BRITISH STANDARD

BS 5564:1978

Incorporating Amendment No. 1

CONFIRMED
DECEMBER 2007

Specification for

High-voltage fuses for the external protection of shunt power capacitors

UDC 621.319.4.022:621.316.923.027.3

Cooperating organizations

The Power Electrical Engineering Standards Committee, under whose direction this British Standard was prepared, consists of representatives from the following Government departments and scientific and industrial organizations:

Associated Offices Technical Committee
Association of Short Circuit Testing Authorities*
British Electrical and Allied Manufacturers' Association (BEAMA)
British Railways Board
British Steel Corporation
Department of Energy (Electricity)
Electrical Contractors' Association
Electrical Contractors' Association of Scotland
Electrical Research Association*
Electricity Supply Industry in England and Wales*
Engineering Equipment Users' Association
Institution of Electrical Engineers
Ministry of Defence*
National Coal Board
Trades Union Congress

The organizations marked with an asterisk in the above list, together with the following, were directly represented on the committee entrusted with the preparation of this British Standard:

Association of Consulting Engineers
Association of Supervisory and Executive Engineers
Electrical Installation Equipment Manufacturers' Association (BEAMA)
Electrical Power Engineers' Association
London Transport Executive
Oil Companies Materials Association

This British Standard, having been prepared under the direction of the Power Electrical Engineering Standards Committee, was published under the authority of the Executive Board on 29 December 1978

The following BSI references relate to the work on this standard:
Committee reference PEL/78
Draft for comment 77/21834 DC

ISBN 0 580 10147 9

Amendments issued since publication

Amd. No.	Date of issue	Comments
6686	April 1991	Indicated by a sideline in the margin

Contents

Foreword

This British Standard, which has been prepared under the direction of the Power Electrical Engineering Standards Committee, substantially agrees with IEC Publication 549 "*High-voltage fuses for the external protection of shunt power capacitors*". It has not been published as a dual-numbered standard because IEC 549 refers to IEC 282-2 for the technical requirements for expulsion fuses whereas this specification refers to BS 2692-2 where the technical requirements are different.

Because of the very specialized nature of this application of fuses, practical difficulties may in some cases be experienced in obtaining certain of the test facilities necessary to establish complete compliance with this standard. Although in such an event the manufacturer and the user may, having taken account of available test evidence and service experience, agree to waive compliance with the relevant requirements, the fuses concerned cannot then be claimed as complying with the requirements of the standard.

Terminology. For ease of reproduction the text of the International Standard has been used as the basis of this standard and some terminology is therefore not identical with that used in British Standards.

Fuses within the scope of this standard are not sensitive to normal electromagnetic disturbances, and therefore no immunity tests are required.

Significant electromagnetic disturbance generated by a fuse is limited to the instant of its operation. Provided that the maximum arc voltages during operation in the type test comply with the requirements of the clause in this standard specifying maximum arc voltage, the requirements for electromagnetic compatibility are deemed to be satisfied.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 10, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Chapter I

1 General

1.1 Scope

This standard applies to external fuses used with high-voltage power capacitors according to BS 1650.

Fuses according to this standard are intended to clear either faults inside a capacitor unit to permit continued operation of the remaining parts of the bank in which the unit is connected (unit fuses) or faults on the whole capacitor bank to isolate the bank from the system (line fuses).

These fuses are not a substitute for a mechanical switching device, but when forming a part of a mechanical switching device such as a fuse-switch or a fuse-disconnector, they shall comply with this standard.

When fuses are used for the external protection of a capacitor unit or a capacitor bank (line fuses), their voltages and breaking ratings shall be adequate for the system.

Fuses according to this standard shall comply with the requirements of BS 2692-1 or BS 2692-2, except those which are specifically excluded in this standard.

1.2 Object

The object of this standard is to formulate uniform requirements and test procedures regarding performance and testing of fuses intended to be used for capacitor protection.

