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IEEE Std C62.42-1992

IEEE Guide for the Application of Gas Tube and Air Gap Arrester Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Surge-Protective Devices

Circuits and Devices

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Surge-Protective Devices Committee

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IEEE Guide for the Application of Gas Tube and Air Gap Arrester Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Surge-Protective Devices

Sponsor

Surge-Protective Devices Committee
of the
IEEE Power Engineering Society

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Abstract: Assistance in selecting the most appropriate type of low-voltage surge-protective device (either gas tube or air gap) 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, breakdown voltage, communication circuits, current, gas tube surge arrester, power circuits

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Introduction

[This introduction is not a part of IEEE Std C62.42-1992, IEEE Guide for the Application of Gas Tube and Air Gap Arrester Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Surge-Protective Devices.]

This guide is a revision of IEEE Std C62.42-1987 and has been rewritten to include air gap devices in addition to gas tube arresters, which were the subject of the original document. Subsequent revisions will include other types of low-voltage surge-protective devices.

This guide supplements IEEE Std C62.31-1987 and IEEE Std C62.32-1981. 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 C62.42-1992 presents an explanation of the electrical environment in which gas tube and air gap surge-protective devices shall operate, a comparison of the major difference between the two types of devices considered, a description and the theory of operation of gas tube and air gap devices, and guidance in applying and interpreting the respective test specifications for the arrester characteristics.

At the time this guide was completed, the membership of the Low-Voltage Surge-Protective Devices Application Guide Working Group of the IEEE Power Engineering Society consisted of:

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Figure 2 was taken from Cianos, N. and Pierce, E. T., *A Ground Lightning Environment for Engineering Usage.* Menlo Park, CA: Stanford Research Institute, Aug. 1972, p. A93.

Figures 5 and 6 were taken from Bodle, D. W., Ghazi, A. J., Syed, M., and Woodside, R. L., *Characterization of the Electrical Environment.* Toronto and Buffalo: University of Toronto Press, 1976.

Figure 9 was taken from Cobine, J. D., *Gaseous Conductors.* New York: Dover Publications Inc., 1958.

Contents

CLAUSE PAGE

IEEE Guide for the Application of Gas Tube and Air Gap Arrester Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Surge-Protective Devices

1. Overview

This guide provides assistance in selecting the most appropriate type of device for a particular application and in evaluating the characteristics of devices to meet specific service requirements.

This guide is divided into six clauses. Clause 1 provides the scope of this guide. Clause 2 lists references to other standards. Clause 3 explains the electrical environment in which gas tube and air gap surge-protective devices shall operate. Clause 4 compares the major difference between the air gap surge arrester and the gas tube surge arrester. Clauses 5 and 6 give a description and the theory of operation of gas tube and air gap devices, and guidance in applying and interpreting the respective test specifications for the arrester characteristics.

This guide also contains three annexes. These provide additional information for understanding and using this guide, but they are not part of the guide. Annex A illustrates the circuit behavior of gas tube arresters. Annex B illustrates the circuit behavior of carbon air gap surge arresters. Annex C contains a bibliography of the references used in developing this guide.

1.1 Scope

This guide applies to surge-protective devices used in systems with voltages equal to or less than 1000 V_{rms} or 1200 Vdc. These protective devices are designed to limit voltage surges on balanced or unbalanced communication circuits and on dc to 420 Hz power circuits. Although telephone circuits are a major application of air gap and gas tube surge arresters, this guide will also provide useful information for many other surge-protection applications.

For protection under the specialized conditions found at power stations, consult IEEE Std 487-1992[1] and IEEE Std C37.90.1-1989. For a recommended practice on surge voltages in low-voltage ac power circuits consult IEEE Std C62.41-1991. For technical performance guidelines for gas tube surge arresters on wire line telephone circuits consult ANSI C62.61-1985.

This guide is intended to complement IEEE Std C62.31-1987 and IEEE Std C62.32-1981 for air gap surge-protective devices. The definitions used in these three standards are the same. For other definitions refer to IEEE Std 100-1992. With this guide the user will be able to evaluate the various types of gas tube and air gap surge arresters in terms of his or her own particular applications. The guide will consider the sources and nature of transients, the characteristics of gas tube and air gap surge arresters, and the concepts necessary to choose the appropriate product.

When used in conjunction with IEEE Std C62.31-1987 and IEEE Std 62.32-1981, this guide will give the user guidance in selecting the right product and interpreting its specifications.

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[1] Information on references can be found in clause 2.

2. References

This guide shall be used in conjunction with the following publications:

Accredited Standards Committee C2-1993, National Electrical Safety Code.[2]

ANSI C62.61-1985, Gas Tube Surge Arresters on Wire Line Telephone Circuits.[3]

ANSI/NFPA 70-1993, National Electrical Code.[4]

IEC 801-4 (1988), Electromagnetic compatibility for industrial process measurement and control equipment, Part 4: Electrical fast transient/burst requirements.[5]

IEEE Std C37.90.1-1989, IEEE Standard Surge Withstand Capability (SWC) Tests for Protective Relays and Relay Systems (ANSI).[6]

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

IEEE Std C62.31-1987, IEEE Standard Test Specifications for Gas-Tube Surge-Protective Devices (ANSI).

IEEE Std C62.32-1981 (Reaff 1987), IEEE Standard Test Specifications for Low-Voltage Air Gap Surge-Protective Devices (ANSI).

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

IEEE Std 80-1986 (Reaff 1991), IEEE Guide for Safety in AC Substation Grounding (ANSI).

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

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronic Terms.

IEEE Std 367-1987, IEEE Recommended Practice for Determining the Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault (ANSI).

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

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[2] The National Electrical Safety Code is available from the Institute of Electrical and Electronics Engineers, Service Center, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

[3] ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

[4] NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

[5] IEC publications are available from IEC Sales Department, Case Postale 131, 3 rue de Varembé, CH 1211, Genève 20, Switzerland/Suisse. 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.

[6] IEEE publications are available from the IEEE Service Center.

3. 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.

3.1 Lightning

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.

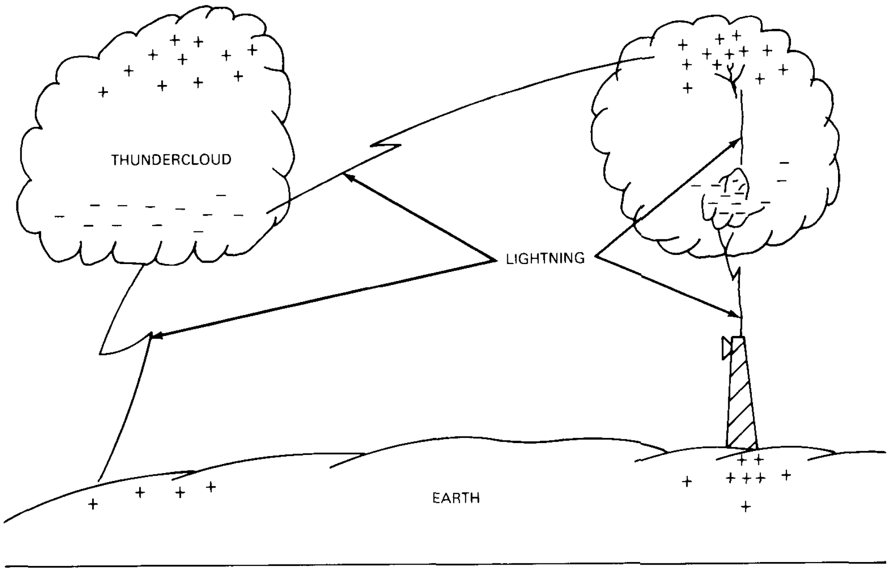

Figure 1—Source of lightning

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 illustrates a typical time history of a lightning flash (see also [B2][7] and [B9]).

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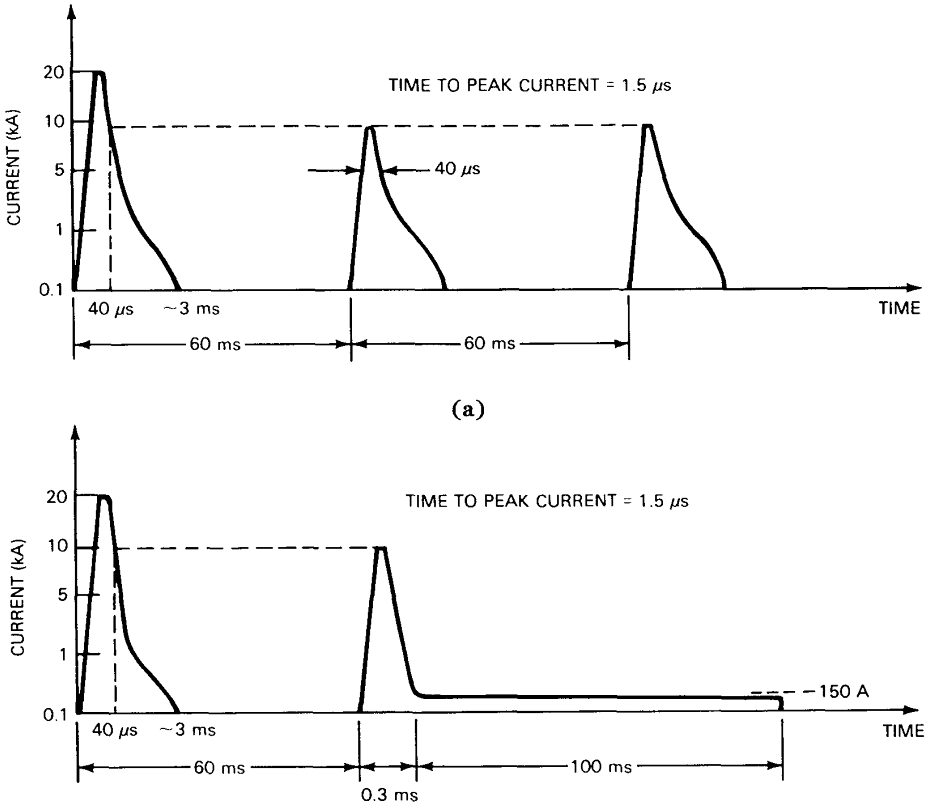
[7] The numbers in brackets correspond to those of the bibliographical references in annex C.



(b)

Figure 2—Time history of typical (basic) lightning models
a) Flash without any continuing current surges
b) Flash with final stage continuing current

3.1.1 Direct lightning stroke

The crest current magnitude of an actual lightning stroke varies widely. Figure 3 illustrates the distribution of a lightning stroke's crest currents to aerial structures (see [B2], [B24], and [B9]). 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 normally not designed to withstand the full crest current of direct strokes.

3.1.2 Indirect lightning stroke

In addition to direct strokes, facilities may be subjected to lightning-caused potentials in the following manners:

a) Induction from nearby strokes to earth
b) Arcing to facilities from the earth, a tree, or a structure incurring a direct stroke
c) 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.

