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**Surge protective devices connected to
low-voltage power distribution systems—
Selection and application principles**

ICS 29.240 ; 29.240.10

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Foreword

This translation has been made based on the original Japanese Industrial Standard established by the Minister of Economy, Trade and Industry through deliberations at the Japanese Industrial Standards Committee according to the proposal of establishing a Japanese Industrial Standard from Electronic Materials Manufacturers Association of Japan (EMAJ)/ Japanese Standards Association (JSA), with a draft of Industrial Standard based on the provision of Article 12 Clause 1 of the Industrial Standardization Law.

This Standard has been made based on IEC 61643-12:2002 *Surge protective devices connected to low-voltage power distribution systems – Selection and application principles* for the purposes of making it easier to compare this Standard with International Standard; to prepare Japanese Industrial Standard conforming with International Standard; and to propose a draft of an International Standard which is based on Japanese Industrial Standard.

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Surge protective devices connected to low-voltage power distribution systems— Selection and application principles

Introduction This Japanese Industrial Standard has been prepared based on the first edition of IEC 61643-12 *Surge protective devices connected to low-voltage power distribution systems—Selection and application principles* published in 2002 without modifying the technical contents.

- 1) **General** Surge protective devices (hereafter referred to as SPDs) are used to protect, under specified conditions, electrical systems and equipment against various overvoltages and impulse currents, such as lightning and switching surges. SPDs should be selected according to their environmental conditions and the acceptable failure rate of the equipment and the SPDs.

This Standard provides information to the user about characteristics useful for the selection of an SPD. This Standard provides information to evaluate, with reference to JIS A 4201, IEC 61662 and JIS C 0364, the need for using SPDs in low-voltage systems. It provides information on selection and co-ordination of SPDs, while taking into account the entire environment in which they are applied. Some examples are: equipment to be protected and system characteristics, insulation levels, overvoltages, method of installation, location of SPDs, co-ordination of SPDs, failure mode of SPDs and equipment failure consequences. It also provides guidance to perform a risk analysis.

Guidance on requirements for product insulation co-ordination is provided by JIS C 0664. Requirements for safety (fire, overcurrent and electric shock) and installation are provided by JIS C 0364.

The JIS C 0364 series of standards provide direct information for contractors on the installation of SPDs. IEC 62066 (published as a technical report) gives more information on the scientific background of surge protection.

- 2) **Keys to understanding the structure of this Standard** The list below summarizes the structure of this Standard and provides a summary of the information covered in each clause and annex. The main clauses provide basic information on the factors used for SPD selection. Readers who wish to obtain more detail on the information provided in clauses 4 to 7 should refer to the relevant annexes.

Clause 1 describes the scope of this Standard.

Clause 2 lists the normative references where additional information may be found.

Clause 3 provides definitions useful for the comprehension of this Standard.

Clause 4 addresses the parameters of systems and equipment relevant to SPDs. In addition to the stresses created by lightning, those created by the network it-

self as temporary overvoltages and switching surges are described.

Clause 5 lists the electrical parameters used in the selection of an SPD and gives some explanation regarding these parameters. These are related to the data given in JIS C 5381-1.

Clause 6 is the core of this Standard. It relates the stresses coming from the network (as discussed in clause 4) to the characteristics of the SPD (as discussed in clause 5). It outlines how the protection given by SPDs may be affected by its installation. The different steps for the selection of an SPD are presented including the problems of co-ordination when more than one SPD is used in an installation (details about co-ordination may be found in annex F).

Clause 7 is an introduction to the risk analysis (considerations of when the use of SPDs is beneficial).

Clause 8 deals with co-ordination between signalling and power lines (under consideration).

Annex A deals with information needed for tenders and explains testing procedures used in JIS C 5381-1.

Annex B provides examples of the relationship between two important parameters of SPDs, U_c and U_p , in the specific case of ZnO varistors and also examples of the relationship between U_c and the nominal voltage of the network.

Annex C supplements the information given in clause 4 on surge voltages in low-voltage systems.

Annex D deals with the calculation of the sharing of lightning current between different earthing systems.

Annex E deals with calculation of temporary overvoltages due to faults in the high-voltage system.

Annex F supplements the information given in clause 6 on co-ordination rules when more than one SPD is used in a system.

Annex G provides specific examples on the use of this Standard.

Annex H provides specific examples of the use of the risk analysis. This annex is under consideration.

Annex I supplements the information given in clause 4 about system stresses.

Annex J supplements the information given in clause 5 on criteria for selection of SPDs.

Annex K supplements the information given in clause 6 on the application of SPDs in various low-voltage systems.

Annex L supplements the information given in clause 7 on the parameters used in risk analysis.

a) List of symbols used in this Standard

dB	Decibel
CWG	Combination wave generator
E_{MAX}	Maximum energy withstand
EMC	Electromagnetic compatibility
GDT	Gas discharge tubes
HV	High voltage
I_c	Continuous operating current
I_f	Follow current
I_{imp}	Impulse current for class I test
I_L	Rated load current
I_{max}	Maximum discharge current for class II test
I_n	Nominal discharge current
IP	Degrees of protection provided by the enclosure
I_{peak}	Current peak value of impulse current
I_{sc}	Short-circuit current
L	Inductance
LPS	Lightning protection system
LPZ	Lightning protection zone
LV	Low voltage
MOV	Metal oxide varistor
HVA	High voltage A (medium voltage, <50 kV)
MV	Medium voltage
N_g	Ground flash density
N_k	Keraunic level
Q	Charge of impulse current
RCD	Residual current device
TOV	Temporary overvoltage
SPD	Surge protective device
U_c	Maximum continuous operating voltage
U_{cs}	Maximum continuous operating voltage of the power system
U_{dyn}	Dynamic sparkover voltage of a gap
U_m	Measured limiting voltage
U_n	Nominal voltage of the system phase to earth
U_0	Line-to-neutral voltage of the system
U_{oc}	Open-circuit voltage for class III test
U_p	Voltage protection level
U_{ref}	Reference voltage of a varistor
U_{res}	Residual voltage
U_T	Temporary overvoltage
U_{TOV}	Temporary overvoltage of the network
$U_{TOV,HV}$	Temporary overvoltage of the network inside the high-voltage system
$U_{TOV,LV}$	Temporary overvoltage of the network inside the low-voltage system
U_W	Voltage withstand
ZnO	Zinc oxide

1 Scope This part of JIS C 5381 specifies the principles for selection, operation, location and co-ordination of SPDs to be connected to 50 Hz to 60 Hz a.c. and to d.c. power circuits and equipment rated up to 1 000 V r.m.s. or 1 500 V d.c.

NOTES 1 The International Standard corresponding to this Standard is as follows.

In addition, symbols which denote the degree of correspondence in the contents between the relevant International Standard and JIS are IDT (identical), MOD (modified), and NEQ (not equivalent) according to ISO/IEC Guide 21.

IEC 61643-12:2002 *Surge protective devices connected to low-voltage power distribution systems—Selection and application principles* (IDT)

- 2 Additional requirements may be necessary for special applications such as electrical traction, etc.
- 3 It should be remembered that JIS C 0364 is also applicable.
- 4 This Standard deals only with SPDs and not with SPDs components integrated inside equipment.

2 Normative references The following standards contain provisions which, through reference in this Standard, constitute provisions of this Standard. If the indication of the year of coming into effect or the year of publication is given to these referred standards, only the edition of the indicated year constitutes the provision of this Standard but the revision and amendment made thereafter do not apply.

JIS A 4201:2003 *Protection of structures against lightning*

NOTE : IEC 61024-1:1990 *Protection of structures against lightning—Part 1: General principles* is equivalent to the said standard.

JIS C 0364-4-41:1997 *Electrical installations of buildings—Part 4: Protection for safety Chapter 41: Protection against electric shock*

NOTE : IEC 60364-4-41:1992 *Electrical installations of buildings—Part 4: Protection for safety—Chapter 41: Protection against electric shock* is identical with the said standard.

JIS C 0364-5-534:2000 *Electrical installations of buildings—Part 5: Selection and erection of electrical equipment Section 534: Devices for protection against overvoltages*

NOTE : IEC 60364-5-534:1997 *Electrical installations of buildings—Part 5: Selection and erection of electric equipment—Section 534: Devices for protection against overvoltage* is identical with the said standard.

JIS C 0367-1:2003 *Protection against lightning electromagnetic impulse—Part 1: general principles*

NOTE : IEC 61312-1:1995 *Protection against lightning electromagnetic impulse—Part 1: General principles* is identical with the said standard.

JIS C 0704:1995 *Insulation test for control gear*

NOTE : IEC 60664-1:1992 *Insulation coordination for equipment within low-voltage systems—Part 1: Principles, requirements and tests* and IEC 60947-1:1996 *Low voltage switchgear and controlgear—Part 1: General rules* are equivalent to the said standard.

JIS C 0920:1993 *Tests to prove protection against ingress of water and degrees of protection against ingress of solid objects for electrical equipment*

NOTE : IEC 60529:1989 *Degrees of protection provided by enclosures (IP Code)* is equivalent to the said standard.