2 Definitions

2.1
capacitor element (or element)

an indivisible part of a capacitor consisting of electrodes separated by a dielectric

NOTE The word "element" in this standard is used according to the definition of BS 1650.

2.2
capacitor unit (or unit)

an assembly of one or more capacitor elements in a single container with terminals brought out

2.3
capacitor bank (or bank)

a group of units, connected electrically to each other, e.g. a three-phase bank may be composed of three single-phase units

2.4
capacitor

in this standard, the word "capacitor" is used when it is not necessary to lay particular stress upon the different meanings of the word "capacitor unit" or "capacitor bank"

2.5
capacitor equipment

an assembly of capacitor units and accessories suitable for connection to a circuit

2.6
bank protection

common name for all protective equipment, except the internal fuses, for a capacitor bank or part thereof

2.7
unbalance protection

a device sensitive to capacitance difference between branches of the bank normally in balance with each other

NOTE The capacitance difference may be due to blown fuse(s) or insulation failure within the bank.

2.8
unit fuse

fuse intended to be used for the protection of a capacitor unit which forms a part of a capacitor bank

2.9
line fuse

fuse intended to be used for the overall protection of a capacitor connected to a given point of a system

2.10
refill unit

a set of replacement parts sufficient to restore a fuse-link to its original condition after an operation

2.11
capacitive breaking current

a current for which the specified conditions of use and behaviour include the opening of the circuit of a capacitor unit or capacitor bank

2.12
rated capacitive breaking current

the maximum capacitive breaking current that the fuse shall be capable of breaking under the conditions of use and behaviour prescribed in this standard

2.13
homogeneous series (of fuse links)

a series of fuse links, deviating from each other only in such characteristics that, for a given test, the testing of one or a reduced number of particular fuse link(s) of the series may be taken as representative of all the fuse links of the series

Chapter II

3 Performance requirements

3.1 General

The fuse is connected in series with the unit(s) which the fuse is intended to isolate if the unit(s) becomes faulty. The range in currents and voltages for the fuse is therefore dependent on the characteristics of the capacitor and the bank in which the fuse is connected as well as the parameters of the supply circuit.

The operation of an external fuse is in general determined by the following two factors:

1. the power-frequency fault current resulting from either a partial or complete capacitor failure;
2. the discharge energy from any units in parallel with the fault.

However, this standard gives a method of separate checking of these factors.

These requirements are valid for capacitors switched by a restrike-free switching device. If the switching device is not restrike-free, other requirements are to be agreed upon.

As used in this standard, U_n is the rated voltage of the capacitor unit and U_{nf} is the rated voltage of the capacitor fuse.

3.2 Breaking requirements

Operating voltages

The fuse shall be so selected as to isolate the faulty unit(s) with a minimum disturbance to the system and to the capacitor unit involved under maximum prevailing system conditions occurring at the time of the fault and at the following voltages:

a) Under transient current conditions, e.g. during energization, the higher limit of the transient voltage between terminals of the unit is $2.0\ U_n \sqrt{2}$, where U_n is the rated voltage of the unit. After operation, the fuse shall be capable of withstanding the above transient voltage.

NOTE The fuse manufacturer shall specify if the fuse capability differs from the above requirements.

b) When the fuse is subjected to power-frequency capacitive currents, it shall be capable of operating against a voltage of $1.1\ U_n$ and then withstanding this voltage plus any d.c. voltage component resulting from any capacitive charge remaining after the operation of the fuse.

Rated capacitive breaking current

For current-limiting fuses, the preferred values of the rated capacitive breaking current are 20 and 50 times the rated current of the highest current rating of a homogeneous series. Other values shall be the subject of an agreement between manufacturer and user.

For expulsion fuses, the preferred values of the rated capacitive breaking current are 20 and 50 times the rated current of the largest refill unit recommended by the manufacturer of renewable fuse-links. Other values shall be the subject of an agreement between manufacturer and user.

3.3 Withstand requirements

Rated voltage: the rated voltage U_{nf} of the fuse must not be less than 1.1 times the rated voltage U_n of the capacitor unit.

