IEEE Guide for the Application of Surge Protectors Used in Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Data, Communications, and Signaling Circuits

Sponsor

Surge Protective Devices Committee
of the
IEEE Power Engineering Society

Approved 16 September 1999

IEEE-SA Standards Board

Abstract: Assistance is provided for the selection of the most appropriate type of low-voltage data, communications, and/or signalling circuit surge protector for a particular application or set of conditions. Surge protector functions and characteristics are also explained and evaluated. AC power circuit applications are not addressed in this document.
Keywords: breakdown voltage, communications circuits, data circuits, signaling circuits, surge protectors, surge-protective devices

The Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue, New York, NY 10016-5997, USA

Print: ISBN 0-7381-1837-0 SH94801
PDF: ISBN 0-7381-1838-9 SS94801

Introduction

[This introduction is not part of IEEE Std C62.43-1999, IEEE Guide for the Application of Surge Protectors Used in Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Data, Communications, and Signaling Circuits.]

The Low-Voltage Data, Communications, and Signaling Circuits Working Group 3.6.7 had the following membership who contributed to the writing of this document:

Michael Parente, *Chair*

Dennis Algozer
George J. Bagnall
Al Bazarian
Chrys Chrysanthou
Gordon S. Clarke
Michael Danks
Frank DeVoss
David W. Hutchins
Wilhelm H. Kapp
Dave Kerr
Albert R. Martin
E. H. Marrow, Jr.
Robert McBrien
James Pelegris
Alan W. Rebeck
P. Richman
William J. Shannon
Donald B. Turner
Diethard Unterweger
Peter Winch

The application guide Working Group 3.6.3 had the following membership who contributed to the writing of this guide:

Robert J. Davidson, *Chair*

Ernie Gallo
Jim Harrison
Wilhelm H. Kapp
Joseph L. Koepfinger
Benny H. Lee
E. H. Marrow, Jr.
Francois D. Martzloff
Michael J. Maytum
Kurt A. Meindorfer
Richard Odenberg
Hans-Wolfgang Oertel
William J. Shannon
Donald B. Turner

The following members of the balloting committee voted on this standard:

Ernest Baker
John S. Bonnesen
William A. Chisholm
James F. Christensen
Douglas C. Dawson
James Funke
Ernie Gallo
Ernie A. Goodman
Willliam Greason
Phillip Havens
Andrew RobertHileman
David W. Jackson
Wilhelm H. Kapp
Ed Knapp
Joseph L. Koepfinger
Carl E. Lindquist
William A. Maguire
Albert R. Martin
Francois D. Martzloff
Nigel P. McQuin
Daleep C. Mohla
Arun Narang
Richard Odenberg
Hans-Wolfgang Oertel
Joseph C. Osterhout
Michael Parente
Percy E. Pool
Alan W. Rebeck
Thomas J. Rozek
John A. Siemon
Keith B. Stump
Donald B. Turner
Diethard Unterweger
Arnold Vitols
Matthew S. Wakeham
Steve G. Whisenant
James Wilson, Jr.
Jonathan J. Woodworth
Donald M. Worden

When the IEEE-SA Standards Board approved this standard on 16 September 1999, it had the following membership:

Richard J. Holleman, *Chair*
Donald N. Heirman, *Vice Chair*
Judith Gorman, *Secretary*

Satish K. Aggarwal
Dennis Bodson
Mark D. Bowman
James T. Carlo
Gary R. Engmann
Harold E. Epstein
Jay Forster*
Ruben D. Garzon
James H. Gurney
Lowell G. Johnson
Robert J. Kennelly
E. G. “Al” Kiener
Joseph L. Koepfinger*
L. Bruce McClung
Daleep C. Mohla
Robert F. Munzner
Louis-François Pau
Ronald C. Petersen
Gerald H. Peterson
John B. Posey
Gary S. Robinson
Akio Tojo
Hans E. Weinrich
Donald W. Zipse

*Member Emeritus

Also included is the following nonvoting IEEE-SA Standards Board liaison:

Robert E. Hebner

Noelle D. Humenick
IEEE Standards Project Editor

National Electrical Safety Code® and NESC® are both registered trademarks and service marks of the Institute of Electrical and Electronics Engineers, Inc.

National Electrical Code® and NEC® are both registered trademarks of the National Fire Protection Association, Inc.

Contents

IEEE Guide for the Application of Surge Protectors Used in Low-Voltage (Equal to or Less than 1000 V_{rms} or 1200 Vdc) Data, Communications, and Signaling Circuits

1. Scope

This guide provides assistance in selecting the most appropriate type of surge protector for a particular data, communication, and/or signaling circuit application.

This guide is divided into four clauses. Clause 1 provides an overview and the scope of this guide. Clause 2 lists references to other standards. Clause 3 explains the electrical environment in which surge protectors intended for data, communications, and signaling circuits shall operate. Clause 4 gives a description and the theory of the operation of surge protectors used in data, communications, and signaling circuit applications, and also gives guidance in applying and interpreting the respective test specifications for the protector characteristics.

This guide also contains informative Annex A, which supplies examples of applications of surge protectors used in low-voltage data, communications, and signaling circuits. The annex provides additional information for understanding and using this guide, but it is not part of the guide. Annex B contains a bibliography of the references used in developing this guide.

This guide applies to surge protectors used in balanced or unbalanced data, communications and signaling circuits with voltages equal to or less than 1000 V_{rms} or 1200 Vdc. The surge protectors covered are multiple-component series or parallel combinations of linear or nonlinear elements, packaged for the purpose of limiting voltage, current, or both.

This guide is intended to complement IEEE Std C62.36-1994.[1] The definitions used in this application guide and the test methods standard are the same. For terms not defined in the guide or the standard, see *The IEEE Standard Dictionary for Electrical and Electronics Terms*[B3].[2]

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

[2]The numbers in brackets correspond to those of the bibliography in Annex B.

This guide is not intended to apply to packaged single component gas tube or air gap arresters/protectors, which are covered by IEEE Std C62.42-1992.

The purpose of this guide is to enable an understanding and an evaluation of the functions of the various types of multiple-component data, communications, and signaling circuit protectors in terms of particular applications. Consideration is given to the characteristics of multiple-component protectors and the concepts necessary to choose the appropriate product and to interpret its specifications.

2. References

This guide shall be used in conjunction with the following standards and publications. When the following standards and publications are superseded by an approved revision, the revision shall apply.