JIS C 61000-4-5:1999 *Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 5: Surge immunity test*

NOTE : IEC 61000-4-5:1995 *Electromagnetic compatibility (EMC)—Part 4: Testing and measurement techniques—Section 5—Surge immunity test* is identical with the said standard.

JIS C 5381-1:2004 *Surge protective devices connected to low-voltage power distribution systems—Performance requirements and testing methods*

NOTE : IEC 61643-1:1998 *Surge protective devices connected to low-voltage power distribution systems—Part 1: Performance requirements and testing methods* is identical with the said standard.

JIS C 8371:1992 *Residual current operated circuit breakers*

NOTE : IEC 61008-1:1990 *Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs)—Part 1: General rules* is equivalent to the said standard.

IEC 60038:1983 *IEC standard voltages*

IEC 60364-4-44:2001 *Electrical installations of buildings—Part 4-44: Protection for safety—Protection against voltage disturbances and electromagnetic disturbances*

IEC 60364-5-53:2001 *Electrical installations of buildings—Part 5-53: Selection and erection of electrical equipment—Isolations, switching and control*

IEC/TR 61000-5-6:2002 *Electromagnetic compatibility (EMC)—Part 5-6: Installation and mitigation guidelines—Mitigation of external EM influences, under consideration*

IEC 61009 (all parts) *Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBOs)*

IEC 61312-4:1998 *Protection against lightning electromagnetic impulse—Part 4: Protection of equipment in existing structures*

IEC TR2 61662:1995 *Assessment of the risk of damage due to lightning*

3 Definitions For the purposes of this part of JIS C 5381, the following definitions apply.

NOTE : These definitions are for the most part reproduced from JIS C 5381-1 (the definition number being indicated within square brackets). Where necessary a note has been added for better understanding regarding application of SPDs.

3.1 surge protective device (SPD) device that is intended to limit transient overvoltages and divert surge currents. It contains at least one non-linear component [see definition 3.1 of JIS C 5381-1]

3.2 continuous operating current (I_c) current flowing through each mode of protection of the SPD when energized at the maximum continuous operating voltage (U_c) for each mode

NOTE : I_c coincides with the sum of current flowing through protective components of SPDs and all internal circuits connected in parallel to protective components of SPDs.

3.3 maximum continuous operating voltage (U_c) maximum r.m.s. or d.c. voltage which may be continuously applied to the SPD's mode of protection. This is equal to the rated voltage [see definition 3.11 of JIS C 5381-1.]

3.4 voltage protection level (U_p) parameter that characterizes the performance of the SPD in limiting the voltage across its terminals, which is selected from a list of preferred values. This value is greater than the highest value of the measured limiting voltages [see definition 3.15 of JIS C 5381-1.]

3.5 measured limiting voltage maximum magnitude of voltage that is measured across the terminals of the SPD during the application of impulses of specified wave-shape and amplitude [see definition 3.16 of JIS C 5381-1.]

3.6 residual voltage (U_{res}) peak value of voltage that appears between the terminals of an SPD due to the passage of discharge current [see definition 3.17 of JIS C 5381-1.]

3.7 temporary overvoltage (U_T) maximum r.m.s. value or d.c. overvoltage that the protective device can withstand and that exceeds the maximum continuous operating voltage (U_c) for a specified time duration. Hereafter temporary overvoltage is referred to as "TOV".

NOTES 1 Adapted from 3.18 of JIS C 5381-1 by adding the following note.

- 2 U_T is a voltage declared by the manufacturer at which the SPD has a defined characteristic for a given specific duration (this means either no change in the performance after application of the temporary overvoltage or the failure should be such that there is no hazard for either personnel, equipment or facility).

3.8 temporary overvoltage of the network (U_{TOV}) power frequency overvoltage occurring on the network at a given location, of relatively long duration. TOVs may be caused by faults inside the LV system ($U_{TOV, LV}$) or inside the HV system ($U_{TOV, HV}$)

NOTE : Temporary overvoltages, typically lasting up to several seconds, usually

originate from switching operations or faults (for example, sudden load rejection, single-phase faults, etc.) and/or from non-linearity (ferroresonance effects, harmonics, etc.)

3.9 nominal discharge current (I_n) crest value of the current through the SPD having a current waveshape of 8/20. This is used for the classification of the SPD for class II test and also for preconditioning of the SPD for class I and II tests [see definition 3.8 of JIS C 5381-1.]

3.10 impulse current (I_{imp}) current peak value (I_{peak}) and the charge (Q) tested according to the test sequence of the operating duty test. This is used for the classification of the SPD for class I test [see definition 3.9 of JIS C 5381-1.]

3.11 combination wave delivered by a generator that applies a 1.2/50 voltage impulse across an open circuit and an 8/20 current impulse into a short circuit. The voltage, current amplitude and waveforms that are delivered to the SPD are determined by the generator and the impedance of the SPD to which the surge is applied. The ratio of peak open-circuit voltage to peak short-circuit current is $2\ \Omega$, this is defined as the fictive impedance (Z_f). The short-circuit current is symbolized by (I_{sc}). The open-circuit voltage is symbolized by (U_{oc}) [see definition 3.24 of JIS C 5381-1.]

3.12 8/20 current impulse current impulse with a virtual front time of 8 μ s and a time to half-value of 20 μ s [see definition 3.23 of JIS C 5381-1.]

3.13 1.2/50 voltage impulse voltage impulse with a virtual front time (time to rise from 10 % to 90 % of the peak value) of 1.2 μ s and a time to half-value of 50 μ s [see definition 3.22 of JIS C 5381-1.]

3.14 thermal runaway operational condition when the sustained power dissipation of an SPD exceeds the thermal dissipation capability of the housing and connections, leading to a cumulative increase in the temperature of the internal elements culminating in failure [see definition 3.25 of JIS C 5381-1.]

3.15 thermal stability an SPD is thermally stable if after the operating duty test causing temperature rise, the temperature of the SPD decreases with time when the SPD is energized at specified maximum continuous operating voltage and at specified ambient temperature conditions [see definition 3.26 of JIS C 5381-1.]

3.16 SPD disconnecter device for disconnecting an SPD from the system in the event of SPD failure. It is to prevent a persistent fault on the system and to give visible indication of the SPD failure

NOTES 1 Adapted from 3.29 of JIS C 5381-1 by adding the following note.

- 2 At least three functions are needed for SPD disconnectors: protection against thermal problems (such as thermal runaway on varistors, etc.), protection against internal short circuits and protection against indirect contact. These functions may be achieved by one or more disconnector(s). Each disconnector may either be integrated into the SPD or external to it. They may be used in the SPD circuit or in line with the supply.

3.17 type tests tests which are made upon the completion of the development of a

new SPD design. They are used to establish representative performance and to demonstrate compliance with the relevant standard. Once made, these tests need not be repeated unless the design is changed so as to modify its performance. In such a case, only the relevant tests need be repeated [see definition 3.31 of JIS C 5381-1.]

3.18 routine tests tests made on each SPD or on parts and materials as required to ensure that the product meets the design specifications [see definition 3.32 of JIS C 5381-1.]

3.19 acceptance tests tests which are made when it has been agreed between the manufacturer and the purchaser that the SPD or representative samples of an order are to be tested [see definition 3.33 of JIS C 5381-1.]

3.20 degrees of protection provided by enclosure (IP code) extent of protection provided by an enclosure against access to hazardous parts, against ingress of solid foreign objects and/or against ingress of water (see JIS C 0920) [see definition 3.30 of JIS C 5381-1.]

3.21 voltage drop (in per cent) (ΔU)

$$\Delta U = [(U_{in} - U_{out}) / U_{in}] \times 100 \%$$

where U_{in} is the input voltage and U_{out} is the output voltage measured simultaneously with a full rated resistive load connected.

This parameter is only used for two-port SPDs [see definition 3.20 of JIS C 5381-1.]

3.22 insertion loss at a given frequency, the insertion loss of an SPD connected into a given power system is defined as the ratio of voltages appearing across the mains immediately beyond the point of insertion before and after the insertion of the SPD under test. This result is expressed in decibels (dB) [see definition 3.21 of JIS C 5381-1.]

NOTE : Requirements and tests are under consideration.

3.23 load-side surge withstand capability for a two-port SPD ability of a two-port SPD to withstand surges on the output terminals originated in loads downstream of the SPD [see definition 3.19 of JIS C 5381-1.]

3.24 short-circuit withstand maximum prospective short-circuit current that the SPD is able to withstand

NOTES 1 Adapted from 3.28 of JIS C 5381-1 by adding the following note.

- 2 This definition refers both to d.c. and a.c. 50/60 Hz. Two short-circuit withstand values may be defined for two-port SPDs or one-port SPDs having separated input and output terminals: one corresponding to an internal short circuit (by-passing the internal active part) and another one corresponding to an external short circuit directly at the output terminals (case of a failure at the load). In JIS C 5381-1, the short-circuit withstand test is only for internal short circuits. An external short-circuit test is under consideration.

