



IEEE Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage [Equal to or Less than 1000 V (ac) or 1200 V (dc)] Circuits

IEEE Power Engineering Society

Sponsored by the
Surge Protective Devices Committee

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IEEE Power Engineering Society

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Abstract: Assistance in selecting the most appropriate type of low-voltage component surge-protective device (gas tube, air gap, metal-oxide varistor, or avalanche junction semiconductor) for a particular application is provided. Evaluation of the characteristics of each device to meet specific service requirements is also given.

Keywords: air gap surge arrester, avalanche junction semiconductor, breakdown voltage, communication circuits, gas tube surge arrester, metal-oxide varistor, power circuits, SPD, surge, surge-protective device, surge protector

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Introduction

This introduction is not part of IEEE Std C62.42-2005, IEEE Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage [Equal to or Less than 1000 V (ac) or 1200 V (dc)] Circuits.

This guide is a revision of IEEE Std C62.42-1992 and has been rewritten to include metal oxide varistor (MOV) and avalanche junction semiconductor component surge-protective devices in addition to gas tube and air gap arresters, which were the subjects of the previous document.

This guide supplements IEEE Std C62.31TM-1987^{a,b}, IEEE Std C62.32TM-1981, IEEE Std C62.33TM-1982, and IEEE Std C62.35TM-1987. The purpose of this guide is to assist in selecting the most appropriate type of device for a particular application, and in evaluating the characteristics of devices to meet specific service requirements.

IEEE Std C62.42-2005 includes an explanation of the electrical environment in which component surge-protective devices shall operate, a comparison of the major difference among the four types of devices considered. It also includes a description and the theory of operation of gas tube, air gap, MOV and avalanche junction semiconductor devices, as well as guidance in applying and interpreting the respective test specifications for the arrester characteristics.

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IEEE Guide for the Application of Component Surge-Protective Devices for Use in Low-Voltage [Equal to or Less than 1000 V (ac) or 1200 V (dc)] Circuits

1. Overview

This guide is intended to provide assistance in selecting the most appropriate type of component surge-protective device, or combination of devices, for use in a surge protector, equipment, or system application. The following are examples of those who can benefit from this guide:

- a) One who designs low-voltage surge protectors and desires an overview of the application of component surge-protective devices, or combination of component surge-protective devices used within surge protectors.
- b) One who designs low-voltage power, data, communications, or signaling products or systems and desires guidance on selecting appropriate component surge-protective devices to be used directly within the product or system as part of the initial product/system design (i.e., protection designed as an integral part of the product or system).
- c) One who needs to solve a surge protection problem in the field and seeks guidance on selecting and installing appropriate component surge-protective devices to solve the problem (e.g., consultants or field service personnel who need to provide ad hoc surge protection for a product or system in order to resolve a problem).
- d) One who desires to ensure appropriate surge protection of a system in the early stages of design and needs to gain an overall appreciation of the technology.

This guide is divided into nine clauses. Clause 1 provides an overview and scope for this guide. Clause 2 lists references. Clause 3 lists definitions. Clause 4 describes the electrical environment. Clause 5 compares some of the major characteristics of component surge-protective devices. Clause 6, Clause 7, Clause 8, and Clause 9 give a description and theory of operation and guidance in applying and interpreting the respective test specifications for component gas tube (Clause 6), air gap (Clause 7), metal-oxide varistor (Clause 8), and avalanche junction semiconductor (Clause 9) surge-protective devices.

This guide also contains five informative annexes, which provide examples of applications of component surge-protective devices in surge protectors, equipment, and/or systems, and a bibliography. These informative annexes provide additional information for understanding and using this guide, but they are not part of the guide.

Annex A, Annex B, Annex C, and Annex D illustrate examples of component gas tube, air gap, metal oxide varistor (MOV), and avalanche junction semiconductor surge-protective devices, respectively, used either as single component surge protectors, or as individual components integral to the protected equipment or system. Annex E contains a bibliography of the sources used in developing this guide.

1.1 Scope

This guide covers the application of component air gaps, gas tubes, MOVs, and avalanche junction semiconductor surge-protective devices for use within surge protectors, equipment, or systems involving low-voltage power, data, communication, and/or signaling circuits. This guide is intended to be used with, or to complement, the related documents referred to in 2.1.

2. Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

This guide shall be used in conjunction with the publications listed in 2.1, 2.2, and 2.3.

2.1 IEEE standard test specifications for component surge-protective devices

The following test standards are used to characterize the surge-protective devices covered by this guide, either as component surge-protective devices, or as single technology, packaged low-voltage surge protectors.

NOTE—The definitions used in the following four standards and in this guide are the same with respect to terms that are common to both.

IEEE Std C62.31™-1987, IEEE Standard Test Specifications for Gas-Tube Surge-Protective Devices.^{1,2}

IEEE Std C62.32™-1981, IEEE Standard Test Specifications for Low-Voltage Air Gap Surge-Protective Devices.

IEEE Std C62.33™-1982 (Reaff 1994), IEEE Standard Test Specifications for Varistor Surge-Protective Devices.

IEEE Std C62.35™-1987, IEEE Standard Test Specifications for Avalanche Junction Semiconductor Surge-Protective Devices.

2.2 IEEE standard test specifications for multiple component surge-protective devices

The following test standards are used to characterize multiple component "black box" surge protectors for use in low-voltage circuits, which constitute applications of the component surge-protective devices covered by this guide.

IEEE Std C62.36™-2000, IEEE Standard Test Methods for Surge Protectors Used in Low-Voltage Data, Communications, and Signaling Circuits.

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IEEE Std C62.62™-2000, IEEE Standard Test Specifications for Surge-Protective Devices for Low Voltage AC Power Circuits.

2.3 General references

Accredited Standards Committee C2-2002, National Electrical Safety Code® (NESC®).³

ANSI C62.61-1993, Gas Tube Surge Arresters on Wire Line Telephone Circuits.⁴

ANSI C101.1-1992, Standard for Leakage Current for Appliances.

NFPA 70, 2005 Edition, National Electrical Code® (NEC®).⁵

IEC 61000-4-4 (1995), Electromagnetic compatibility for industrial process measurement and control equipment, Part 4: Electrical fast transient/burst requirements.⁶

IEEE Std 80™-2000, IEEE Guide for Safety in AC Substation Grounding.

IEEE Std 81™-1983, IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.

IEEE Std 367™-1996, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault.

IEEE Std 487™-1992, IEEE Recommended Practice for the Protection of Wire Line Communications Facilities Serving Electric Power Stations.

IEEE Std C37.90.1™-1989, IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems.

IEEE Std C62.1™-1989, IEEE Standard for Gapped Silicon-Carbide Surge Arresters for AC Power Circuits.

IEEE Std C62.34™-2001, IEEE Standard for Performance of Low-Voltage Surge-Protective Devices (Secondary Arresters).

IEEE Std C62.41™-1991, IEEE Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits.

IEEE Std C62.92.1™-1987, IEEE Guide for the Application of Neutral Grounding in Electrical Utility Systems, Part 1—Introduction.

UL 943, Ground Fault Circuit Interrupters.⁷

UL 1449, 2nd Ed, Transient Voltage Surge Suppressors.

³ The NESC is available from the Institute of Electrical and Electronics Engineers Inc, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

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⁶ IEC publications are available from the Sales Department of the International Electrotechnical Commission, Case Postale 131, 3, rue de Varembe, CH-1211, Genève 20, Switzerland/Suisse (<http://www.iec.ch/>). IEC publications are also available in the United States from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

⁷ UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

3. Definitions

The terms and definition used in this document are found in *The Authoritative Dictionary of IEEE Standards Terms* [B14]⁸. In some instances, the definition in the current edition of *The Authoritative Dictionary of IEEE Standards Terms* [B14] may be either too broad or too restrictive; in such a case, an additional definition or note is included in this clause.

3.1 component surge-protective device (component SPD): A discrete surge-protective device involving a single specific technology and intended to be installed as a component within a surge protector or as a component housed within the equipment to be protected.

NOTE—Examples are “component air gap surge-protective device,” “component gas tube surge-protective device,” “component varistor surge-protective device,” and “component avalanche junction semiconductor surge-protective device”. The term surge arrester is also used to describe a single component.

3.2 component surge-protective device—voltage limiting type: A component surge-protective device that has a high impedance when no surge is present, but that can limit voltage by progressively and smoothly reducing its impedance when responding to a surge. Examples are component varistor and avalanche junction semiconductor surge-protective devices.