Accredited Standards Committee C2-1997, National Electrical Safety Code®, NESC®.[3]

ANSI/NFPA 70-1999, National Electrical Code®, NEC®.[4]

IEEE Std C62.36-1994, IEEE Standard Test Methods for Surge Protectors Used in Low-Voltage Data, Communications, and Signaling Circuits.[5]

IEEE Std C62.42-1992 (Reaff 1999), IEEE Guide for the Application of Gas Tube and Air Gap Arrester Low-Voltage (Equal to or Less than 100 V_{rms} or 1200 Vdc) Surge-Protective Devices.

3. Electrical environment

For a description of the electrical environment in which these protectors are intended to be used, refer to Clause 3 of IEEE Std C62.42-1992.

4. Description and theory of operation

This clause provides the description and theory of operation of surge protectors used in low-voltage data, communications, and signaling circuits. These protectors comprise one or more series or parallel elements used to limit excessive voltages, currents, or both, while maintaining the system operation to a given performance level.

These devices are used on electronic equipment where voltage and current surges on the signal line can cause system malfunction or failure. The devices have two distinct states: in the quiescent state they are essentially transparent to the system; in the operated state they provide voltage limiting, current limiting, or both. The devices are operated by the voltage or current surge (i.e., they are self-triggering) and may also self-reset to their quiescent state.

Multiple-component surge protectors may contain voltage limiting devices, which are connected in parallel with the terminals to be protected. They may also contain current limiting devices in series with the protected terminals. Descriptions and theory of operation of certain voltage limiting devices that may be

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

[4]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (http://www.ansi.org/).

[5]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (http://standards.ieee.org/).

used in multiple-component surge protectors are found in IEEE Std C62.42-1992 in subclauses 4.1, 4.2, 4.3, and 4.4. Voltage limiters that are of different technologies from those covered in IEEE Std C62.42-1992, or current limiters that use different technologies from the examples in this guide, may also be used in multiple-component protectors.

4.1 Positive temperature coefficient devices

4.1.1 Description

Positive temperature coefficient (PTC) devices are used in surge protectors to limit excessive current. They consist of two metallic electrodes separated by a material having a resistance versus temperature response similar to that shown in Figure 1. 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 2 illustrates, in a simplified manner, the functional components of a typical PTC device and its circuit symbol.