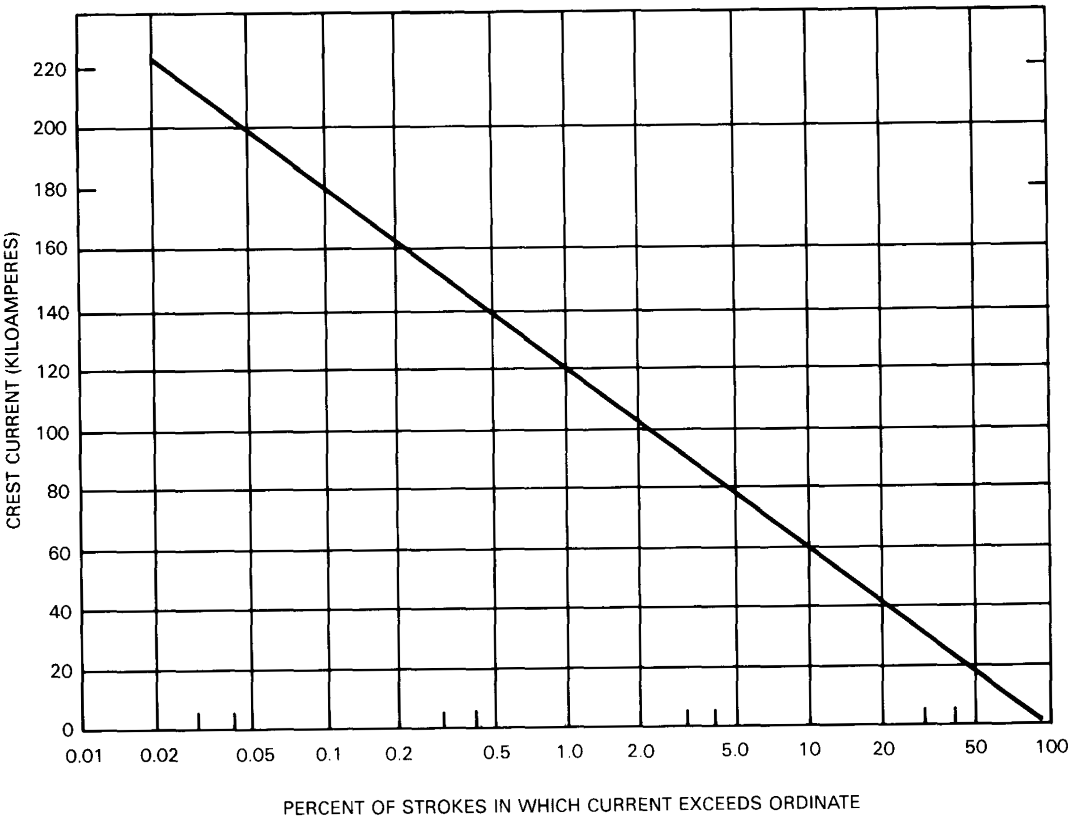
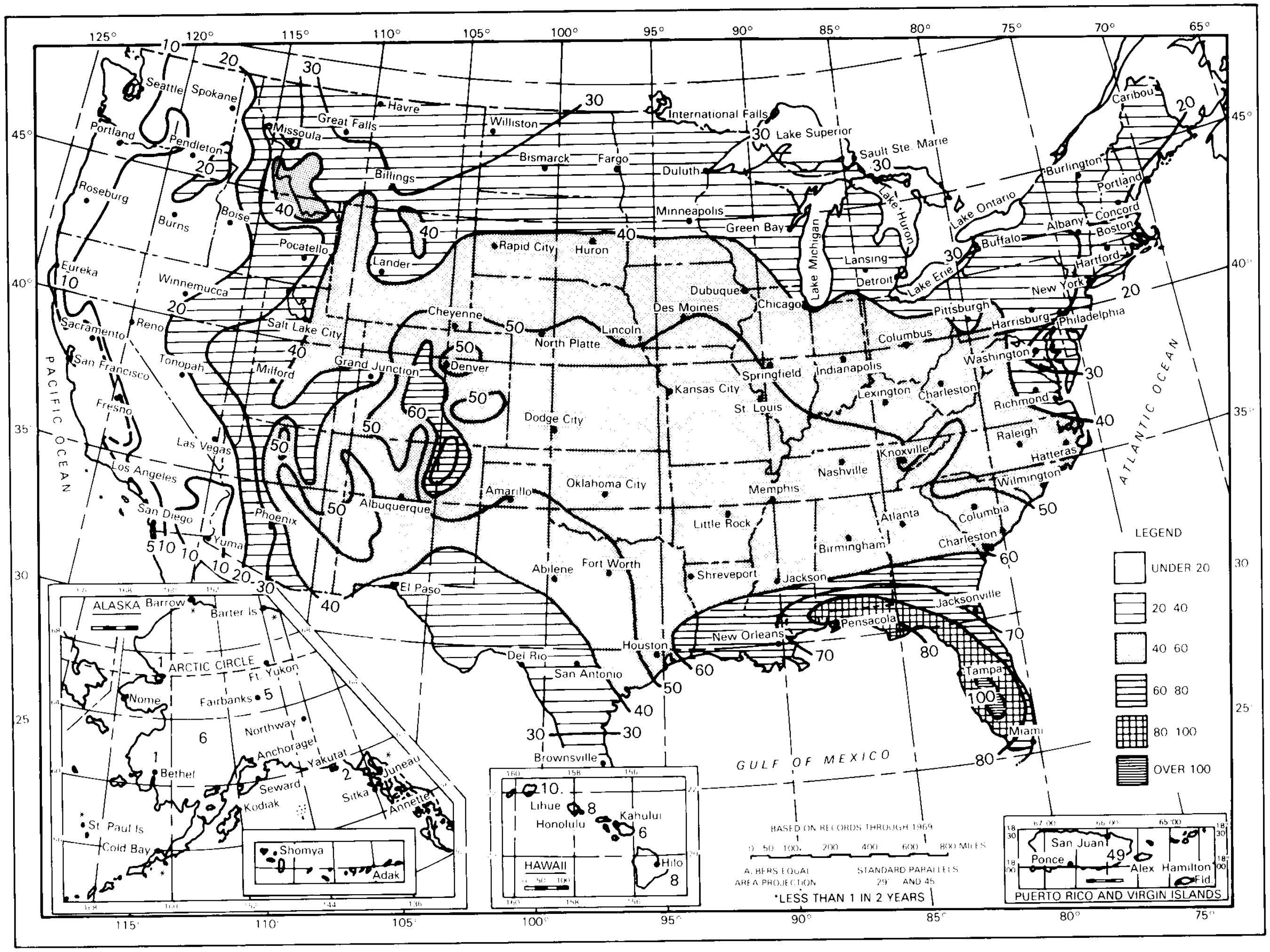


Figure 3—Distribution of lightning stroke crest currents to aerial structures

3.1.3 Factors affecting the exposure to lightning damage

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

a) *Storm frequency or incidence*
    1) The traditional measure of storm frequency is the number of *thunderstorm days* experienced at a given location during the year. A *thunderstorm day* is defined as any day during which thunder can be heard at a specific observation point. An isokeraunic map in figure 4 shows the mean annual number of days the United States has thunderstorms (see [B3]). Similar information for Canada is shown in figure 5 and for the world in figure 6 (see [B5]).
    2) The *thunderstorm day* statistics allocate equal weighting to a day with one storm or to a day with numerous storms occurring for hours. The hazard of damage is obviously greater for long duration or multiple-occurrence storms. An improved description of the lightning hazard could be provided by an estimate of the number of thunderstorms expected at a location. A report is available (see [B10]), which provides a representative analysis of the monthly and annual frequency of thunderstorms for the contiguous United States. This publication includes the mean annual number of thunderstorms for the United States, as shown in figure 7, as well as monthly maps.



Source: National Oceanic and Atmospheric Administration, National Climatic Data Center, Asheville, NC.

Figure 4—Mean number of days with thunderstorms (USA) [B3]

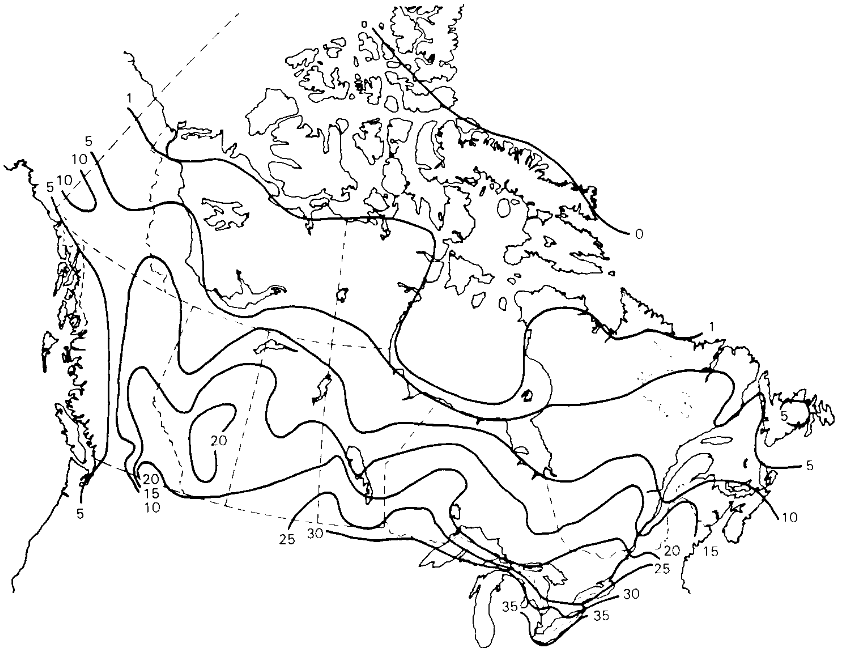


Figure 5—Mean annual number of days with thunderstorms (Based on the period 1941–1960) (Canada) [B5]

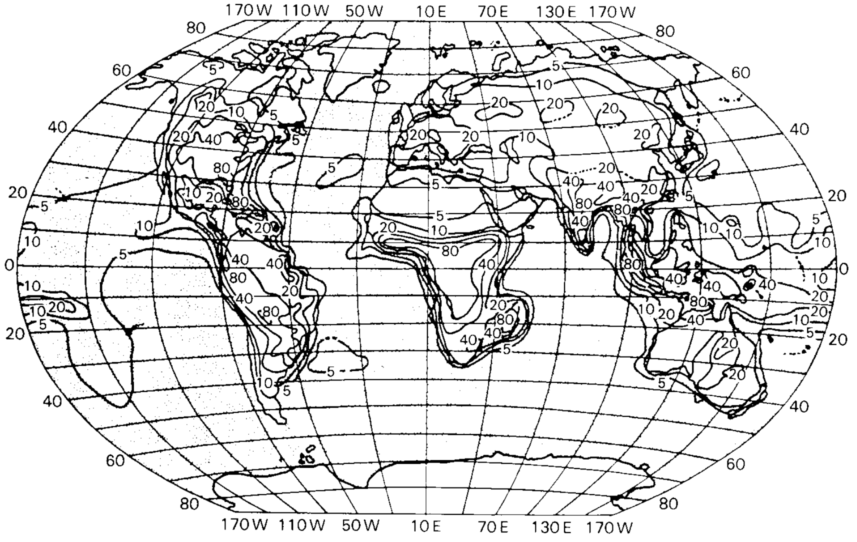
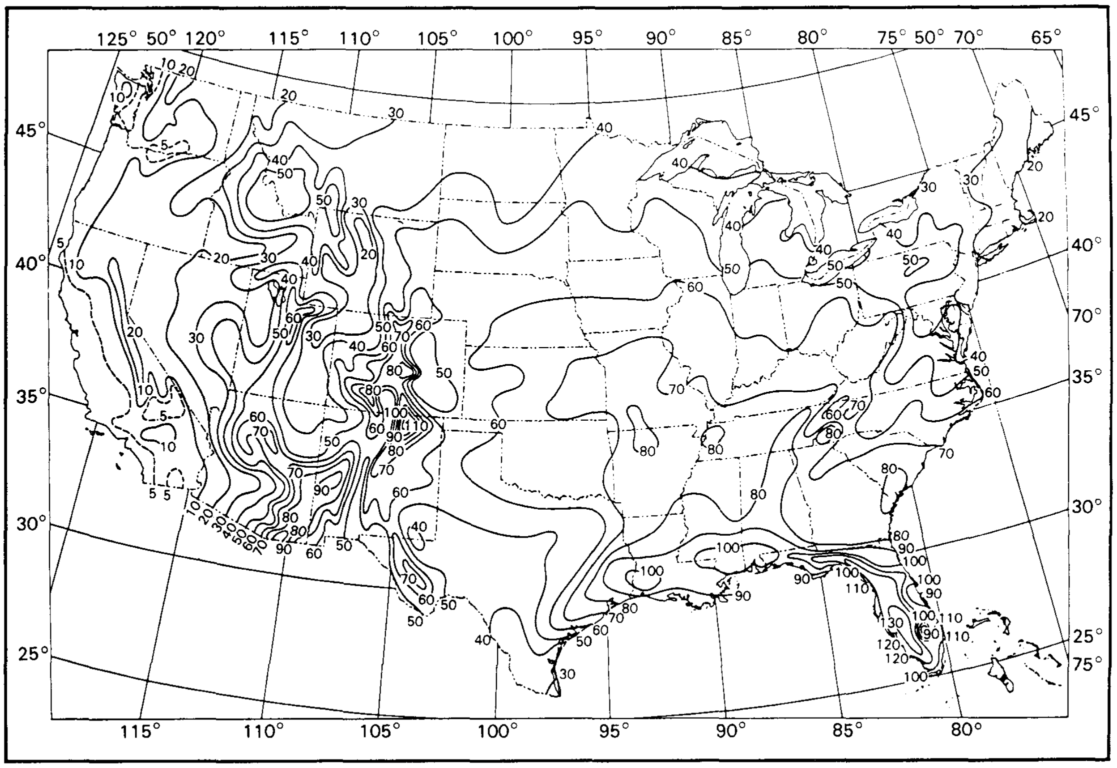


Figure 6—Average annual number of days with thunderstorms (World) [B5]



Source: National Climatic Data Center, National Thunderstorm Frequencies for the Contiguous United States, Nov. 1981.

Figure 7—Mean number of thunderstorms (USA, annual) [B10]

d) *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 [B14] 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.

e) *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.

3.2 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.

3.3 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 367-1987 and IEEE Std 487-1992.

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

Refer to [B19] and IEEE Std 487-1992. An electrical power network consists of many kinds of systems that generally fall into two types of circuit configurations (see also [B5]).

3.3.1.1 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.

3.3.1.2 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 [B19].
    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 a 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 [B5] and [B19]). A survey conducted on communications lines (see [B21]) indicates that the continuous levels experienced are normally very low, although on long exposures it is possible for the potential to exceed 50 V_{rms}. 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 [B21]).

3.4 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 801-4 (1988).
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 3.3.1.2 a and c). 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 801-4 (1988).

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 connecting discharge capacitors.

3.5 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 3.6), 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.

3.5.1 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 [B26] and [B27]).

3.5.2 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 amps 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.

3.5.3 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.

3.5.4 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.

3.5.5 Field strengths

The only published measurements of ESD fields to date are for indirect personnel ESD. From this data, field strengths 10 cm from the 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.

3.5.6 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 two to three hours. 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 hours. In an uncontrolled environment, peak currents of 20 A or more would only occur about every 10 hours. In any case, however, the frequency of occurrence is too great to be ignored.