NOTE—Also commonly referred to as a “voltage clamping” device.

3.3 component surge-protective device—voltage switching type: A component surge-protective device that has a high impedance when no surge is present, but that can have a sudden voltage collapse to a low impedance state when responding to a surge. Examples are component air gap and gas tube surge-protective devices.

NOTE—Also commonly referred to as a “crowbar” device.

3.4 surge protector: A specific complete surge-protective device, as opposed to a component of a surge protector or a generic surge-protective device.

4. Electrical environment

Electrical and electronic systems and networks (facilities) are subject to disturbances from external sources of electrical energy. These sources include electric power circuits and natural phenomena, such as lightning and low-energy static influences. The effects of such disturbances may be confined to interference with normal use or operation, as in the case of noise or interference with signaling; or may be capable of creating hazards to users, maintenance personnel, and equipment.

4.1 Lightning and its effects

Lightning is a transient high-current electrical discharge. It occurs when some region of the atmosphere attains an electrical charge of sufficient potential to cause dielectric breakdown of the air.

The most common source of lightning is the thundercloud. Charged regions of the thundercloud emerge as shown in Figure 1. This concentration of charge induces a similar, but opposite, concentration of charge in the earth beneath the cloud, in another portion of the same cloud, or in another cloud. When the electric field gradient exceeds the dielectric strength of the air, lightning discharges (cloud-to-cloud, within a cloud, or cloud-to-ground) take place as shown in Figure 1.

⁸ The numbers in brackets correspond to those in the bibliography in Annex E.

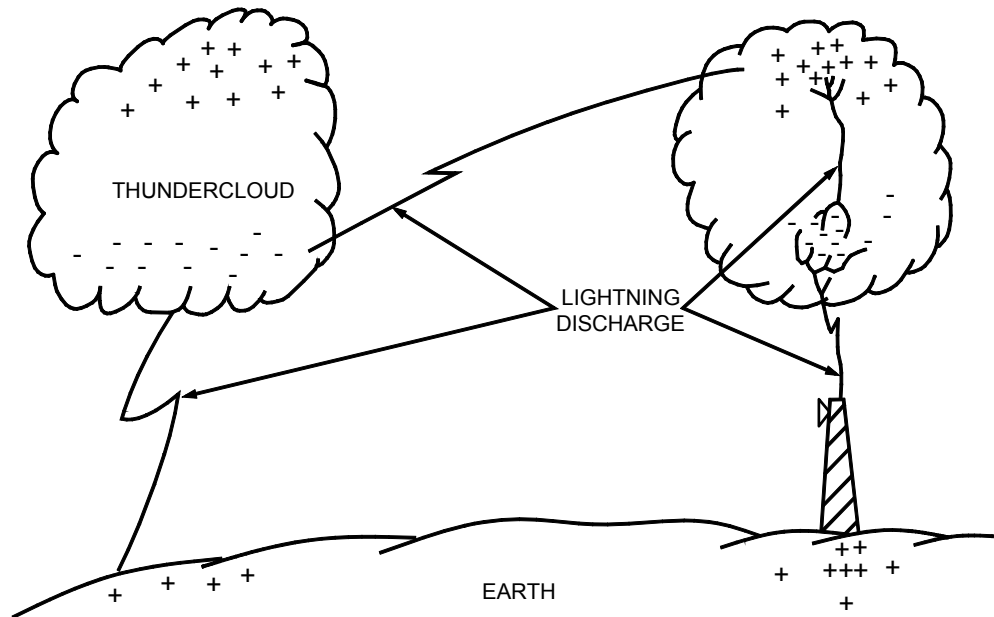


Figure 1—Source of lightning

A complete lightning flash may last as long as 0.25 s, and may consist of several strokes of high-current discharge separated by periods of up to 0.1 s when current flow is significantly reduced. Figure 2-1 and Figure 2-2 illustrate the typical time history of a lightning flash (see Anderson and Erickson 1980 [B1] and Cianos and Pierce 1972 [B3]). Some studies have shown that typical times to peak current for most subsequent strokes is less than $1.5\ \mu\text{s}$, with most values between $0.1\ \mu\text{s}$ and $0.7\ \mu\text{s}$ (see Sandia Laboratories [B30]). IEC 61312-1 [B13] specifies a front time of $0.25\ \mu\text{s}$ as a lightning current parameter for a stroke subsequent to the first stroke.

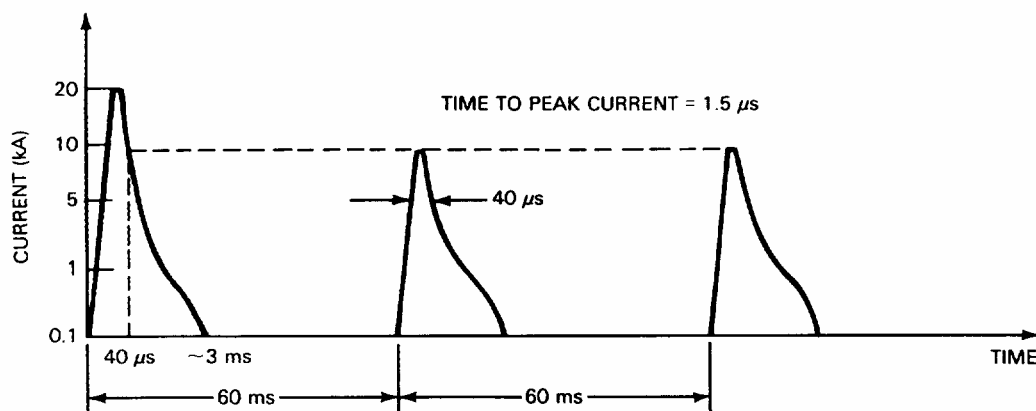


Figure 2-1—Time history of typical (basic) lightning models—flash without any continuing current surges

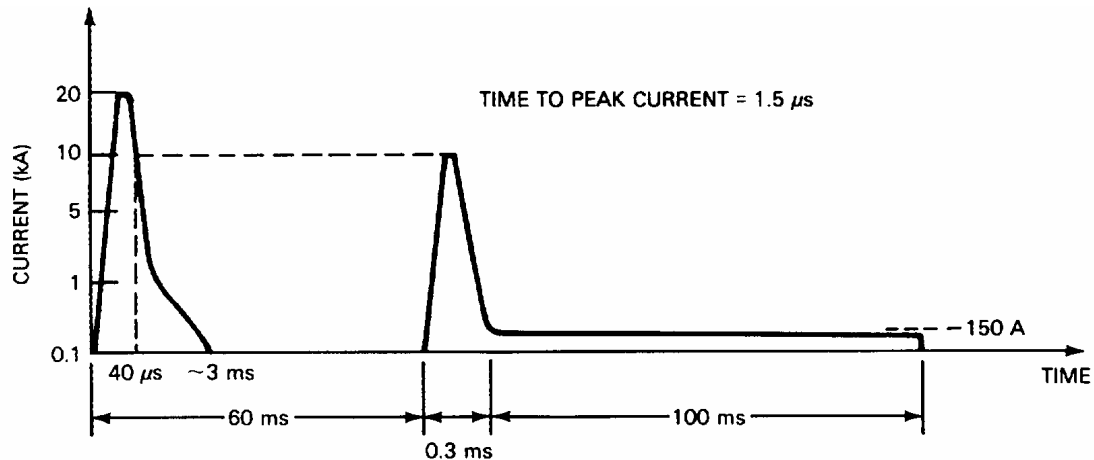


Figure 2-2—Time history of typical (basic) lightning models—flash with final stage continuing current

The crest current magnitude of an actual lightning stroke varies widely. Figure 3 illustrates the distribution of a lightning stroke's crest currents to structures (see Anderson and Erickson 1980 [B1], Sunde 1968 [B33], and Cianos and Pierce 1972 [B3]). Typical surges conducted or induced into wire line facilities would be considerably smaller because of the availability of alternate paths. As a result, protectors at the terminations of these facilities are not designed to withstand the full crest current of direct strokes.