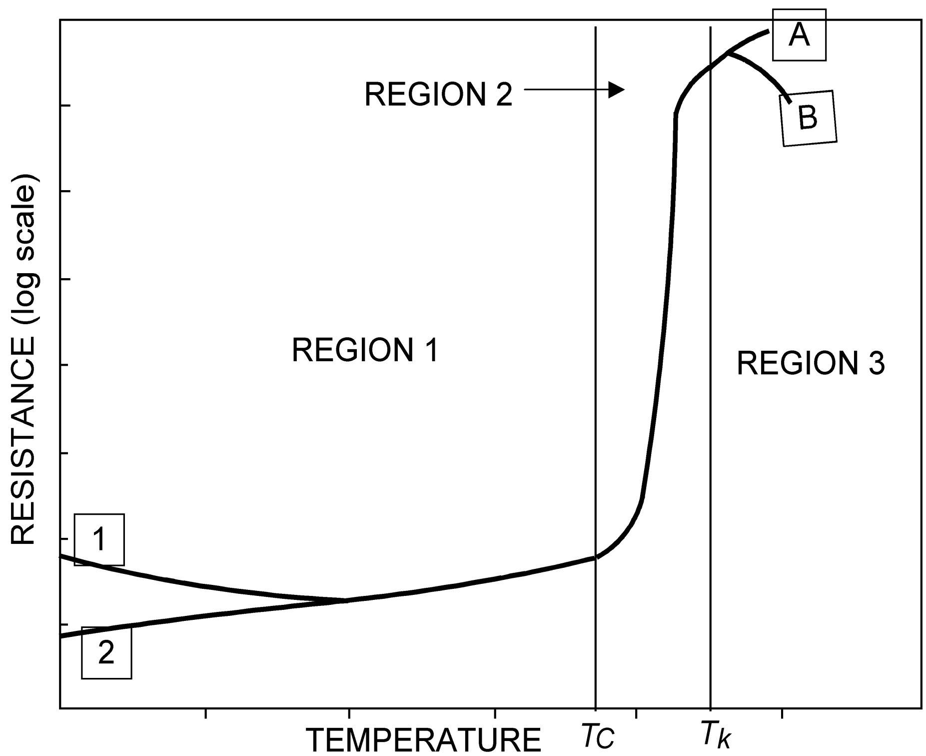


Figure 1—Resistance vs. temperature for a PTC device

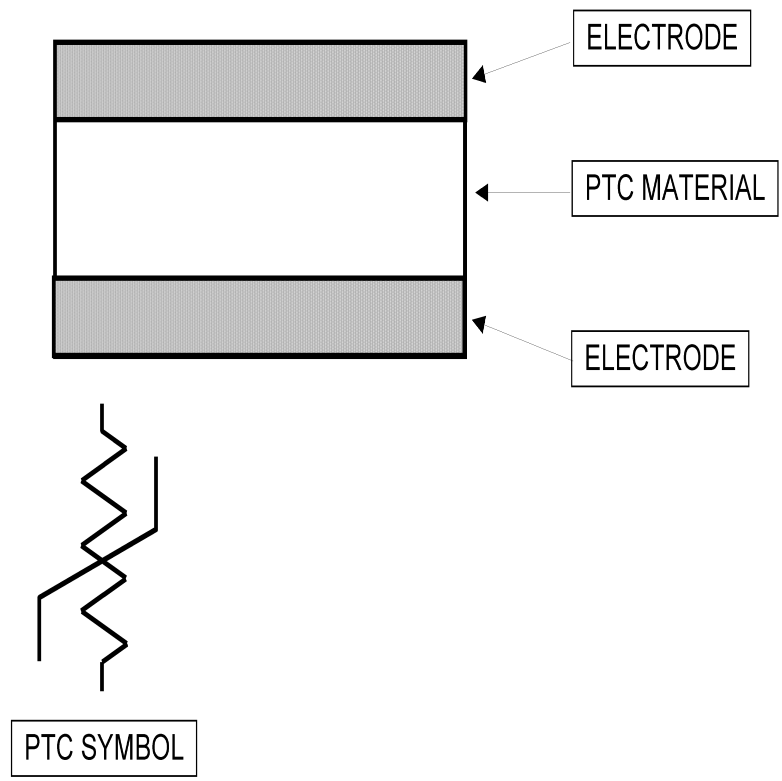


Figure 2—Functional components for PTC devices

4.1.2 Operation

4.1.2.1 Device operation

PTC devices are characterized by a resistance versus temperature plot that has three regions, as illustrated in Figure 1. In region 1, the device temperature is below a critical temperature T_C, and its resistance is low. In this region, the resistance has a negative temperature coefficient (NTC) characteristic if the device is ceramic (curve 1), or a PTC characteristic if the device is made from a conductive polymer (curve 2). This low resistance is called the base resistance. In region 2, the device temperature is above the critical temperature but below the upper knee temperature T_k. In this region, the resistance increases exponentially with temperature. In region 3, the device temperature is above T_k. In this region, the coefficient of resistance may remain positive and resistance continues to increase with temperature (curve A), or the coefficient may become negative and resistance decreases with temperature (curve B). Curve A is characteristic of conductive polymer devices that have been cross-linked. Curve B is characteristic of ceramic PTC devices and conductive polymer devices that have not been cross-linked.

4.1.2.2 Operation in a circuit

In a typical application, the PTC device is connected in series with a load. When current is conducted, I^2R losses increase device temperature (device power generated curve, Figure 3). At the same time, heat is lost from the device by radiation and conduction (power lost to ambient curve, Figure 3). The temperature stabilizes at a level where power dissipated in the device is balanced by heat lost from the device by radiation and conduction. The device power generated curve in Figure 3 is relatively flat with temperature, until I^2R heating causes the device resistance to enter region 2 (Figure 1), where a slight increase in temperature causes the resistance to increase greatly. The peak in the device power generated curve (P_m in Figure 3) occurs when the resistance of the PTC device equals the Thevenin equivalent source resistance of the circuit containing the PTC device. The power lost to ambient line is approximated by the linear relation

$$H_d = k(T_d - T_A)$$

where

H_d is the heat dissipated (W),
T_d is the temperature of the device (°C),
T_A is the ambient temperature (°C),
k is a dissipation constant for the device (W/°C).

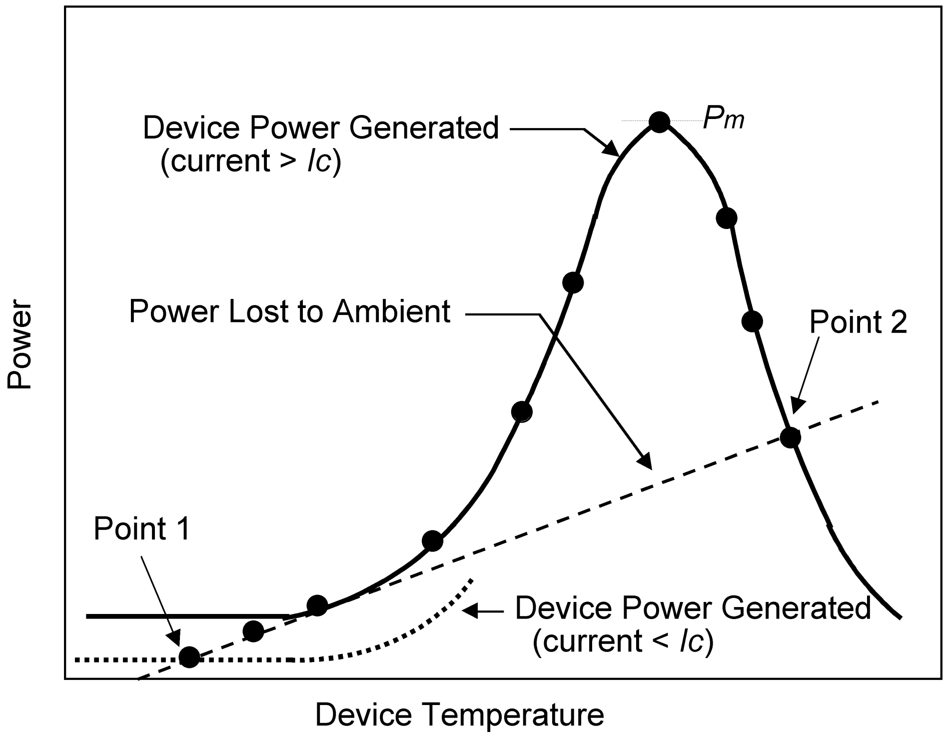


Figure 3—Power generated in the device and power lost by the device to ambient, as a function of temperature

4.1.2.3 Normal operation (rated current)

In normal operation, the PTC device is in its low, or base, resistance state. The base resistance is generally much less than the series load resistance. If, when power is applied, the current through the device is less than a critical value called the rated current (I_c), the power generated curve lies below the power lost to ambient line, and the device stabilizes at a temperature only slightly above ambient (Point 1 in Figure 3).

4.1.2.4 Tripping action (transition current)

When a current in excess of I_c is conducted, heat is generated faster than it is dissipated. In this case, the device power generated curve lies above the power lost to ambient line, and the device temperature can stabilize only at a relatively high level (Point 2 in Figure 3). At this high temperature, the device resistance is much higher than that of a normal load, so the current through the load is reduced to a value much lower than normal. This action, called tripping, protects the load from damage caused by overcurrent. The minimum current at which tripping occurs is called the transition current. The path followed by power generated in the device as current is increased is shown by the large dots in Figure 3. Note that increasing the ambient temperature lowers the power lost to ambient line. Since the device trips when the power generated in the device exceeds the power dissipated, and the device power lost to ambient is lower at higher temperature, less power needs to be generated in the device to cause tripping (curves labeled Ta' in Figure 4). The equilibrium point after tripping at the higher temperature is Point 2. A PTC device will, therefore, trip when the ambient temperature is raised to the point where the power lost to ambient line falls just below the device power generated curve. For this reason, PTC devices are sometimes mounted directly on a load to limit the temperature rise of that load.

