T_H$, a tightness test should be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the by-pass switch is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate should not exceed the permissible temporary leakage rate of Table 12 of IEC 60694.

p) After 24 h at the temperature $T_H$, the by-pass switch should be closed and opened at rated values of supply voltage and operating pressure. The closing time and the opening time should be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

q) The by-pass switch should be closed and left closed for 24 h at the temperature $T_H$.

r) During the 24 h period with the by-pass switch in the closed position at the temperature $T_H$, a tightness test should be performed (if applicable). An increased leakage rate is acceptable, provided that it returns to the original value when the by-pass switch is restored to the ambient air temperature $T_A$ and is thermally stable. The increased temporary leakage rate should not exceed the permissible temporary leakage rate of Table 12 of IEC 60694.

s) At the end of the 24 h period, 50 opening and 50 closing operations should be made at rated values of supply voltage and operating pressure with the by-pass switch at the temperature $T_H$. An interval of at least 3 min should be allowed for each cycle or sequence. The first opening and closing operation should be recorded to establish high temperature operating characteristics. Contact velocity should be recorded if feasible.

   Following the first opening operation (O) and the first closing operation (C) three OC operation cycles (no intentional time delay) should be performed. The additional operations should be made by performing O - $t_a$ - C - $t_a$ operating sequences ($t_a$ is defined in Table 3).

t) After completing the 50 opening and 50 closing operations, the air temperature should be decreased to ambient air temperature $T_A$, at a rate of change of approximately 10 K/h.

   During the temperature transition period, the by-pass switch should be subjected to alternate O - $t_a$ - C - $t_a$ - O and C - $t_a$ - O - $t_a$ - C 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 by-pass switch will be in the closed and open positions for 30 min periods between the operating sequences.

u) After the by-pass switch has stabilised thermally at ambient air temperature $T_A$, a recheck should be made of the by-pass switch settings, operating characteristics and tightness as in items l) and m) for comparison with the initial characteristics.

   The accumulated leakage during the complete high temperature test sequence from item l) to item u) should not be such that lock-out pressure is reached (reaching alarm pressure is allowed).

### 6.101.4 Humidity test

The humidity test does not apply to by-pass switches.

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

The test under severe ice conditions is applicable only to by-pass switches having moving external parts and for which a class of 10 mm or 20 mm of ice thickness is specified. The test should be performed under the conditions described in IEC 60129.

### 6.101.6 Static terminal load test

#### 6.101.6.1 General

The static terminal load test is performed to demonstrate that the by-pass switch operates correctly when loaded by stresses resulting from ice, wind and connected conductors.

The static terminal load test is applicable only to by-pass switches having a rated voltage to earth of 52 kV and above.

If the manufacturer, using calculations, can prove that the by-pass switch can withstand the stresses, tests need not be performed.

Ice coating and wind pressure on the by-pass switch should be in accordance with 2.1.2 of IEC 60694.

Some examples of forces due to flexible and tubular connected conductors (not including wind or ice load or the dynamic loads on the by-pass switch itself) are given as a guide in Table 4.

The tensile force due to the connected conductors is assumed to act at the outermost end of the by-pass switch terminal.

For simultaneous action of ice, wind and connected conductors, the resultant terminal forces, $F_{shA}$, $F_{shB}$ and $F_{sv}$ respectively (see Figure 5) are defined as rated static terminal loads.

#### 6.101.6.2 Tests

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

The tests should be made on at least one complete pole of the by-pass switch. 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 by-pass switches that are symmetrical about the pole unit vertical centreline, only one terminal need be tested with the rated static terminal load. For by-pass switches which are not symmetrical, each terminal should be tested.

Tests should be made separately, firstly with a horizontal force, $F_{shA}$, applied in longitudinal axis of the terminal (direction A in Figure 6), 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 6) and thirdly, with a vertical force, $F_{sv}$ applied in two directions successively (directions $C_1$ and $C_2$ in Figure 6). To avoid the need to apply a special force representing the force of wind acting at the by-pass switch's centre of application of pressure, this wind load may be applied at the terminal (see Figure 5) and reduced in magnitude in proportion to the longer lever arm (the bending moment at the lowest part of the by-pass switch should be the same).

Two operations should be performed for each of the five terminal load tests.

**Table 4 – Examples of static horizontal and vertical forces for static terminal load test**

| Rated voltage range to earth | Rated current range | Static horizontal force $F_{th}$ | | Static vertical force (vertical axis-upward and downward) |
|---|---|---|---|---|
| | | Longitudinal | Transversal | |
| $U_{re}$ | $I_r$ | $F_{thA}$ | $F_{thB}$ | $F_{tv}$ |
| kV | A | N | N | 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 – 362 | 1 600 – 4 000 | 1 250 | 1 000 | 1 250 |
| 420 – 800 | 2000 – 4 000 | 1 750 | 1 250 | 1 500 |

### 6.102 Miscellaneous provisions for by-pass making and insertion tests

The following subclauses are applicable to all by-pass making and insertion tests.

Where applicable, prior to the commencement of the tests, the manufacturer should declare the values of

– minimum conditions of the operating mechanism guaranteeing the rated operating sequence (for example the minimum functional pressure for operation in case of a hydraulic operating mechanism);

– minimum conditions of the interrupting device guaranteeing the rated operating sequence (for example the minimum functional pressure for by-passing and insertion in case of a gas by-pass switch).

#### 6.102.1 General

By-pass switches should be capable of by-passing all currents up to and including the rated by-pass making current. In addition, by-pass switches should be capable of inserting all currents up to and including the rated by-pass insertion current.

This is demonstrated when the by-pass switch is subjected to the particular by-pass making current and insertion current tests outlined in this specification.

By-pass making current and insertion current tests are normally performed in single-phase on a complete pole, see also 6.102.4.1.

The by-pass making current test is normally performed with a single power source (pre-charged capacitor bank) while the insertion current test may be performed with several sources where all of the current, or a major part of it, is obtained from one source and the recovery voltage is obtained only, or in part, from a separate source (synthetic tests).

During testing of a metal enclosed by-pass switch, the insulation to earth is not stressed with the full voltage phase-to-earth voltage occurring during a by-pass or insertion operation. It may be necessary to prove that the insulation to earth is capable of withstanding this full voltage after the required test duties. The influence of exhaust gases should also be taken into account.

NOTE Where the by-pass switch consists of three poles in one enclosure, the test procedure should be modified as suggested in IEC 61633 for capacitive current switching.

If, due to limitations of the testing facilities, the overall performance of the by-pass switch cannot be proved in the above way, several methods employing either direct or synthetic test methods may be used either singly or in combination, unit testing, depending on the by-pass switch type.

### 6.102.2 Number of test specimens

Subclause 6.1.1 of IEC 60694 is applicable with the following addition:

For the performance of by-pass making current and insertion current tests a unique test specimen should be used without any maintenance permitted between the test duties.

### 6.102.3 Arrangement of by-pass switch for tests

#### 6.102.3.1 General

The by-pass switch under test should be mounted on its own support or on an equivalent support. A by-pass switch supplied as an integral part of an enclosed unit should be assembled on 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.

To facilitate consistent control of the closing and opening operation, the closing and/or opening releases can be supplied at their maximum supply voltage, provided that the contact speed is not affected. If the contact speed is dependent on the supply voltage, the operating device should be operated in the manner specified and in particular, if it is electrically or spring operated, closing solenoid or shunt closing releases and shunt opening releases should be supplied at their respective minimum voltages guaranteeing successful operation (85 % of the rated voltage if a.c. 70 % if d.c. of the rated voltage for the closing solenoid or shunt closing releases, 85 % of the rated voltage for the opening releases). When it is required that pneumatically or hydraulically operated devices be operated at the minimum functional pressure for operation the following procedure applies. This procedure is based on the fact that the by-pass making and insertion test-duties call for separate C and O operations.

e) before performing by-pass making current and insertion current tests and starting from the minimum functional pressure for operation as per 3.7.137, all the pressures during the rated operating sequence carried out at no-load should be recorded;

f) the recorded values should be compared with the minimum values declared by the manufacturer as guaranteeing successful operations as separate C and O;

g) when required, tests should be carried out at the pressure for operation set at the minimum functional value resulting from a) and b) above, whatever is the lower, for the corresponding operation in the test-duty; the pressure values should be reported in the test report.

Interlocking devices associated with pressure interlocks should be made inoperative during the tests, if they interfere with the intent of the test.

It should be shown that the by-pass switch will operate satisfactorily under the above conditions at no-load as specified in 6.102.6. When required, the pressure of the compressed gas for by-passing, insertion and/or insulation, if any, should be set at its minimum functional value according to 3.7.138.

The by-pass switch should be tested according to its type as specified in 6.102.3.2 and 6.102.3.3.

#### 6.102.3.2 Common enclosure type

Generally not applicable for by-pass switches, see note of 6.102.1.