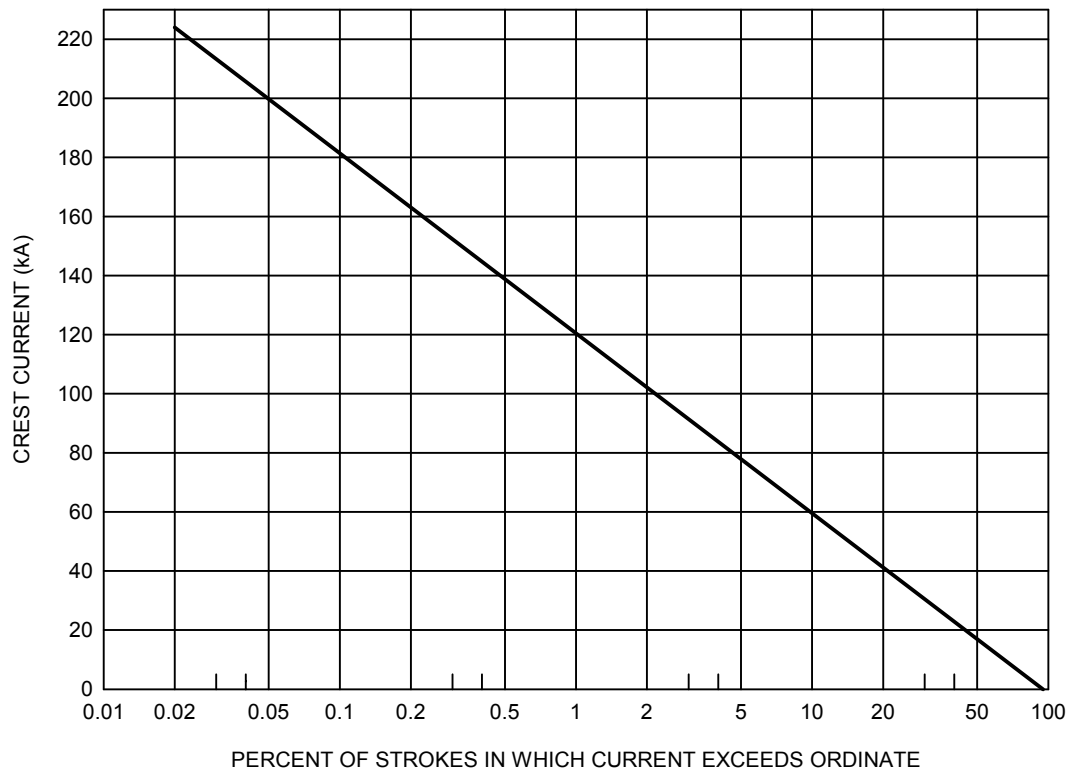


Figure 3—Distribution of lightning stroke crest currents

Facilities may be subjected to lightning-caused potentials in the following manners:

- Induction from nearby strokes to earth.
- Arcing to facilities from the earth, a tree, or a structure incurring a direct stroke.
- Lightning currents also may be conducted to wire line facilities when strokes take place near grounded points. For example, a stroke to ground near a protected terminal will raise the earth potential at the protector so that surge currents will flow from the protector ground, through the protector, to other ground points outside the direct influence of the stroke.

4.1.1 Factors affecting the exposure to lightning damage

When estimating the exposure to lightning damage, several variables shall be considered. Briefly, they include:

- Lightning flash density.* Lightning flash density, or ground flash density (GFD), can be used as a measure of potential exposure to lightning damage. GFD is the number of ground flashes per square kilometer per year in a specified region. Maps showing the average U.S. lightning flash density are available (see Global Atmospherics [B12]).

In cases where only thunderstorm days or thunderstorm hours are known, GFD can be estimated as follows:

Converting thunderstorm days to GFD

$$N_g = 0.04 T_D^{1.25}$$

where

T_D is Keraunic level in thunderstorm days/year

N_g is GFD (flashes per square kilometer each year)

Converting thunderstorm-hours to GFD

$$N_g = 0.05 T_H^{1.1}$$

where

T_H is thunderstorm-hours/year

N_g is GFD (flashes per square kilometer each year)

- b) *Earth resistivity.* Earth resistivity is also important in determining the exposure to lightning damage. The unit of earth resistivity, the ohm-meter, is defined as the resistance, in ohms, between opposite faces of a cube of earth one cubic meter in volume (see U.S. Department of Agriculture 1982 [B7] and IEEE Std 81-1983). If earth resistivity is high, the distance through the earth over which a given stroke would arc to a buried conductor or structure, and the distance that lightning currents would have to travel along a conductor before attenuating to harmless values are greater than if the earth resistivity is low. The result is that the exposure to lightning damage may be greater in some areas of the country with high earth resistivity and only moderate incidence of storms, than it is in other locations with low resistivity and greater incidence. Earth resistivity varies from a few ohm-meters to more than 10 000 ohm-meters.
- c) *Other considerations.* Engineering judgment, based on the best available experience and information, needs to be exercised to obtain optimum protection for the system under consideration. For example, a microwave tower in a low-lightning incidence area, but on a hilltop, may require special protection while facilities in a city of tall buildings located in an area of high-lightning incidence, but served by cable in duct runs, may require only minimal protection.

4.2 Low-energy static source

In some areas, open wire lines are subjected to excessive static potentials through wind-blown sand or snow. Such potentials are low in energy, the latter being proportional to the capacitance between line and earth and therefore, proportional to the length of the lines involved. The resulting interference effects are in the category of circuit noise, mainly due to intermittent breakdown of protective devices.

4.3 Power interference

The power network is an important environmental factor that can adversely affect low-voltage wire line facilities in a number of ways. Capacitive or inductive coupling, ground faults, or direct contacts can produce hazardous voltages. They can also cause damage to facilities as a result of overstressed or overheated elements. Permissible induced ac interference voltages should be considered when determining the minimum dc breakdown voltage of a gas tube surge arrester. See IEEE Std 367-1996 and IEEE Std 487-1992.

4.3.1 Characteristics of ac power systems and their effects on wire line facilities

An electrical power network consists of many kinds of systems that generally fall into two types of circuit configurations (see Klewe [B17], Bodle et al 1976 [B2], IEEE Std 487-1992, and IEEE Std C62.92.1-1987).

4.3.1.1 Types of circuits

- a) *Ungrounded circuits.* In an ungrounded circuit, single line-to-ground faults produce low-ground return currents, since the only return path to the source is the distributed capacitance-to-ground of the ungrounded line. These low currents are unlikely to induce disturbing currents and voltages into nearby wire line facilities. However, the low currents are unlikely to de-energize the power circuit and a second line-to-ground fault on another phase conductor of the same line may produce disturbing currents or voltages.
- b) *Grounded circuits.* Grounded circuits permit high currents during single line-to-ground faults because of the low-impedance return path. These currents may be high enough to induce disturbing voltages into nearby wire line facilities. However, rapid de-energization of faults is easier to achieve on these systems and the disturbance is likely to be of short duration.

4.3.1.2 Forms of coupling

There is usually more than one form of coupling between power systems and low-voltage wire line facilities. A combination of capacitive, resistive, and inductive coupling is usually present.

- a) *Capacitive coupling.* A steady state voltage can appear on a low-voltage wire line facility located in the electric field of a power system. The voltage level of an insulated wire line is determined by the relative position of the two facilities and by the voltage of the power line facility. The current that can flow to ground from a wire line is dependent upon the capacitance between the two facilities, and is therefore a function of the length of exposure. Electric influence through capacitive coupling is rarely a problem on properly terminated low-voltage wire lines.
- b) *Resistive coupling.* Resistive coupling can be divided into two categories:
 - 1) *Power contact.* Damage to wire line facilities due to accidental contacts between electric power supply lines and low-voltage wire line facilities (aerial or underground) is a possible hazard requiring protection measures. In extreme cases, the potential on the low-voltage wire line facility may approach that of the power conductor and currents may cause fusing of the low-voltage plant. Fault current duration may range from a fraction of a second to 5 s if the fault is interrupted automatically, or otherwise to indefinitely large time intervals (see Klewe [B17]).
 - 2) *Ground potential rise.* When a fault to ground occurs on a transmission or distribution line terminating in a grounded-neutral transformer bank at a power station or substation, fault current will flow from ground to the system neutral by way of the station grounding system. Since the grounding system has finite impedance to ground, it will experience a rise in potential with respect to remote earth, because of this ground-return fault current. Grounded facilities near the power station or substation can experience a portion of this voltage with respect to wire line facilities that are remotely terminated. These same effects can be experienced in the vicinity of the power fault.