3.6 Electromagnetic pulse (EMP)

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 the creation of a band of air molecules with a positive charge inside of a band of electrons with a negative charge. A current flow takes place between these two bands of oppositely charged particles, and this causes an electromagnetic pulse (EMP) to be generated, which can cover an extremely large geographical area. 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 [B15], [B16], [B17], [B20], and [B25]).

4. Comparison and selection of air gaps vs. gas tubes

Air gap surge arresters and gas tube surge arresters do not normally provide interruption-free service. They are crowbar-type devices that effectively short-circuit or ground the communication or power conductors during surges or excessive foreign voltage occurrences. These devices can be used in conjunction with other components to avoid a short-circuit being applied to the line for critical services. (See, for example, IEEE Std 487-1992).

Air gap surge arresters typically have a wider statistical variation of dc and impulse breakdown voltage than gas tube surge arresters 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 surge arresters at both ends of the statistical performance distribution would both interfere with normal operation and allow damage to the protected equipment. With gas tube surge arresters, this adverse characteristic is much reduced.

The impulse breakdown voltage of gas tube and air gap surge arrester devices increases with increasing voltage rate of rise. For applications on typical communications and signalling lines, the difference in sensitivity to voltage rate of rise between air gap and gas tube surge arresters is not significant enough to be of importance. For gas tube surge arrester applications where surges with high rates of rise (greater than 1000 V/us) are present, the use of specialized gas tube surge arresters should be considered.

Surge protective devices having three or more electrodes in a common sealed chamber are available in gas tubes but not air gap surge arresters. The common chamber makes possible gas tube surge arresters that are designed to have reduced impulse or ac transverse breakdown voltage. This feature is not available with air gap surge arresters.

Generally, gas tube surge arrester devices exhibit a glow-mode characteristic that is usually not found with carbon air gap surge arresters. 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 surge arresters may have shorter ac life at certain current levels than air gap surge arresters.

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

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

5. Gas tubes

This clause presents a description, theory of operation, test characteristics, and an application guide for gas tube arresters.

5.1 Description

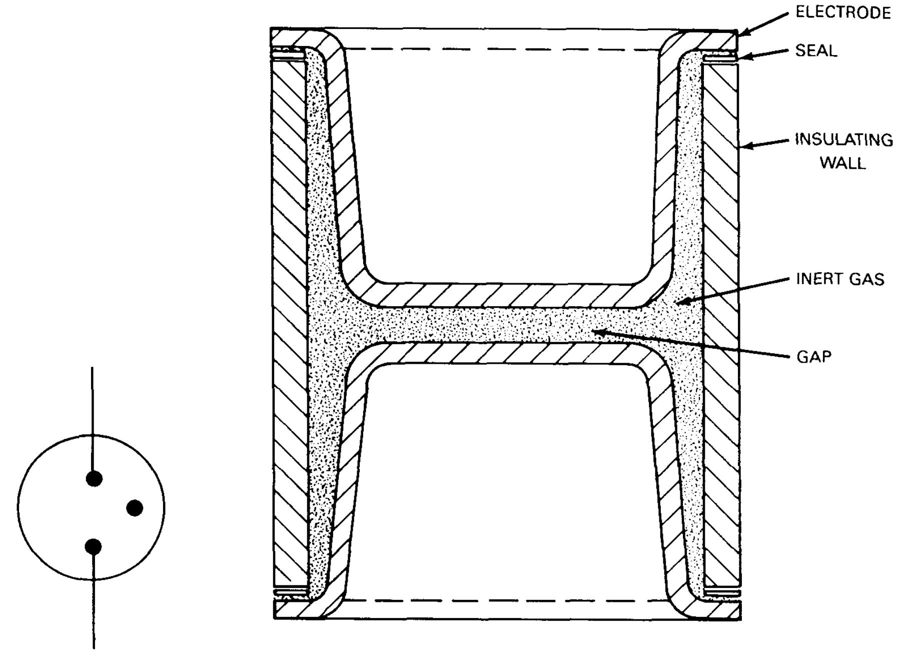
Gas tube arresters consist of two or more metallic electrodes that are separated by gap(s) in a hermetically sealed envelope containing an inert gas or mixture of gases, usually at less than atmospheric pressure. Some of the gases used are Argon, Helium, Hydrogen, and Nitrogen. Electrode spacing is maintained 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 8 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.

5.2 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.

The finite length of time that elapses after a voltage, of sufficient magnitude to cause breakdown, is applied across a gap may be considered to be in two periods. The first is a statistical function of the time required for the appearance in the gap of a suitably charged particle to initiate the process of multiplication of electrons by ionization. The second period of time is one in which ionization processes occur to generate a discharge. For detailed information of the finite length of time for this process (see [B11]).

For a particular electrode material and configuration, the dc breakdown potential for a certain gas or gas mixture follows Paschen's law, which states: *The breakdown voltage is a function only of the product of the gas pressure multiplied by the distance between the plane electrodes*. Curves, called Paschen curves, have been derived showing the breakdown voltage as a function of this product. See figure 9 (see also [B11] and [B13]).



GAS TUBE ARRESTER SYMBOL

*Not to scale.

Figure 8—Cross-sectional view of the functional components of a two electrode gas tube arrester (Simplified)

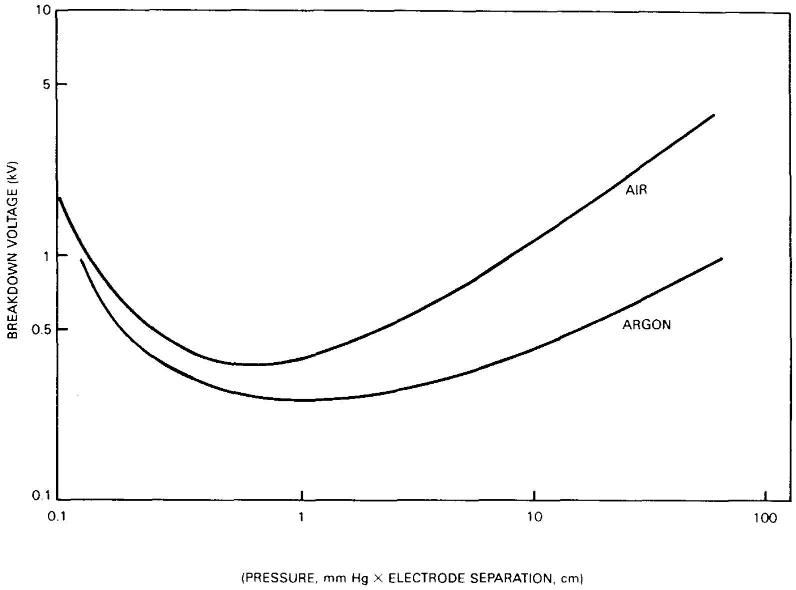


Figure 9—Paschen curves for air and argon

Minute quantities of radioactive isotopes, or conductive deposits on the inside wall of the gas tube arrester, are sometimes used for the purpose of reducing the statistical time lag prior to discharge. They have the effect of stabilizing and reducing the breakdown voltage level. The radioactive substance is either a gas or a solid within the sealed envelope of the gas tube arrester. Some substances used are Cs^{137}, Kr^{85}, Ni^{63}, Pm^{147}, and H^3. Several other methods have been successfully utilized to stabilize gas tube arrester operation.

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 10). 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 increases 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.

5.3 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.

5.3.1 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/μs.

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.

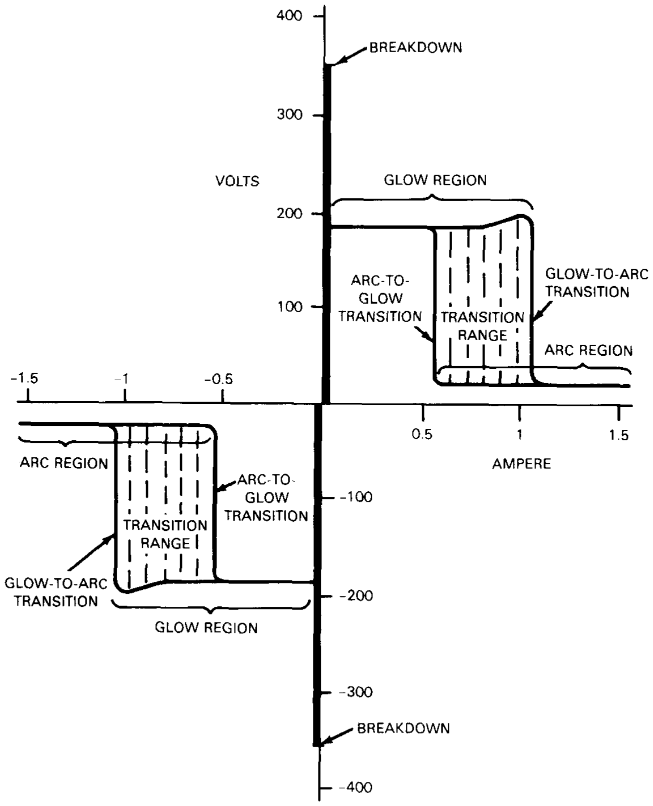


Figure 10—Typical voltampere characteristic

5.3.2 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 1 pF to 5 pF. Considering the upper value of 5 pF and a line frequency of 1.0 MHz, the impedance to ground is approximately 31.8 kΩ. 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.

5.3.3 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.

5.3.4 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/μs, 500 V/μs, 5 kV/μs, and 10 kV/μs. See IEEE Std C62.31-1987, figure 3, for typical test waveforms.

5.3.5 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 μs and 8/20 μs 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.

5.3.6 Impulse life test

One of the most important measures of the capability of gas tube arresters is the impulse life test. IEEE Std C62.31-1987, table 1, 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.

Isokeraunic maps (see figures 4, 5, and 6) are published showing the mean annual number of thunderstorm days. Statistical data has been gathered giving stroke factors, that is, the number of strokes to ground per square mile. 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 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 surge arresters. Failure criteria for this test are defined in IEEE Std C62.31-1987.

The useful life of the 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.

5.3.7 AC discharge current test

The ability of an 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.

5.3.8 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 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.

5.3.9 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.

5.3.10 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.

5.3.11 Impulse transverse voltage test

The impulse transverse voltage is the metallic voltage that appears across the line terminals of the gas tube arrester(s) 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 11). 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.

5.3.12 AC transverse voltage test

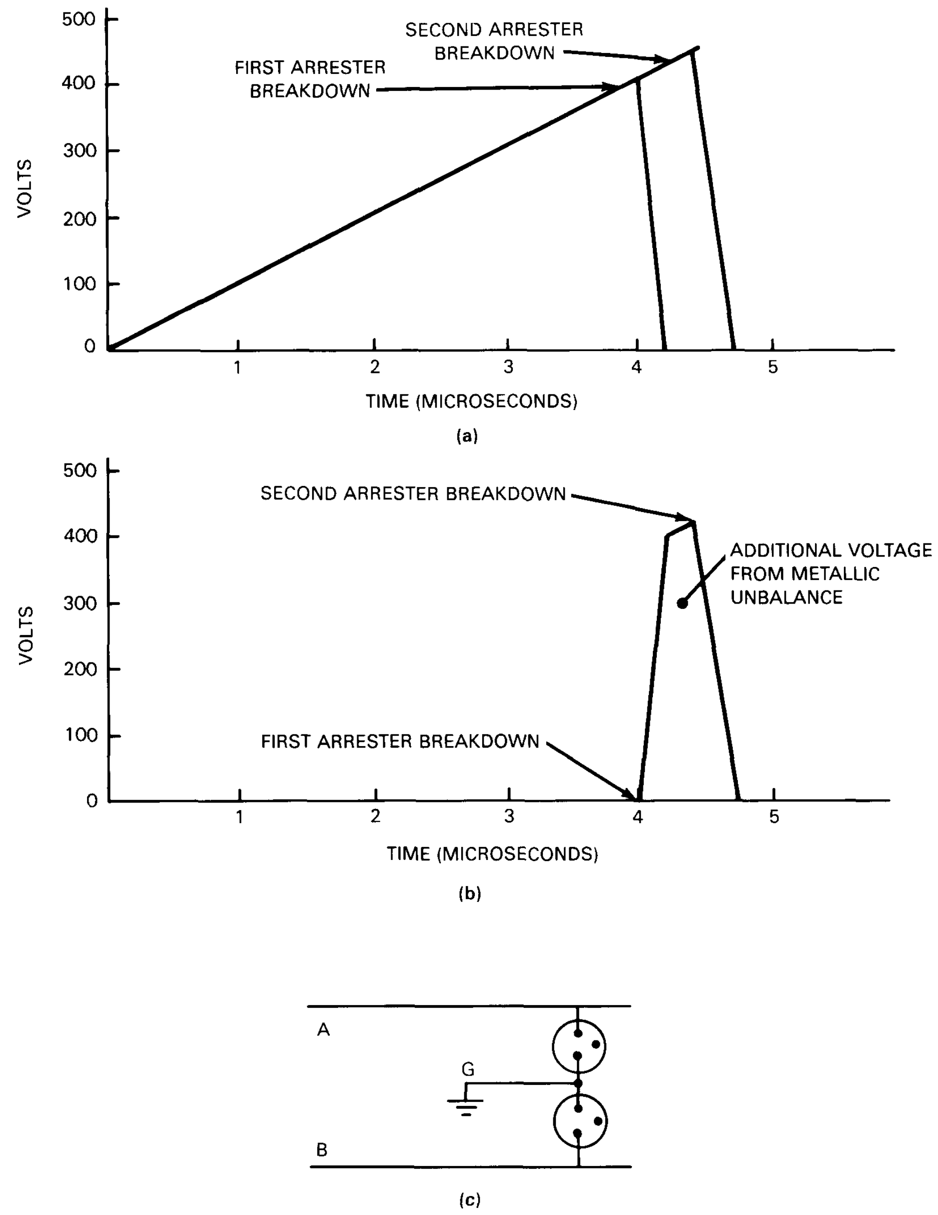
The ac transverse voltage test is similar to the impulse transverse voltage test except that a 50 Hz or 60 Hz source is used. This test is primarily intended for gas tube arresters with three or more electrodes. It is a measure of the energy that is transferred to the circuit or component being protected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

5.3.13 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 10).