3.25 one-port SPD SPD connected in shunt with the circuit to be protected. A one-port device may have separate input and output terminals without a specified series impedance between these terminals

NOTES 1 Adapted from 3.2 of JIS C 5381-1 by adding the following note.

- 2 Figure 1 shows some typical one-port SPDs and the generic drawing for a one-port SPD (figure 1c). A one-port SPD may be connected in shunt, figure 1a, or in line with the power supply, figure 1b. In the first case, the load current is not flowing through the SPD. In the second case, the load current is flowing through the SPD and the temperature rise under load current and the associated maximum admissible load current may be determined as for a two-port SPD. Figure 3b to 3d show the response of various types of one-port SPD to an 8/20 impulse applied via a combination wave generator.

3.26 two-port SPD SPD with two sets of terminals, input and output. A specific series impedance is inserted between these terminals

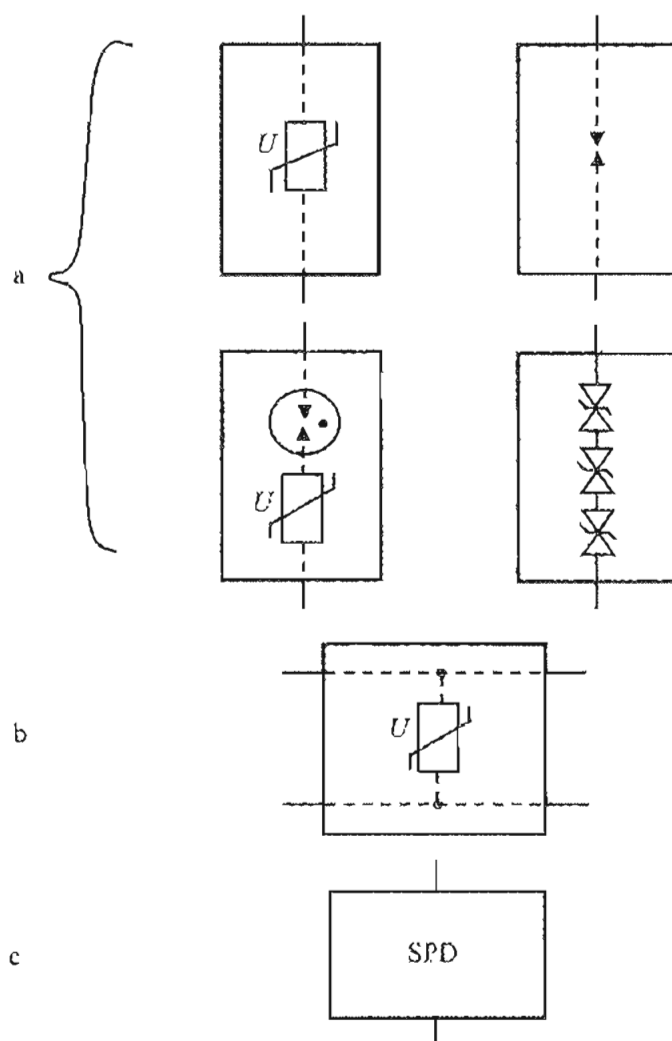
NOTES 1 Adapted from 3.3 of JIS C 5381-1 by adding the following note.

- 2 The measured limiting voltage may be higher at the input terminals than at the output terminals. Therefore, equipment to be protected is to be connected to the output terminals. Figure 2 shows typical two-port SPDs. Figure 3e and figure 3f show the response of a two-port SPD to an 8/20 impulse applied via a combination wave generator.

3.27 voltage switching type SPD SPD that has a high impedance when no surge is present, but can have a sudden change in impedance to a low value in response to a voltage surge. Common examples of components used as voltage-switching devices are spark-gaps, gas discharge tubes (GDT), thyristors (silicon-controlled rectifiers) and triacs. These SPDs are sometimes called "crowbar type"

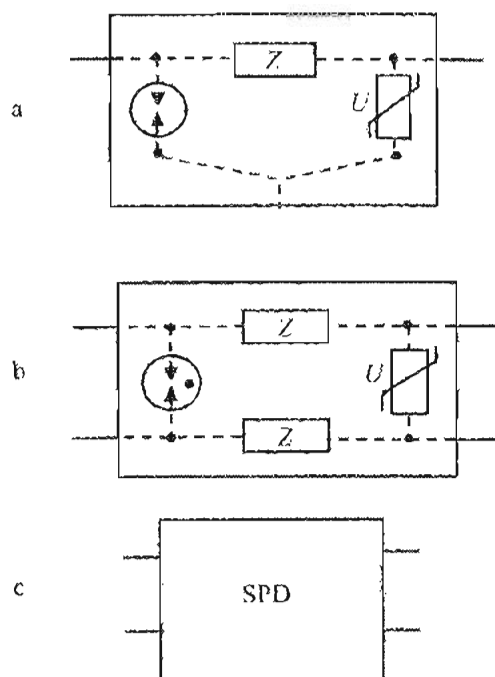
NOTES 1 Adapted from 3.4 of JIS C 5381-1 by adding the following note.

- 2 A voltage-switching device has a discontinuous U versus I characteristic. Figure 3c shows the response of a typical voltage switching SPD to an impulse applied via a combination wave generator.



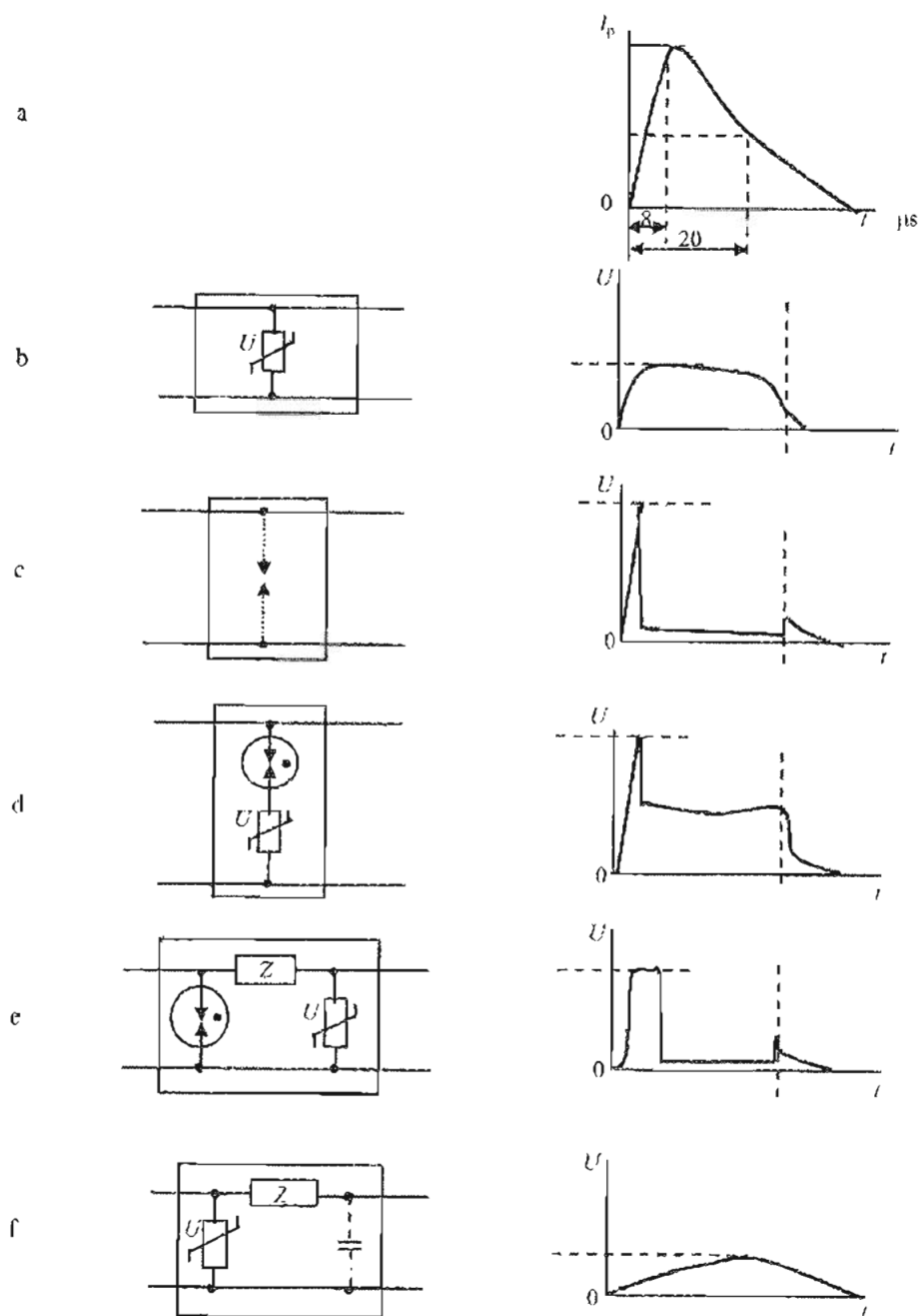
- a : One-port SPDs
b : One-port SPD with separate input and output terminals
c : Generic symbol for a one-port SPD

Figure 1 Examples of one-port SPDs



- a : Three-terminal two-port SPD
b : Four-terminal two-port SPD
c : Generic symbol for a two-port SPD
Z : Series impedance between input and output terminals

Figure 2 Examples of two-port SPDs



- a : Applied current waveform
 b : Response of voltage limiting type SPD
 c : Response of voltage switching type SPD
 d : Response of one-port combination type SPD
 e : Response of two-port combination type SPD
 f : Response of two-port voltage limiting type SPD with filtering

NOTE : The voltage levels are only representative and not an indication of actual values.