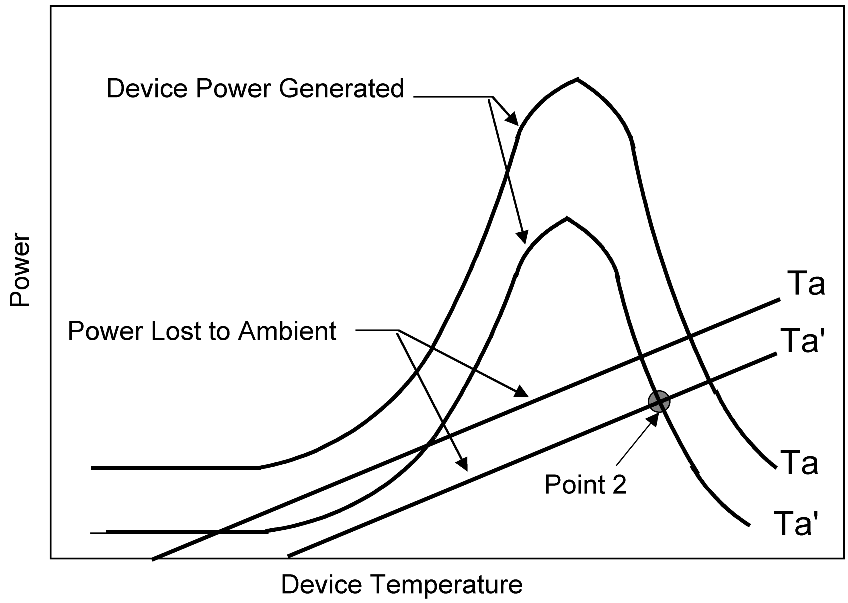


Figure 4—Power generated in the device and power lost by the device to ambient, as a function of temperature. Ta and Ta' are ambient temperatures where Ta' > Ta

4.1.2.5 Current response time

The response time of a PTC device is proportional to the difference between the rate at which heat is generated in the device and the rate at which it is dissipated. Response time can range from thousands of seconds to a few milliseconds, as the current conducted by the device is increased from slightly above I_c (heat generated is only slightly in excess of heat dissipated). Ordinarily, this delay time prevents PTC devices from tripping as a result of brief overloads.

4.1.2.6 Reset

Whether tripped by high current or by high ambient temperature, a tripped PTC device generally remains latched in a high resistance state as long as source power is maintained. Thus, for reset, power is usually removed from the device, and the device is allowed to return to its base resistance region. The exception to this rule occurs when the power generated in the device is always less than the peak of the device power generated curve (P_m in Figure 3). In this case, the PTC device will automatically reset after a transient tripping condition, such as a short circuit across the load. Since the reset time and current level of PTC devices are dependent on temperature, conditions such as mounting, airflow, and packaging, which affect the temperature of the device, should be considered.

4.1.3 Application considerations

In applications that use several protectors mounted adjacent to one other, particularly telecommunications line protection, the upper limit to the current that PTC devices can carry is established while all PTC devices are conducting rated current, and are subjected to the highest ambient temperature caused by nearby heat-generating components. This test is especially necessary if service is provided by a current loop, with PTC devices connected serially in both conductors (source and return, or *tip* and *ring*) of the loop. Since the PTC devices are connected in series, they both are energized during this test, and both generate heat. If the PTC devices are in close proximity, the ambient temperature near the devices rises higher and faster than if only one of the devices is energized. The resulting higher ambient temperature should be taken into account to ensure the PTC devices do not trip during normal service.

In addition to verifying that PTC devices carry the rated current of the circuit without tripping, it is necessary to verify that each PTC device in a multiple PTC protector trips during a fault condition when only that device is activated and no nearby heat sources are present.

Those applications requiring multiple PTC devices sometimes also require a certain similarity in PTC device resistance (i.e., balance), so as to reduce the amount of noise generated in the equipment in the presence of common-mode signals, such as those induced by ac power lines. A large PTC resistance imbalance may result in a significant and undesirable potential difference across the equipment, which can interfere with the equipment's normal operation.

PTC devices are typically used in combination with overvoltage protection devices to protect equipment against those overcurrents that do not activate the overvoltage devices. (These low-voltage overcurrents are sometimes called *sneak* currents.) The overvoltage protection devices are usually located in the circuit between the PTC devices and the source of the surge. In that position, they protect the load from overvoltages and also limit surges to less than the rated voltage of the PTC devices for surges that last long enough to operate the PTC devices.

Finally, since PTC devices are usually placed in series with the load, they introduce signal loss into the circuit. If their resistance is too high compared to the load resistance, this loss may become unacceptable.

4.2 Bimetallic devices

4.2.1 Description

A protection device using a bimetallic sensing element can be activated by current, temperature, or a combination of both. The device is placed in series or in parallel with the line. The contacts allow current to flow to the equipment until excess current or external temperatures heat the bimetallic sensing element to the trip point. This activates the contact and opens, or grounds, the line, removing power from the equipment. As the bimetal cools down, automatic reset occurs when the temperature reaches the reset point. Manual reset can be achieved through mechanical means.

4.2.2 Theory of operation

The sensing element of a bimetallic device consists of a composite material made up of two or more metallic layers with different coefficients of thermal expansion. When subjected to an increase in temperature, the high expansion side will be under compression while the low expansion side is under tension. These forces produce a moment that causes the element to bend. This action, which, based on the design, can be a creep action or a snap-action device, opens or closes a contact that controls current flow. Creep-action devices, which have a slow make or break, are generally acceptable for low-voltage (< 24V) applications while snap-action devices can be used up to 600 V and 250 A. Heating of the bimetallic element can be achieved by an external heat source as well as through ohmic heating. Bimetallic elements can be made in a wide range of electrical resistance and physical configurations such that actuating currents from milliamperes to hundreds of amperes can be obtained. Because of the mass and physical movement required, the response time as well as cycle life cannot approach the performance of semiconductors. However, the fact that the bimetallic element is both the sensing element and the actuating element can make it a low-cost alternative for many applications.

4.2.3 Application considerations

Performance of a bimetallic device is affected by the ambient temperature. At a given current, a device trips sooner at high ambients and takes longer to trip at low ambients. These changes in trip time must be considered in the final application.