#### 6.102.3.3 Multi-enclosure type

A three-pole by-pass switch consisting of three independent single-pole switching devices is normally tested single-phase according to 6.102.4.1. The manufacturer should give testing evidence to show compliance with 5.101.

A three-pole by-pass switch not having completely independent switching devices should also be tested single-phase. However, the mechanical and electrical conditions applied during the tests should be equivalent to, or not in a more favourable condition than, the complete three-pole by-pass switch over the range of tests in respect of

– mechanical travel characteristics in a by-pass making current operation (for the evaluation method, see 6.102.4 and 6.102.7);
– mechanical travel characteristics in an insertion current operation (for the evaluation method, see 6.102.4 and 6.102.7);
– availability of arc-extinguishing medium;
– power and strength of closing and opening devices;
– rigidity of structure.

If these conditions cannot be fulfilled, the manufacturer and user should agree upon a suitable test procedure.

### 6.102.4 General considerations concerning testing methods

#### 6.102.4.1 Single-phase testing of a single pole of a three-pole by-pass switch

According to this method, a single-pole of a three-pole by-pass switch is tested single-phase, applying to the pole the same test currents and the same voltage that would be impressed upon the most highly stressed pole during three-phase by-pass making current and insertion current tests by the complete three-pole by-pass switch under corresponding conditions.

A three-pole operated by-pass switch can be tested single-pole provided that a three-pole assembly is provided for the tests.

#### 6.102.4.2 Unit testing

Certain by-pass switches are constructed by assembling identical by-pass and/or insertion 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 by-pass making and insertion performance of a by-pass switch to be tested by carrying out tests on one or more units. The requirements of 6.101.1.1, 6.102.3 and 6.102.4.1 also apply for unit testing. Since therefore at least a complete pole assembly has to be made available for the verification tests on one or more units, the test results relate only to this specific pole design.

The following situations can be distinguished:

h) The by-pass switch pole consists of units (or assemblies of units) which are separately operated and which have no mutual connections for the arc extinguishing medium.

   In this case unit testing is acceptable. However, the mutual influence through the electrodynamic forces of the current on the units and the arc in the units should be taken into account (see Figure 8). This may be done by substitution of the second unit by a conductor with equivalent shape.

i) The by-pass switch pole consists of units (or assemblies of units) which are separately operated but which have a mutual connection for the arc extinguishing medium.

In this case, unit testing is acceptable for the insertion current test-duty only. For the by-pass making current test-duty, unit testing can be also acceptable if the units not under test arc during the test.

j) The by-pass switch pole consists of units (or assemblies of units) which are not separately operated.

In this case, unit testing is acceptable for the insertion current test-duty only. Moreover, the influence of electrodynamic forces (see also item a) above) should be covered.

For the by-pass making current test-duty, unit testing can be also acceptable if the units not under test arc during the test.

k) For insertion current test-duty, single-unit testing is permissible if the arc extinguishing medium volume of the single unit under test is proportional to the applicable part of one assembly of units having the same arc extinguishing medium.

The mechanical no-load travel characteristics for single-unit testing and for full-pole testing should be the same.

When carrying out unit tests, it is essential that the units are identical and that the static voltage distribution for the type of test is known.

#### 6.102.4.2.1 Identical nature of the units

The units of the by-pass switch should be identical in their shape, in their dimensions and in their operating conditions; only the devices for controlling the voltage distribution among units may be different. In particular, the following conditions should be fulfilled.

a) *Operation of contacts*

The opening, in insertion current tests, or the closing, in by-pass making current tests, of the contacts of one pole should 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 one-eighth of a cycle of rated frequency. Rated operating pressures and voltages should be used to determine this time interval.

b) *Supply of the arc-extinguishing medium*

For a by-pass switch using a supply of arc-extinguishing medium from a source external to the units, the supply to each unit should, be independent of the supply to the other units, and the arrangement of the supply pipes should be such as to ensure that all units are fed essentially together and in an identical manner.

#### 6.102.4.2.2 Voltage distribution

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

The voltage distribution between units of a pole, as affected by the influence of earth, should be determined for the relevant test conditions.

Where the units are not symmetrically arranged, the voltage distribution should be determined also with reverse connections.

The voltage distribution is determined either by measurement or by calculations. Values used in the calculations should be supported by measurements of the stray capacitances of the by-pass switch. Such calculations and supporting measurements verifying the assumptions used in the calculations are the responsibility of the manufacturer.

The voltage distribution may be calculated or measured at power frequency only.

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

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

#### 6.102.4.2.3 Requirements for unit testing

When testing a single unit, the test voltage should be the voltage of the most highly stressed unit of the complete pole of the by-pass switch, determined in accordance with 6.102.4.2.2.

When testing a group of units, the voltage appearing at the terminals of the most highly stressed unit of the group should be equal to the voltage of the most highly stressed unit of the pole, both determined in accordance with 6.102.4.2.2.

### 6.102.4.3 Multi-part testing

Multi-part testing is not applicable to by-pass switches.

### 6.102.5 Synthetic tests

Synthetic testing methods can be applied for insertion current tests. Synthetic testing techniques and methods proposed for capacitive current switching as described in IEC 60427 can be used as reference.

### 6.102.6 No-load operations before tests

Before commencing by-pass making current and insertion current tests, no-load operations and no-load operating sequences (C, OC and C - $t$ - OC) should be made and details of the operating characteristics of the by-pass switch recorded. Details such as closing time and opening time should be recorded.

In addition, it should be demonstrated that the mechanical behaviour of the by-pass switch, or sample under test, conforms to that of the reference mechanical travel characteristics required in 6.101.1.1. For this test the operational conditions stated in 6.101.1.1 apply.

The pressure of the fluid for by-passing and insertion should be set at its minimum functional value according to 3.7.138.

For electrically or spring-operated by-pass switches, operations should be made with the closing solenoid or shunt-closing releases energised at 100 % and 85 % in the case of a.c. or 70 % in the case of d.c. of the rated supply voltage of the closing device and with the shunt-opening release(s) energised at 100 % and 85 % of the rated supply voltage.

For pneumatic or hydraulic operating devices, the operations should be made under the following conditions:

a) pressure of the fluid for operation set at its minimum functional value as per 3.7.137 with the shunt opening releases energised at 85 % and with the shunt closing releases energised at 85 % in case of a.c., 70 % in case of d.c. of the rated supply voltage.

b) pressure of the fluid for operation set at its rated value as per 4.10 with the shunt releases energised at the rated supply voltage.

### 6.102.7 Alternative operating mechanisms

If the by-pass switch is designed for use with alternative operating mechanisms, a separate series of by-pass making current and insertion current test-duties should 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 closing and opening characteristics of the by-pass switch.

If this can be satisfactorily shown, the test-duties do not need to be repeated.

Evidence of the equivalence of an alternative operating mechanism should be produced by use of the following verification test.

a) On each of the by-pass switches (with an original operating mechanism and with an alternative operating mechanism) a no-load open-close operation should be performed. For each of the tests the course of the contact stroke should be recorded. The course of the contact stroke during the test with the original mechanism should be used as the reference (see Figure 7a). The curves obtained during opening and closing with the alternative operating mechanism should be within the two envelope curves as described in 6.101.1.1 from the instant of contact separation to the end the contact travel and from the start of contact travel to contact touch, respectively.

b) On each of the by-pass switches a by-pass making current operation should be performed. The test results should be evaluated according to the method prescribed under a) above.

### 6.102.8 Behaviour of by-pass switch during tests

During by-pass and insertion tests, the by-pass switch should not

– show signs of distress;

– show harmful interaction with adjacent laboratory equipment;

– exhibit behaviour which could endanger an operator.

For by-pass switches which are designed to have discharge of interrupting medium to atmosphere during the by-passing and insertion tests, the above requirements are considered to have been met, provided

– for oil by-pass switches, there is no outward emission of flame, and the gases produced, together with the oil carried with the gases, should be conducted from the by-pass switch and directed away from all live conductors and locations where persons may be present;

– for other types of by-pass switches, such as air blast or air break, there is an outward emission of flame, gas and/or metallic particles. If such emissions are appreciable it may be required that the tests should 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 should specify. The screens should be insulated from earth but connected thereto by a suitable device to indicate any significant leakage current to earth. There should be no indication of significant leakage currents to the by-pass switch earthed structure, or screens when fitted, during the tests.

NOTE If no other devices are available, 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.

If faults occur which are not persistent or due to defect in design, but rather are due to errors in assembly, the faults can be rectified and the by-pass switch subjected to a repetition of all test-duties. In those cases, the test report should include reference to the invalid tests.

### 6.102.9 Condition of by-pass switch after tests

#### 6.102.9.1 General

The by-pass switch should be inspected after completion of all test-duties. Its mechanical parts and insulators should be in essentially the same condition as before the test-duties. Visual inspection is usually sufficient for verification of the insulating properties. In case of doubt, the condition checking test according to 6.2.11 is sufficient to prove the insulation properties.

For by-pass switches with sealed-for-life units, the condition checking test is mandatory, except as stated in 6.102.9.2.