Figure 3 Response of one-port and two-port SPDs to a combination wave impulse

3.28 voltage limiting type SPD SPD that has a high impedance when no surge is present, but will reduce it continuously with increased surge current and voltage. Common examples of components used as non-linear devices are: varistors and suppressor diodes. These SPDs are sometimes called "clamping type"

NOTES 1 Adapted from 3.5 of JIS C 5381-1 by adding the following note.

- 2 A voltage-limiting device has a continuous U versus I characteristic. Figure 3b shows the response of a typical voltage-limiting SPD to an impulse applied via a combination wave generator.

3.29 combination type SPD SPD that incorporates both voltage switching type components and voltage limiting type components may exhibit voltage-switching, voltage-limiting, or both voltage-switching and voltage-limiting behaviour depending upon the characteristics of the applied voltage

NOTES 1 Adapted from 3.6 of JIS C 5381-1 by adding the following note.

- 2 Figure 3d and figure 3e show the response of various typical combination type SPDs to a combination wave impulse.

3.30 modes of protection SPD protective components may be connected line to line or line to earth or line to neutral or neutral to earth and combination thereof. These paths are referred to as modes of protection [see definition 3.7 of JIS C 5381-1.]

3.31 follow current (I_f) current supplied by the electrical power system and flowing through the SPD after a discharge current impulse. The follow current is significantly different from the continuous operating current (I_c) [see definition 3.13 of JIS C 5381-1.]

3.32 maximum discharge current (I_{max}) for class II test crest value of a current through the SPD having an 8/20 waveshape and magnitude according to the test sequence of the class II operating duty test. I_{max} is greater than I_n [see definition 3.10 of JIS C 5381-1.]

3.33 degradation change of original performance parameters as a result of exposure of the SPD to surge, service or unfavourable environment

NOTES 1 Adapted from 3.27 of JIS C 5381-1 by adding the following note.

- 2 Degradation is a measure of the ability of an SPD to withstand the conditions for which it is designed throughout its service life. Two type tests are applied to provide confidence with respect to degradation. The first one is the operating duty test and the second is the ageing test. However, these two tests may be combined. The operating duty test is conducted by applying a specified number of defined current wave-shapes to the SPD. Permitted changes in the SPD characteristics are given in JIS C 5381-1. The ageing test is carried out at a specified temperature with a voltage of specified magnitude and duration applied to the SPD. Permitted changes in the SPD characteristics are given in this Standard (this test is under consideration).

This can be used to determine the SPD prospective installed life which should also consider the following:

- replacement policy;
- location and accessibility;
- acceptable failure rate;
- operating practices.

3.34 residual current device (RCD) mechanical switching device or association of devices intended to cause the opening of the contacts when the residual or unbalanced current attains a given value under specified conditions [see definition 3.37 of JIS C 5381-1.]

3.35 nominal voltage of the system voltage by which a system or equipment is designated and to which certain operating characteristics are referred (for example, 230/400 V). Under normal system conditions, the voltage at the supply terminals may differ from the nominal voltage as determined by the tolerances of the supply systems

NOTE : In this Standard a tolerance of $\pm 10\%$ is used.

The nominal voltage of the system phase to earth is called U_n (see IEC 60038).

NOTE : The line-to-neutral voltage of the system is called U_0 .

3.36 impulse test classification

3.36.1 class I test test carried out with the nominal discharge current (I_n) defined in 3.9, the 1.2/50 voltage impulse defined in 3.13, and the maximum impulse current I_{imp} for class I test defined in 3.10

3.36.2 class II test test carried out with the nominal discharge current (I_n) defined in 3.9, the 1.2/50 voltage impulse defined in 3.13, and the maximum discharge current I_{max} for class II test defined in 3.32

3.36.3 class III test tests carried out with the combination wave (1.2/50, 8/20) defined in 3.11

NOTE : Adapted from 3.35.3 of JIS C 5381-1.

3.37 rated load current (I_L) maximum continuous rated r.m.s. or d.c. current that can be supplied to a load connected to the protected output of an SPD

NOTES 1 Adapted from 3.14 of JIS C 5381-1 by adding the following note.

- 2 This is only relevant to SPD(s) having separate input and output terminals.

3.38 backup overcurrent protection overcurrent device (for example, fuse or circuit-breaker), which is a part of the electrical installation located externally upstream of the SPD, to avoid overheating and destruction in case the SPD is unable to interrupt the power frequency short-circuit current [see definition 3.36 of JIS C 5381-1.]

3.39 maximum continuous operating voltage of the power system at the SPD location (U_{cs}) maximum r.m.s. or d.c. voltage to which the SPD may be subjected at the point of application of the SPD. This takes into account only voltage regulation and/or voltage drop or increase. It is directly linked to U_0 . Also called actual maximum system

voltage (see figure 6).

NOTE : This voltage does not take into account harmonics, faults, TOVs or transient conditions.

3.40 sparkover voltage of a voltage-switching SPD maximum voltage value before disruptive discharge between the electrodes of the gap of an SPD

NOTES 1 Adapted from 3.38 of JIS C 5381-1 by adding the following note.

2 A voltage-switching SPD may be based on components other than gaps (for example, silicon-based components).

3.41 lightning protection system (LPS) complete system used to protect a structure and its contents against the effects of lightning

4 Systems and equipment to be protected When evaluating an installation with regard to the use of an SPD, two factors need to be considered:

- a) the characteristics of the low-voltage power distribution system on which it will be used, including expected types and levels of overvoltage and current;
- b) the characteristics of the equipment requiring protection.

4.1 Low-voltage power distribution systems Low-voltage power distribution systems are basically characterized by the type of system earthing (TNC, TNS, TNC-S, TT, IT) and the nominal voltage (see 3.35). Various types of overvoltages and currents may occur. In this Standard, the overvoltages are classified into three groups:

- a) lightning;
- b) switching;
- c) temporary overvoltages.

4.1.1 Lightning overvoltages and currents In most cases lightning stress is the main factor for the selection of an SPD's class of test and associated current or voltage values (I_{imp} , I_{max} or U_{oc} , according to JIS C 5381-1).

Evaluation of the waveshape and current (or voltage) amplitude of the lightning surges is necessary for the proper selection of an SPD. It is important to determine if the voltage protection level of the SPD will be adequate to protect the equipment in such circumstances.

NOTE : For example, areas prone to frequent lightning strikes may require an SPD suitable to withstand class I or class II tests.

Generally (for example, in the case of direct strike to the lines or induced surges on the lines), higher stresses occur on the electrical installation external to the structure. Within the structure, the stresses are decreased when moving from the installation's entrance to internal circuits. The decrease is due to the change of circuit configuration and impedances. The need for protection against lightning surges depends on

- a) the local ground flash density N_g (average annual ground flash density, in light-

ning flashes per km² per year, concerning the region where the structure is located). Modern lightning location systems can provide information on N_g with reasonable accuracy;

- b) the exposure of the electrical installation, including incoming services. Underground systems are generally considered to be less exposed than overhead systems.

Even if the supply is provided by an underground cable, the use of an SPD may be recommended to provide protection. To determine if surge protection is needed, the following are some items that should be considered:

- the installation has a lightning protection system in its vicinity;
- the length of the cable is not sufficient to provide adequate separation (attenuation) of the installation from the overhead part of the network;
- high surges of atmospheric origin can be expected on the overhead line supplying the MV (medium voltage) side of the transformer connected to the installation;
- the underground cable may be affected by direct lightning in the presence of high soil resistivity;
- the size or height of the building powered by the cable is large enough to significantly increase the risk for direct strikes to the building. The risk for direct strikes to other incoming (outgoing) services (telephone lines, antenna systems, etc.) that may affect the power system and equipment;
- other overhead services are present.

When many buildings are supplied from a single supply system, those buildings which do not have SPDs may have high stresses on their electrical systems. For SPD installations in a structure which is equipped with an external lightning protection system, it is (in case of direct lightning to the structure) generally sufficient to make calculations using earthing d.c. resistance readings (for example, earthing of the building and power distribution system, pipes, etc), to determine the current distribution through the SPDs.

Annex C and annex I give more information about lightning stress.

4.1.2 Switching overvoltages These stresses, in terms of peak current and voltage, are usually lower than lightning stresses but may have longer duration. However, in some cases, particularly deep inside a structure or close to switching overvoltage sources, the switching stress can be higher than the stresses caused by lightning. The energy related to these switching surges needs to be known to permit the choice of appropriate SPDs. The time duration of the switching surges, including transients due to faults and fuse operations, can be much longer than the lightning surge duration. Annex C gives more information about switching stress.