There are typically three methods to connect a bimetallic device into a protection circuit, as follows:

a) The bimetallic device is connected, in series, with the current loop. Excess current in the loop causes ohmic heating and actuating of the device, which opens the current loop. As the bimetal cools, it automatically resets, unless equipped with a manual reset device.
b) The bimetallic device is thermally coupled to a heating element that is in the current loop. Excess current in the loop generates heat in the heater, which actuates the device. The bimetallic device may or may not reset automatically.
c) Both heater and bimetallic device are in the current loop. Excess current causes ohmic heating of the bimetal as well as generating heat in the heater to actuate the device. This combination typically results in the fastest trip time and is also used for low-current applications. This type of device is sometimes referred to as a combination device. As the bimetallic device cools, it automatically resets, unless equipped with a manual reset mechanism.

Overvoltage protection devices are usually located in the circuit between the source of the surge and the bimetallic devices. In that position, they protect the load from overvoltages and also limit surges to less than the voltage rating of the bimetallic device.

Since all three methods employ contacts that open, or short, the protection circuit, a voltage and current interrupting-and-making capability is assigned to each device. This voltage value must exceed the voltage limiting level of the overvoltage protection device. Care must be taken to ensure that the current interrupting-and-making capability of the bimetallic device contacts are not exceeded. These considerations are especially important if dc is to be interrupted because possible arcing is not extinguished by a periodic zero crossing of current, as in ac applications.

In some applications using *combination devices*, the rated current of multiple devices is verified while all the devices are conducting the specified current. Simultaneously, energizing devices in close proximity to one other raise the temperature near the devices faster and higher than if only one of the devices is energized. The resultant higher ambient temperature should be taken into account so that the devices do not interfere with normal service by operating.

However, the transition current of combination devices is measured while only one device in the protector is energized. This is done to ensure that even the last unoperated device is able to operate by itself.

Those applications requiring multiple combination devices sometimes also require a certain similarity in resistance (i.e., balance), so as to reduce the amount of noise generated in the equipment during the presence of common-mode signals, such as those induced by ac power lines. A large imbalance may result in a significant and undesirable potential difference across the equipment, which can interfere with the equipment's normal operation.

Finally, combination devices are usually placed in series with the load, so they introduce signal loss into the circuit. If their resistance is too high compared to the load resistance, this loss may become unacceptable.

4.3 Heat coils

4.3.1 Description

A heat coil is a device used to protect equipment from sustained overcurrent conditions. Heat coils are usually placed in series with the equipment, so as to sense the level of current passing through the equipment. A heat coil normally releases a shorting mechanism when the current exceeds a predetermined level, as opposed to a fuse, which open-circuits when excess current is conducted. However, large currents can cause the heat coil to open-circuit like a fuse, and the shorting mechanism may or may not be released. Although manually resettable heat coils are available, a typical heat coil can operate only once, and has to be replaced after activation.

Heat coils are typically constructed by winding a length of high resistance (heater) wire around a solder joint that holds a metallic tube to a metallic pin. In addition, this soldered assembly compresses a separate spring mechanism. Each end of the heater wire is connected (usually welded) to appropriate locations inside a protector such that normal operating currents and abnormal overcurrents pass though the wire itself. The melt temperature of the solder is selected by design to meet the rated current (non-operate) and transition current (operate) specification requirements, as determined by the application. In selecting the melting temperature of the solder, consideration is also given to choosing a melting temperature low enough to prevent overheating of the plastic parts used in protectors, if such overheating would otherwise result from sustained overcurrents.

4.3.2 Theory of operation

Overcurrents of sufficient magnitude and duration cause the high resistance (heater) wire to melt the solder joint. Typically, this releases the compressed spring mechanism, which pushes the metal tube along the length of the pin until the tube makes contact with a third conductor, usually at ground potential. This action diverts the overcurrent away from the equipment, thereby protecting the equipment from the overcurrent.

Heat coils are characterized by three basic parameters: resistance, rated current, and transition current. The resistance of the heater wire, the melting temperature of the solder, the surface area of the solder joint, the volume of the solder, and the mass of the metallic tube and pin determine the performance of the heat coil. In general, the rated current and the transition current of a heat coil are inversely proportional to the heat coil's resistance, as is seen by the descriptions of three types of frequently used heat coils listed in Table 1.

Table 1—Typical heat coil ratings (20 °C)

Resistance	3-hour rated current	210-second transition current
21 Ω max.	150 mA	250 mA
4 Ω max.	350 mA	540 mA
0.4 Ω max.	1.200 A	1.875 A

A heat coil is designed such that it does not activate at current levels at, or below, the rated current. A duration of 3 h typically is used to approximate the condition of continuous current and temperature stabilization. The transition current is the current level needed to release the shorting mechanism within the specified time period.

4.3.3 Application considerations

A heat coil's performance is affected by the ambient temperature. Higher ambient temperatures make it easier for the solder to melt, so that both the rated current and transition current of the heat coil decrease as the ambient temperature rises.

Conversely, lower ambient temperatures increase a heat coil's rated current and transition currents. In addition, the resistance of the heater wire changes slightly with temperature, usually having a positive temperature coefficient (i.e., the resistance increases as temperature increases). The three key heat-coil parameters should be evaluated at the temperature extremes appropriate for the application.

In some applications, particularly telecommunications line protection, the rated current of multiple heat coil protectors is verified while all the heat coils are conducting the specified current. This is done because telecommunications service is provided by a current loop, with heat coils connected serially in both conductors (source and return, or tip and ring) of the loop. The heat coils each conduct the same level of current at the same time. Simultaneously, energized heat coils in close proximity to one other, or to other nearby heat-generating components, raise the temperature near the heat coils faster and higher than if only one of the devices is energized. The resultant higher ambient temperature should be taken into account so that the heat coils do not interfere with normal service by tripping.

However, the transition current of a multiple heat coil protector is measured while only one heat coil in the protector is energized. This is done to ensure that even the last heat coil to trip its shorting mechanism has the capability of melting the solder joint by itself. Once the other heat coils have tripped, they no longer generate heat, so the last untripped heat coil should provide enough heat on its own to melt the solder.

Those applications requiring multiple heat coils sometimes also require a certain similarity in heat coil resistance (i.e., balance), so as to reduce the amount of noise generated in the equipment during the presence of common-mode signals, such as those induced by ac power lines. A large heat coil resistance imbalance may result in a significant and undesirable potential difference across the equipment, which can interfere with the equipment's normal operation.

Since heat coils are usually placed in series with the load, they introduce signal loss into the circuit. If the resistance of the heat coils is too high compared to the load resistance, this loss may become unacceptable. In addition, the tightly-packed windings of the heat coil's heater wire give the heat coil some self-inductance. Therefore, the signal loss introduced by a heat coil will be larger at higher frequencies.