- c) *Inductive coupling.* Low-voltage wire line facilities are subject to inductive coupling from power lines. The resulting induced voltages may be present continuously at permissible levels, in which case they should be accommodated in the system design, or they may be present at high levels during power faults, and require protective measures. The magnitude of the induced voltage is determined by the power line currents and the mutual impedance of the two systems (see Bodle et al 1976 [B2] and Klewe [B17]). A survey conducted on communications lines (see Bell Communications Research 1987 [B19]) indicates that the continuous levels experienced are normally very low, although on long exposures it is possible for the rms potential to exceed 50 V. During power line ground faults or periods of abnormal operation (for example, two-phase operation of a three-phase line and unbalanced phase currents, which may occur at different times of day), inductive coupling to the wire line may result in voltages up to several thousand volts. Fault current duration may range from a fraction of a second to 5 s if the fault is interrupted automatically, or otherwise to indefinitely long time intervals (see Bell Communications Research 1987 [B19]).

4.4 Switching transients

Switching transients can be divided into two general categories—internal switching transients and external switching transients.

- a) *Internal switching transients.* Internal switching transients occur in wire line facilities when inductances (relay coils, transformers, etc.) are switched off. Parameters such as the amplitude of the switching current and the stored energy are usually known. Therefore, the surge voltage magnitude can be calculated. See IEEE Std C37.90.1-1989, IEEE Std C62.41-1991, and IEC 61000-4-4 (1995).
- b) *External switching transients.* Transients may be induced in wire line facilities by means of capacitive or inductive coupling when switching occurs in nearby power systems [see item a) and item c) of 4.3.1.2].

Capacitively coupled transients are possible if high rates of change of voltage are generated in power lines. For example, voltage transients can occur during switching operations in power systems. See IEEE Std C37.90.1-1989, IEEE Std C62.1-1989, IEEE Std C62.41-1991, and IEC 61000-4-4 (1995).

Inductively coupled transients are possible if high current rates of change are generated in power lines. For example, current transients can occur during fault conditions or when switching power factor correction capacitors.

4.5 Electrostatic discharge

Electrostatic discharge (ESD) is one of the most common types of pulsed electromagnetic interference (EMI) that plagues electronic equipment. Although the energy contained in an ESD pulse is low compared to other threats, such as electromagnetic pulse (EMP) (see 4.6), the extremely high frequencies associated with ESD result in radiated coupling of the ESD to even short connections in electronic circuits. This coupling is frequently at a sufficient level to upset electronic circuits.

The sources of ESD are virtually limitless. The only requirement is that two dissimilar materials be brought into contact in order to develop a charge. This can occur through activities such as paper moving through a printer, a chair being moved across the floor, or the familiar case of a person walking across a carpet.

The two most common sources of ESD, for many electronic products, are personnel and mobile furnishings, such as chairs on casters or equipment carts. These two broad categories are identified as personnel ESD and furniture ESD.

ESD can be further subdivided into direct and indirect ESD events. In a direct ESD event, the arc from the intruder terminates directly on the equipment victim. However, in an indirect ESD event, the ESD arc terminates on an object other than the equipment victim. In the case of indirect ESD, it is the electromagnetic field from a nearby ESD event that threatens the equipment victim.

Floor-standing electronic equipment is commonly subjected to direct ESD from both personnel and furniture sources. However, tabletop equipment is usually only subjected to direct ESD from personnel because furniture typically cannot touch tabletop products directly. Of course, both floor-standing and tabletop equipment are subjected to indirect ESD from both personnel and furniture.

4.5.1 Charge voltages

Personnel can achieve charge voltages as high as 15 kV, with levels as high as 20 kV in extreme cases. In the case of furniture ESD, charge voltages seldom reach such high levels. Typically, furnishings have sharp corners or radii that encourage corona discharge. As a result, furnishings usually do not achieve charge voltages in excess of 6 kV, or 8 kV in extreme situations (see IEC 801-2 [B15] and CISPR-22 [B16]).

4.5.2 ESD current

Although ESD threat levels are often specified in terms of charge voltage, it is in fact the discharge current that is more indicative of the threat level.

For personnel ESD, peak discharge currents can attain levels of up to tens of amps. However, this peak current may only exist for a few nanoseconds or less. For furniture ESD, peak current levels may be much higher than for personnel ESD, even though the maximum charge voltages are lower. Peak currents of greater than 100 A may be achieved from furniture ESD. In addition, this high current level may last for several nanoseconds. As a result, even though the charge voltages associated with furniture ESD are less than those for personnel ESD, furniture ESD is typically a much more severe threat to electronic equipment.

4.5.3 ESD frequency spectrum

An ESD pulse contains a broad spectrum of frequency components. The spectrum ranges from tens of MHz to as high as 5 GHz, or more. The upper boundary of the frequency spectrum is related to many factors including the charge voltage. For personnel ESD, the fastest pulse rise times (and thus highest frequencies) typically occur at charge voltages of less than 4 kV. These fast rise times are usually faster than 350 ps. At higher charge voltage levels, such as 10 kV or more, ESD pulse rise times are typically much slower. Rise times as slow as 20 ns are possible.

With furniture ESD, the initial rise time of the pulse may also be faster for lower charge voltages. In fact the initial rise time of furniture ESD may also be less than 350 ps, just as for personnel ESD. However, the rise time of furniture ESD at higher charge voltages is typically not slowed to the same degree as for personnel ESD. Thus, the maximum frequency would show less variation for furniture ESD than for personnel ESD.

4.5.4 Energy levels

Because the energy stored in an ESD is related to the square of the charge voltage, and since personnel ESD can involve higher charge voltages, it is typically possible for personnel ESD to have a higher energy level than for furniture ESD. In the case of personnel ESD, the energy stored would typically not exceed 15 mJ, although levels as high as 80 mJ could be achieved in extreme cases. With furniture ESD, the energy stored would typically not exceed 5 mJ, although levels as high as 15 mJ could be achieved in extreme cases.

4.5.5 Field strengths

Field strengths for indirect personnel ESD 10 cm from an arc were calculated to reach 4 kV/m for the E-field and 15 A/m for the H-field. Because furniture ESD is typically more likely to cause failure than fields from personnel ESD, it is believed that fields from furniture ESD are even higher than those for personnel ESD.

4.5.6 Rate of occurrence

The rate at which ESD occurs is dependent on the degree to which static charging is controlled. For example, if charging is controlled by the use of such items as antistatic carpets and controlled humidity, ESD at peak current levels of 5 A or higher, may be expected every 2 h to 3 h. However, if no special ESD preventive measures are taken, ESD peak currents of more than 5 A may be expected to occur once per hour. Higher ESD currents, of course, occur less frequently. In a controlled environment, peak ESD current levels of more than 20 A would occur only about once every 70 h. In an uncontrolled environment, peak currents of 20 A or more would only occur about every 10 h. In any case, however, the frequency of occurrence is too great to be ignored.

4.6 Electromagnetic pulse

When a nuclear device explodes at high altitudes, gamma rays are generated, traveling away from the explosion at the speed of light. When these gamma rays collide with molecules, electrons are knocked off (Compton effect). This results in a band of high speed Compton electrons, moving generally towards earth. The interaction between these electrons and the earth's magnetic field creates a very fast rising, single radiated pulse. The effects of this pulse will be felt on all the earth's surface visible from the point of the explosion. The extended geographical coverage, high-peak field strength, and fast rise time may result in high-amplitude transients on wire lines and may threaten terminal equipment (see NATO 1977 [B8]; Dept. of Defense 1972, [B9] and [B10]; Lerner 1981[B18]; and Vance [B36]).

5. Comparison and selection of component surge-protective devices

This clause provides a general discussion of the similarities and differences between the component SPDs covered by this guide. It is intended to assist the reader in selecting the appropriate component, or combination of components, in order to achieve the characteristics desired of a surge protector, or to achieve the desired level of protection for a specific product or system within which the component SPD is installed as an integral part.

Component SPDs generally fall into one of two types: 1) voltage switching ("crowbar") or 2) voltage limiting ("clamping") (see Clause 3). 5.1 provides a general comparison between these two types of SPDs. 5.1.1 provides a general comparison between voltage switching SPDs. 5.1.2 provides a general comparison between voltage limiting SPDs. 5.1.3 and Table 1 provides a broad comparison between related device parameters of component SPDs.

5.1 Comparison between voltage switching and voltage limiting component SPDs

Component air gaps and gas tubes are voltage switching SPDs that effectively behave as short circuits when operating in response to voltage surges. In so doing, these devices may be used to divert substantial surge current resulting in voltages significantly lower than the normal operating voltage. When this occurs, the energy of the surge needs to be dissipated elsewhere in the circuit.

Component varistors and avalanche junction semiconductors are voltage limiting component SPDs that effectively behave like low non-linear impedances, but not short circuits, when operating in response to voltage and current surges. Therefore, for the same level of surge current, these devices need to be capable of dissipating greater power than air gaps and gas tubes.