### 6.102.9.2 Condition after the by-pass current making and insertion test duties

The by-pass switch should, after performing the by-pass making current and insertion current test-duties specified in 6.105 and 6.106 be capable of operating satisfactorily at any by-pass making current and insertion current up to its rated by-pass making current and insertion current.

In addition the by-pass switch should be capable of carrying its rated normal current with a temperature rise not in excess of the temperature rise permitted by Table 3 of IEC 60694. In case of class BP2 by-pass switches, the temperature rise should not exceed the values permitted by Table 3 of IEC 60694 by more than 10 K.

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

Degradation of the components in the current carrying path should not reduce the integrity of the normal current carrying path.

If, during the insertion current tests, one restrike occurred, the dielectric condition checking test according to 6.2.11 should be performed before visual inspection, provided that the tested peak transient recovery voltage during the insertion current tests is lower than the peak voltage of the specified dielectric condition checking test. The subsequent visual inspection should demonstrate that the restrike occurred between the arcing contacts only. There should be no evidence of puncture, flashover or permanent tracking of internal insulating materials. Wear of the parts of arc control devices exposed to the arc is permissible as long as it does not impair the by-pass making and insertion capability. Moreover, the inspection of the insulating gap between the main contacts, if they are different from the arcing contacts, should not show any trace of a restrike.

If no restrike occurred during the insertion current tests visual inspection is sufficient. The dielectric condition checking test according to 6.2.11 is not necessary.

For by-pass switches with sealed-for-life by-pass units, the dielectric condition checking test according to 6.2.11 should be performed, whether a restrike occurs during testing or not, provided that the tested peak transient recovery voltage during the insertion current tests is lower than the peak voltage of the specified dielectric condition checking test.

### 6.102.9.3 Reconditioning after a test-duty

The by-pass switch should not be reconditioned during and in between the by-pass making current and insertion current test-duties.

If local safety rules require depressurising to enter the test cell, it is allowed to decrease the pressure in the by-pass switch provided that the gas is reused when refilling the circuit-breaker.

### 6.103 Invalid tests

In the case of an invalid test, it may become necessary to perform a greater number of tests than are required by this specification. An invalid test is one where one or more of the test parameters demanded by the specification are not met. This includes, for example, current, voltage and time factors as well as point-on-wave requirements (if specified) and the additional features in synthetic testing such as correct auxiliary switching device operation and correct injection time.

The deviation from the specification could make the test less or more severe. Four different cases are considered in Table 5.

The invalid part of the test-duty may be repeated without reconditioning of the by-pass switch. However, in the case of a failure of the by-pass switch during such additional tests, or at the discretion of the manufacturer, the by-pass switch may be reconditioned and the complete test-duties repeated. In those cases the test report should include reference to the invalid test.

If any record of an individual operation cannot be produced for technical reasons, this individual operation is not considered invalid, provided that evidence can be given in another manner that the by-pass switch did not fail and the required testing values were fulfilled.

**Table 5 – Invalid tests**

| Test conditions related to specification | By-pass switch | |
|---|---|---|
| | Passes | Fails |
| More severe | Test valid, result accepted | Test to be repeated with correct parameters<br><br>Modification of the design of the by-pass switch not required |
| Less severe | Test to be repeated with correct parameters<br><br>Modification of the design of the by-pass switch not required | By-pass switch failed the test. Modification of the design of the by-pass switch required, aiming for improvement of the by-pass making and insertion capability.<br><br>Tests to be re-started on the modified by-pass switch |

### 6.104 Sequence of the tests

The by-pass making current test-duty and the insertion current test-duty should be performed in the following order:

a) half of the required making operations at minimum functional pressures for operation and/or by-passing, insertion and insulation;

b) half of the required insertion operations at minimum functional pressures for operation and/or by-passing, insertion and insulation;

c) half of the required making operations at rated functional pressures for operation and/or by-passing, insertion and insulation;

d) half of the required insertion operations at rated functional pressures for operation and/or by-passing, insertion and insulation.

Maintenance is not permitted between the test-duties.

NOTE 1 It is also acceptable to perform the tests in the order a), c), b), d). This procedure requires more gas treatment operations. This should not be done without the consent of the manufacturer.

NOTE 2 It is also acceptable to perform all tests at minimum functional pressures for operation and/or by-passing, insertion and insulation. This should not be done without the consent of the manufacturer.

### 6.105 By-pass making current test duty

#### 6.105.1 General

Two classes of by-pass switches are defined according to their specific use (see 3.4.104 and 3.4.105).

This test-duty is valid for both rated frequencies i.e. for 50 Hz or 60 Hz systems.

### 6.105.2 Characteristics of supply circuit

It is recommended to use an oscillatory circuit (LC circuit, see Figure 9). The test circuit should fulfil the following requirements:

a) the characteristics of the test circuit should be such that the instantaneous applied voltage, just before the making operation, be equal to the limiting peak voltage of the overvoltage protector ($U_{LIM} \times \sqrt{2}$). A d.c. voltage can be applied.

b) the components of the oscillatory circuit (series inductance and precharged capacitor bank) should be selected in order to obtain the required by-pass current (first peak, $I_{BP}$) at the rated by-pass current discharge frequency ($f_{BP}$).

NOTE 1 The by-pass making performance is to be covered when the product of the required peak by-pass making current times the by-pass current discharge frequency ($I_{BP} \times f_{BP}$) is equal to or lower than the product of the actual values used in the test-duty.

c) the damping ratio of the by-pass current (sinusoidal exponential decaying current) may be adjusted to the service condition damping ratio by inserting an additional resistor in the oscillatory circuit. The damping ratio is defined as the ratio between the second peak and the first peak of the same polarity of the by-pass discharge current.

The damping ratio obtained during tests should be indicated in the test report.

In order to be a valid test-duty for a specific series capacitor installation, the damping ratio obtained during tests should be equal to or higher than the actual damping ratio at site.

NOTE 2 A deficiency to meet the damping ratio can be compensated by an higher by-pass making test current provided that the arc energy during the pre-arcing period is equal to or higher than the pre-arcing energy required by the applicable test parameters.

### 6.105.3 Test voltage

For both by-pass switch classes, the instantaneous test voltage to be applied across the by-pass switch, prior to the by-pass making tests, should be the limiting peak voltage of the overvoltage protector ($U_{LIM} \times \sqrt{2}$; $^{+5}_{-0}$ %).

### 6.105.4 Test current

For both by-pass switch classes, the first peak of the by-pass discharge current should be 1,0 × rated by-pass making current ( $^{+5}_{-0}$ EMBED %) at rated by-pass discharge current frequency ( $^{+5}_{-0}$ EMBED%).

### 6.105.5 Number of making operations

The by-pass making current test-duty comprises:

– *For by-pass switch class BP1 (see 3.4.104)*:
20 closing operations (20 C).

– *For by-pass switch class BP2 (only for applications without protective gap, see 3.4.105)*:
100 closing operations (100 C).

The by-pass switch conditions should be in accordance with 6.102.3.1. If the by-pass switch has a non-symmetrical current path, the terminal connections should be reversed for half of the number of required operations.

NOTE The number of operations for by-pass switch class BP2 may be reduced if the by-pass making current peak is increased from the rated value. The number of operations has to be reduced by considering the square value of the over-current factor. As an example, if the test current is 1,4 times the rated by-pass making current, the number of closing operations may be reduced to 50.

### 6.106 Insertion current test duty

#### 6.106.1 General

Re-ignitions during the insertion current test-duty are permitted but restrikes are not permitted unless otherwise indicated (a low expected probability of restrike is required).

NOTE 1 The restrike probability is related to the performance during the series of type tests.

NOTE 2 Phenomena occurring after a restrike or a re-ignition event are not representative of service conditions as the test circuit does not adequately reproduce the post-event voltage and current conditions.

To cover 50 Hz and 60 Hz application with one single test-duty, the transient recovery voltage should have a time-to-peak of 4,1 ms and follow a "1-cos" curve.

NOTE 3 System simulations showed that to cover the effect of the undertone frequency which is dependent of the compensation factor and the recovery voltage peak shift caused by power swing during insertion, the recovery voltage frequency has to be higher than the system power frequency. The envelope of the specified recovery voltage should cover most of the practical cases. Different recovery voltage waveshapes may be specified if required and justified by systems studies.

NOTE 4 For by-pass switches exclusively rated for 50 Hz systems, the transient recovery voltage time-to-peak should be increased to 5,0 ms.

The time-to-peak of 4,1 ms will result in a transient recovery voltage frequency of 120 Hz, the border delimiting a re-ignition and a restrike should therefore be set at 2,1 ms (1/4 of the recovery voltage frequency period).

NOTE 5 For by-pass switches exclusively rated for 50 Hz systems, the border delimiting a re-ignition and a restrike should be increased to 2,5 ms.

The test circuit branch supplying the power frequency test current should have a frequency ranging from 49 Hz to 61 Hz. The test circuit branch providing the transient recovery voltage should have a time-to-peak of 4,1 ms with a tolerance of ± 10 %.