4.1.3 Temporary overvoltages U_{rov}

4.1.3.1 General Any SPD can be exposed to a temporary overvoltage U_{rov} during its lifetime that exceeds the maximum continuous operating voltage of the power system.

A temporary overvoltage has two dimensions, magnitude and time. The time duration of the overvoltage primarily depends upon the earthing of the supply system (this includes both the high-voltage supply system as well as the low-voltage system to which the SPD is connected). In determining the temporary overvoltages, consideration should be given to the maximum continuous operating voltage of the power system (U_{co}). Annex I provides more information about temporary overvoltage.

4.1.3.2 Standardized values IEC 60364-4-44 gives the maximum values of U_{TOV} to be expected in low-voltage networks (for a more detailed calculation of these values, refer to annex E).

Lower values are possible depending on many factors such as the location of the SPD, the type of network, etc. The maximum values (see also figure 4) given in table 1 are at the consumer installation for transformer location (see table 1, note 2).

Table 1 Maximum TOV values as given in IEC 60634-4-44

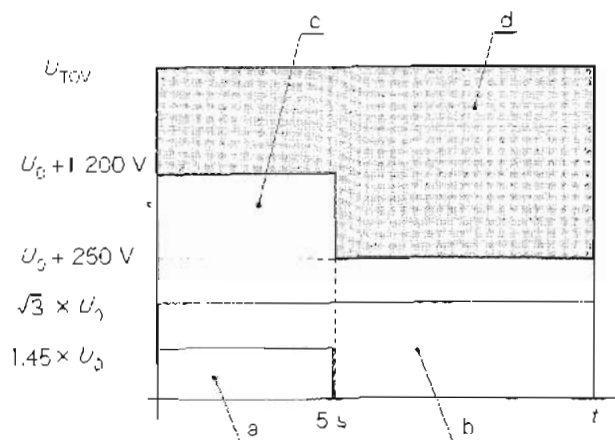
Occurrence of U_{TOV}	System	Maximum values for $U_{TOV, HV}$
Between phase and earth	TT, IT	$U_0 + 250 \text{ V}$ for duration $>5 \text{ s}$
		$U_0 + 1\,200 \text{ V}$ for duration up to 5 s
Between neutral and earth	TT, IT	250 V for duration $>5 \text{ s}$
		$1\,200 \text{ V}$ for duration up to 5 s
The above values are extreme values related to faults in the high-voltage network and may be calculated depending on the type of network according to annex E.		
Occurrence of U_{TOV}	System	Maximum values for U_{TOV}
Between phase and neutral	TT and TN	$\sqrt{3} \times U_0$
The above value is related to a loss of the neutral conductor in the low-voltage system.		
Between phase and earth	IT system [TT system: see note (1)]	$\sqrt{3} \times U_0$
The above value is related to accidental earthing of the phase conductor in the low-voltage system.		
Between phase and neutral	TT, IT and TN	$1.45 \times U_0$ for a duration up to 5 s
The above value is related to short circuit between a line conductor and the neutral conductor.		

Note (1) It has been demonstrated that such high TOVs can also occur in TT systems for durations up to 5 s . See annex E for more details. This is not addressed in IEC 60364-4-44.

NOTES 1 Maximum TOV values at the transformer location may be different from the table above (higher or lower). See annex E for more details.

2 Loss of neutral is not used for selection of SPDs.

For further information, see annex E.



- a : Area of $U_{rov, LV}$ between phase and neutral for TT, TN and IT systems for a fault in the LV installation (short circuit)
- b : Area of $U_{rov, LV}$ between phase and earth for IT [TT see note (1)] system for a fault in the LV installation (accidental earthing of a phase conductor) and area of $U_{rov, LV}$ between phase and neutral for TT and TN systems for a fault in the LV installation (loss of neutral)
- c : Maximum value for $U_{rov, hv}$ at the consumer installation between phase and earth for TT and IT systems in the case of a fault occurring in the HV system
- d : Undefined area

Figure 4 Maximum values of U_{rov} according to IEC 60634-4-44

4.2 Characteristics of the equipment to be protected Under consideration.

For the time being refer to JIS C 0704 for the impulse withstand of equipment and to IEC 61000-4-5 for the impulse immunity of equipment.

5 Surge protective devices

5.1 Basic function of SPDs The SPDs considered in this Standard are those installed external to the equipment to be protected. Their function can be described as follows.

- a) In power systems in the absence of surges: the SPD should not have a significant influence on the operational characteristics of the system to which it is applied.
- b) In power systems during the occurrence of surges: the SPD responds to surges by lowering its impedance and thus diverting surge current through it to limit the voltage to its protective level. The surges may initiate a power follow current through the SPD.
- c) In power systems after the occurrence of surges: the SPD recovers to a high-impedance state after the surges and extinguishes any possible power follow current.

The characteristics of SPDs are specified to achieve the above functions under normal service conditions. The normal service conditions are specified by the frequency of the power-system voltage, load current, altitude (i.e. air pressure), humidity and ambient air temperature.

5.2 Additional requirements Depending upon the application of the SPD, additional requirements may be needed such as:

- protection of SPDs against direct contact (it should be in accordance with JIS C 0364-4-41);
- safety in the event of SPD failures.

An SPD may fail or be destroyed when surges are greater than its designed maximum energy and discharge current capability. For the purpose of this Standard, failure modes of SPDs are divided into open-circuit and short-circuit mode.

In the open-circuit mode the system to be protected is no longer protected. In this case, failure of an SPD is usually difficult to detect since it has almost no influence on the system. To ensure that the failed SPD is replaced before the next surge, an indication function may be required.

In the short-circuit mode, the system is severely influenced by the failed SPD. The short-circuit current flows through the failed SPD from the power source. Energy dissipated during the conduction of short-circuit current may be excessive and cause a fire hazard. The short-circuit withstand capability test of JIS C 5381-1 covers this problem. In cases where the system to be protected has no suitable device to disconnect the failed SPD from its circuit, a suitable disconnecting device may be required to be used in conjunction with a SPD which has a short-circuit failure mode.

5.3 Classification of SPDs

5.3.1 SPD: classification Surge protective devices are classified according to JIS C 5381-1 as follows.

- a) Number of ports : one or two
- b) Design topology : voltage switching, voltage limiting or combination
- c) Class I , II and/or III tests
- d) Location : indoor or outdoor
- e) Accessibility : accessible, non accessible
- f) Mounting method : permanent or portable
- g) Disconnecter : location (external, internal, both external and internal, none) and function (thermal, leakage current, overcurrent)
- h) Back-up overcurrent protection : specified or not
- i) Degree of protection provided by the SPD enclosure (IP code)
- j) Temperature range

NOTE : By definition, outdoor means outside closed shelters. Hence, such SPDs are subjected to all external conditions. Indoor means inside closed shelters. Hence, such SPDs are subjected to indoor atmospheric conditions.

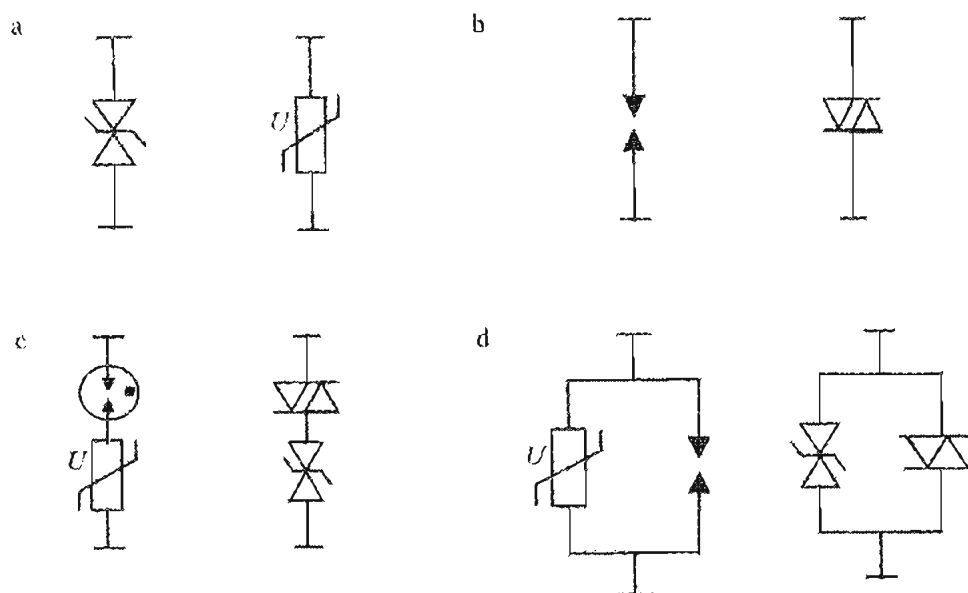
Some of the above choices are linked to the technology used and are defined by the manufacturer.

5.3.2 Typical design and topologies The main protective components used in SPDs belong to two categories:

- voltage-limiting components: varistors, avalanche or suppressor diodes, etc.;
- voltage-switching components: air gaps, gas discharge tubes, thyristors (silicon-controlled rectifiers), triacs, etc.