Rated current: the rated current of the fuse shall be at least 1.43 times the rated current I_n of the capacitor.

NOTE 1 In principle, the continuous current does not exceed 1.3 times I_n, but as the capacitance may reach 1.1 times the value corresponding to the rated output, the current may have a maximum value of $1.3 \times 1.1 = 1.43$ times the rated current.

NOTE 2 When the air temperature at the fuse location exceeds 40 °C, it is recommended to consult the manufacturer.

NOTE 3 For certain types of fuse-links having an overload capability, it is recommended to take this property into consideration.

Chapter III

4 Type tests

4.1 General

To comply with this standard, fuses shall be subjected to the tests specified in Table I.

NOTE For fuses belonging to a homogeneous series it is allowed that tests made on a reduced number of current ratings shall be valid for the other current ratings. Detailed information is given in Sub-clauses **4.2**, **4.3.1** and **4.3.2**.

Table I

Tests	Fuses to be used where inductive currents can flow See 2 below		Fuses to be used where inductive currents are not likely to flow See 3 below
	Line fuses	Unit fuses	
Inductive currents See 1 below	X	X	
Capacitive currents (Sub-clause **4.2**)	See 4 below	X	X
Discharge (Sub-clause **4.3**)	X	X	X

1. These tests shall comprise the following:
   Test duties 1 and 2 according to BS 2692-1 or BS 2692-2.
2. Examples of such applications are:
   — line fuses;
   — unit fuses in delta-connected banks without units in series;
   — unit fuses in star-connected banks without units in series and with earthed neutral.
3. Examples of such applications are:
   — unit fuses in star-connected banks with unearthed neutral;
   — banks where units are used in series.
4. For use with unearthed star-connected banks, line fuses shall be tested on capacitive currents.

Test practices

The fuse shall be new, clean and in good condition.

The fuse-link shall be tested in a fuse-base as specified by the manufacturer of the fuse-link.

In making tests of a test duty within a series of renewable fuse-links, only the fuse-elements, refill units and parts normally replaceable shall be replaced. A new fuse-carrier shall be used for tests of the other test duty.

4.2 Capacitive breaking current tests

For both current-limiting fuses and expulsion fuses belonging to a homogeneous series tests shall be made on the fuse-links with the highest current rating.

4.2.1 *Description of tests to be made*

These tests are intended to prove the ability of the fuse to break capacitive currents and shall include two test duties.

Test duty A: verification of the rated capacitive breaking capacity (see Clause **3**).

Test duty B: verification of the operation with a current value resulting in a pre-arcing time of (5 ± 2) min.

The test circuits specified in Sub-clause **4.2.2** and the parameters specified in Sub-clause **4.2.5** have been so chosen as to reproduce as closely as possible the duty which the fuses experience in actual applications.

When applied as unit fuses, the mode of failure of the capacitor units determines the magnitude of the current which the fuse must break.

For the complete failure of a capacitor unit, the bank configuration (see Table I) determines the magnitude and characteristics (inductive or capacitive) of the current through the unit and its fuse. Test duty A simulates the condition where the fuse breaks capacitive current.

For progressive element failure in the capacitor unit, the current increases until it reaches a magnitude that will just melt the fuse. Test duty B simulates this condition.

4.2.2 *Test circuits*

The tests shall be made with single-phase alternating current and with single fuses.

The supply circuit shall have an impedance such that the voltage variation caused by switching the capacitive current shall not exceed 10 %. The power factor of the supply circuit shall not exceed 0.15 lagging and its capacitance shall be as low as possible.

For test duty A on unit fuses, the load circuit shall be as shown in Figure 1, page 8.

Operation of the fuse is initiated by closing the switch S in series with the fuse, in order to simulate the total failure of a capacitor unit protected by the fuse.

C_T represents the capacitance in the bank which limits the fault current and C_P represents the capacitors which are in parallel with the failed unit. The value of C_P in microfarads shall be $C_P \geqslant \frac{1000}{U^2_{nf}}$, U_{nf} being expressed in kilovolts.