5.3.14 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.



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

Figure 11—Simplified illustration of line-to-line voltage unbalance
a) Line-to-ground voltage A-G, B-G
b) Line-to-line voltage A-B
c) Schematic of arresters connected A-G, B-G

5.4 Application of gas tube surge arresters

The application of gas tube surge arresters to limit voltages at the terminals of electrical apparatus requires the selection of an arrester with suitable characteristics, and then the proper physical arrangement of the 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 12. 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. The a) arrangement in each configuration limits longitudinal (common mode) surge voltages. The b) 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. The c) arrangement limits transverse mode surge voltages, but does not provide protection against common mode surge voltages. An additional arrester (see [B12]) may be added to this last arrangement, connected between one of the terminals and ground, to provide longitudinal mode protection.

The application principles will be discussed in detail for the configuration consisting of two signaling terminals and a ground terminal (see figure 13), the objective being to limit the magnitude of surge potentials that may occur between the two signaling terminals and between either terminal and ground.

5.4.1 Operational compatibility

In the quiescent state an unoperated gas tube surge arrester should not interfere with transmission of information, control, or test signals. Leakage resistance of the gas tube surge arrester, measured at the voltages applied by the system, should be sufficiently high to avoid significant insertion loss. The low-capacitance of gas tube surge arresters generally causes insignificant insertion loss as compared to the transmission line at the protected terminals. However, if capacitance is of concern (such as in high-frequency applications), its maximum permissible value should be specified at the frequency of the applied transmission signal.

Unwanted clipping of signals is avoided by specifying the minimum dc breakdown voltage to be greater than the largest signal level, including any superimposed dc bias or any acceptable induced ac interference voltage, at the protected terminals. Gas tube surge arresters do not incorporate a current-limiting element to extinguish follow currents after a surge has been conducted. Conduction is interrupted if the load line of the source intersects the voltampere characteristic of the *off* state after the surge has decayed (see annex A). Extinguishing capability is established by testing for holdover with a test source having the equivalent load line of the actual source at the protected terminals. Since reactive components (that is, transmission line, connected apparatus) may effect extinguishing, they should be included in the holdover test circuit.

5.4.2 Voltage limiting

The gas tube surge arrester is intended to limit the magnitude of unwanted voltage transients to levels that are below the withstand threshold of apparatus being protected (with suitable margin for aging of the apparatus). Protection of the circuit of in figure 13 requires that the voltages between terminals A-G, B-G, and A-B all be limited. In many applications, surges are of like polarity with respect to ground, and the maximum voltage between terminals A-B does not exceed the arrester surge limiting voltage between A-G or B-G. Accordingly, two surge arresters, placed between A-G and B-G, are normally sufficient to protect all three terminals. If the application is such that metallic transients can occur without a longitudinal component, then the two-arrester arrangement will permit metallic voltages as high as the sum of the two limiting voltages. In this situation, a third arrester placed between terminals A-B may be necessary to limit metallic transients to lower values.

If protection against fast-rising transients is desired, the voltage rate-of-rise of the transients should be specified. If the rate of rise is not known, suggested values are 100 V/μs for lightning transients on metallic shielded communication or signaling lines and 500 V/μs on unshielded lines, 100 kV/μs for EMP, 5 kV/μs for ac power switching transients. Protection against 50 Hz or 60 Hz overvoltages is usually provided by selecting the maximum dc breakdown voltage to equal the peak value of the tolerable ac overvoltage.

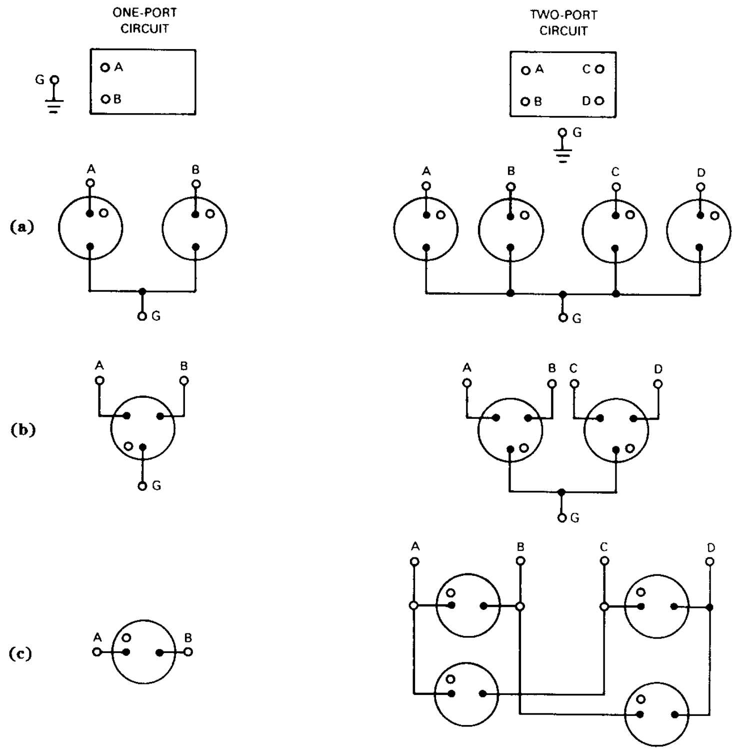


Figure 12—Typical arrangements of gas tube surge arresters

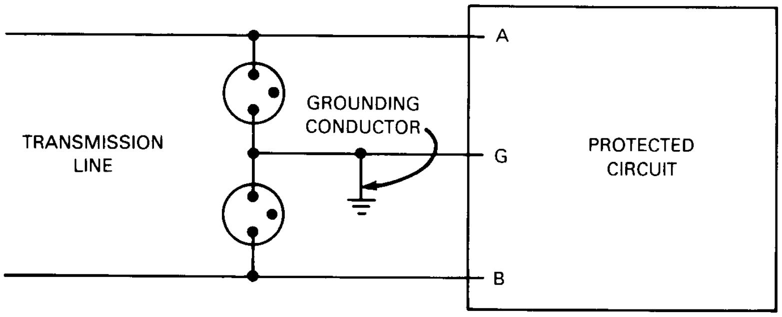


Figure 13—Protection of circuit composed of two signaling leads and a ground terminal

5.4.3 Failure mode

Since the failure mode of the gas tube surge arrester affects protection of terminal equipment, the preferred failure mode of the arrester should be specified. Arrester failure modes are of two types—those that may interfere with system operation, and those that do not. In the first category are the short-circuit failure mode, the low-breakdown voltage failure mode, and the low-insulation resistance failure mode. These failure modes are often detectable by the user of the protected system and are usually preferred where protection of people, property, or terminal equipment is paramount. In the second category is the high-breakdown voltage failure mode. This failure mode is not normally noticeable to the user (without special testing), and may be preferred where uninterrupted system operation is paramount.

Failure of an arrester may be caused by several mechanisms. Among them are mechanical shock, corrosion, hermetic seal failure, and repeatedly or excessively large surge operation. Each of these mechanisms may produce different failure modes in a given arrester, so that both the type of stress and the preferred failure mode should be considered.

5.4.4 Operations to failure

Repeated discharges of impulse and alternating currents eventually cause a gas tube surge arrester to degrade. This degradation causes disruption of transmission or loss of protection if one or more of the device characteristics (for example, insulation resistance, breakdown voltage) do not satisfy desired values. The number of impulse or ac discharge current operations that cause a device characteristic to fail specifications is a measure of arrester lifetime. Since in-service discharges are likely to be of widely different amplitudes and durations, discharge tests made in accordance with IEEE Std C62.31-1987, are a convenient approximation of actual service life conditions.

The required number of operations before failure depends upon the severity of the environment and the desired length of service. Since the lifetime of an arrester may depend on its mounting, and since many protectors contain mechanisms (internal, external, or both to the arrester) that conduct when the conducting capacity of the arrester has been exceeded, the arrester should be tested in its protector mounting.

Protectors that are applied to exterior transmission lines may be subjected to surges from lightning or from nearby power lines. Because of the many conductive paths that are present, lightning-caused surges are normally lower than the currents delivered by the flash from the thundercloud. Lines in areas of high thunderstorm activity and lines without a grounded metallic shield experience the greatest number of high-current lightning surges. Only a limited amount of surge current data for in-service facilities is available (see [B19] and [B21]). Peak values of these currents typically are less than 100 A, but may be higher on unshielded facilities (see [B24]). Discharge currents resulting from faults on 50 Hz or 60 Hz power lines are normally of short duration (less than 5 s) because of automatic disconnect devices on the power system.

However, high-impedance power faults may last indefinitely, actuating the heat-sensing mechanism in the protector, and permanently short-circuiting the arrester. Arresters on ac power service lines may be subjected to repeated short duration surges caused by lightning, operation of nearby electrical equipment, or power system switching transients (see [B22]).

5.4.5 Grounding and bonding

In figure 13, the connection between the protector ground terminal and the local grounding electrode, the *grounding conductor*, shall be capable of conducting the sum of the currents of the two arresters, as well as from other paths. The grounding electrode is likely to be the ground for the neutral of a power system, a buried metallic water pipe, building steel, a ground-rod or mat, or a combination of these. In any case, the electrode establishes a local ground reference that is different in potential from a remote location in the earth. Nearby metallic systems should be connected to the same grounding electrode so that the potential difference to the electrode, rather than to remote earth, determines the difference in potential between nearby systems.

The impedance of the grounding conductor multiplied by the current conducted during a surge will determine the voltage difference between point G of figure 13 and other systems connected to the same electrode. If the arresters operate, the difference in potential between terminals A-B-G will be the conducting voltage of the arresters, but all three terminals will be at an elevated potential with respect to the ground electrode as determined by the voltage drop in the grounding conductor. For example, if the grounding conductor is 30 ft (9.14 m) of 14 AWG copper wire the total resistance will be about 0.08 Ω and the inductance about 12 μH. If the total surge current in the two arresters is 200 A, with a rise time of 100 A per microsecond, the resistive component of voltage will be 16 V and the inductive, 1200 V.

The voltage appearing in the grounding conductor is minimized with short conductors. In the case of circuits that are bonded together, only that portion of the grounding conductor, which is not common to the protected circuits, contributes to the potential difference between circuits.

5.4.6 Location of arresters

Protectors equipped with two-electrode or three-electrode gas tubes arresters are connected to the terminals to be protected, as in the configurations in figures 12 a) and 12 b). The physical location should minimize the effect of grounding conductor impedance.

Care should be exercised to avoid an inadvertent hazard to the building in which the protected equipment is located. ANSI/NFPA 70-1993, Section 800-30 (b), requires that, where the protector is installed inside the building, it shall be located as close as practicable to the point at which the exposed conductors enter the building. Figure 14 a) illustrates the hazard that can result if this requirement of ANSI/NFPA 70-1993, Section 800-30 (b) is violated. Sustained conduction of 50 Hz or 60 Hz current to the protector ground can overheat the interior wiring and cause a fire hazard.

Even when the primary protector is located at the building entrance, a low-longitudinal impedance to ground of the protected circuit can result in a hazard. The sustained conduction of 50 Hz or 60 Hz current to the protected circuit ground, due to a voltage that is insufficient to operate the primary protector, can be large enough to overheat the interior wiring or the protected circuit and again cause a fire hazard. If a secondary protector is installed, as illustrated in figure 14 b), either to eliminate voltages in the grounding circuit, to induce overvoltages directly into the interior wiring, or to reduce overvoltages to a level lower than that which will cause the primary protector to operate, a fire hazard may still exist. The hazard may be reduced if the installation complies with ANSI/NFPA 70-1993, Section 800-32. Section 800-32 requires that when a secondary protector is installed in series with the interior wiring between the primary protector and the protected circuit, it shall be listed for the purpose and shall incorporate a means for limiting the current, and thereby the heating, in the interior wiring. In addition, the impedance of the interior wiring between primary and secondary protectors and the current limiting means of the secondary protector may be sufficient to assure operation of the primary protector.

5.4.7 Codes and standards

Arresters used for the protection of communication circuits should be mounted in protectors that comply with the provision of ANSI/NFPA 70-1993, Article 800 and/or Accredited Standards Committee C2-1993, where these are applicable. Both of these standards address the requirement for the provision of protectors. In addition, ANSI/NFPA 70-1993 addresses the location and grounding requirements for protectors on communications circuits that are subject to contact by power conductors operating at voltages above 300 V to ground. Typical safety test requirements are described in UL 497 (see [B28]) for communications circuit protectors and in UL 497A (see [B29]) for secondary protectors.