Component air gaps and gas tubes exhibit very high resistance and low capacitance under normal (i.e., non-surge) operating conditions. Consequently, under non-surge conditions these devices conduct little or no current in the circuit.

Component varistors and avalanche junction semiconductors exhibit lower resistance and higher capacitance under normal (i.e., non-surge) operating conditions than air gaps or gas tubes. Consequently, under non-surge conditions attention needs to be paid to the current conducted by these devices in the circuit.

In the case of air gaps and gas tubes, the voltage across the terminals of these devices when responding to a surge can be lower than the voltage that is normally present across the terminal under non-surge conditions. If the circuit impedance between these devices and normal operating voltage source is low at normal operating frequencies of the circuit, these devices might effectively short-circuit or ground the circuit conductors during surges resulting in follow (power) current. Consequently, the operation of these devices when connected directly across a low impedance line does not normally provide interruption-free service unless they are used in conjunction with other components to avoid a short-circuit being applied to the line. This may be particularly important to maintain critical services (see, for example, IEEE Std 487-1992). In many communication and signaling circuits, the gas tube component device can be designed to self-reset (see Annex A).

In contrast to air gaps and tubes, the voltage appearing across the terminals of MOVs and avalanche junction semiconductor devices during a surge is greater than the normal voltage. Consequently, power follow current is not normally a concern for these devices as it is with air gaps and gas tubes, and their operation does not normally interfere with the circuit.

Finally, the published impulse breakdown voltages of gas tube and air gap surge arrester devices are defined for specific voltage rates of rise. Higher voltage rates of rise may result in measured limiting voltages greater than the published impulse breakdown voltage. In contrast, the published clamping voltage of a varistor or avalanche junction semiconductor is determined for specific current amplitudes and current waveforms. Higher current amplitudes or faster rising current waveshapes may result in measured voltages greater than the published voltage clamping levels.

The differences in characteristics between voltage limiting and voltage switching component SPDs are such that they can be made to complement each other when used in combinations that take advantage of the strengths of each.

5.1.1 Comparison between voltage switching SPDs (air gaps and gas tubes)

Air gap SPDs typically have a wider statistical variation of dc (or ac) and impulse breakdown voltage than gas tube surge SPDs of similar nominal dc breakdown voltage rating. Thus, in cases where the difference between normal operating voltage levels and the required protection voltage level is small, it is possible that some percentage of air gap SPDs at both ends of the statistical performance distribution would both interfere with normal operation and allow damage to the protected equipment. Consequently, in applying air gap SPDs the user should apply an appropriate margin between normal operating voltage and the published dc (or ac) breakdown voltage. With gas tube SPDs this adverse characteristic is much reduced (see 6.2).

For applications on typical communications and signaling lines, the difference in sensitivity to voltage rate of rise between air gap and gas tube surge SPDs is not significant enough to be of importance. For gas tube applications where surges with high rates of rise (greater than 1000 V/μs) are present, the use of specialized gas tubes should be considered. SPDs having three or more electrodes in a common sealed chamber are available in gas tubes but not air gap SPDs. The common chamber design in multi-electrode gas tube SPDs provides an improved balance between the line terminals by reducing the impulse or AC transverse voltage.

Generally, gas tube devices exhibit a glow-mode characteristic that is not found with air gap devices. A device in the glow mode will operate at a higher temperature than a device not in the glow mode conducting the same current. As a result, gas tube SPDs may have shorter ac life at certain current levels than air gap surge arresters.

Hermetically sealed gas tube SPDs with long surface leakage paths between electrodes are less susceptible than air gap SPDs to dust, insect contamination, and temperature and humidity variations. These conditions may cause failure of an air gap SPD due to low-insulation resistance or low-breakdown voltage. Some gas tube SPDs contain minute amounts of radioactive material; air gap SPDs do not.

The most significant difference between air gap and gas tube SPDs is their useful impulse life in actual service and in impulse life tests, and their sensitivity to dust, insect contamination, temperature, and humidity. For a given set of impulse life test criteria, gas tube SPDs typically survive from 4 to 40 times more life test surges than air gap SPDs. Consideration should be given to short-term versus long-term cost benefits for one type of device over the other.

5.1.2 Comparison between voltage limiting type SPDs

MOVs and avalanche junction semiconductors are available in a variety of rated parameter values (see IEEE Std C62.33-1982 and IEEE Std C62.35-1987). Avalanche junction semiconductors can limit voltages to very precise levels and are available in low-voltage ranges. MOVs have symmetrical volt-ampere characteristics, while avalanche junction semiconductor devices are available with both symmetrical and asymmetrical volt-ampere characteristics. For avalanche junction semiconductor devices reference should be made to the manufacturer's data for clamping level for both polarities. The capacitance for both types of devices is relatively high and varies with the applied bias. Generally, the capacitance for both these devices varies inversely with rated voltage, with the capacitance being greatest at the lower voltage ratings. The capacitance associated with these devices should be taken into account when connecting the devices between ungrounded ac circuit conductors and the equipment ground, since objectionable capacitively coupled leakage currents to ground may be introduced.

Generally, the failure mode in avalanche junction semiconductors and varistors is the short-circuit mode. It is suggested that the need for overcurrent protection be determined for both devices.

5.1.3 Comparison between related device parameters

Table 1 is intended to provide an overview of some of the parameters of gas tubes, air gaps, MOVs, and avalanche junction semiconductor devices. The ranges shown in the table are for typical, commercially available single component devices. Values outside these ranges are also possible for individual devices, or packages incorporating multiple devices connected in parallel. Although the descriptions of the related device parameters in Table 1 are grouped based on their similarities, the clauses and subclauses referenced in the table, which are contained in this guide and which provide a general description of the meaning of the related device parameters, must be reviewed before attempting to compare different devices. The reader is cautioned that for a particular component the parameters in this table may be higher or lower, may not be independent of one another, and that some combinations of parameters may not be available. The reader is cautioned that the test surges used to obtain performance values for different types of SPDs are in some cases different though they may appear at first to be the same, thus making a direct comparison of values possibly inappropriate. An example is an 8/20⁹ test current wave that actually flows through a component SPD under test versus a current wave supplied by a combination wave generator to a hybrid SPD in which case the current wave is an 8/20 generator short-circuit current wave, and may not be the actual test current that passes through the device.

Reference should be made to the complete specifications for a given device and a detailed analysis of the specific application should be conducted.

⁹ "The impulse waveshape designation indicates the time in microseconds for a surge waveform to rise to its peak value followed by the time in microseconds for that surge waveform to decay to 50% of its peak value. This nomenclature is more thoroughly defined in IEEE Std C62.1-1989, Clause 2, Definitions [wave shape designation (of an impulse)]; in IEEE Std C62.37-1996, Annex A, Definition A.2.12(1); and in IEEE Std C62.37.1-2000, Clause 7.2.1."

Table 1—Comparison of different device parameters (higher or lower values are possible)

Related device parameters	Gas tubes/ air gaps	MOVs	Avalanche junction semiconductors
DC breakdown voltage	75 V to >1200 V	—	—
Nominal varistor voltage, V_n	—	3.5 V to >1200 V	—
Breakdown Voltage, $V_{(br)}$	—	—	3 V to >850 V
Clauses and subclauses	6.3.1/7.3.2	8.3.6	9.3.7
Capacitance	0.5 pF to 5 pF	3 pF to 30 000 pF	5 pF to 10 000 pF
Clauses and subclauses	6.3.2/7.3.5	8.3.8	9.3.12
Maximum single impulse discharge current	5000 A to 100 000 A (8/20)	—	—
Rated single pulse transient current I_{tm}	10 A to 2000 A (10/1000)	8 A to 80 000 A (8/20)	—
Rated peak impulse current I_{ppm}	—	—	2.5 A to 40 A (10/1000)
Clauses and subclauses	6.3.5/7.3.5	8.3.2	9.3.2
Impulse breakdown voltage	250 V to >1500 V (100V/μs)	—	—
Clamping voltage V_c	—	17 V to 4000 V (8/20)	7 V to 540 V (10/1000)
Clauses and subclauses	6.3.4/7.3.4	8.3.1	9.3.1
Rated RMS voltage, V_m	—	3 V to 1500 V	—
Rated stand-off voltage, V_{wm}	—	—	3 V to 700 V
Clauses and subclauses	8.3.4	9.3.3	
DC stand-by current, I_d	—	0.5 μA to 200 μA	0.01 μA to 1000 μA
Insulation resistance	1 GΩ to 10 GΩ	—	—
Clauses and subclauses	6.3.3/7.3.3	8.3.5	9.3.4

NOTE—The purpose of this table is to show similarities among established parameter terminology of the different component technologies. This application guide uses existing terms; it does not create new terms or change existing ones. Table 1 groups different parameter terms for easy comparison.