Based on these components, typical SPD designs are given below (see figure 5):

- single voltage-limiting component (figure 5a): limiting type SPD;
- single voltage-switching component (figure 5b): switching type SPD;
- combination of voltage-limiting and switching components (figures 5c and 5d): combination type SPD.



a : Voltage-limiting components

b : Voltage-switching components

c : Voltage-limiting components in series with voltage-switching components

d : Voltage-limiting components in parallel with voltage-switching components

Figure 5 Examples of components and combinations of components

Not all SPDs are defined by a simple arrangement of basic components. They may additionally incorporate indicators, disconnectors, fuses, inductors, capacitors and other components.

Additionally an SPD can be configured as: one-port SPD (see 3.25) or two-port SPD (see 3.26).

5.4 Characteristics of SPDs

5.4.1 Service conditions described in JIS C 5381-1 Normal service conditions:

- The frequency of the supply mains is between 48 Hz and 62 Hz a.c. or d.c.
- The altitude should not exceed 2 000 m.
- Operating and storage temperature: normal range $-5\text{ }^{\circ}\text{C}$ to $+40\text{ }^{\circ}\text{C}$, extended range $-40\text{ }^{\circ}\text{C}$ to $+70\text{ }^{\circ}\text{C}$.
- The relative humidity in indoor temperature conditions should be between 30 % and 90 %.

NOTES 1 The user determines the location where the SPD is to be applied (outdoor, indoor, etc.) and should decide whether the environmental temperature conditions are within the normal or the extended range.

2 JIS C 5381-1 also gives indications regarding maximum continuous operating voltage of the SPDs. See 6.2.1 of this Standard.

Abnormal service conditions:

- Exposure of the SPD to abnormal service conditions may require special consideration in the design or application of the SPD and should be called to the attention of the manufacturer.
- Solar radiation: most SPDs are not exposed to solar radiation. In general, solar radiation is not considered during type testing. Where SPDs are exposed to solar radiation, this should be taken into account and tested accordingly.

NOTE : In general, the degree of protection of the SPD enclosure should be greater than IP20. In some instances, other values could be used (for example, for outdoor SPDs).

5.4.2 List of parameters for SPD selection The following is a non-exclusive list of parameters needed by the user(s) to properly select the SPD(s).

NOTE : Some of these parameters are defined for each mode of protection.

- a) U_c and I_c : Maximum continuous operating voltage and continuous operating current
- b) U_T : (Temporary overvoltage) (under consideration)
- c) I_n : Nominal discharge current (only for class I and for class II tests)
- d) I_{max} for class II tests, I_{imp} for class I tests and U_{oc} for class III tests
- e) U_p : voltage protection level
- f) Degradation (under consideration)
- g) Failure modes
- h) Short-circuit withstand
- i) Maximum continuous load current (for two-port SPDs or one-port SPDs with separate input and output terminals)

- j) Voltage drop (for two-port SPDs or one-port SPDs with separate input and output terminals)

Figure 6 shows the relationship between U_p , U_0 , U_c and U_{cs} .

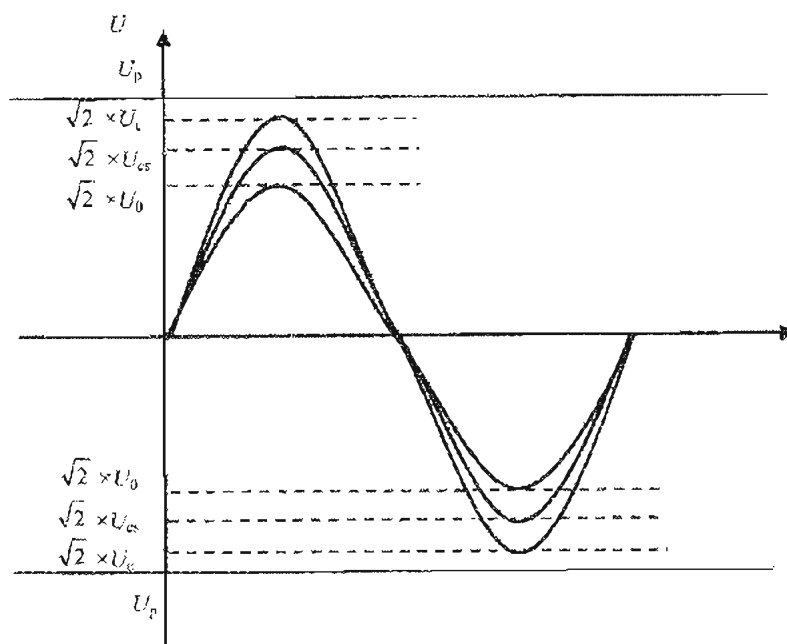


Figure 6 Relationship between U_p , U_0 , U_c and U_{cs}

5.5 Additional information on characteristics of SPDs

5.5.1 Information related to power-frequency voltages

5.5.1.1 U_c and I_c : Maximum continuous operating voltage and continuous operating current U_c should be selected in order to minimize any changes in SPD characteristics (ageing, thermal runaway, etc.) under normal conditions. I_c is the value of current through the SPD when U_c is applied. The current flowing through the earth (PE) terminal, if any, is called the residual current. This current is used in selecting an SPD to avoid unnecessary operation of overcurrent devices or other protective devices (for example RCDs) (see 5.3.1.212 of IEC 60364-5-53). See annex J for further information on how the effect of the operation of an overcurrent or other protective device depends on the configuration of the system.

5.5.1.2 U_T : Temporary overvoltages U_T is used to define the characteristics of the SPD under temporary overvoltage conditions. It is defined ideally by a curve. In practice a few pairs of values of power frequency or d.c. overvoltage versus time (up to several seconds) are sufficient to characterize the SPD with respect to U_T . Typical durations for TOVs considered by different standards are 0.2 s and 5 s. An example of such a curve is shown in figure J.1.

The U_T characteristic should be given by the manufacturer. Standardization of a test to obtain the U_T curve is under consideration. In general, it can be determined by test:

ing (by applying a voltage U for a certain duration after which either no significant change should have occurred in the SPD's performance or no hazard to personnel, equipment or facility should be observed) or it can be determined by calculation. When such a characteristic is not known, the user should consider that $U_T = U_c$ (this means that one should use a value of U_c that is greater than all temporary overvoltages expected to occur in the system).

NOTES 1 At the present time, JIS C 5381-1 only deals with temporary overvoltage failure mode, i.e. when the SPD is not able to withstand the value of the temporary overvoltage for a sufficient time.

2 Selecting an SPD with both a high temporary overvoltage withstand and a low-voltage protection level may be difficult.

The user can select the most suitable SPD by comparing the temporary overvoltage values of the SPD (U_T) and the temporary overvoltages really occurring in the field (U_{rov}) taking into account the time characteristics of U_T and U_{rov} .

5.5.2 Information related to surge currents, voltage protection levels and other characteristics The factors discussed below relate to the voltage, current and time characteristics of the surge waveform. Different surge waveforms and levels are used for testing depending upon the stresses to which the SPD is expected to be exposed.

Guidance to the selection of the appropriate test class(es) for an SPD is given in the introduction to JIS C 5381-1, which states the following.

- The class I test is intended to simulate partial conducted lightning current impulses. SPDs subjected to class I test methods are generally recommended for locations at points of high exposure, for example, line entrances to buildings protected by lightning protection systems.
- SPDs tested to class II or III test methods are subjected to impulses of shorter duration. These SPDs are generally recommended for locations with lesser exposure to direct impulses.

NOTE : The class II test applies an impressed current to the SPD. The class III test applies a voltage to the SPD, and the resultant current depends on the characteristics of the SPD.

When selecting an SPD it is necessary to consider both the test class and the magnitude of the impulse for which it is rated.

5.5.2.1 I_n : Nominal discharge current (8/20) (for SPDs according to class I and II tests) This is the current that is used as one test parameter for determining the measured limiting voltage for SPDs tested according to the class I and class II tests. This current is also used during preconditioning (applied 15 times) for the operating duty test for class I and class II.

I_n is lower than I_{max} and corresponds to a current that is expected to occur quite frequently in the installation.

The preferred values for I_n are: 0.05; 0.1; 0.25; 0.5; 1.0; 1.5; 2.0; 2.5; 3.0; 5.0; 10; 15 and 20 kA.

5.5.2.2 I_{imp} and I_{max} (for SPDs according to class I and II tests) I_{imp} and I_{max} and their submultiples are test parameters used in the operating duty test for class I and class II tests respectively. They are related to the maximum values of discharge currents, which are expected to occur only very rarely at the location of the SPD in the system. I_{max} is associated with class II tests and I_{imp} is associated with class I tests.

The preferred values for I_{imp} (I_{peak} , Q), according to JIS C 5381-1, are given in table 2.

Table 2 Preferred values of I_{imp}

I_{peak} (kA)	1	2	5	10	20
Q (AS)	0.5	1	2.5	5	10

NOTE : In general I_{imp} is associated with longer waveshapes than I_n . In general $I_n < I_{\text{peak}}$.