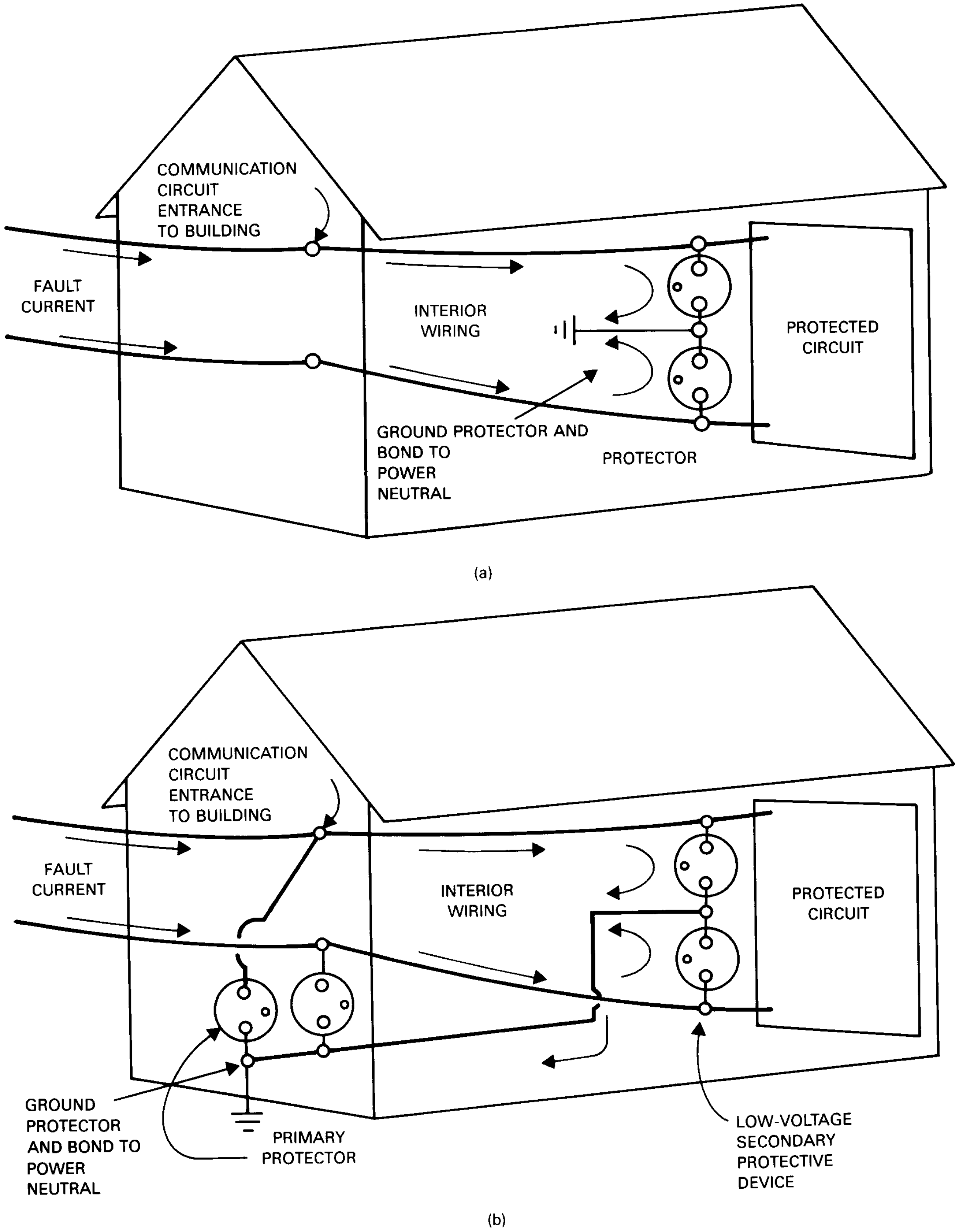


Figure 14—Possible overheating of interior wiring
a) When protector is located remotely from building entrance
b) When secondary protector without current limiting is used

6. Air gaps

This clause presents a description, theory of operation, test characteristics, and an application guide for air gap arresters and when to use backup air gap surge arresters.

Air gap surge arresters may generally be divided into two types—carbon electrode, which have for decades provided the principal primary protection for telecommunications; and backup air gap, which are used to avoid possible loss of protection in the event of venting to the atmosphere by a primary gas tube device.

6.1 Description

Carbon arresters are used for the purpose of diverting damaging energy from equipment or cable and are usually connected between line conductors and ground.

A carbon arrester consists of two carbon electrodes separated by an air gap, the dimensions of which establish the normal breakdown voltage. Electrode spacing is maintained by means of ceramic, glass, or other insulating materials. The electrodes can be fitted with a variety of terminations suitable for mounting on circuit boards, clip terminals, sockets, or for incorporation in a protector. Figure 15 illustrates, in a simplified manner, the functional components of a commonly used two-electrode air gap surge arrester with its circuit symbol.

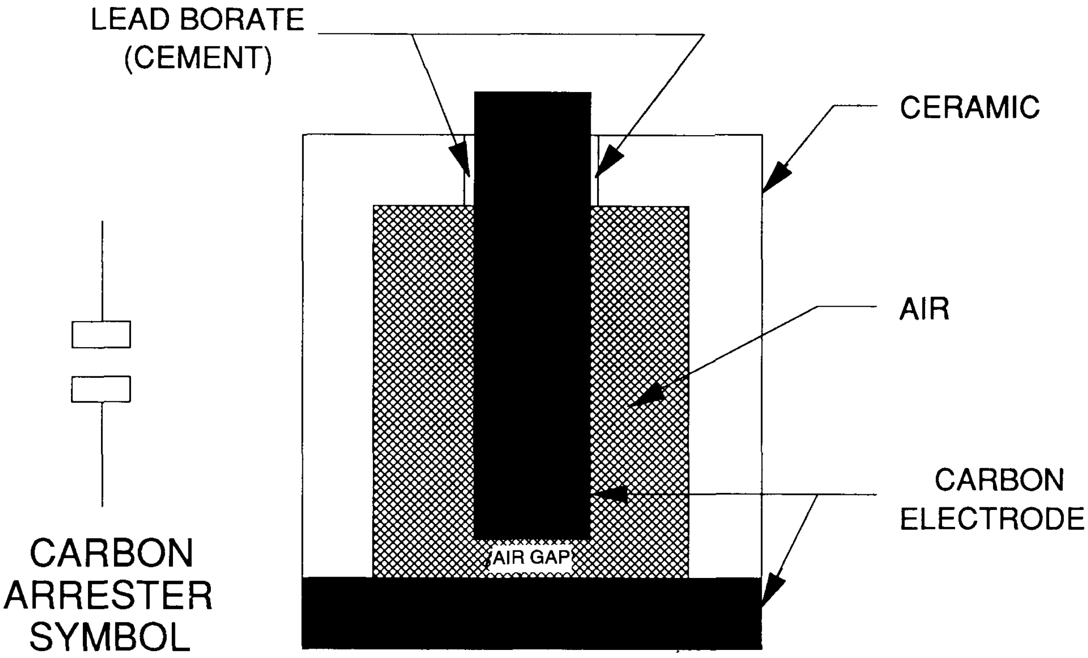


Figure 15—Cross-sectional view of the functional components of a two electrode carbon arrester (Simplified)

6.2 Theory of operation

A carbon arrester electrode may be either an anode or cathode, depending on the polarity of the applied voltage. When the gap of a carbon arrester is subjected to an increasing field intensity, it will breakdown at a voltage that is determined by the gap spacing, material, surface preparation, electrical configuration, atmospheric pressure, 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.

In the unoperated state, the carbon arrester has a very high resistance, in the order of several thousand megohms. In the operational state, that is, when breakdown of the carbon arrester occurs, a high conductance state is produced, and the voltage across the arrester is reduced to the arc mode voltage of about 30 V, regardless of the current flowing through the arrester. The energy remaining in the disturbing transient is shunted and reflected away from the components to be protected.

For all practical purposes, the glow-mode characteristic exhibited by gas tube arresters does not exist for carbon arresters and is, therefore, not discussed.

The useful life of an air gap arrester is ended when degradation results in interference with transmission or signaling, such as from low-breakdown voltage or from excessive noise due to low-insulation resistance. The useful life is also ended when the breakdown voltage of the arrester rises to a level where it fails to protect. Degradation may be caused by conduction of ac or impulse currents, by mechanical disturbances, or by climatic conditions.

6.3 Arrester test characteristics

This subclause applies to all air-gap devices, except back-up air gaps, which are discussed in 6.5. For further information about the following tests, see IEEE Std C62.32-1981.

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 1000 V/s is used for this test. Breakdown voltages of many air gap arresters will vary, but slightly, when the rate of rise is less than 2 kV/s. To speed up life testing, a ramp speed of 2 kV/s is often used.

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 air gap arrester. Should this crest value exceed the dc breakdown voltage of the air gap arrester, causing it to sparkover, interruption of the transmission or signaling on the circuit will occur.

During the life of air gap arresters, after being exposed to a number of transients and disturbances, the air gap 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 air gap 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 that is to be protected. Moreover, it should be low enough so that the air gap arrester breakdown will occur before a low-frequency voltage can rise to destructive magnitudes.

6.3.2 Capacitance test

Capacitance of air gap arresters installed on low-frequency lines is usually of small concern due to the inherent low-capacitance of the air gap arresters. The capacitance of a two-electrode air gap arrester is usually in the range of 1 pF to 5 pF. Considering the upper value of 5 pF and a line frequency of 1.0 MHz, the impedance to ground is approximately 31.8 kΩ.Capacitance of air gap arresters is usually constant over a wide range of frequencies. The unit-to-unit capacitance variation between air gap arresters of the same type is usually quite small. Capacitance of air gap 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 air gap arresters is in the order of thousands of megohms. During the field life of an air gap 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 air gap arresters on each side of the 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 an air gap 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 selected impulse breakdown voltage should not be 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, high enough to cause breakdown and the actual ionization process, faster rates of rise cause higher breakdown voltages. Curves plotting breakdown voltages versus rates of rise are published by air gap arrester manufacturers. In the absence of special test requirements, the rates of rise should be one or more of the following: 100 V/μs, 500 V/μs, 1 kV/μs, 5 kV/μs, and 10 kV/μs. See IEEE Std C62.32-1981, figure 4, for typical test waveforms.

6.3.5 Maximum single impulse discharge current test

The maximum single impulse discharge current test is a measure of the capability of an air gap arrester to withstand a single large surge. Nearby lightning strikes can produce such surges. IEEE Std C62.32-1981 specifies waveforms of 10/1000 μs and 8/20 μs as well as failure modes. The impulse 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.

6.3.6 Impulse life test

The impulse life test measures the ability of an air gap arrester to survive repeated impulse current discharges. Although actual impulse currents on communication and signaling lines have complex waveshapes, standardized waveforms and test methods have been adopted as a reasonable laboratory simulation. The applications will determine the test parameters, including peak current and waveshape, number of applied impulses, and failure modes.

IEEE Std C62.32-1981, 4.12.5, suggests peak currents and current waveshapes to be used. In this same standard, suggested failure modes for impulse life tests are listed in 4.12.4.

In some cases, the life of an air gap arrester may be greater using higher test currents than when using lower currents. This may be due to a clearing action when using higher current values. Furthermore, the electrode surfaces of a carbon air gap may be affected by currents passed through the gap during measurement of insulation resistance. If a clearing source is to be used during impulse life testing, it should simulate a clearing source that is present in the application such as that described in IEEE Std C62.32-1981, 4.12.3.

6.3.7 AC discharge current test

The ability of an arrester used on communication 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, such as during a load unbalance on a power system. Power contact currents of hundreds of amperes are possible, but the high currents are usually interrupted in less than 5 s by power system protective devices (circuit breakers, fuses, etc.).

6.3.8 Pulsed ac life test

This test, described in 4.14.1 of IEEE Std C62.32-1981, characterizes the ability of a device to conduct a series of 50 Hz or 60 Hz pulses that may occur on communication and signaling circuits exposed to power system induction. Experience shows that pulses of 1.0 A_{rms} current for one second durations are reasonable.

6.3.9 Pulsed ac gap erosion test

Due to normal clearing action, considerable deterioration of device characteristics (such as leakage or low-breakdown voltage) may occur before a failed device is detected and replaced. Prior to replacement, arc erosion may cause widening of the gap to values allowing unacceptably high breakdown voltages. See 4.14.2 of IEEE Std C62.32-1981.

6.3.10 Alternating follow current test

The alternating follow current test measures the ability of an air gap arrester to extinguish under specified conditions. IEEE Std C62.32-1981 suggests voltages and frequency to be used. This ability is of particular interest when arresters are used on circuits intended to carry ac power; it characterizes their ability to extinguish, restoring normal service, after passage of a surge. During the time that conduction occurs service is interrupted.

6.3.11 Holdover test

In applications where a dc voltage exists on a line, the holdover test is a measure of the ability of an air gap arrester to extinguish after it is subjected to an impulse large enough to cause it to conduct. During the time that the air gap 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 air gap arrester. Holdover becomes increasingly probable as the dc line voltage and available line current increase. The holdover of an air gap arrester is strongly influenced by the external circuit in that it is operating. Significant circuit parameters that may influence holdover are open circuit voltage, short circuit current, source regulation characteristics and values of reactive components.