6. Gas tubes

This clause presents a description, theory of operation, test characteristics, and an application guide for component gas tube arrester surge-protective devices.

6.1 Description

Gas tube arresters consist of two or more metallic electrodes that are separated by gap(s) in a hermetically sealed envelope containing an inert gas or mixture of gases, usually at less than atmospheric pressure. Some of the gases used are argon, helium, hydrogen, and nitrogen. Electrode spacing is maintained by means of ceramic, glass, or other insulating materials, that may form a part of the sealed envelope. The electrodes are fitted with a variety of terminations suitable for mounting on circuit boards, clip terminals, sockets, or for incorporation in a protector. Figure 4 illustrates in a simplified manner the functional components of a typical two-electrode gas tube arrester and its circuit symbol. Other types of gas tube geometries, including those that employ more than two electrodes, are also in common use.

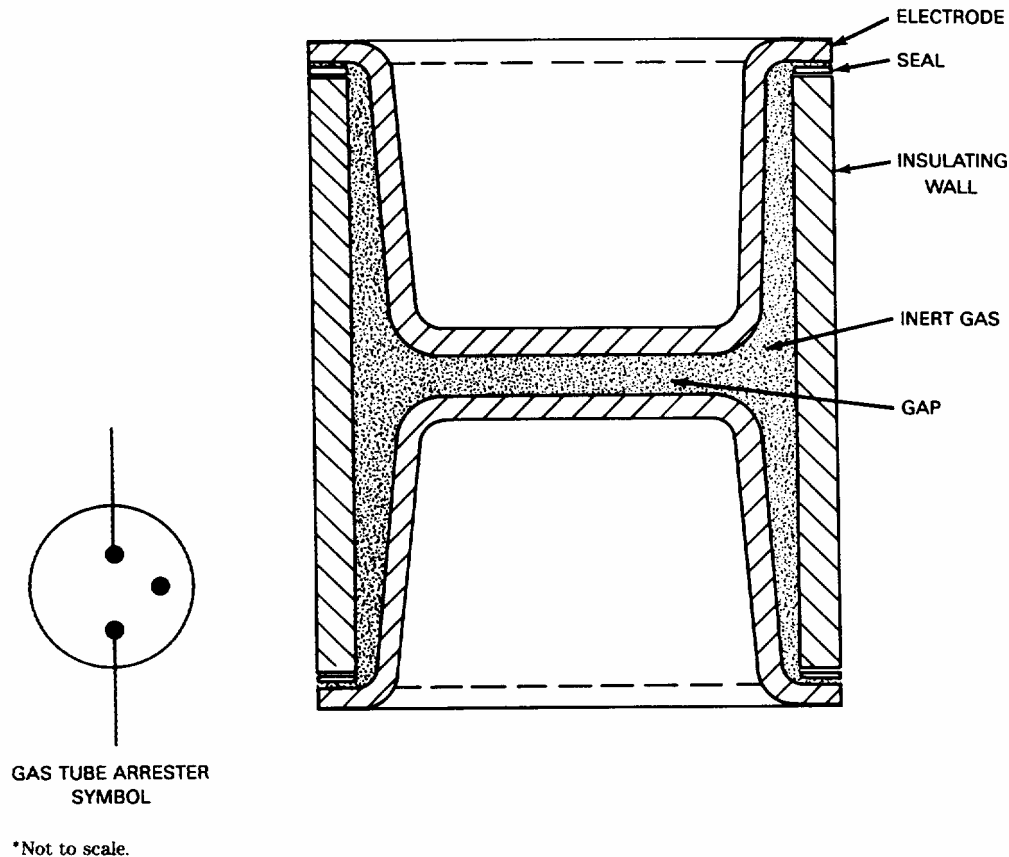


Figure 4—Cross-sectional view of the functional components of a two-electrode gas tube arrester (simplified)

6.2 Theory of operation

Gas tube arresters operate as cold cathode discharge tubes. An electrode may serve as either an anode or a cathode, depending on the polarity of the applied voltage. When the gap of a gas tube arrester is subjected to an increasing field intensity due to a voltage surge, it will break down at some voltage that is determined by the design of the gas tube arrester, and the rate of rise of the voltage surge. The faster the rate of rise of the surge wavefront, the higher the impulse breakdown voltage. Design factors include spacing between electrodes, type of gas used, gas pressure, electrode configuration, and surface coating.

Because the inter-electrode distance in a gas tube is finite and the flight time of an electron across this gap is also finite, time is needed to begin and to form the electron avalanche required for breakdown. This time is dependent on the amount of overvoltage above the DC breakdown voltage of the tube. If the applied voltage wave is increasing rapidly, of the order of volts per microsecond, the small amount of time required to begin and form the avalanche may allow the rapidly rising voltage to exceed the DC breakdown voltage by an amount sufficient to harm the equipment intended to be protected. Generally, the faster the rate of rise, the higher the overvoltage required for operation of the tube. In order to minimize this effect, gas tube manufacturers may place graphite lines on the interior walls of the insulator. These act to provide free electrons from partial gas discharge at their ends.

For a particular electrode material and configuration, the dc breakdown potential for a certain gas or gas mixture follows Paschen's law, which states that the breakdown voltage is a function only of the product of

the gas pressure multiplied by the distance between the plane electrodes. See Cobine 1958 [B4] and Druyvesteyn and Penning [B6].

Small amounts of radioactive material may be placed inside the gas tube during manufacture. These radioisotopes may be introduced as a solid or in gaseous form. Their purpose is to provide a constant low level source of free electrons. A gas tube operating in the light will have free electrons present in its gas chamber due to photoionization. In the dark this source of free electrons is absent and the DC breakdown of the tube can be considerably higher. With the addition of a radio isotope a constant source of electrons is available to stabilize breakdown.

In the nonconducting state, the gas tube arrester has a very high resistance, in the order of several thousand megohms. Once breakdown occurs, various operating states are possible, depending upon the external circuitry. These states are exhibited in the voltampere characteristic, typical of a gas tube arrester (see Figure 5). At currents less than the glow-to-arc transition current, a glow region exists. At low currents in the glow region, the voltage is nearly constant; at high glow currents, some arrester types may enter an abnormal glow region in which the voltage increases. Beyond this abnormal glow region the tube impedance decreases in the transition region into the low-voltage arc condition. The arc-to-glow transition current may be lower than the glow-to-arc transition. The voltampere characteristic, in conjunction with the external circuitry, determines the ability of the gas tube arrester to extinguish after passage of a surge, and also determines the energy dissipated in the arrester during the surge. Specific examples of circuit behavior of gas tube arresters can be found in Annex A. The voltampere characteristic is controlled by the design of the gas tube arrester.

When breakdown of a gas tube arrester occurs, a low-impedance condition is produced. The energy remaining in the disturbing transient is shunted and reflected away from the components to be protected.