NOTE 6 Tests performed with a current source frequency ranging from 49 Hz to 61 Hz are considered to prove the insertion capability for both system frequencies i.e. 50 Hz or 60 Hz.

#### 6.106.2 Characteristics of supply circuit

An oscillatory circuit (double frequency LC circuit, see Figure 10) with one oscillatory circuit branch feeding the power frequency current and another circuit branch producing the transient recovery voltage. Other test circuits as proposed by IEC 60427 for synthetic capacitive current switching tests may also be used. Other examples of synthetic and direct test circuits are shown in figures 11 and 12. The test circuit should fulfil the following requirements:

d) the characteristics of the test circuit current branch should be such that the instantaneous peak current, just before interruption, is equal to peak value of the rated insertion current. The current circuit should produce, as nearly as possible, a sinusoidal current waveshape (with the proposed synthetic test circuit, it will be a sinusoidal exponential decaying current). This condition is considered to be met if the ratio of the r.m.s. value to the r.m.s. value of the fundamental component does not exceed 1,2.

   Moreover, the current to be interrupted should not go through zero more than once per half-cycle of power frequency.

e) the characteristics of the test circuit voltage branch should be such that a recovery voltage having "1-cos" waveshape is generated across the by-pass switch terminals. The time-to-peak of the voltage waveshape should be 4,1 ms. The initial voltage jump that can appear at the beginning of the "1-cos" waveshape should be as small as possible and should never exceed 5 % of the recovery voltage peak.

#### 6.106.3 Test voltage

For both by-pass switch classes (BP1 and BP2), the recovery voltage peak to be applied across the by-pass switch should be the limiting peak voltage of the overvoltage protector ($U_{LIM} \times \sqrt{2}$; $^{+5}_{-0}$ %).

### 6.106.4 Test current

For both by-pass switch classes (BP1 and BP2), the test current should be the rated insertion current (±20 %).

### 6.106.5 Number of operations

For both by-pass circuit-breaker classes (BP1 and BP2), the insertion current test-duty comprises:

A total of two sets of 24 opening operations (2×24 O). The opening operations should be performed in the following manner:

– 6 O at minimum arcing on one polarity;
– 6 O at minimum arcing on the other polarity;
– Additional tests to achieve 24 O, distributed in both polarities (step: 30°);
– Reversal of the connections for the second set if the current path is not symmetrical;
– 6 O at minimum arcing on one polarity;
– 6 O at minimum arcing on the other polarity;
– Additional tests to achieve 24 O, distributed in both polarities (step: 30°)

NOTE 1 It is understood that to comply with this requirement, a search for the minimum arcing time should be done. These test shots are included in the total of 24 O for each individual set.

NOTE 2 It is understood that when following this procedure, the number of shots distributed at 30° steps at each polarity may not be equal. This is acceptable.

The minimum arcing time should be determined by changing the setting of the contact separation on opening by periods of approximately 6°. Using this method, several tests may be necessary to demonstrate the minimum arcing time and the maximum arcing time.

NOTE In order to obtain more consistent opening time of the by-pass switch, by agreement of the manufacturer, voltages even higher than the relevant upper tolerance limit of the supply voltages of the operating devices may be applied during these tests.

If a maximum arcing time is obtained instead of an expected minimum arcing time this is a valid test and should be included in the count for the total requirement. In such an event, the following will be necessary:

– advance the setting of the control of the tripping impulse by 6° and repeat the test. The new setting should be kept for other tests at minimum arcing time;
– make one less opening operation to retain the overall total count of tests.

The number of operations at minimum arcing time as stated above should be achieved, even if the specified total number of operations is exceeded.

A re-ignition followed by interruption at a later current zero should be treated as a insertion operation with long arcing time.

The by-pass switch conditions should be in accordance with Clause 6.102.3.1. If the by-pass switch has a non-symmetrical current path, the terminal connections should be reversed for the second set of operations as shown above.

### 6.107 Criteria to pass the test-duties

The by-pass switches should have successfully passed the tests if the following conditions are fulfilled:

a) the behaviour of the by-pass switch during by-pass making current and insertion current test-duties fulfils the conditions given in 6.102.8;

b) either no restrikes occurred during the insertion current test-duty, or, if only one restrike occurs in one of the two sets, then the set should be completed and repeated on the same test sample without any maintenance. No restrike should occur during the further tests. External flashover and phase-to-ground flashover should not occur;

c) the condition of the by-pass switch after the test series corresponds to the conditions given in 6.102.9.2. If no restrike occurred during the insertion test-duty, visual inspection is sufficient.

## 7 Routine tests

Clause 7 of IEC 60694 is applicable with the following addition:

### 7.1 Dielectric test on the main circuit

Subclause 7.1 of IEC 60694 is applicable with the following addition:

In the case of by-pass switches constructed by assembling identical by-pass units in series, the test voltage to be applied across each single unit, when open, should be the higher fraction of the total withstand voltage resulting from actual power-frequency voltage distribution with the by-pass switch fully open and one terminal earthed.

With reference to Figure 2 of IEC 60694, which shows a diagram of a three-pole by-pass switch, the test voltage should be applied, according to Table 6. For single pole by-pass switches the required tests are limited to two tests, one with the by-pass switch in the closed position and one with the by-pass switch in the open position. The required test levels for both positions can be different.

**Table 6 – Application of voltage for dielectric test on the main circuit**

| Test condition No. | By-pass switch | Voltage applied to | Earth connected to |
|---|---|---|---|
| 1 | Closed | AaCc | BbF |
| 2 | Closed | Bb | AaCcF |
| 3 | Open | ABC | abcF |

NOTE 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.

### 7.2 Dielectric test on auxiliary and control circuits

Subclause 7.2 of IEC 60694 is applicable.

### 7.3 Measurement of the resistance of the main circuit

Subclause 7.3 of IEC 60694 is applicable.

### 7.4 Tightness test

Subclause 7.4 of IEC 60694 is applicable.

### 7.5 Design and visual checks

Subclause 7.5 of IEC 60694 is applicable with the following addition:

The by-pass switch should be checked to verify its compliance with the order specification.

The following items should be checked as applicable:

– 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 connected to the main circuit.

### 7.101 Mechanical operating tests

Mechanical operating tests should include the following:

a) at maximum supply voltage of operating devices and of auxiliary and control circuits and maximum pressure for operation (if applicable):
   – five closing operations;
   – five opening operations.
b) at specified minimum supply voltage of operating devices and of auxiliary and control circuits and minimum functional pressure for operation (if applicable):
   – five closing operations;
   – five opening operations.
c) at rated supply voltage of operating devices and of auxiliary and control circuits and rated pressure for operation (if applicable):
   – five open-close operating cycles with the closing mechanism energised by the opening of the main contacts through the auxiliary switch;

Mechanical operating tests should be made on the complete by-pass switch. However, when by-pass switches are assembled and shipped as separate units, routine tests may be performed on components according to 6.101.1.2. In such cases, the manufacturer should produce a programme of commissioning tests for use at site to confirm the compatibility of such separate units and components when assembled as a by-pass switch. A guide for commissioning tests is given in 10.2.101.

For all required operating sequences the following should be performed and records made of the closing and opening operations:

– measurement of operating times;
– where applicable, measurement of fluid consumption during operations, for example pressure difference.

Proof should be given that the mechanical behaviour conforms to that of the test specimen used for type testing. For example, a no-load operating cycle, as described in 6.101.1.1, can be performed to record the no-load travel curves at the end of the routine tests. Where this is done, the curve should be within the prescribed envelope of the reference mechanical travel characteristic, as defined in 6.101.1.1, from the instant of contact separation to the end of contact travel or from the start of contact travel to the instant of contact touch.

Where the mechanical routine tests are performed on sub-assemblies, the reference mechanical travel characteristics should be confirmed to be correct, as above, at the end of the commissioning tests on site.

If the measurement is performed on site, the manufacturer should state the preferred measuring procedure. If other procedures are used, the results may be different and the comparison of the instantaneous contact stroke may be impossible to achieve.

The mechanical travel characteristics can be recorded directly, using a travel transducer or similar device on the by-pass switch contact system or at other convenient locations on the drive to the contact system where there is a direct connection, and a representative image of the contact stroke can be achieved. The mechanical travel characteristics should be

preferably a continuous curve as shown in Figure 7a). Where the measurements are taken on site, other methods may be applied which record points of travel during the operating period.

In these circumstances, the number of points recorded should be sufficient to derive the time to, and contact speed at, contact touch and contact separation, together with the total travel time.

After completion of the required operating sequences, the following tests and inspections should be performed (if applicable):

– connections should be checked;
– the control and/or auxiliary switches should correctly indicate the open and closed positions of the by-pass switch;
– all auxiliary equipment should operate correctly at the limits of supply voltage of operating devices and of auxiliary and control circuits and/or pressures for operation.