5.5.2.3 Voltage protection level provided by SPDs

5.5.2.3.1 Measured limiting voltage

a) Class I and class II tests The determination of the measured limiting voltage is made by performing two tests:

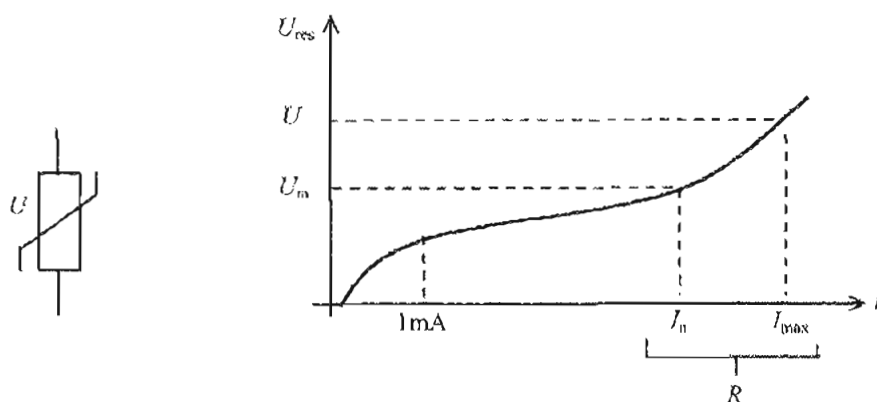
- measurement of the residual voltage at various values of current using 8/20 wave;
- measurement of the sparkover voltage using a 1.2/50 wave.

The measured limiting voltage is the highest voltage value of

- either the residual voltage, for the range of current from $0.1 \times I_n$ up to I_{peak} or I_n whichever is the greater for class I test; from $0.1 \times I_n$ up to $1.0 \times I_n$ for class II test;
- or the sparkover voltage.

SPDs with voltage-limiting components

Figure 7 shows a typical curve U_{res} versus I for a ZnO varistor. This shows that the residual voltage of the SPD at I_{max} should also be considered. If this voltage is higher than the voltage protection level and especially if it is higher than the impulse withstand voltage of the equipment to be protected, then there is a risk that the SPD will survive such a stress but the equipment will not be protected. Voltage protection level and surge current withstand of the SPD should, therefore, be selected accordingly.



U_m : Measured limiting voltage = U_{res} at I_n for SPD tested according to class II tests.

$U > U_m$ as $I = I_{max} > I_n$

V: ZnO varistor

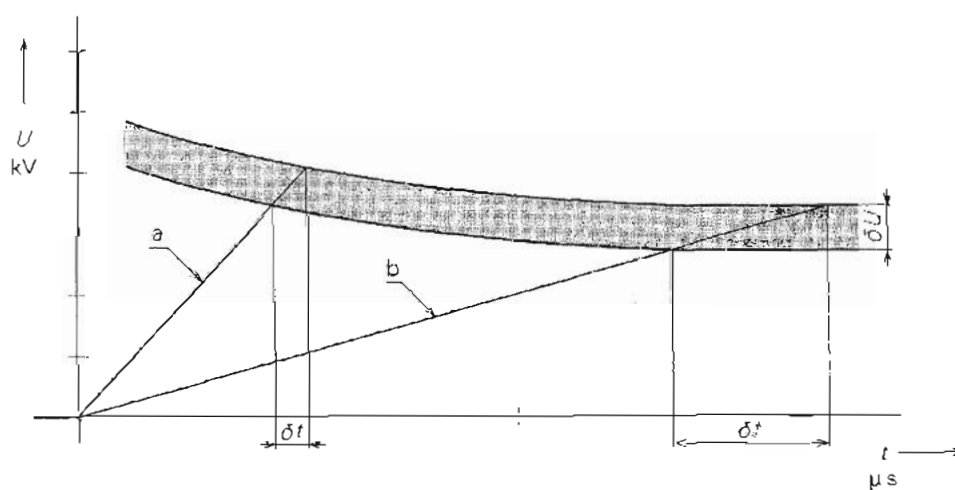
R: Range of several kA

Figure 7 Typical curve of U_{res} versus I for ZnO varistors

— SPDs with voltage-switching components

The impulse sparkover voltage of a spark gap device (gas discharge tube etc.) is dependent upon the rate of rise (dU/dt) of the applied transient overvoltage.

Generally, an increase in the voltage rate of rise (dU/dt) of the transient leads to an increase of the impulse sparkover voltage. As impulse sparkover voltage is a statistical value at a defined dU/dt , there will be a spread in the measured values (see figure 8).



a : Higher rate of rise — 10 kV/μs

b : Lower rate of rise — 1 kV/μs

δt : Spread in time of sparkover

δU : Spread in voltage of sparkover

Figure 8 Typical curve for a spark gap

- b) **Class III tests** For SPDs tested according to class III, a combination wave generator is used. The maximum value measured during the test is then used as the measured limiting voltage.

5.5.2.3.2 Voltage protection level U_p U_p is declared by the manufacturer. By definition it is equal to or greater than, the highest value of the measured limiting voltage. Selection of this value by the manufacturer should allow for manufacturing tolerances.

The preferred voltage protection levels are: 0.08; 0.09; 0.10; 0.12; 0.15; 0.22; 0.33; 0.4; 0.5; 0.6; 0.7; 0.8; 0.9; 1.0; 1.2; 1.5; 1.8; 2.0; 2.5; 3.0; 4.0; 5.0; 6.0; 8.0; 10 kV.

Annex B gives a typical relationship between the nominal voltage of the system and the voltage protection level of the SPD for a ZnO varistor.

5.5.2.4 SPD failure modes These modes are used to define the compatibility of the SPD with other equipment, with its application and with the devices used in conjunction with the SPD. Failure mode of the SPD is dependent on the magnitude, number and waveshape of the surge current and voltage, short-circuit capacity of the power system and value of the voltage applied to the SPD at the time of the failure.

This Standard considers that there are two failure modes of an SPD:

- short-circuit;
- open-circuit.

Sometimes SPDs may enter an indeterminate state for some period of time. This state involves energy absorption and eventually leads (itself or in conjunction with the disconnect or the back-up overcurrent protection) to an open-circuit or short-circuit condition. For the purpose of this Standard, it is assumed that this state is temporary and, as such, is not addressed. See annex J for further information on how the effect of the operation of an overcurrent or other protective device depends on the configuration of the system. Changes in the characteristics of the SPD are not considered as a failure mode, but are addressed in 5.5.2.8.

5.5.2.5 Short-circuit withstand The SPD alone or in conjunction with its disconnect or with back-up overcurrent protection is able to withstand the short-circuit withstand current declared by the manufacturer and checked by tests without creating damage to the environment (in particular, devices located close to it). It is necessary to be sure that the SPD will not be used at a place where the short-circuit current available is higher than this short-circuit withstand current. It is also necessary to be sure that the adequate disconnect or back-up protection as suggested by the manufacturer is present and working.

5.5.2.6 Rated load current I_L (for two-port SPDs or one-port SPDs with separate input and output terminals) It is necessary to check that the load connected downstream of a two-port SPD or a one-port SPD connected in line with the supply is compatible with the rated load current.

NOTE : It is also necessary to consider the type of load. For example some loads may have in-rush currents which can be as high as three times the r.m.s. value. These peak currents can produce additional heating within series

elements of two-port SPDs.

5.5.2.7 Voltage drop (for two-port SPDs or one-port SPDs with separate input and output terminals) It is necessary to check that the installation of a two-port SPD, or one-port SPD with separate input and output terminals, does not result in a voltage drop at the equipment located downstream, that is outside its acceptable limits.

5.5.2.8 Change of characteristics of SPDs The topology of certain SPDs may enter an intermediate state when subjected to higher stress than that defined in the standard tests. In this case some of their characteristics may change from the designed values, for example: U_p , I_n , I_c , etc. In particular, this may occur for SPDs having active parts in parallel where one of these active parts may be disconnected after a surge. In these instances the user may not be aware of these changes in characteristics. Any such intermediate state should be avoided in the design of an SPD, unless there is a clear indication of the state when it occurs.

6 Application of SPDs in low-voltage power distribution systems

6.1 Installation and its effect on the protection given by SPDs When a risk analysis is performed (see clause 7), the stresses in the system (clause 4) and the characteristics of the SPD (clause 5) being identified can be specified. In applying an SPD in a power-distribution system the flow chart shown in figure 9 may be used.