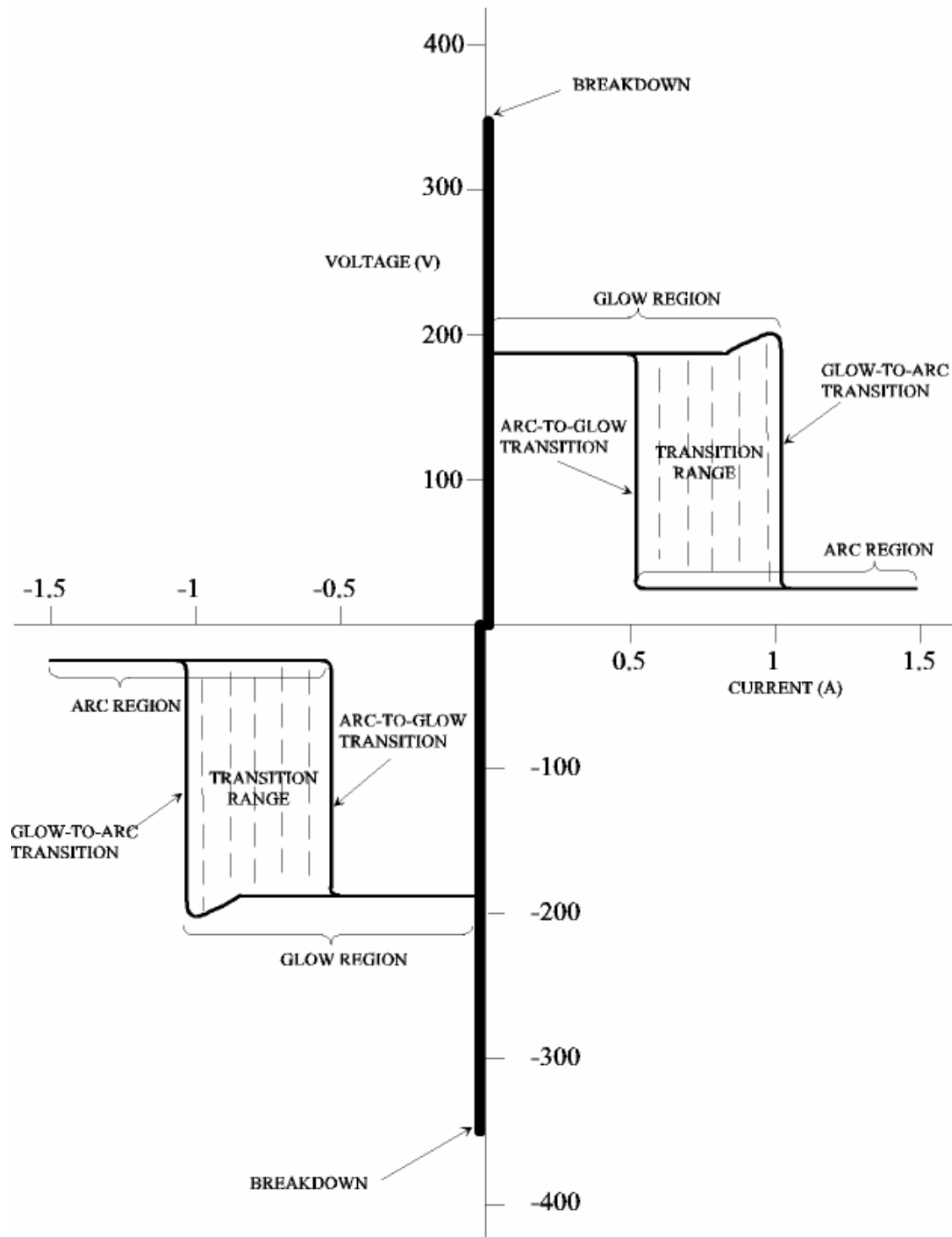


Figure 5—Typical voltampere characteristic for gas tube arresters

6.3 Gas tube arrester test characteristics

This subclause applies to all gas tube surge-protective devices. For further information about the following tests, see IEEE Std C62.31-1987.

6.3.1 DC breakdown voltage test

DC breakdown is a breakdown caused by a slowly rising voltage. Unless otherwise specified, a rate of rise not exceeding 2 kV/s is used for this test. Breakdown voltages of many gas tube arresters will only vary slightly, when the rate of rise is less than 2 kV/s.

Low dc breakdown voltage is of concern where the crest value of the sum of the system operating voltages and any permissible low-frequency extraneous voltages (for example, induction from power lines) approach the lower-limit dc breakdown value of the gas tube arrester. Should the crest value exceed the dc breakdown voltage of the gas tube arrester, causing it to sparkover, interruption of the transmission or signaling on the circuit will occur.

During the life of gas tube arresters, after being exposed to a number of transients and disturbances, the gas tube arrester usually deteriorates in a manner whereby the dc breakdown voltage changes (typically the breakdown voltage is reduced). This may be accompanied by a degradation of other parameters, such as insulation resistance and impulse breakdown voltage.

If the dc breakdown voltage is too high, the gas tube arrester will fail to break down and will not conduct a disturbing low-frequency current to ground, thus failing to protect the circuit.

In general, dc breakdown should be high enough so as not to interfere with the normal operation of equipment to be protected. It should be low enough so that the gas tube arrester breakdown will occur before a low-frequency voltage can rise to destructive magnitudes.

The dc breakdown voltage for gas tubes covered by the scope of this guide can range from 75 V $\pm$ 20% to 1200 V $\pm$ 20%. The low end of the range of voltage breakdown is limited by the ionization potentials of gases used in the manufacturing of the tube. The high end is more flexible, capable of up to tens of thousands of volts depending on the application requirement.

6.3.2 Capacitance test

Capacitance of gas tube arresters installed on low-frequency lines is usually of small concern due to the inherent low-capacitance of the gas tube arresters. The capacitance of a two-electrode gas tube arrester is usually in the range of 0.5 pF to 5 pF. Considering the upper value of 5 pF and a line frequency of 1.0 MHz, the impedance between terminals is approximately 31.8 k Ω . Capacitance of gas tube arresters is usually constant over a wide range of frequencies. The unit-to-unit capacitance variation between gas tube arresters of the same type is usually quite small. Capacitance of gas tube arresters is normally so low that signal loss and unbalance are insignificant in most applications.

6.3.3 Insulation resistance test

The initial insulation resistance of gas tube arresters is in the order of thousands of megohms. During the field life of a gas tube arrester, the insulation resistance decreases due to the formation of internal and external leakage paths. A substantial decrease in insulation resistance could result in noisy conditions and ultimately in a loss of transmission or signaling. Unbalance caused by a substantial difference in insulation resistance to ground of gas tube arresters on each side of line could be a contributing factor in causing noise. The lowest tolerable insulation resistance depends on the system application.

6.3.4 Impulse breakdown voltage test

The impulse breakdown voltage characterizes the ability of a gas tube arrester to limit fast rising voltage transients. The breakdown voltage should be less, by a suitable margin, than the withstand ability of the component or circuit that is to be protected. The impulse breakdown voltage should not be set so low that the dc breakdown voltage, which would normally be lower, interferes with system operation.

Due to a time lag between the presence of voltage that is high enough to cause breakdown and actual ionization process, faster rates of rise cause higher breakdown voltages. Curves plotting breakdown voltages versus rates of rise are published by gas tube manufacturers. In the absence of special test requirements, the rates of rise should be one or more of the following: 100 V/ μ s, 500 V/ μ s, 1 kV/ μ s, 5 kV/ μ s, and 10 kV/ μ s. See Figure 3 of IEEE Std C62.31-1987 for typical test waveforms.

Impulse breakdown voltage for devices covered under the scope of this guide range from 250 V to greater than 1200 V. Impulse breakdown voltage is typically 500 V at the rate of rise of 100 V/ μ s and 900 V at the rate of rise of 10 kV/ μ s.

6.3.5 Maximum single impulse discharge current test

The maximum single impulse discharge current test is a measure of the capability of a gas tube arrester to withstand a single large surge. Nearby lightning strikes can produce such surges. IEEE Std C62.31-1987 specifies waveforms of 10/1000 μ s and 8/20 μ s as well as failure modes. This magnitude is determined by the possibility of exposure to a severe impulse. The test is of greatest importance in applications involving exposed facilities located in areas of high thunderstorm activity or high soil resistivity. The maximum single impulse current is mainly determined by factors such as the electrode area, the electrode material, the heat dissipation path, etc. Values for 8/20 current range from 5 kA to 100 kA. Typical values for this current are 20 kA for 8/20 current waves and 2 kA for 10/1000 current waves.

6.3.6 Impulse life test

One of the most important measures of the capability of gas tube arresters is the impulse life test. Table 1 of IEEE Std C62.31-1987 suggests waveforms and currents to be used. The individual application will determine the extent of life test requirements needed.

Applications in areas of high lightning incidence or severe exposure may justify the use of gas tube arresters with high-impulse life characteristics.

Lightning flash density maps (see Global Atmospherics [B12]) are published showing ground flashes per kilometer squared per year. From the severity and incidence of lightning, the type of facilities, the desired reliability of service, and the exposure to lightning, a determination can be made of the gas tube arrester's life requirements.

Although lightning occurs in multiple flashes, usually averaging two to six flashes within a few tenths of a second, a standardized life test method has been accepted. Test results can be used for comparing cost/performance trade-offs and to indicate the durability of gas tube arresters. Failure criteria for this test are defined in IEEE Std C62.31-1987.

The useful life of the gas tube arrester is ended when degradation results in interference with transmission or signaling, or when the breakdown voltage reaches a point where the gas tube arrester fails to protect.