Furthermore the following tests and inspections should be made (if applicable):

– 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);
– recharging duration(s);
– 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 by-pass switch.

## 8 Guide to the selection of by-pass switches for service

This Clause does not apply to by-pass switches.

## 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 by-pass switch, the following particulars should be supplied by the enquirer:

a) particulars of systems, i.e. nominal and highest voltages to earth and across the by-pass unit, frequency, number of phases;
b) service conditions including minimum and maximum ambient air temperatures, 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;
c) characteristics of by-pass switch.

The following information should be given:

| | Type of information | Reference |
|---|---|---|
| 1) | number of poles | |
| 2) | environmental conditions (temperature, wind, ice, etc.) | 2 |
| 3) | rated voltage to earth and across poles | 4.3 |
| 4) | rated insulation level to earth and across poles where a choice exists between different insulation levels corresponding to a given rated voltage, or, if other than standard, the desired insulation level | 4.2 |
| 5) | rated frequency | 4.3 |
| 6) | rated normal current | 4.4 |
| 7) | rated short-time withstand current | 4.5 |
| 8) | rated peak withstand current | 4.6 |
| 9) | duration of short-circuit | 4.7 |
| 10) | rated operating sequence | 4.101 |
| 11) | rated by-pass making current | 4.102 |
| 12) | rated by-pass insertion current | 4.103 |
| 13) | rated reinsertion voltage | 4.104 |
| 14) | maximum closing time | 4.105 |
| 15) | maximum open-close time | 4.105 |
| 16) | maximum limiting peak voltage of the overvoltage protector | 4.104 |
| 17) | minimum time-to-peak voltage during insertion | 4.104 |
| 18) | the type tests specified under special request (for example artificial pollution and radio interference, etc.) | |
| 19) | the number of mechanical operating sequences (class M1 or M2) | 4.106 |
| 20) | if applicable, the application class (class BP1 or BP2) | 4.107 |
| 21) | if applicable, any test exceeding the standardised type, routine and commissioning tests | |

d) characteristics of the operating mechanism of by-pass switch and associated equipment, in particular:

   1) number and type of spare auxiliary switches;
   2) rated supply voltage and rated supply frequency;
   3) number of releases for closing, if more than one;
   4) number of releases for opening, if more than one.

e) requirements concerning the use of compressed gas 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.

### 9.102 Information to be given with tenders

When the enquirer requests technical particulars of a by-pass switch, the following information (those which are applicable) should be given by the manufacturer, with the descriptive matter and drawings:

a) rated values and characteristics:

| | Type of information | Reference |
|---|---|---|
| 1) | number of poles | |
| 2) | class: environmental conditions (temperature, wind, ice-coating) | 2 |
| 3) | rated voltage to earth and across pole | 4.1 |
| 4) | rated insulation level to earth and across pole | 4.2 |
| 5) | rated frequency | 4.3 |
| 6) | rated normal current | 4.4 |
| 7) | rated short-time withstand current | 4.5 |
| 8) | rated peak withstand current | 4.6 |
| 9) | rated duration of short-circuit | 4.7 |
| 10) | rated operating sequence | 4.101 |
| 11) | rated by-pass making current | 4.102 |
| 12) | by-pass discharge current frequency | 4.102 |
| 13) | rated insertion current | 4.103 |
| 14) | maximum limiting peak voltage of the overvoltage protector | 4.104 |
| 15) | minimum time-to-peak voltage during insertion | 4.104 |
| 16) | rated maximum closing time and rated maximum open-close time | 4.105 |
| 17) | the type tests specified under special request (for example artificial pollution and radio interference, etc.) | |
| 18) | class M1 or class M2 for mechanical endurance | 4.106 |
| 19) | application class BP1 or class BP2 | 4.107 |

b) type tests:

certificate or report on request;

c) constructional features:

The following details are required where they are applicable to the design:

1) mass of complete by-pass switch without fluids for insulation, by-passing, insertion and operation;
2) mass/volume of fluid for insulation, its quality and operating range, including the minimum functional value;
3) mass/volume of fluid for by-passing and insertion (where different fluid to items 2) and/or 4)), its quality and operating range, including the minimum functional value;
4) mass/volume of fluid for operation (where different fluid to items 2) and/or 3)), its quality and operating range, including the minimum functional value;
5) tightness qualification;
6) mass/volume of fluids per pole to fill to a level sufficient to prevent deterioration of internal components during storage and transportation;
7) number of units in series per pole;
8) minimum clearances in air:
   - between poles;
   - to earth;
   - the safety boundaries during a by-passing operation, for by-pass switches with an external exhaust for ionised gasses or flame;
9) any special arrangements (for example heating or cooling) to maintain the rated characteristics of the by-pass switch at the required temperatures of the ambient air;

d) operating mechanism of by-pass switch and associated equipment:

1) type of operating mechanism;
2) rated supply voltage and/or pressure of closing mechanism, pressure limits where different to or expanding data required in c) 4) of 9.102;

3) current required at rated supply voltage to close the by-pass switch;
4) energy expended to close the by-pass switch, for example measured as a fall in pressure;
5) rated supply voltage of shunt opening release;
6) current required at rated supply voltage for shunt opening release;
7) number and type of spare auxiliary switches;
8) current required at rated supply voltage by other auxiliaries;
9) setting of high and low pressure interlocking devices;
10) number of releases for closing, if more than one;
11) number of releases for opening, if more than one;

e) overall dimensions and other information:

The manufacturer should give the necessary information as regards the overall dimensions of the by-pass switch and details necessary for the design of the foundation.

General information regarding maintenance of the by-pass switch and its connections should be given.

## 10 Rules for transport, storage, installation, operation and maintenance

Clause 10 of IEC 60694 is applicable, with the following additions:

### 10.1 Conditions during transport, storage and installation

Subclause 10.1 of IEC 60694 is applicable.

### 10.2 Installation

Subclauses 10.2.1 to 10.2.4 of IEC 60694 are applicable, with the following addition:

#### 10.2.101 Guide for commissioning tests

After a by-pass switch has been installed and all connections have been completed, commissioning tests are recommended to be performed. The purpose of these tests is to confirm that transportation and storage have not damaged the by-pass switch. In addition, when a large part of the assembly and/or of the adjustment is performed on site, as identified in 7.101, the tests are required to confirm compatibility of the sub-components and the satisfactory nature of both the site work and the functional characteristics dependent upon it.

In addition to the requirements of 10.2.102, a minimum of 50 no-load operations should be performed on site on the by-pass switch where major sub-assemblies are combined at site without previous routine tests on the complete by-pass switch. These operations should be performed after assembly, all connections and checks having been made and the programme of commissioning tests having been completed. These operations may include deferred routine test operations forming part of the commissioning programme only where they are made after all site adjustments and tightness checks are complete. The purpose of these tests is to reduce occurrences of maloperation and failure early in the operational life of the by-pass switch.

The manufacturer should produce a programme of site commissioning checks and tests. Repetition of the full programme of routine tests, already performed in the factory, should be avoided as the purpose of commissioning tests is for confirmation of

– absence of damage;
– compatibility of separate units;
– correct assembly;

– correct performance of the assembled by-pass switch.

In general, this is achieved when the commissioning tests include, but are not limited to, the programme given in 10.2.102. The results of the tests should be recorded in a test report.

### 10.2.102 Commissioning checks and test programme

#### 10.2.102.1 Checks after installation

Subclause 10.2.101 requires the manufacturer to produce a programme of commissioning checks and tests. This should be based on, but is not limited to, the programme of checks and tests given here.

##### 10.2.102.1.1 General checks

– assembly conforms to manufacturer's drawings and instructions;
– tightness of by-pass switch, its fastenings, fluid systems and control devices;
– external insulation and, where applicable, internal insulation are undamaged and clean;
– paint and other corrosion protection are sound;
– operating devices, especially operating releases, are free from contamination;
– adequacy and integrity of the earth connection up to and including the interface with the substation earthing system;

and, where applicable:

– record the number on the operations counter(s) at delivery;
– record the number on the operations counter(s) at completion of all site testing;
– record the number on the operations counter(s) at first energisation.

##### 10.2.102.1.2 Checks of electrical circuits

– conformity to the wiring diagram;
– correct operation of signalling (position, alarms, lockouts, etc.);
– correct operation of heating and lighting.

##### 10.2.102.1.3 Checks of the insulation and/or extinguishing fluid(s)

| | |
|---|---|
| Oil | Type, dielectric strength (IEC 60296), level |
| $SF_6$ | Filling pressure/density, and quality checks, to confirm the acceptance levels of IEC 60376, IEC 60480 and IEC 61634. These quality checks are not required on sealed equipment and new gas used from sealed bottles. A dewpoint check and a check of the total impurities should be carried out to confirm the manufacturer's acceptance levels |
| Gas mixtures | Quality to be confirmed prior to energisation |
| Compressed air | Quality (if applicable) and pressure |

##### 10.2.102.1.4 Checks on operating fluid(s), where filled or added to on site

| | |
|---|---|
| Hydraulic oil | Level and, unless otherwise agreed, confirmation that the moisture content is sufficiently low to prevent internal corrosion or other damage to the hydraulic system |
| Nitrogen | Filling pressure and purity (for example oxygen free or 1 % tracer gas) |

#### 10.2.102.1.5 Site operations

Confirmation should be given that the programme of commissioning checks and tests required by 7.101 has been completed and, where applicable, extended by the additional 50 operations required by 10.2.101.