Heat coils are typically used in combination with overvoltage protection devices to protect equipment against those overcurrents that do not activate the overvoltage devices. (These low-voltage overcurrents are sometimes called sneak currents). The overvoltage protection devices are usually located in the circuit between the source of the surge and the heat coils. In that position, they protect the load from overvoltages. They also limit overvoltages to within the voltage capability of the heat coils in the case where an overcurrent condition causes the heat coils to become open circuited. Heat coils are available for placement by themselves, or they can be placed in the same housing with the overvoltage protection device(s).

4.4 Fuses

A fuse functions as an intentional weak link in a circuit, intended to safely open the circuit in response to a sustained overload current or short-circuit current condition.

In a common configuration, the fuse is in series with the line that is protected by a voltage limiter. When the voltage limiting device functions to limit an overvoltage, it typically diverts current to ground, causing that current to be conducted by the fuse.

For overvoltages caused by lightning, the fuse is designed to withstand the predetermined impulse current waveform, without opening or permanently changing resistance. However, for sustained overvoltages caused by a power line contact to a communication line, or by induction, the fuse should operate (open) before damage occurs to the voltage limiter, which remains shorted under constant overvoltage conditions, or other circuit components. In this case, the fuse should be capable of operating at voltages and currents up to the maximum values encountered in the application.

The fuse element melts and breaks because of the sustained overcurrent. The fuse should be designed to extinguish the arc and permanently clear (or open) the circuit, while containing the energy of the discharge.

4.5 Multiple-component surge protectors

Numerous combinations of series and parallel components can be contained in surge protectors and a comprehensive characterization is too complex to describe completely in this document. Therefore, several examples of these combinations are given in the following paragraphs to describe these protectors and to illustrate how internal component interactions occur. This information is organized according to the six basic configurations defined in IEEE Std C62.36-1994. (These configurations are repeated as Figure 5 of this guide.)

Some of the description and theory of operation discussed in 4.5 is common to many or all of the various configurations to follow.

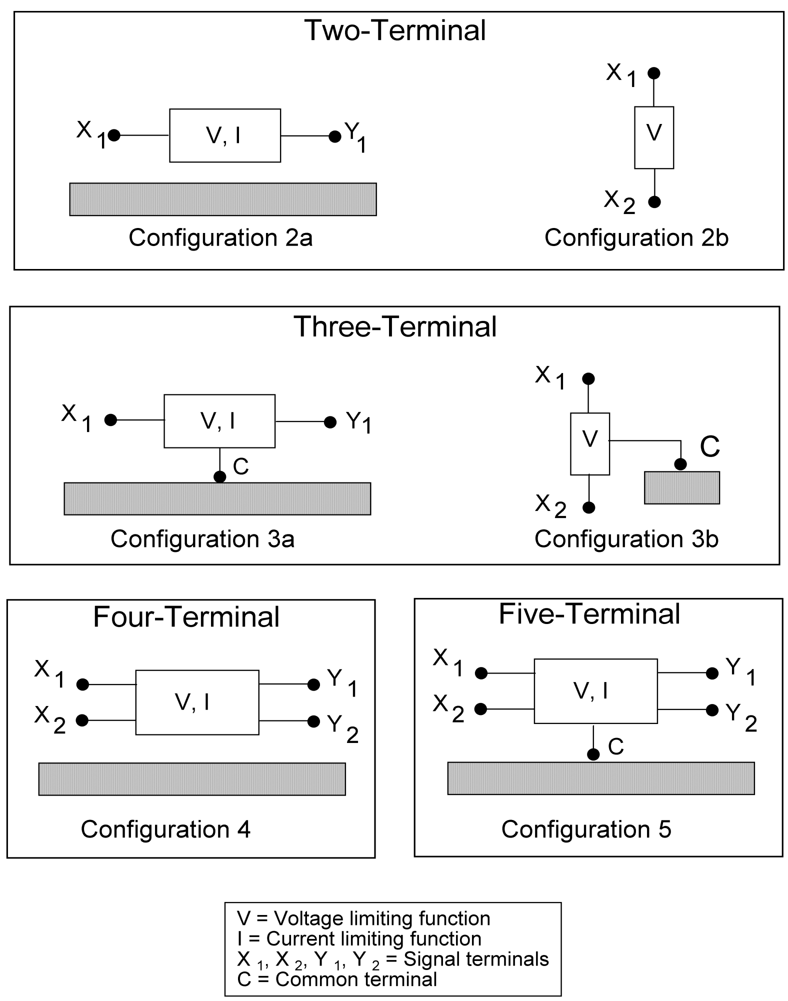


Figure 5—Basic configurations

4.5.1 General description

Each of the overvoltage (V) or overcurrent (I) protector elements contained in the basic protector configurations may be a single component (also called a surge-protective device), or it may consist of a pair of parallel or series components for redundant, additive, or backup protection features.

Examples of the overvoltage protection element are:

a) An air gap
b) A gas tube
c) A solid state device
d) A combination of these

Examples of the overcurrent protection element are:

a) A fuse
b) A positive-temperature-coefficient resistor
c) A circuit breaker
d) A heat coil
e) A semiconductor
f) A combination of these

For signal and data line applications, the voltage limiting device should present a high resistance across the protected elements. The rated voltage should be greater than any voltages on the line during normal operation. Examples of such voltages are the dc supply voltage plus the peak of any superimposed signaling or ringing voltage.

Selection of the voltage limiting component with regard to current handling is determined by the nature of the surges likely to be encountered. If application of the protector is in a high lightning area, impulse life is an important factor. For exposure to contacts with ac power lines, or induction from nearby ac power lines, the alternating current life is important.

The protector elements and their interconnections are usually contained in a plastic or metallic housing, although they may also be openly mounted on a circuit board or other substrate. Electrical connections to the network and equipment to be protected may include screw terminals, lugs, pins, card-edge connectors, spring loaded leaf or button contacts, insulation displacement terminals, or other means.

4.5.2 General theory of operation

The purpose of having the overcurrent or overvoltage element consist of two separate or integral components in parallel may be to provide redundant, additive, or backup protection.

For redundant protection, both components may be expected to be equally capable of performing the primary protection function. For example, two paralleled gas tubes should have approximately the same breakdown and energy-handling characteristics such that if one failed to operate (high-breakdown voltage), the other would take over the protective function completely. On the other hand, if one degraded in a low breakdown voltage mode, it would very likely continue to handle the overvoltage surges and the other redundant gas tube may not operate.