The source voltage E_S should be so chosen that, taking into account the ratio of the capacitances $\frac{C_T}{C_P}$, the specified power-frequency recovery voltage given in Table II is obtained. It is expected that, in the light of some further empirical evidence, a more precise relationship between E_S and E_F may be evolved.

For test duty B on unit fuses, the load circuit shall be as shown in Figure 2, page 9.

Operation of the fuse is initiated by opening the switch S in parallel with the fuse.

C_T represents the remaining healthy elements of the capacitor unit and C_P represents the other units in the bank which are in parallel with the failed unit. The value of C_P in microfarads shall be $C_P \geqslant \frac{1000}{U^2_{nf}}$, U_{nf} being expressed in kilovolts.

NOTE In both circuits, the effect of capacitance on the recovery voltage appearing across the fuse when it operates is taken into account by C_P. The minimum value specified represents between 300 kvar and 400 kvar (depending on frequency), i.e. the size of the smallest capacitor bank on which individual fuses would normally be applied. Experience has shown that the value of C_P is not critical in its effect on the capacitive current-breaking performance of fuses, and therefore only a minimum value is specified.

For test duties A and B on line fuses, the load circuit shall be as shown in Figure 1, page 8, except that capacitance C_P shall be omitted.

The waveform of the current to be broken should, as nearly as possible, be sinusoidal. This condition is considered to be complied with if the ratio of the r.m.s. value of the current to the r.m.s. value of the fundamental component does not exceed 1.2.

The current to be broken shall not pass through zero more than once per half-cycle.

4.2.3 *Arrangement of the equipment*

Expulsion and current-limiting fuses which automatically provide an isolating gap after operation shall be mounted as they will be in a capacitor bank. An energized fuse shall be placed on each side of the fuse under test to determine adequately that any expulsion of gas or reduction of clearance does not cause flashovers which might initiate operation of the adjacent fuses.

Other current-limiting fuses may be mounted in any convenient manner.

4.2.4 *Test procedure*

The test procedure to obtain the specified prospective current shall be that specified for the breaking tests in BS 2692-1 and BS 2692-2.

4.2.5 *Parameters to be used for tests*

The parameters to be used when making the tests are given in Table II.

Table II

Parameters	Test duty A	Test duty B
Power-frequency recovery voltage (i.e. excluding d.c. voltage component)	$1.0\ U_{nf}\ ^{+5}_{0}\ \%$	$1.0\ U_{nf}\ ^{+5}_{0}\ \%$
Power factor (leading)	$\leqslant 0.15$	
Prospective current	Rated capacitive breaking current	Current value resulting in a pre-arcing time of (5 ± 2) min
Making angle after voltage zero	From 0° to 20°[a]	Random timing
Number of tests	3	2

[a] This produces the most severe condition for the fuse since closing the circuit near voltage zero minimizes discharge current from the parallel capacitance and its effect on the pre-arcing time of the fuse.

For expulsion fuses and current-limiting fuses which automatically provide an isolating gap after operation, the voltage shall be maintained on the fuse for 1 s. For other current-limiting fuses, the time shall be 60 s.

4.3 Discharge tests

These tests are made to verify:

— the I^2t to which the fuse-link can be subjected for repetitive discharges (endurance discharge tests);

— the energy which the fuse can withstand without bursting (breaking discharge tests).

A calibration test shall be made by replacing the fuse-link under test by a link of negligible impedance compared with that of the test circuit. This test may be made with a reduced voltage.

The circuit shall be adjusted to give the specified discharge I^2t or energy, oscillatory frequency and decrement. This shall be verified by an oscillographic record. The ratio between successive peaks shall be from 0.8 to 0.95 for the endurance discharge tests and from 0.8 to 0.85 for the breaking discharge tests.

Tests shall be made on new fuses with the amounts of I^2t and energy specified by the manufacturer (see Chapter IV).