### 10.2.102.2 Mechanical tests and measurements

#### 10.2.102.2.1 Measurements of the characteristic insulating and/or by-passing and insertion fluid pressures (where applicable)

##### 10.2.102.2.1.1 General

The following measurements should be taken in order to compare them with the values both recorded during the routine tests and guaranteed by the manufacturer. These values serve as the reference for future maintenance and other checks and will enable any drift in operating characteristics to be detected.

These measurements involve a check of the operation of the alarm and lockout devices (pressure switches, relays, transducers, etc.) where applicable.

##### 10.2.102.2.1.2 Measurements to be taken

a) Where applicable, on rising pressure:
   - the reset value of the closing lockout;
   - the reset value of the opening lockout;
   - the reset value of the auto-reopening lockout;
   - disappearance of the low-pressure alarm.

b) Where applicable, on dropping pressure:
   - appearance of low-pressure alarm;
   - operating value of lockout of the auto-reopening feature;
   - operating value of lockout of the opening;
   - operating value of lockout of the closing.

#### 10.2.102.2.2 Measurements of characteristic operating fluid pressures (if applicable)

##### 10.2.102.2.2.1 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.).

##### 10.2.102.2.2.2 Measurements to be taken

a) On a rise in pressure with the pumping device (pump, compressor, controlled valve, etc.) in service:
   - the reset value of the closing lockout;
   - the reset value of the opening lockout;
   - the reset value of the auto-reopening 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 10.2.102.2.5.2).

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-reopening (if applicable);

– lockout of the opening;

– lockout of the closing.

In the case of a hydraulic control, the pre-inflation pressure of the accumulators should be indicated together with the ambient air temperature before the tests are performed.

#### 10.2.102.2.3 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 consumption during each of the following operations or operating sequence should be evaluated:

– O;

– C;

– OC.

The steady-state pressure after each operation or operating sequence should be noted.

#### 10.2.102.2.4 Verification of the rated operating sequence

The ability of the by-pass switch 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 10.2.102.2.3.

Evidence should be given to demonstrate the coordination between the interlocking device intervention levels and the minimum pressures for operation measured during the rated operating sequence.

The site supply voltage is the on-load voltage available at the by-pass switch from the normal site supply and should be compatible with the rated supply voltage of auxiliary and control circuits.

#### 10.2.102.2.5 Measurement of time quantities

##### 10.2.102.2.5.1 Characteristic time quantities of the by-pass switch

a) Closing and opening times, time spread

The following measurements should be made at maximum pressure (cut-off of pumping device) and at the supply voltage, measured at the terminals of the equipment:

– closing time of each pole, time spread of the poles and when possible time spread of the by-passing 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 by-passing units or groups of units of each pole.

In the case of multiple close and trip coils, all should be tested and the times recorded for each.

The supply voltage before and during the operations should be recorded.

b) Operation of control and auxiliary contacts

The timing of the operation of one of each kind (by-pass and insertion) of control and auxiliary contacts should be determined in relation to the operation of the main contacts, on closing and on opening of the by-pass switch.

#### 10.2.102.2.5.2 Recharging time of the operating mechanism

a) 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 operating sequence, starting each time with minimum pressure (cut-in of the pumping device):

  – C;

  – O;

  – OC.

b) Spring-operated mechanism

The recharging time of the motor after an opening operation should be measured at the site supply voltage.

#### 10.2.102.2.6 Record of mechanical travel characteristics

As required by 7.101, a record can be made of the mechanical travel characteristics where the by-pass switch has been assembled as a complete by-pass switch for the first time on site or where all or part of the routine tests are performed on site. The record should confirm satisfactory performance by comparison with the reference mechanical travel characteristics obtained during the reference no-load tests detailed in 6.101.1.1.

#### 10.2.102.2.7 Checks of certain specific operations

#### 10.2.102.2.7.1 Auto-reopening at the minimum functional pressure for operation (if applicable)

With the pumping device out of service, the control pressure should be lowered to the lockout value for auto-reopening and an auto-reopening operating sequence be carried out (under site conditions it may be necessary to use a separate timing device to initiate reopening). The test should be conducted at the supply voltage of the equipment. The supply voltage before and during the operations should be recorded. The final pressure should be noted and it should be ensured that there is sufficient safety margin to the minimum functional pressure for operation for closing, 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 minimum functional pressure for operation for auto-reopening (short-circuited contact). It should then be verified that a closing operation is still possible.

#### 10.2.102.2.7.2 Closing at the minimum functional pressure for operation (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 the supply voltage of the equipment. The supply voltage before and during the operations should be recorded. The final pressure should be noted.

#### 10.2.102.2.7.3 Opening at the minimum functional pressure for operation (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 the supply voltage of the equipment. The supply voltage before and during the operations should be recorded. The final pressure should be noted and a sufficient safety margin is ensured to the minimum functional pressure for closing.

In case of doubt, an alternative test to the one described above may be performed, starting with a lower pressure than the minimum functional pressure for opening (short-circuited contact). It should then be verified that a closing operation is still possible.

#### 10.2.102.2.7.4 Simulation of fault-making operation and check of anti-pumping device

Measurement should be taken of the time during which the by-pass switch remains open on a OC operating cycle with the close circuit energised by the closing of the auxiliary contact.

The test also allows checking of the anti-pumping device operation and the absence of malfunction for any mechanical, hydraulic or pneumatic reasons, caused by the rapid application of the closing command.

The opening 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 opening command is applied and maintained, while a consecutive closing command is applied.

#### 10.2.102.2.7.5 Behaviour of the by-pass switch on an opening command while a closing command is already present

It should be verified that the by-pass switch meets the technical specifications in the presence of an opening command when previously a closing command is applied and maintained.

#### 10.2.102.2.7.6 Application of a closing command on both releases simultaneously (if applicable)

It may happen that both releases (normal and emergency) are energised 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.

#### 10.2.102.2.7.7 Protection against pole discrepancy (if applicable)

Protection against pole discrepancy should be checked by either of the following tests:

– with the by-pass switch open, the closing release of one of the poles should be energised and a check carried out to see that all poles close;
– with the by-pass switch closed, the opening release of one of the poles should be energised and a check carried out to see that it opens and then closes.

### 10.2.102.3 Electrical tests and measurements

#### 10.2.102.3.1 Dielectric tests

Dielectric tests on auxiliary circuits should be performed to confirm that transportation and storage of the by-pass switch have not damaged these circuits. However, it is recognised that such circuits contain vulnerable sub-components and the application of the full testing voltage for the full duration can cause damage. In order to avoid this, and to avoid the temporary removal of proven connections, the supplier should detail the test process that demonstrates that damage has not occurred as well as the method of recording the results from this test process.

For dielectric tests on the main circuit of metal-enclosed switchgear and controlgear, IEC 60298 and IEC 60517 are applicable (see bibliography).

#### 10.2.102.3.2 Measurement of the resistance of the main circuit

Measurement of the resistance of the main circuit need only be made if by-passing units have been assembled on site. The measurement should be made with a direct current in accordance with 7.3 of IEC 60694.

### 10.3 Operation

Subclause 10.3 of IEC 60694 is applicable.

### 10.4 Maintenance

Subclause 10.4 of IEC 60694 is applicable with the following addition:

In addition, the manufacturer should give information regarding the maintenance of by-pass switches following by-pass making current and insertion current operations.

This information should include the number of operations after which the by-pass switch is to be overhauled.

Subclauses 10.4.1 to 10.4.3 of IEC 60694 are applicable. The checks required in 10.2.102.1.3 apply.

#### 10.4.101 Resistors and capacitors (if applicable)

When checking resistors and capacitors, allowed variations of the values should be given.

## 11 Safety

Clause 11 of IEC 60694 is applicable with the following addition:

Any known chemical and environmental impact hazards should be identified in the by-pass switch handbook/manual.

*Notes to the following figures 1 through 3*:

NOTE 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.

NOTE 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.