6.3.7 AC discharge current test

The ability of a gas tube arrester used on communications lines to withstand an ac current is significant in applications where power contacts and power induction are factors. Experience has shown that induced currents are usually less than 5 A, but may be of very long duration. Power contact currents of hundreds of amperes are possible, but the high currents are usually interrupted in less than 5 s by disconnect devices.

6.3.8 Alternating follow current test

The alternating follow current test measures the ability of a gas tube arrester to extinguish under specified conditions. IEEE Std C62.31-1987 suggests voltages and frequency to be used. This ability is of particular interest for gas tube arresters used on circuits intended to carry ac power because it characterizes their ability to extinguish, thus restoring normal service, after the passage of a surge. During the time that conduction occurs, service is interrupted.

6.3.9 Holdover test

In applications where a dc voltage exists on a line, the holdover test is a measure of the ability of a gas tube arrester to extinguish after it is subjected to an impulse large enough to cause it to conduct. During the time that the gas tube arrester is in a holdover condition (that is, conducting), transmission and signaling are interrupted. Further, a potentially destructive condition is introduced, possibly causing overheating of the gas tube arrester. Holdover becomes increasingly probable as dc line voltages and available line current increases. The holdover of a gas tube arrester is strongly influenced by the external circuit in which it is operating. Significant circuit parameters, which may influence holdover, are open circuit voltage, short circuit current, source regulation characteristics and values of the reactive components.

6.3.10 Transition time test

Transition time is the time required for the voltage across a conducting gap to drop into the arc region after the gap initially begins to conduct. Indirectly, it is a measure of the energy dissipation of a gas tube arrester during breakdown. The faster the transition time, the less energy the tube is required to dissipate during the breakdown interval.

6.3.11 Impulse transverse voltage test

The impulse transverse voltage is the metallic voltage that appears across the line terminals of the gas tube arrester when a longitudinal voltage is impressed on each of the lines.

The impulse transverse voltage test is primarily intended to test gas tube arresters with three or more electrodes. In balanced communications or signaling circuits, two-electrode gas tube arresters can be used to protect each conductor of a pair. If one gas tube arrester breaks down and the other does not or is delayed, a metallic voltage results. This metallic (transverse, normal mode) voltage can cause equipment damage (see Figure 6-1, Figure 6-2, and Figure 6-3.). Gas tube arresters with three or more electrodes can be designed to reduce the metallic voltage. However, transverse voltages are unlikely to be eliminated completely, and the application should accommodate such circumstances.

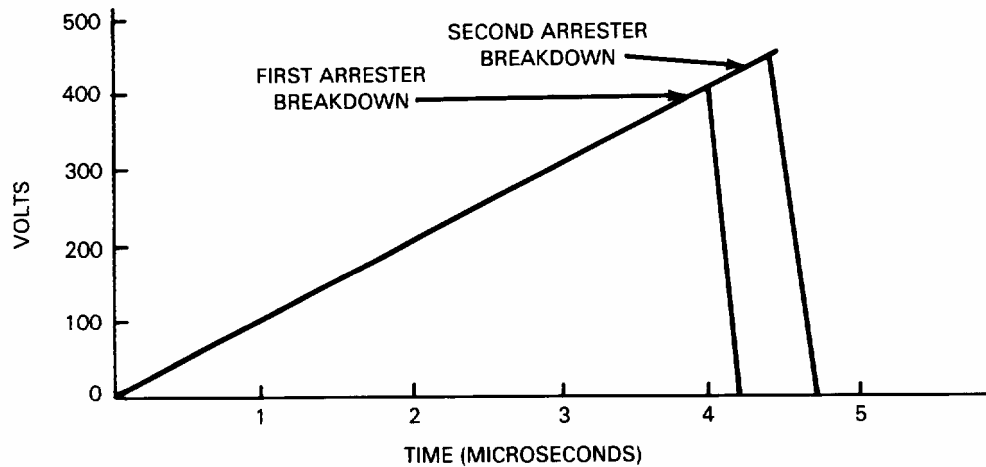


Figure 6-1—Simplified illustration of line-to-line voltage unbalance—line-to-ground voltage A-G, B-G

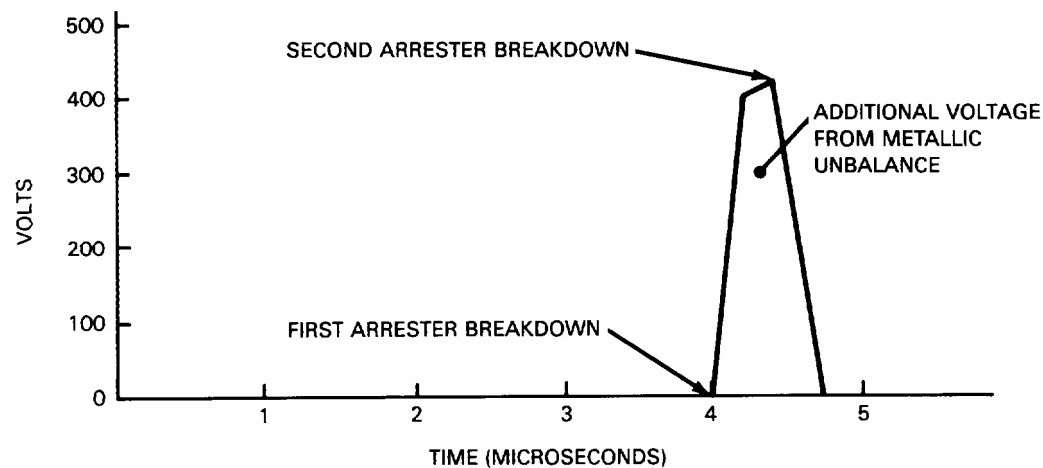


Figure 6-2—Simplified illustration of line-to-line voltage unbalance—line-to-line voltage A-B

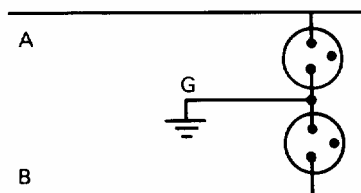


Figure 6-3—Simplified illustration of line-to-line voltage unbalance—schematic of arresters connected A-G, B-G

NOTE: Surges of equal rates of rise are simultaneously applied to line A and line B. After the first arrester breakdown occurs there is a time delay until the second arrester breakdown occurs, resulting in a metallic voltage.

6.3.12 AC transverse voltage test

The ac transverse voltage test is similar to the impulse transverse voltage test except that a 50 Hz or 60 Hz source is used. This test is primarily intended for gas tube arresters with three or more electrodes. It is a measure of the energy that is transferred to the circuit or component being protected under specific load and line conditions, where a balanced longitudinal 50 Hz or 60 Hz voltage is impressed on the line.

6.3.13 Voltampere characteristic test

The voltampere characteristic is portrayed as a graph and usually shown as a plot of current versus voltage. It includes dc breakdown, glow voltage, glow-to-arc transition current, arc voltage, and arc current (see Figure 5).

6.3.14 Crosstalk test

IEEE Std C62.31-1987 describes a method to measure crosstalk loss between vertically and horizontally adjacent pairs on multipair protector assemblies. Since crosstalk is a function of the wires, leads, and cable stubs rather than the gas tube arrester itself, the test is generally unnecessary in selecting a gas tube arrester for a specific application.

6.4 Application of gas tube surge arresters (telecommunications)

The application of gas tube surge arresters to limit voltages at the terminals of electrical apparatus requires the selection of a gas tube arrester with suitable characteristics, and then the proper physical arrangement of the gas tube arrester in the electrical circuit. It also requires the selection or design of equipment that will withstand the energy that bypasses the selected arresters in their circuit configuration. An overall economic choice of both equipment and arresters should be made.

The electrical configurations of the most common applications are illustrated in the matrix in Figure 7. The configurations have one or more signaling terminals and usually include a ground terminal. The one-port configuration may represent a communication line or terminating equipment for communication facilities. The two-port configuration may represent a communication line repeater. Figure 7a)'s arrangement in each configuration limits longitudinal (common mode) surge voltages. Figure 7b)'s arrangement uses multigap surge arresters to limit longitudinal voltages while also minimizing metallic (transverse mode) voltages. The multi-gap arresters may also afford a size reduction as compared to the single-gap arrangement. Figure 7-3c)'s arrangement limits transverse mode surge voltages, but does not provide protection against common mode surge voltages. An additional arrester (see Demircioglu et al 1978 [B5]) may be added to this last arrangement, connected between one of the terminals and ground, to provide longitudinal mode protection.