4.3.1 *Endurance discharge tests*

For both current-limiting fuses and expulsion fuses belonging to a homogeneous series tests shall be made on the fuse-links with the highest and the lowest current ratings.

These tests may be made at any convenient voltage and shall include two test duties:

a) 5 discharges on the same fuse-link within 10 min.

The discharge oscillatory frequency shall be:

$f\,(\text{kHz}) = 1.2\ U_{nf}\,(\text{kV})\ ^{+20}_{0}\ \%$ for fuse-links with rated currents not exceeding 31.5 A.

$f\,(\text{kHz}) = 0.8\ U_{nf}\,(\text{kV})\ ^{+20}_{0}\ \%$ for fuse-links with rated currents exceeding 31.5 A.

b) 100 discharges on the same fuse-link at a time interval set by the manufacturer.

The discharge oscillatory frequency shall be 8 kHz $^{+20}_{0}\ \%$.

The value of I^2t shall be estimated from the oscillogram of current or by an equivalent method.

After this test, the fuse-link shall be still conducting.

4.3.2 *Breaking discharge tests*

For current-limiting fuses belonging to a homogeneous series tests shall be made on the fuse-link with the highest current rating.

For expulsion fuses belonging to a homogeneous series tests shall be made on the fuse-link rating with the largest distance between arcing terminals. If there are a number of fuse-links with the same distance, tests shall be on the one having the lowest current rating.

4.3.2.1 *Test circuit*

Tests shall be made with a capacitor the capacitance of which is such that the stored energy has the specified value at the test voltage specified below. This capacitor shall be charged by means of d.c. to one of the following voltages:

$1.82\ U_{nf}\ \sqrt{2}$ for current-limiting fuses.

$1.10\ U_{nf}\ \sqrt{2}$ for expulsion fuses unless otherwise specified.

The capacitor shall be discharged through the fuse under test in a circuit in which the oscillatory frequency is:

$f\,(\text{kHz}) = 1.2\ U_{nf}\,(\text{kV})\ ^{+20}_{\ 0}\,\%$ for fuse-links with rated currents not exceeding 31.5 A.

$f\,(\text{kHz}) = 0.8\ U_{nf}\,(\text{kV})\ ^{+20}_{\ 0}\,\%$ for fuse-links with rated currents exceeding 31.5 A.

4.3.2.2 *Test procedure*

Two tests shall be made. For expulsion fuses, the second test shall be made on a completely new fuse.

For fuses that do not introduce a visible air gap in the circuit upon operation, the voltage shall be maintained on the fuse for 10 min after operation. This requires the capacitor used for the test to be without discharge resistance.

For other fuses, no requirements concerning the maintained voltage are specified.

For current-limiting fuses, the residual voltage across the capacitor shall be measured immediately after the discharge to determine the amount of energy dissipated in the fuse-link. The residual voltage shall be recorded in the test report.

4.3.2.3 *Standard conditions of behaviour with respect to breaking tests*

a) Flashover to earth or to adjacent capacitor units shall not occur during operation when mounted in accordance with the recommendations of the manufacturer.

A current-limiting fuse-link shall not emit flame or powder; although a minor emission of flame from a striker or indicating device is permissible, provided this does not cause breakdown or significant leakage current to earth.

b) After the fuse has operated, the components of the fuse, apart from those intended to be replaced after each operation, shall be in substantially the same condition as at the beginning of the test except for the erosion of the bore of the fuse tube of expulsion fuses.

For current-limiting fuses, it shall be possible to remove the fuse-link in one piece after the operation.

However, after the discharge breaking test, the components of the fuse may be damaged and require replacement to restore the fuse to operating condition.

c) After operation, the fuse shall be capable of withstanding the voltages specified in Sub-clause **3.2** a) across its terminals. When a fuse which automatically provides an isolating gap after operation has operated, it must also provide the specified dielectric properties.

Chapter IV

5 Information to be given to the user

— Rated voltage of the fuse.