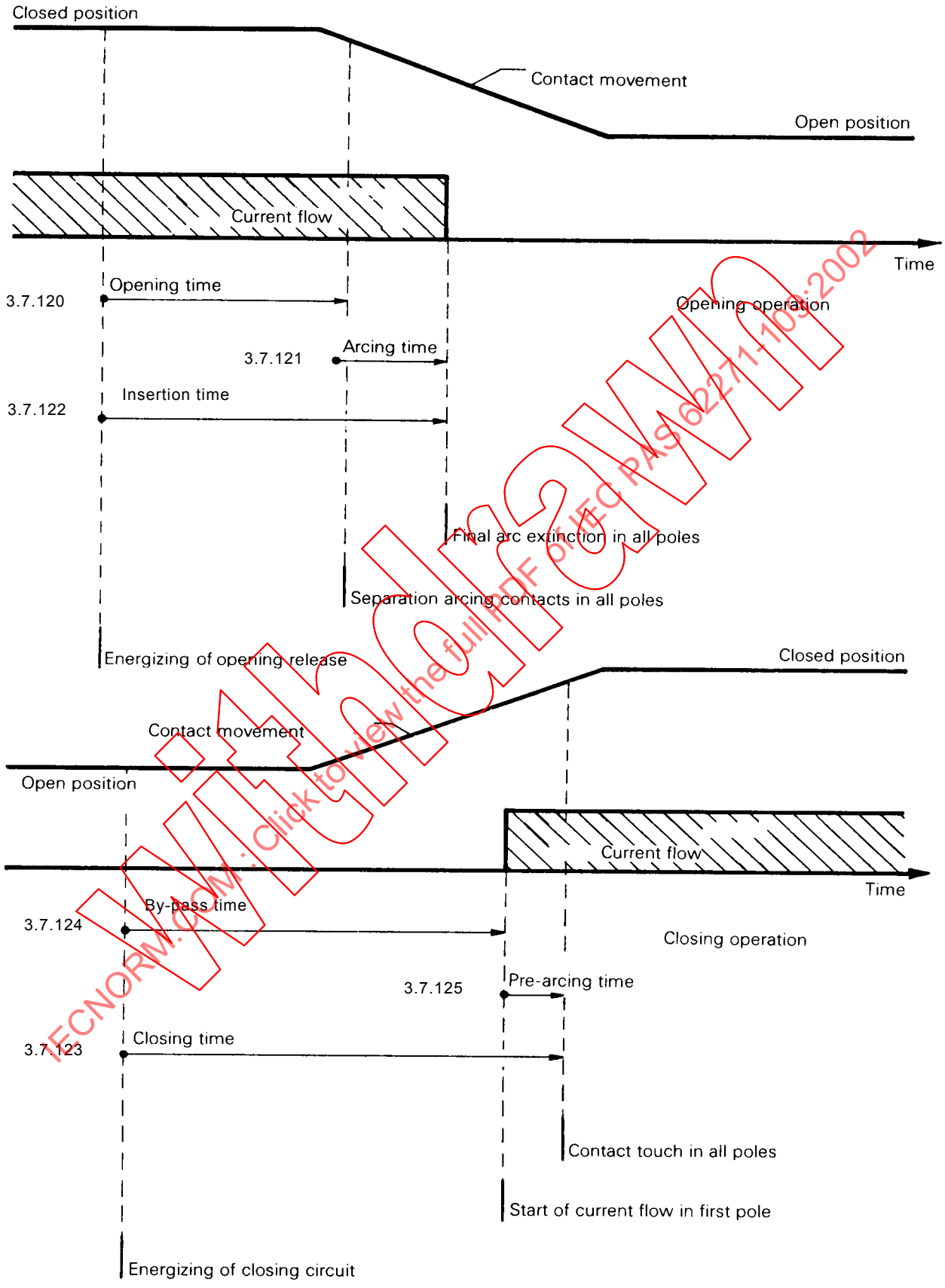



**Figure 1 – By-pass switch; Opening and closing operations**

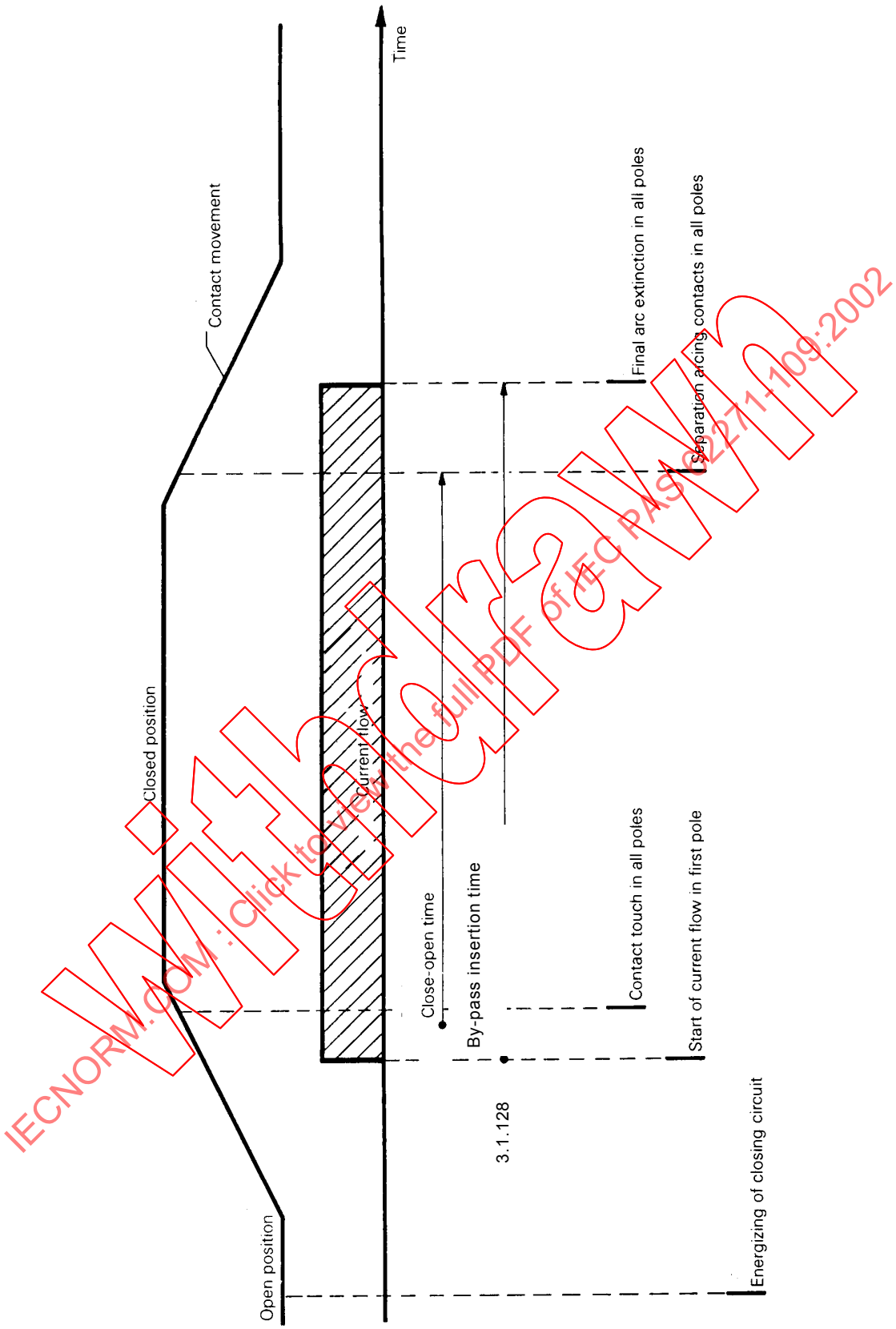





**Figure 2 – By-pass switch – Close-Open cycle**

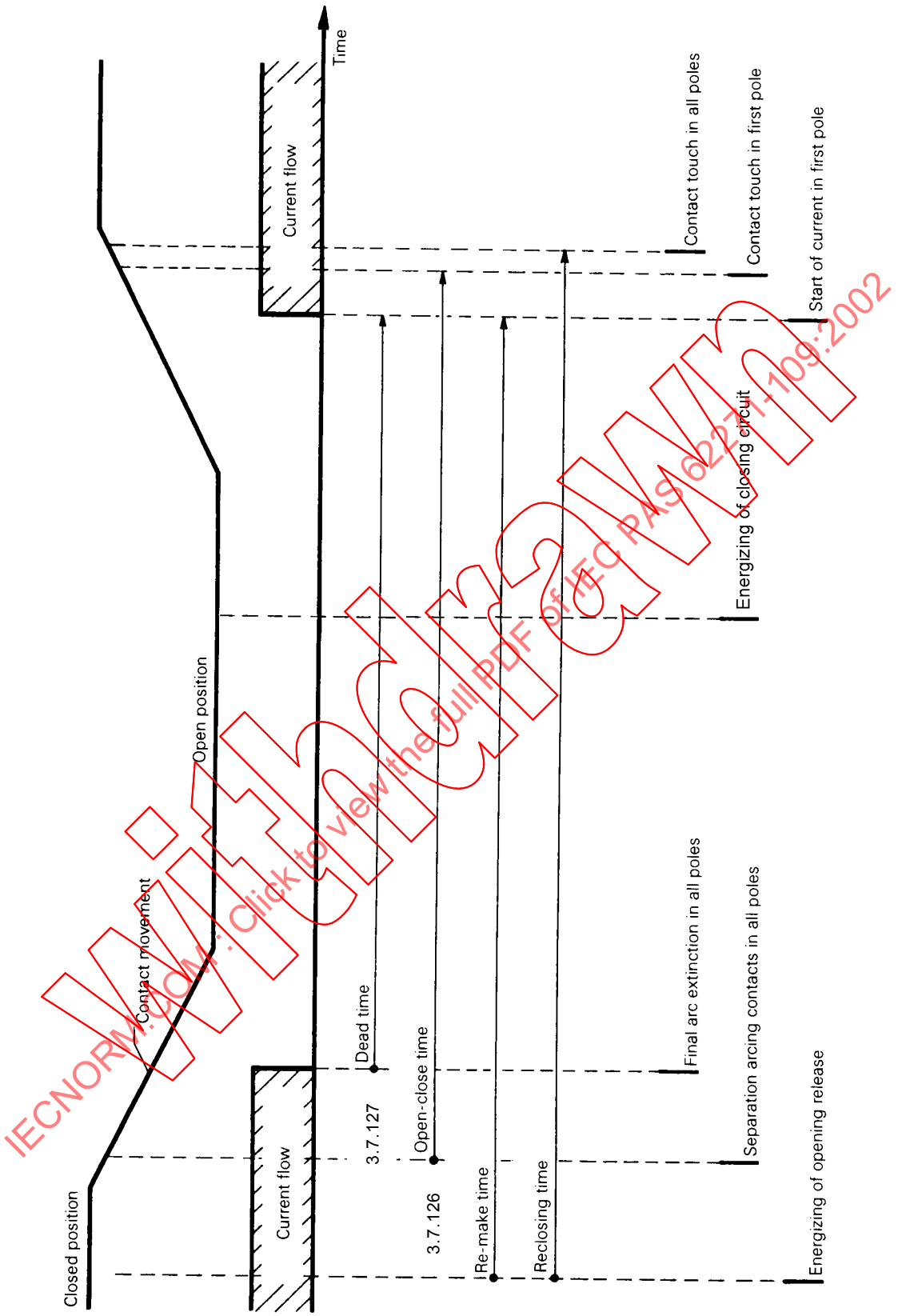
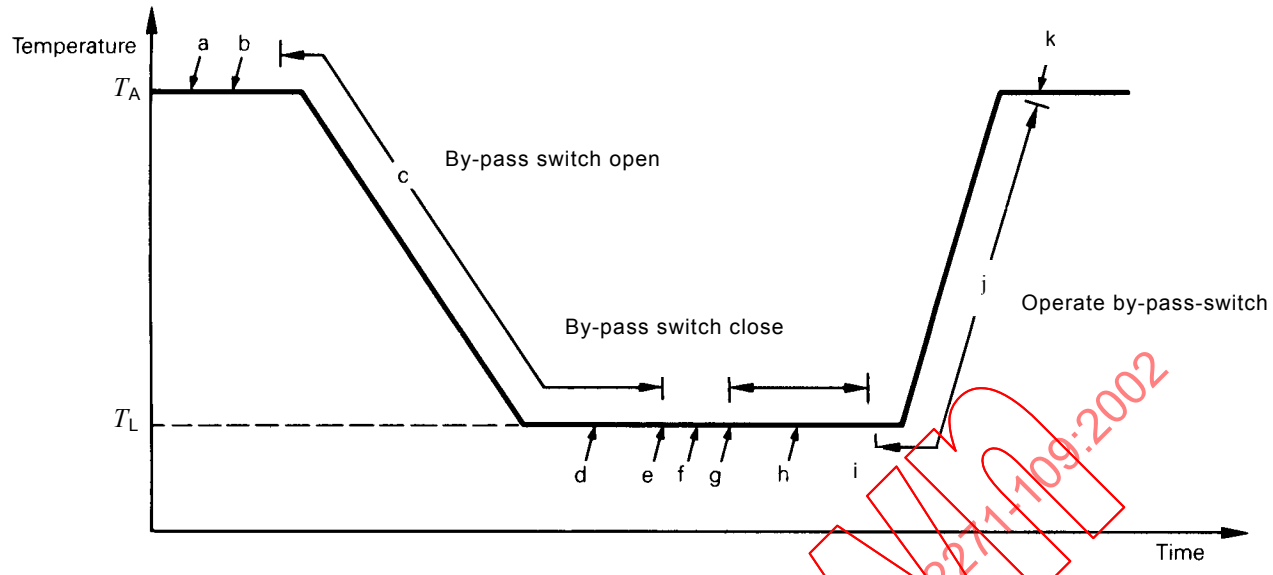
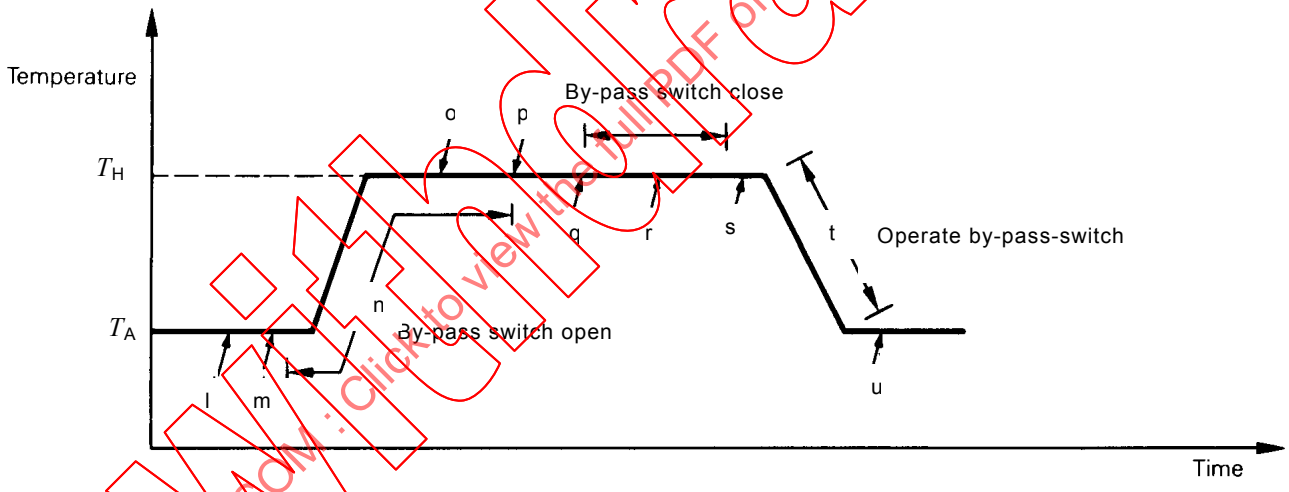





**Figure 3 – By-pass switch – Open-Close cycle**



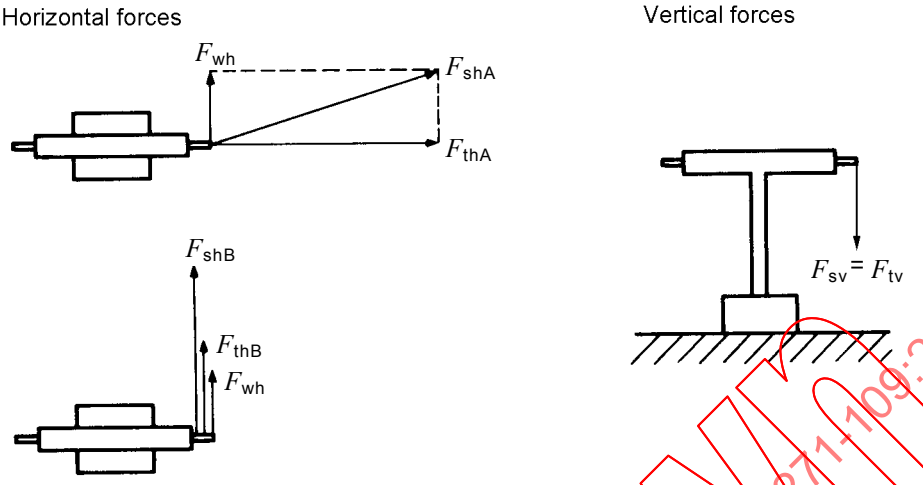

**a) Low temperature test**




**b) High temperature test**

NOTE Letters a to u identify application points of tests specified in 6.101.3.3 and 6.101.3.4.

**Figure 4 – Test sequences for low and high temperature tests**




**Key**

| | |
|---|---|
| $F_{thA}$ | 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 by-pass switch due to wind pressure on ice-coated by-pass switch |
| $F_{shA}$, $F_{shB}$, $F_{sv}$ | rated static terminal load (resultant forces) |

NOTE Refer to Figure 6 for directions A, B and C.

**Figure 5 – 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 4 |
| Forces due to wind and ice on by-pass switch* | $F_{wh}$ | O | Calculated by manufacturer |
| Resultant force | $F_{shA}$, $F_{shB}$ | $F_{sv}$ | |

* The horizontal force on the by-pass switch, 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 by-pass switch should be the same.)