For additive protection, both devices are needed in order to meet the total protection requirement. Each device may be addressing a different function or fault.

For backup protection, the two devices may be designed to operate at different overcurrent or overvoltage levels. The normal operating function for the primary device is to suppress an overcurrent or overvoltage condition at a predetermined level below the operating range of the secondary device. In the event of a malfunction (high-breakdown voltage or high-current interrupt level) of the primary device, the secondary device is intended to operate at a coordinated higher current or voltage. The secondary device is deliberately set to a higher level so that it does not interfere with the operation of the lower current or voltage primary device.

4.5.3 Two-terminal basic configuration

A two-terminal multi component overcurrent protector, such as depicted by configuration 2a (Figure 5), may consist of two overcurrent components mounted in series within a common enclosure.

A two-terminal multi component overvoltage protector, such as depicted by configuration 2b (Figure 5), may consist of two separate overvoltage components mounted in parallel within a common enclosure.

4.5.4 Three-terminal basic configuration

For single-conductor signal lines that have a common ground, the configuration of overvoltage and overcurrent protectors may be as shown in configurations 3a1, 3a2, 3a3 or 3a4 of Figure 6. The components included in the protector may consist of two or more overvoltage protector components connected in parallel with one other, as well as overcurrent-protector components as shown, mounted within a common enclosure.

Configurations 3a1 and 3a2 depict nonsymmetrical protector component arrangements wherein the applied surge encounters the overvoltage component either before or after the overcurrent component. The application defines which side of the protector is to receive the surge and which side is to be connected to the protected equipment.

Configurations 3a3 and 3a4 depict symmetrical protector component arrangements wherein the protector is designed to handle surges entering from either X or Y terminals. If the 3a3 and 3a4 configuration protectors are intended to have fully symmetrical capabilities (i.e., if they are designed to handle the same surge energy at each terminal irrespective of how they are connected to the system or equipment to be protected), then all the protection components may be of the same type and have the same energy ratings. If, on the other hand, the protector is to be applied in a nonsymmetrical situation where the expected surges imposed on the Y terminal are of much lower energy content than those expected at the X terminal, then the corresponding protection components might be of much different types and energy ratings. In this latter case, the overcurrent components might also include an impedance to ensure that the primary or higher energy overvoltage component operates on surges having more current flowing through the overcurrent component than the secondary overvoltage component can handle (configuration 3a4).

For two-conductor signal lines that have a common terminal, the configuration of overvoltage protectors may be as shown in configurations 3b1, 3b2, and 3b3 of Figure 7. The components included in the protector may consist of two or more overvoltage components connected in parallel with one other and mounted within a common enclosure. In configuration 3b1, the components are connected between each signal line and common. In configuration 3b2, components are connected between each signal line and common and another component is connected between the two signal lines. In configuration 3b3, a single three-terminal component is shown.