— Current rating of the fuse-link or refill unit; in addition, the maximum continuous current capability may also be specified.

— Current rating of the fuse-base or fuse-carrier contacts.

— Time-current characteristics as specified in BS 2692-1 and BS 2692-2 for an ambient air temperature of 20 °C.

NOTE 1 Information shall be available on request concerning ambient air temperatures in the range – 40 °C to + 75 °C.

NOTE 2 If tolerances on the current closer than ± 20 % are required, they shall be specified on request.

— Rated capacitive breaking current, where appropriate (see Table I).

— Rated inductive breaking current, where appropriate (see Table I).

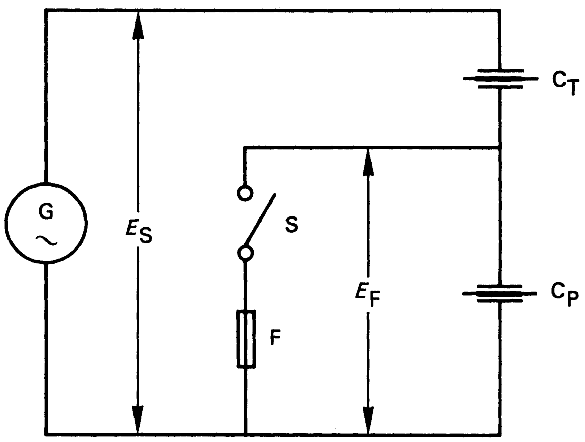
— Maximum I^2t values which the fuse can withstand for 5 and 100 discharges.

— Maximum available capacitor energy which the fuse can withstand at the voltages specified in Sub-clause **4.3.2.1** without bursting (unless otherwise specified, 40 kJ for current-limiting fuses).

— Minimum pre-arcing I^2t (under substantially adiabatic conditions) and maximum total clearing I^2t at inductive and capacitive power-frequency currents.

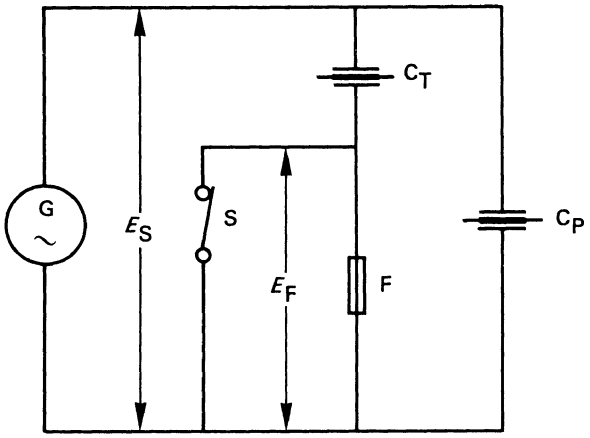
— Cold resistance of the fuse-link and percentage tolerance of resistance value.

— External creepage distance along the fuse-link (for other than fuses which automatically provide an isolating gap after operation).



G Generator
E_S Source voltage
E_F Recovery voltage
F Fuse
S Switch
C_T Capacitors to produce the test current
C_P Capacitors corresponding to the capacitors in parallel with the failed unit.

Figure 1 — Test circuit for test duty A



G Generator
E_S Source voltage
E_F Recovery voltage
F Fuse
S Switch
C_T Capacitors to produce the test current
C_P Capacitors corresponding to the capacitors in parallel with the failed unit.

Figure 2 — Test circuit for test duty B

blank

Publications referred to

BS 1650, *Capacitors for connection to power-frequency systems.*
BS 2692, *Fuses for voltages exceeding 1 000 V a.c.*
BS 2692-1, *Current limiting fuses.*
BS 2692-2, *Expulsion fuses.*
IEC 282-2, *High-voltages fuses*[1].
IEC 282-2-2, *Expulsion and similar fuses.*
IEC 549, *High voltage fuses for the external protection of shunt power capacitors*[1].

[1] Referred to in the foreword only.

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