6.4 Application of air gap surge arresters

The application of air gap surge arresters to limit voltages at the terminals of electrical apparatus requires the selection of an arrester with suitable characteristics, and then the proper physical arrangement of the 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 of figure 12 (when the gas tube components are replaced with air gap devices). 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. The a) arrangement in each configuration limits longitudinal (common mode) surge voltages. Air gap arresters are not normally packaged in multielement configurations. Arrangement b) of figure 12 thus would not be relevant. The c) arrangement limits transverse mode surge voltages, but does not provide protection against common-mode surge voltages. An additional arrester (see [B12]) may be added to this last arrangement, connected between one of the terminals and ground, to provide longitudinal mode protection.

The application principles will be discussed in detail for the configuration consisting of two signaling terminals and a ground terminal as shown in figure 13 (when the gas tube components are replaced with air gap devices), the objective being to limit the magnitude of surge potentials that may occur between the two signaling terminals and between either terminal or ground.

6.4.1 Operational compatibility

In the quiescent state an unoperated air gap surge arrester should not interfere with transmission of information, control, or test signals. Leakage resistance of the air gap surge arrester, measured at the voltages applied by the system, should be sufficiently high to avoid significant insertion loss. The low-capacitance of air gap surge arresters generally causes insignificant insertion loss as compared to the transmission line at the protected terminals. However, if capacitance is of concern, such as in high-frequency applications, its maximum permissible value should be specified at the frequency of the applied transmission signal.

Unwanted clipping of signals is avoided by specifying the minimum dc breakdown voltage to be greater than the largest signal level, including any superimposed dc bias or any acceptable induced ac interference voltage, at the protected terminals. Air gap surge arresters do not incorporate a current-limiting element to extinguish follow currents after a surge has been conducted. Conduction is interrupted if the load line of the source intersects the voltampere characteristic of the off state after the surge has decayed (see annex B). Extinguishing capability is established by testing for holdover with a test source having the equivalent load line of the actual source at the protected terminals. Since reactive components (that is, transmission line, connected apparatus) may effect extinguishing, they should be included in the holdover test circuit.

6.4.2 Voltage limiting

The air gap surge arrester is intended to limit the magnitude of unwanted voltage transients to levels that are below the withstand threshold of apparatus being protected (with suitable margin for aging of the apparatus). Protection of the circuit of figure 13 requires that the voltages between terminals A-G, B-G, and A-B all be limited. In many applications, surges are of like polarity with respect to ground, and the maximum voltage between terminals A-B does not exceed the arrester surge limiting voltage between A-G or B-G. Accordingly, two surge arresters, placed between A-G and B-G, are normally sufficient to protect all three terminals. If the application is such that metallic transients can occur without a longitudinal component, then the two-arrester arrangement will permit metallic voltages as high as the sum of the two limiting voltages. In this situation, a third arrester placed between terminals A-B may be necessary to limit metallic transients to lower values.

If protection against fast-rising transients is desired, the voltage rate-of-rise of the transients should be specified. If the rate-of-rise is not known, suggested values are 100 V/μs for lightning transients on metallic shielded communication or signaling lines, and 500 V/μs on unshielded lines; 100 kV/μs for EMP; 5 kV/μs for ac power switching transients. Protection against 50 Hz or 60 Hz overvoltages is usually provided by selecting the maximum dc breakdown voltage to equal the peak value of the tolerable ac overvoltage.

6.4.3 Failure mode

Since the failure mode of the air gap surge arrester affects protection of terminal equipment, the preferred failure mode of the arrester should be specified. Arrester failure modes are of two types—those that may interfere with system operation, and those that do not. In the first category are the short-circuit failure mode, the low-breakdown voltage failure mode, and the low-insulation resistance failure mode. These failure modes are often detectable by the user of the protected system and are usually preferred where protection of people, property, or terminal equipment is paramount. In the second category is the high-breakdown voltage failure mode. This failure mode is not normally noticeable to the user (without special testing), and may be preferred where uninterrupted system operation is paramount.

Failure of an arrester may be caused by several mechanisms. Among them are mechanical shock, corrosion, and repeated or excessively large surge operation. Each of these mechanisms may produce different failure modes in a given arrester, so that both the type of stress and the preferred failure mode should be considered. Air gap surge arresters usually fail in the low breakdown voltage failure mode.

6.4.4 Operations to failure

Repeated discharges of impulse and alternating currents eventually cause an air gap surge arrester to degrade. This degradation causes disruption of transmission or loss of protection if one or more of the device characteristics (for example, insulation resistance or breakdown voltage) do not satisfy desired values. The number of impulse or ac discharge current operations that cause a device characteristic to fail specifications is a measure of arrester lifetime. Since in-service discharges are likely to be of widely different amplitudes and durations, discharge tests made in accordance with IEEE Std C62.32-1981 are a convenient approximation of actual service life conditions.

The required number of operations before failure depends upon the severity of the environment and the desired length of service. Since the lifetime of an arrester may depend on its mounting, and since many protectors contain mechanisms (internal, external, or both to the arrester) that conduct when the conducting capacity of the arrester has been exceeded, the arrester should be tested in its protector mounting with normal orientation.

Protectors that are applied to exterior telecommunication lines may be subjected to surges from lightning or from exposure to nearby power lines. Because of the many conductive paths that are present, lightning-caused surges are normally lower than the currents delivered by the flash from a thundercloud. Lines in areas of high-thunderstorm activity and lines without a grounded metallic shield experience the greatest number of high-current lightning surges. Only a limited amount of surge current data for in-service facilities is available (see [B19] and [B21]). Peak values of these currents typically are less than 100 A, but may be higher on unshielded facilities (see [B24]). Discharge currents resulting from faults on 50 Hz or 60 Hz power lines are normally of short duration (less than 5 s) because of automatic disconnect devices on the power system.

However, high-impedance power faults may last long enough to actuate the heat-sensing mechanism in the protector, and permanently short-circuit the arrester.

Arresters on ac power service lines may be subjected to repeated short duration surges caused by either lightning, operation of nearby electrical equipment, or power system switching transients (see [B22]).

6.4.5 Grounding and bonding

In figure 13, the connection between the protector ground terminal and the local grounding electrode, the *grounding conductor*, has to be capable of conducting the sum of the currents of the two arresters, as well as from other paths. The grounding electrode is likely to be the ground for the neutral of a power system, a buried metallic water pipe, building steel, a ground-rod or mat, or a combination of these. In any case, the electrode establishes a local ground reference that is different in potential from a remote location in the earth. Nearby metallic systems should be connected to the same grounding electrode so that the potential difference to the electrode, rather than to remote earth, determines the difference in potential between nearby systems. If separate electrodes are employed or required, they should be bonded together.

The impedance of the grounding conductor multiplied by the current conducted during a surge will determine the voltage difference between point G of figure 13 and other systems connected to the same electrode. If the arresters operate, the difference in potential between terminals A-B-G will be the conducting voltage of the arresters, but all three terminals will be at an elevated potential with respect to the ground electrode as determined by the voltage drop in the grounding conductor. For example, if the grounding conductor is 30 ft

(9.14 m) of 14 AWG copper wire the total resistance will be about 0.08 Ω and the inductance about 12 μH. If the total surge current in the two arresters is 200 A with a rise time of 100 A per microsecond, the resistive component of voltage will be 16 V and the inductive, 1200 V.

The voltage appearing in the grounding conductor is minimized with short conductors. In the case of circuits that are bonded together, only that portion of the grounding conductor that is not common to the protected circuits contributes to the potential difference between circuits.

6.4.6 Location of arresters

Protectors equipped with air gap arresters are connected to the terminals to be protected, as in the configurations of in figure 12 a). The physical location should minimize the effect of grounding conductor impedance.

Care should be exercised to avoid an inadvertent hazard to the building in which the protected equipment is located. ANSI/NFPA 70-1993, Section 800-30 (b) requires that, where the protector is installed inside the building, it shall be located as close as practicable to the point at which the exposed conductors enter the building. Figure 14 a) illustrates the hazard that can result if this requirement of ANSI/NFPA 70-1993, Section 800-30 (b) is violated. Sustained conduction of 50 Hz or 60 Hz current to the protector ground can overheat the interior wiring and cause a fire hazard.

Even when the primary protector is located at the building entrance, a low-longitudinal impedance-to-ground of the protected circuit can result in a hazard. The sustained conduction of 50 Hz or 60 Hz current to the protected circuit ground, due to a voltage that is insufficient to operate the primary protector, can be large enough to overheat the interior wiring or the protected circuit and again cause a fire hazard. If a secondary protector is installed, as illustrated in figure 14 b), either to eliminate voltages in the grounding circuit, to induce overvoltages directly into the interior wiring, or to reduce overvoltages to a level lower than that which will cause the primary protector to operate, a fire hazard may still exist. The hazard may be reduced if the installation complies with ANSI/NFPA 70-1993, Section 800-32. Section 800-32 requires that when a secondary protector is installed in series with the interior wiring between the primary protector and the protected circuit, it shall be listed for the purpose and shall incorporate a means for limiting the current, and thereby the heating, in the interior wiring. In addition, the impedance of the interior wiring between primary and secondary protectors and the current limiting means of the secondary protector may be sufficient to assure operation of the primary protector.

6.4.7 Codes and standards

Arresters used for protection of communications circuits should be mounted in protectors that comply with the provisions of ANSI/NFPA 70-1993, Article 800 and/or Accredited Standards Committee C2-1993, where these are applicable. Both of these standards address the requirement for the provision of protectors. In addition, ANSI/NFPA 70-1993 addresses the location and grounding requirements for protectors on communications circuits, which are subject to contact by power conductors operating at voltages above 300 V to ground. Typical safety test requirements are described in UL 497 (see [B28]) for communications circuit protectors and in UL 497A ([B29]) for secondary protectors.

6.5 Backup air gap surge arresters

Because of their relatively narrow gaps (small spacing between electrodes), low-voltage air gap arresters typically have the characteristic of *not* failing in a high-breakdown voltage mode. Instead, they usually fail in one of the following modes: shorted, low-insulation resistance, or low-breakdown voltage. This characteristic is especially true of carbon air gap surge arresters.

It is possible for certain types of air gap surge arresters to fail in the high-breakdown voltage mode. This is because they incorporate relatively wide gaps and are sealed at subatmospheric pressure. If for some reason they lose this seal (that is, become "vented"), air will enter causing the internal pressure to rise to 1 atm, resulting in an increase in breakdown voltage.

Although not required in all applications, a common method of protecting against a failure by high breakdown voltage due to gas tube venting is to use gas tube surge arresters in parallel with backup air gaps. The backup air gap is designed to have a higher breakdown voltage than the sealed gas tube, but provide an acceptably low dc and impulse breakdown voltage if venting occurs. If the breakdown voltage levels of the two gaps are carefully controlled and are sufficiently separated, then the resulting arrester assembly will have gas tube performance with safety from high-breakdown failure mode due to venting. Since loss of the gas tube seal is a rare event, the only life test requirement on the backup air gap is that failure shall not occur in the high-breakdown voltage failure mode. One example of the use of backup air gaps is found in protectors that incorporate them to meet the "vent test" requirements of UL 497 (see [B28]).

Annexes

(These annexes are not a part of IEEE Std C62.42-1992, IEEE Guide for the Application of Gas Tube and Air Gap Arrester Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Surge-Protective Devices, but are included for information only.)