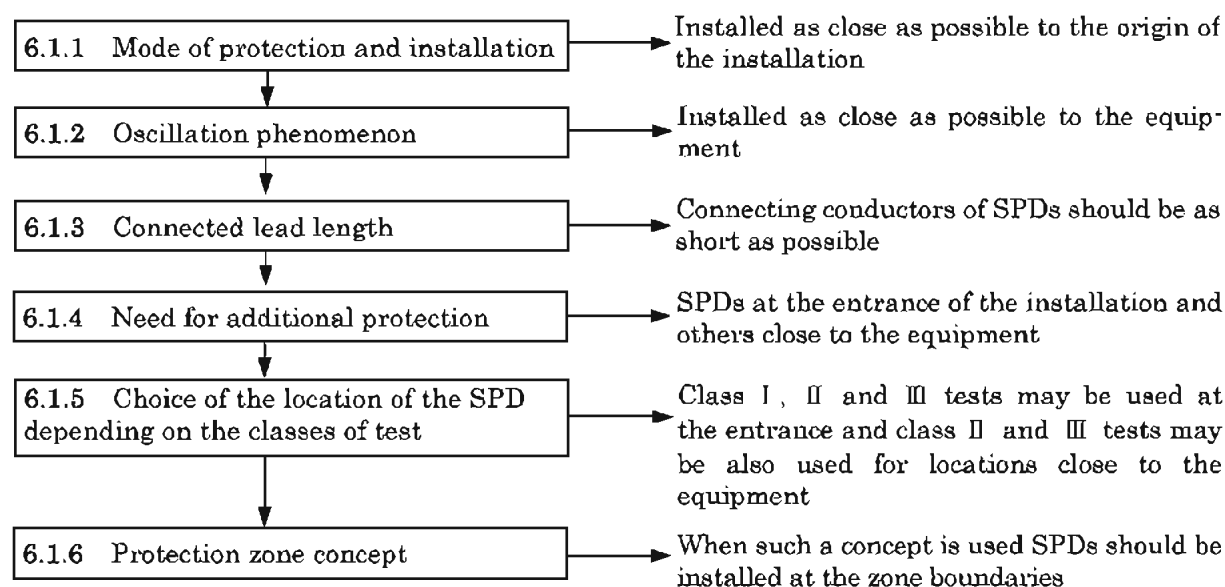


Figure 9 Flow chart for SPD application

6.1.1 Possible modes of protection and installation When the equipment to be protected has a sufficient overvoltage withstand or is located close to the main distribution board, one SPD may be sufficient. In this case, the SPD should be installed as close as possible to the origin of the installation. The SPDs should have sufficient surge withstand capability for this location. Figures K.1 to K.5 show typical connections of SPDs

located at the origin of the installation for different types of systems. Figure K.5 represents the particular case of a TN C-S system. Table 3 indicates the possible modes of protection that may be required for various LV systems.

- NOTES 1 If more than one SPD is connected on the same conductor, it is necessary to ensure co-ordination between them.
- 2 The number of modes of protection depends on the type of equipment to be protected (for example, if the equipment is not connected to earth, line- or neutral-to-earth protection may not be necessary), the withstand of the equipment according to each mode of protection, the electrical system structure and earthing and the characteristics of the incoming surge. For example, protection between phase/neutral and PE conductor or between phase and neutral are generally sufficient, and protection between phase and phase is not generally used.
- 3 Installation of SPDs before the electricity supplier's meter should be carried out with the agreement of the electricity supplier.

Table 3 Possible modes of protection for various LV systems

SPD between	TT	TN-C	TN-S	IT
Line and neutral	×		×	× ⁽²⁾
Line and PE	×		×	×
Line and PEN		×		
Neutral and PE	×		×	× ⁽²⁾
Line to line	×	×	×	×

Note ⁽²⁾ When the neutral is distributed.

It is recommended that the power and signalling networks enter the structure to be protected close to each other and are bonded together at a common bonding bar. This is especially important for structures made of non-shielding material (wood, bricks, concrete, etc.).

For further information, see annex K.

6.1.2 Influence of the oscillation phenomena on the protective distance When an SPD is used to protect specific equipment or when the SPD located at the main distribution board cannot provide enough protection for some equipment, SPDs should be installed as close as possible to the equipment to be protected. If the distance between the SPD and the equipment to be protected is too large, oscillations could lead to a voltage at the equipment terminals which is generally up to two times higher than U_p but, under some circumstances, can even exceed this level. This can cause a failure of the equipment to be protected, in spite of the presence of the SPD (see figures K.8 to K.10). Acceptable distance (called protective distance) depends on SPD type, type of system, steepness and waveform of the incoming surge and connected loads. In par-

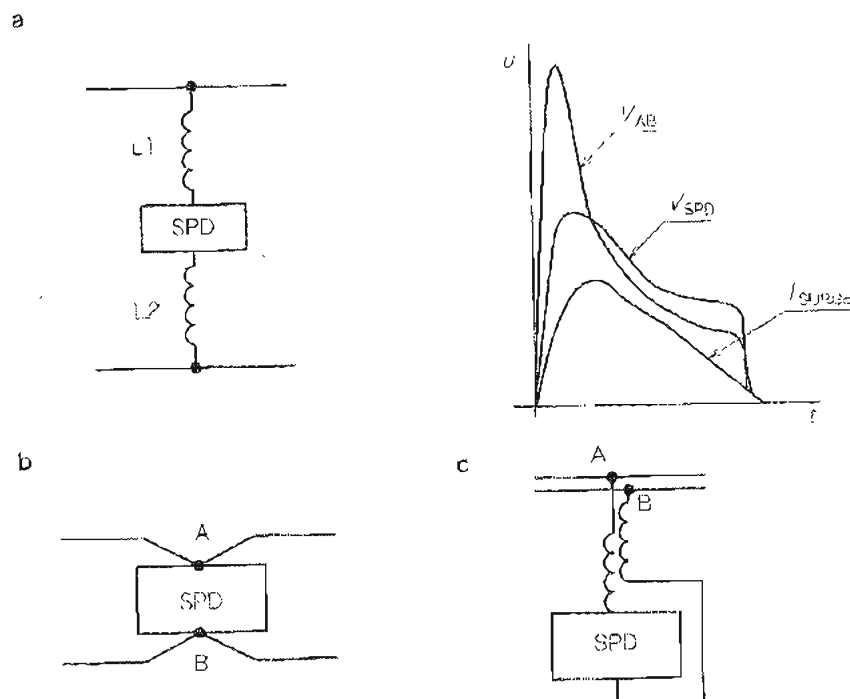
ticular, this doubling is only possible if the equipment corresponds to a high impedance load or if the equipment is internally disconnected. Figure K.10 shows an example of a doubling of voltage in such conditions to illustrate the phenomenon.

In general, oscillations may be disregarded for distances less than 10 m. Figures K.9 and K.10 show a case where even with 10 m a doubling is possible, but this is only because the load is a pure capacitance. Sometimes the equipment has internal protective components (for example, varistors), that will significantly reduce oscillations even at longer distances. Care is necessary in this last case to avoid co-ordination problems between the SPD and the protective component inside the equipment. For further information, see annex K.

6.1.3 Influence of the connecting lead length In order to achieve optimum overvoltage protection, connecting conductors of SPDs should be as short as possible. Long lead lengths will degrade the protection offered by the SPD. Therefore, it may be necessary to select an SPD with a lower voltage protection level, in order to provide efficient protection. The residual voltage transferred to equipment will be the sum of the residual of the SPD and the inductive voltage drop along the connecting leads. The two voltages may not peak exactly at the same instant, but for most practical purposes, may simply be added. Figure 10 shows the effect of the inductance of connecting leads on the voltage measured between connection points of the SPD during the impulse discharge current.

As a general rule, the lead inductance is assumed to be $1 \mu\text{H/m}$. This inductive voltage drop, when caused by an impulse with a rate of rise of $1 \text{ kA}/\mu\text{s}$ will be approximately 1 kV/m of lead length. Furthermore, if the steepness of dI/dt is greater, this value will be increased. As far as possible, it is better to use the scheme b shown in figure 10 where the effect of this inductance is considerably reduced. Scheme c can be used when it is not possible to use scheme b. As far as possible scheme a should be avoided.

NOTE : If the return current path is magnetically coupled to the incoming current conductors by placing the conductors in close proximity the inductance will be reduced (see figure 10c).



a $L1, L2$: inductances corresponding to lead lengths $l1, l2$

I_{surge} : Curve of surge current versus time

V_{SPD} : Voltage at the SPD terminals during the surge

V_{AB} : Voltage between points A and B during the surge = V_{SPD} + voltage drop due to inductance $L1 + L2$

This scheme is to be avoided when possible, especially when either $L1$ or $L2$ is large.

b This scheme is to be preferred

c This scheme is acceptable where scheme b is not possible

Figure 10 Influence of SPD connecting lead lengths

For further information, see annex K.

6.1.4 Need for additional protection In some conditions one SPD is sufficient, for example, if the stresses at the entrance to the structure are low. It is then better to install the SPD close to the mains entrance (see 6.1.1). Additional protection close to the equipment to be protected may be necessary in some special cases, for example where

- very sensitive equipment (electronic, computer) is present;
- the distance between the SPD located at the entrance and the equipment to be protected is too long (see 6.1.2);
- there are electromagnetic fields inside the structure created by lightning discharges and internal interference sources.

It is necessary to consider the voltage withstand (U_w , see JIS C 0704) of the most sensitive equipment to be protected in the system. The SPD located closest to this equipment should be selected with a voltage protective level of U_{p2} at least 20 % below