Annex A
Circuit behavior of gas tube arresters

(informative)

The idealized circuit of figure A1 illustrates the behavior of a two-electrode gas tube arrester in a circuit consisting of terminal equipment to be protected, a 50 Vdc source (*Vdc*), and a source resistor (*R*). In figure A2 the introduced surge *e(t)* has a peak value (V_p) of 750 V and the resulting waveform. Figure A3 contains a rectilinear approximation to the voltampere characteristic of a gas tube arrester along with several superimposed source load lines. The characteristic has two discontinuities that provide the following three branches:

a) An *off* branch terminating in the breakdown point (V_b)
b) A glow-mode branch characterized by a constant intermediate voltage at currents below the glow-to-arc transition current
c) An arc-mode branch characterized by a low, nearly constant voltage for all currents above the glow-to-arc transition

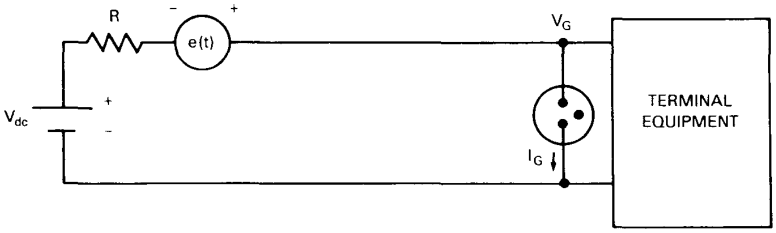


Figure A1—Idealized surge-protection circuit

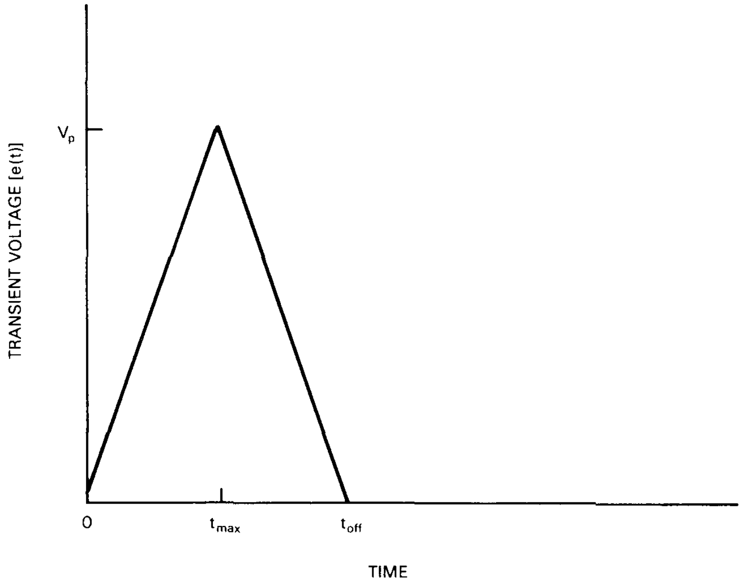
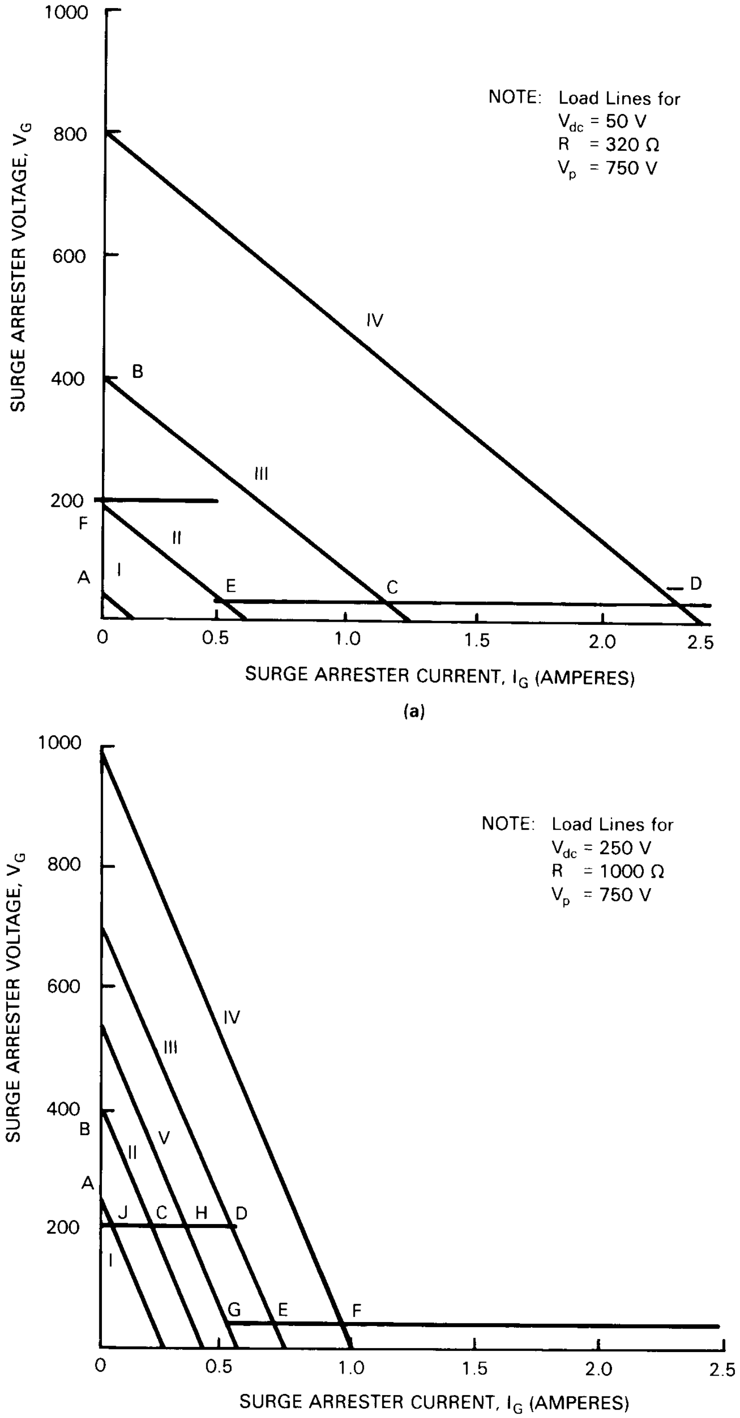


Figure A2—Simulated transient voltage surge



(a)

(b)

Figure A3—Rectilinear voltampere characteristic of gas tube surge arresters

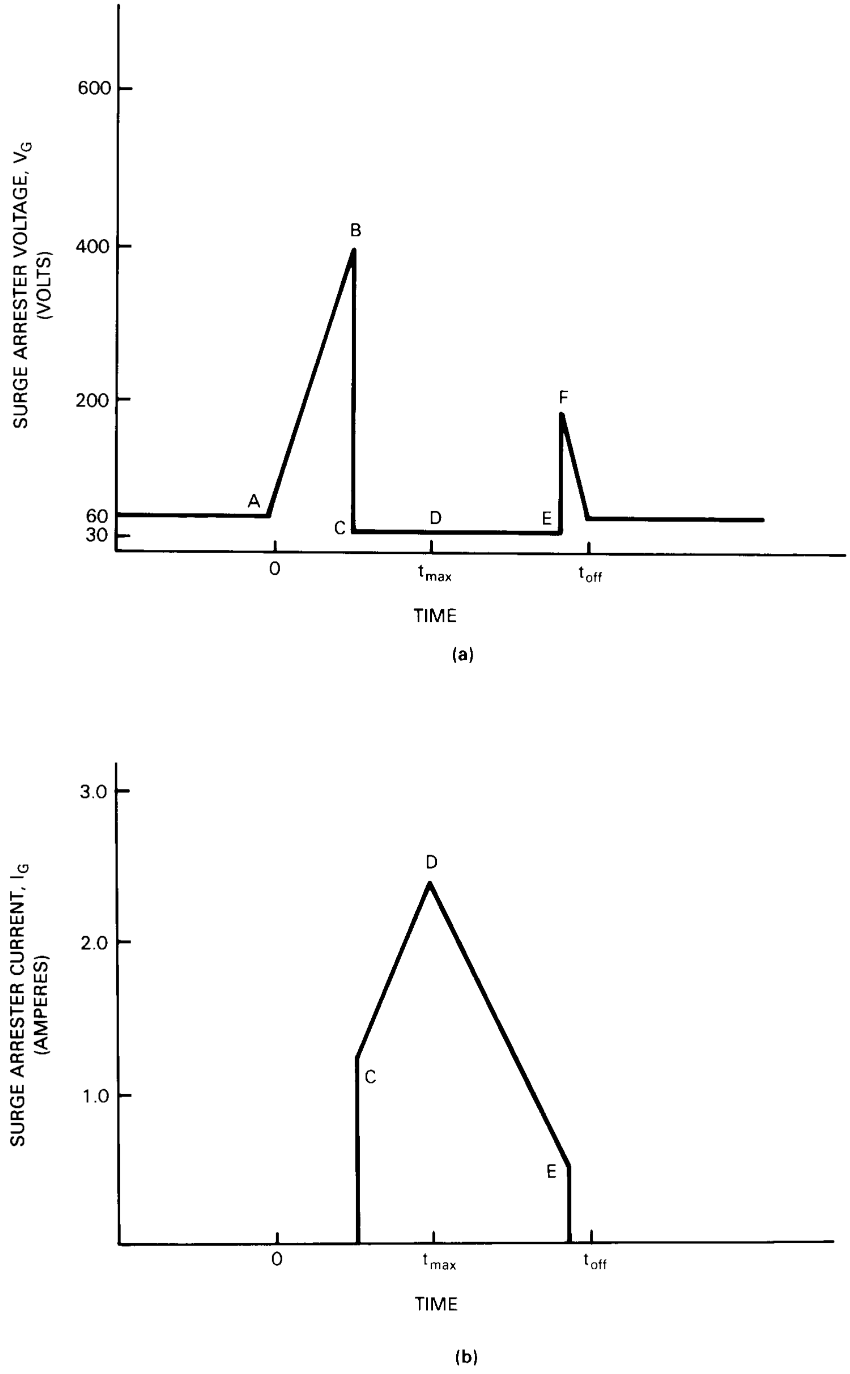
As an aid to understanding the behavior of this idealized surge arrester, the following representative values for the critical parameters are assumed:

a) 400 V = breakdown voltage
b) 200 V = glow-mode voltage
c) 30 V = arc-mode voltage
d) 0.5 A = glow-to-arc transition current

As a first example, assume that the dc source (*Vdc*) is 50 V, the source resistance (*R*) is 320 Ω, and the terminal equipment has infinite input impedance. The load line for this source is labeled I in figure A3 a), and the stable operating point on the voltampere characteristic is in the *off* condition at point *A*. The protector remains in this condition until the transient voltage of figure A2 appears, at which time the operating point rises along the voltage axis until it reaches point *B*, and breakdown occurs. The operating point then transfers to point *C*, the intersection of the load line *III* with the arc-mode branch. As the transient continues to its peak value, the surge arrester discharge current moves from point *C* to *D* determined by load line *IV*,which intersects the voltage axis at *Vdc* + *e(t)* = 50 + 750 = 800 V, and has a slope of 320 Ω. As the transient subsides the discharge current decreases to point *E* and then transfers to point *F* along load line *II*, and the surge arrester returns to the *off* condition. At t_{off} the operating point returns to its original position at point *A*. The resulting surge arrester voltage V_G and current I_G waveforms during the surge appear in figure A4. Notice that, since the arrester voltage equals the terminal equipment voltage, the arrester has limited the voltage at the equipment terminals to 400 V, and the duration of the excursion above *Vdc* is less than the duration of the incident surge. The load line selected for this example did not involve the glow region. In practice, reactive components or circuit parasitics may cause a brief glow period during the transitions between *off* and *arc*.

A second example will involve the glow region and will also illustrate circuit conditions that inhibit the surge arrester from extinguishing (holdover). The dc source (*Vdc*) is 250 V (see figure A1), the resistor (*R*) is 1000 Ω, and the transient *e(t)* is 750 V peak. The *off* condition of the surge arrester of figure A3 b) is on load line *I* at point *A*. The transient causes the surge arrester to sparkover at 400 V, point *B*. Because of the high source resistance, the operating point transfers to point *C* in the glow mode on load line *II*, and then remains in the glow mode until the current increases to the glow-to-arc transition current at point *D* on load line *III*. A transfer to the arc region at point *E* follows, and the discharge current reaches a maximum, point *F* on load line *IV*, when the transient voltage is maximum at t_{max}. As the transient decays, the arc-mode discharge current decreases to point *G* on load line *V*, and the operating point then transfers back to the glow mode at point *H*. The glow-mode current decreases until the transient decays to zero at t_{off}. The operating point is *J* on load line *I*. This operating point is a stable portion of the glow mode sustained by the source *Vdc*. The surge arrester remains in this holdover condition indefinitely. The surge arrester discharge current and terminal voltage for this example appear in figure A5. The example has been idealized, and a gas tube surge arrester may extinguish under these circuit conditions if reactive components are present, if the voltampere characteristic changes due to heating, or if the transient decay is so rapid that a stable glow mode cannot be established.

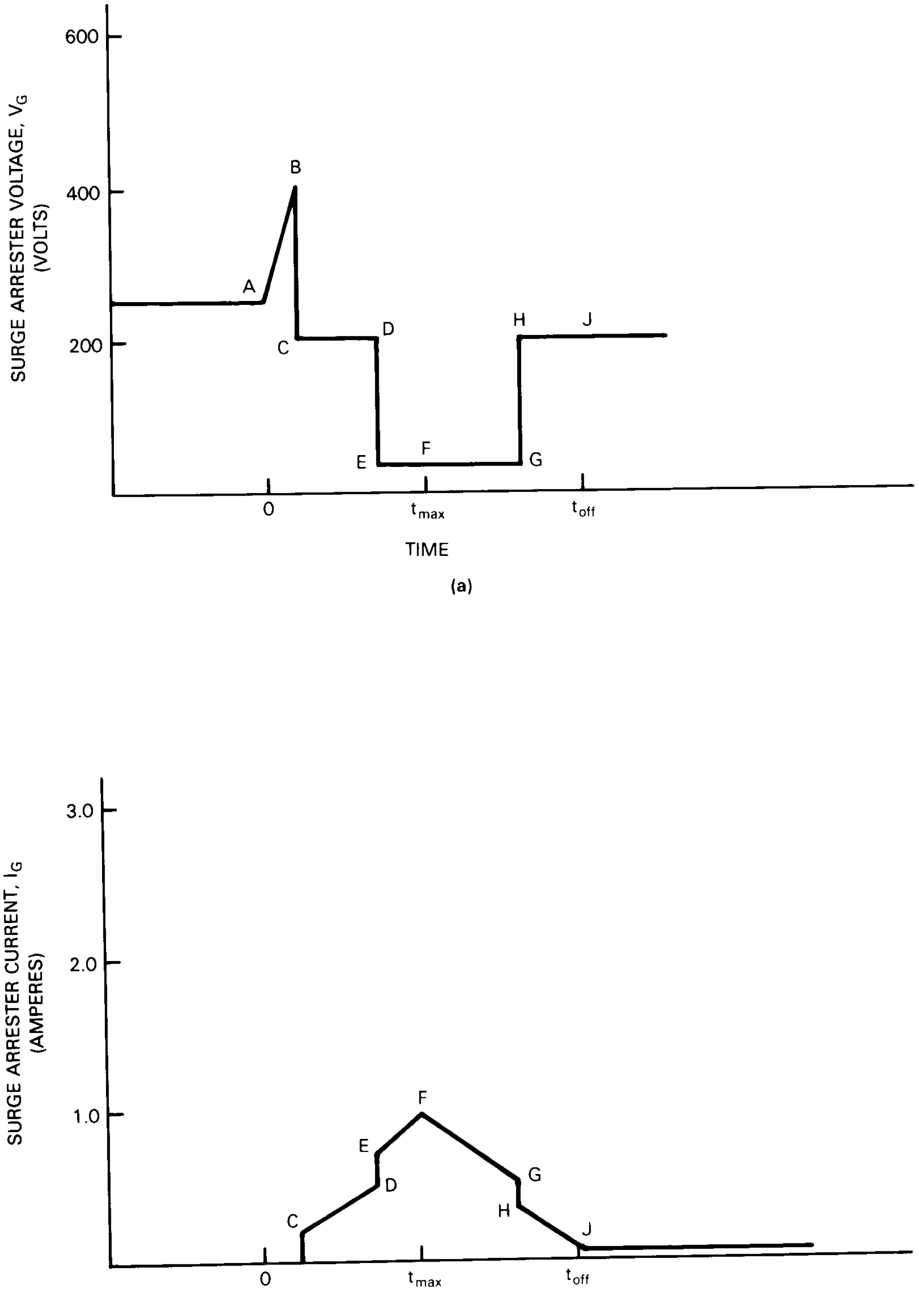
NOTE—In some gas tube arresters the arc-to-glow transition current is significantly lower than the glow-to-arc transition current causing hysteresis in the voltampere characteristic. This phenomenon is not considered in the examples, but may be important in practice.



(a)

(b)

Figure A4—Surge arrester voltage and current for figure A3 a)



(a)

(b)

Figure A5—Surge voltage and current for figure A3 b)

Annex B
Circuit behavior of carbon air gap surge arresters

(informative)

The most common nonbackup air gap surge arrester utilizes carbon electrodes. This annex addresses the behavior of such carbon air gap arresters.

The idealized circuit of figure B1 illustrates the behavior of a two-electrode air gap arrester in a circuit consisting of terminal equipment to be protected, a 50 Vdc source (*Vdc*), and a source resistor (*R*). The introduced surge *e(t)* has a peak value (V_{max}) of 750 V and the waveform of figure B2. Figure B3 contains a rectilinear approximation to the voltampere (VA) characteristic of a carbon air gap arrester along with several superimposed source load lines. The characteristic has one discontinuity that provides two branches:

a) An *off* branch terminating in the breakdown point (0, *B*)
b) An arc-mode branch characterized by a low, nearly constant voltage for all currents

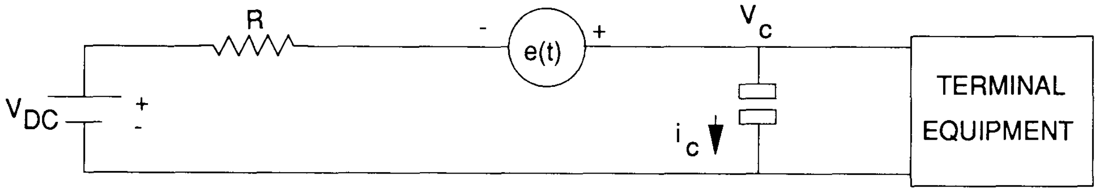


Figure B1—Idealized surge-protection circuit

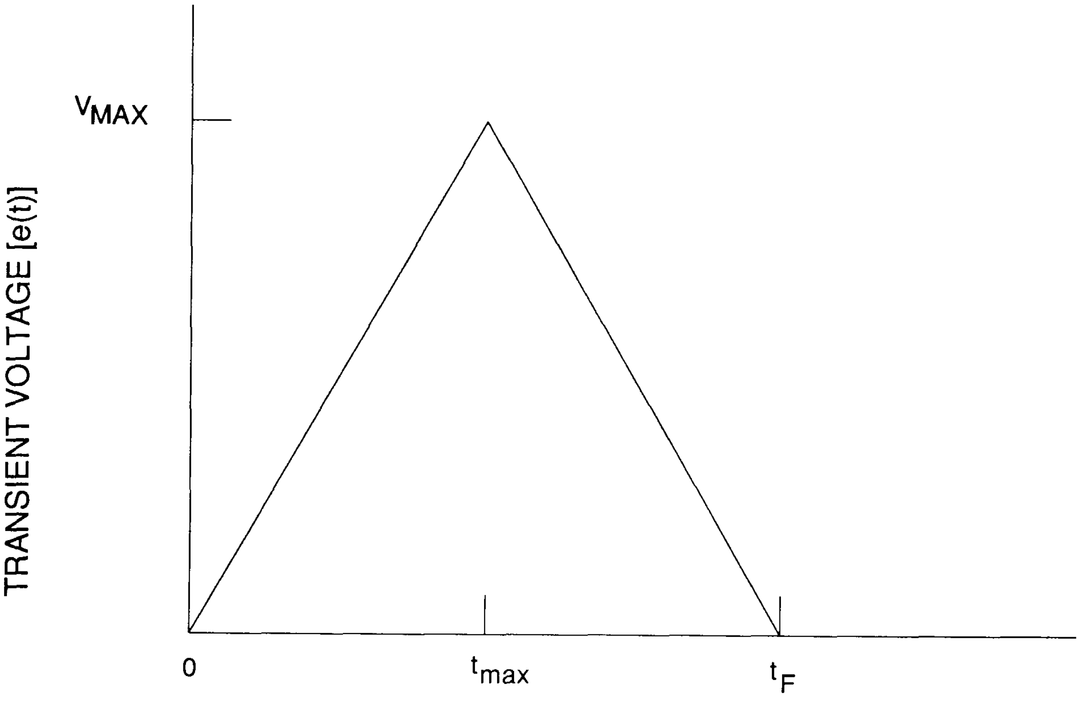


Figure B2—Simulated transient voltage surge

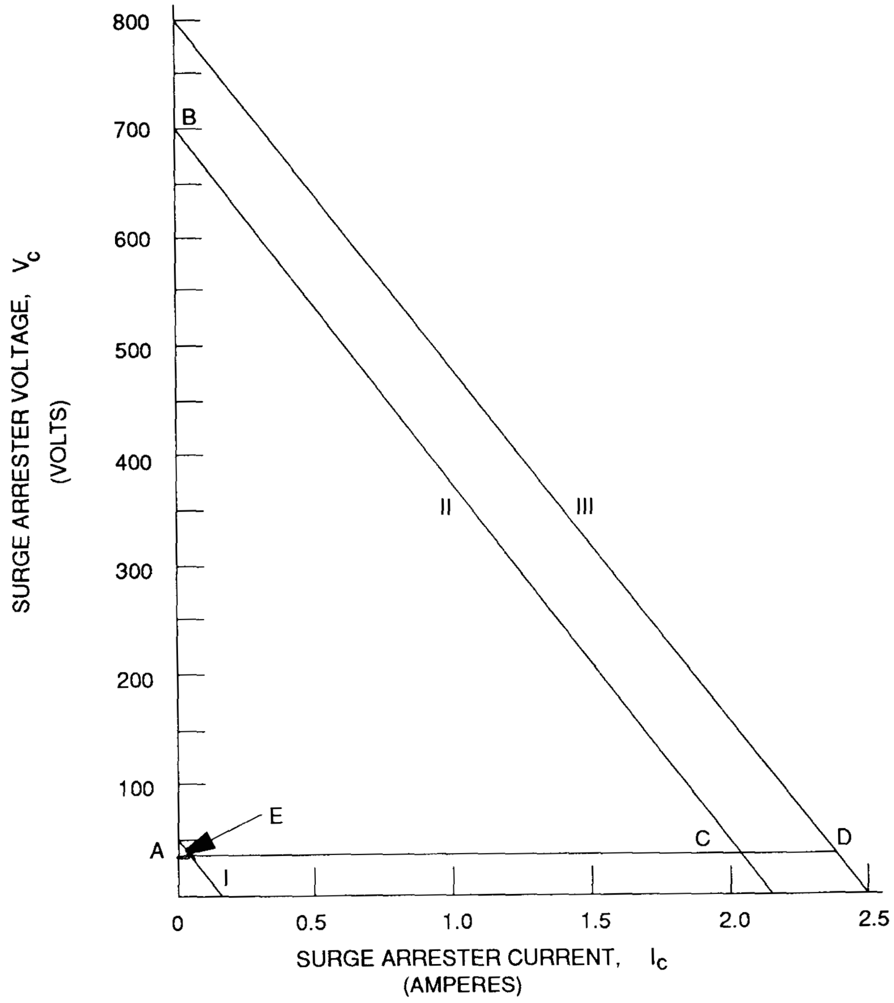


Figure B3—Rectilinear voltampere characteristic of carbon surge arrester

As an aid to understanding the behavior of this idealized air gap surge arrester, the following representative values for the critical parameters are assumed:

a) 700 V = breakdown voltage
b) 40 V = arc-mode voltage

As an example that illustrates the undesirable holdover condition, assume that the dc source (*Vdc*) is 50 V, the source resistance (*R*) is 320 Ω, and the terminal equipment has infinite input impedance. The load line for this source is labeled *I* in figure B3, and the stable operating point on the VA characteristic is in the off condition at point *A*. The air gap surge arrester remains in this condition until the transient voltage of figure B3 appears, at which time the operating point rises along the voltage axis until it reaches point *B*, and breakdown occurs. The operating point then transfers to point *C*, the intersection of the load line *II* with the arc-mode branch. As the transient continues to its peak value, the air gap surge arrester discharge current moves from point *C* to point *D* determined by load line *III* that intersects the voltage axis at $Vdc + e(t) = 50 + 750 = 800$ V, and has a slope of 320 Ω. As the transient subsides, the discharge current decreases until the transient decays to zero at time t_F; the operating point is point *E* on load line *I*. This operating point is a stable portion of the arc mode sustained by the source *Vdc*. In this undesirable circumstance, the air gap surge arrester remains in this holdover condition indefinitely.

The resulting air gap surge arrester voltage (V_C) and current (I_C) waveforms during the surge appear in figure B4. Notice that since the air gap surge arrester voltage equals the terminal equipment voltage, the arrester has limited the voltage at the equipment terminals to 700 V, and the duration of the excursion above *Vdc* is less than the duration of the incident surge. This example has been idealized, and a carbon air gap surge arrester may extinguish under these circuit conditions if reactive components are present, if the VA characteristic changes due to heating, or if the current at point *E* is so low as to result in an unstable arc condition. In any of these conditions the arc will extinguish and the operating condition will return to point *A* in the *off* state. A different choice of circuit parameters, such as an increased value of *R* or reduced value of *Vdc*, should be made to avoid this condition.

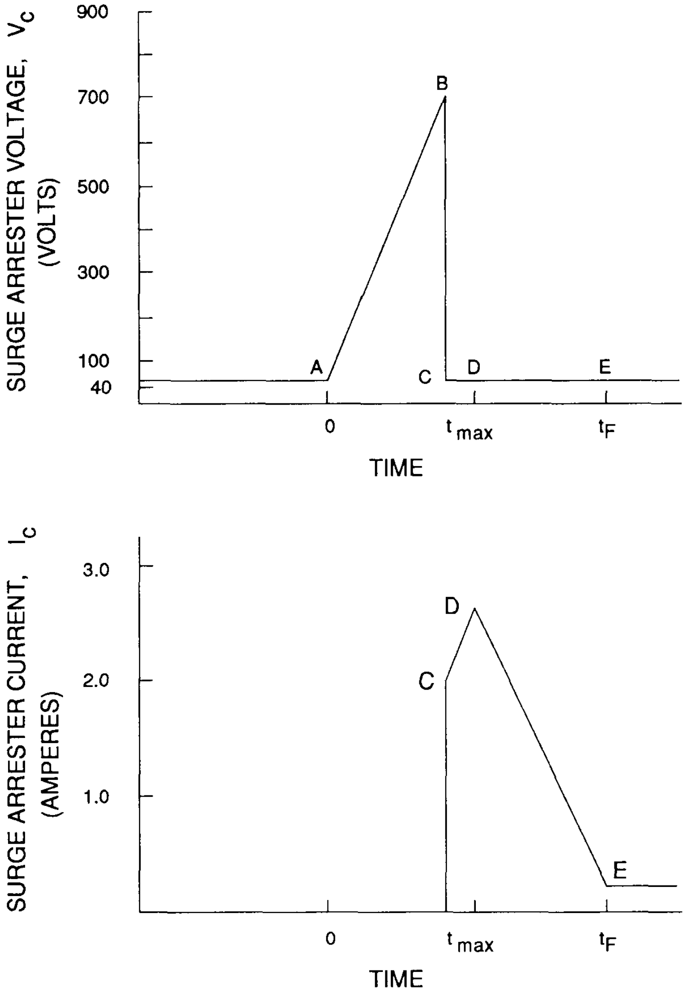


Figure B4—Surge arrester voltage and current for figure B3

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