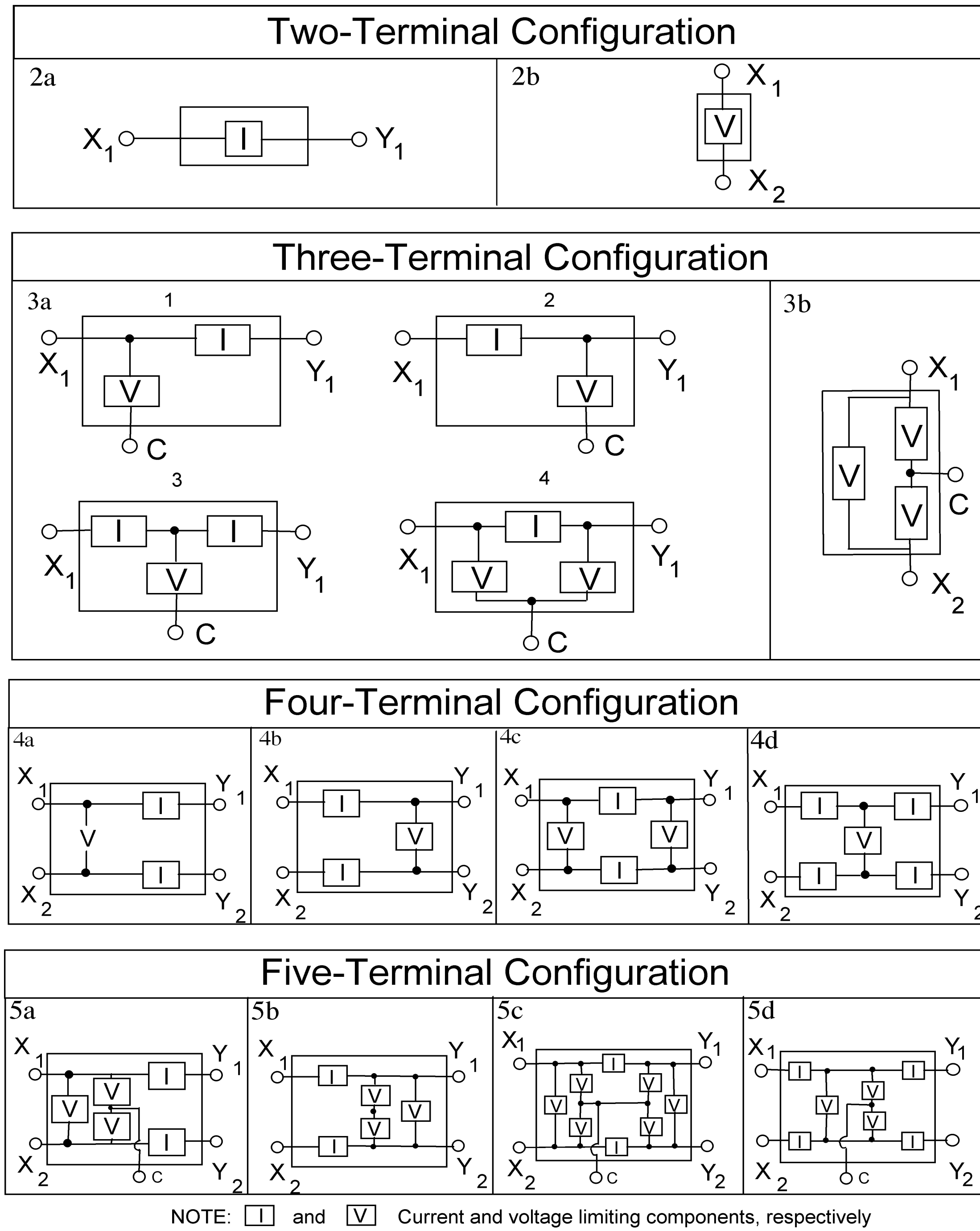


Figure 6—Possible internal arrangement of protector components

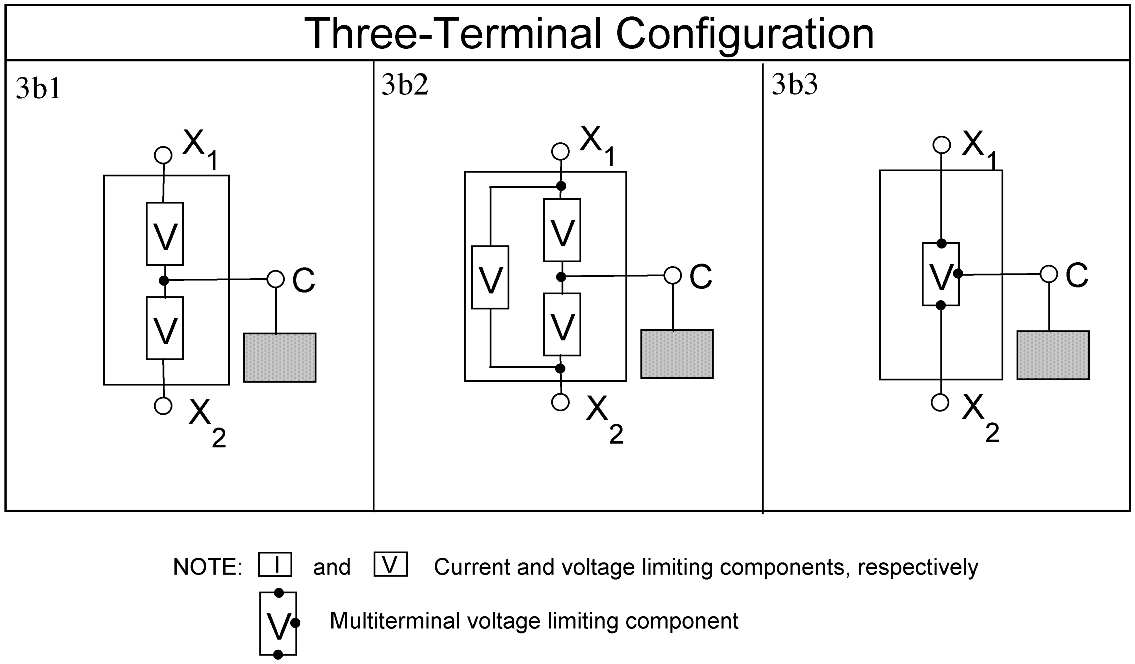


Figure 7—Detail of configuration 3b

The configurations of 3b2 and 3b3 may be used to minimize the differential voltages caused by operation of the protection component. The components may be three-element gas tubes or three-terminal solid-state components. Circuits that include gas tubes may include shunt overvoltage air gaps for backup protection against venting. When three-terminal solid-state components are used, these may consist of either two or three solid-state chips that may be selected for matched conditions and molded in one package. Because of the dominant short-circuit failure mode of solid-state components, the backup-type components used with gas tubes are not needed, normally.

4.5.5 Three-terminal theory of operation

Configuration 3a protectors of Figure 6 limit common mode overvoltage and overcurrent surges. Configuration 3a1 opens the line to surge currents conducted by the protector, but will maintain overvoltage protection at the X terminal. Configuration 3a2 opens the line to surge currents conducted by the protector and isolates the overvoltage component from further surge activity at the X terminal. In either case, the overcurrent component can be designed to limit surge currents driven by voltages too low in magnitude to operate the overvoltage component.

Configuration 3a3 requires that a surge be conducted by an overcurrent protective component before it appears at the overvoltage component, regardless of which terminal is surged. The overcurrent components may be selected so that the protector opens the line being surged and the overvoltage component is isolated from further surges on that line. The other overcurrent component may or may not isolate the overvoltage component from the opposite line.

In configuration 3a4 if the overcurrent protector components open the line, any high voltage present on either side of the protector is shunted to ground by the overvoltage protector component. The overvoltage components may have equal performance ratings for fully symmetrical applications, or they may be different components selected for additive or backup protection features in non-symmetrical applications.

The overvoltage protectors of configuration 3b1 (Figure 7) limit the common-mode voltage (longitudinal voltage) to a low level and will also limit the normal mode (differential mode). However, the maximum differential voltage could be as large as twice the common mode. This would occur when the two-conductor signal lines carry transient voltages of opposing polarity. If the components used have breakdown values that are nearly equal, for coincidental voltage surges on both signal lines, the differential voltage generated at the output terminals is minimal. If large differences exist in breakdown levels, the resulting overvoltage imposed on the load may be significant.

The three-terminal protector of configuration 3b3 provides protection for both signal lines within one component. The effect of a surge on one line is to ground that line, or to provide a low resistance path to ground, and to enhance the breakdown of the other line almost simultaneously, thereby minimizing the differential voltage.

The functional interaction of the primary overvoltage component with a backup component is determined by the application. Some voltage limiters should never short the line for longer than the duration of the surge, since to do so would cause an unacceptable malfunction of the signaling system. For telephone network equipment, shorting of the lines is permitted since a temporary shorted condition is acceptable. The protector continues to provide protection until manual restoration is completed. The short-circuit failure mode may be inherent in the primary component, or may be obtained by the mechanical action of a secondary component such as a heat coil.

If a gas tube loses its hermetic seal or if a solid-state component fails open because of excessive stress, a parallel backup component may be used with voltage limiting above the limits of the primary protector. The backup component for these applications should be designed to have a minimum operating level that is above the maximum breakover condition exhibited by the primary component at all expected voltage rates-of-rise.

4.5.6 Four-terminal basic configuration

The four-terminal protector configuration (Figure 5) may provide overvoltage protection for differential fault conditions. Its primary function is to provide series overcurrent protection in the form of a series-connected current limiting device.

In the case of a four-terminal protector, the overvoltage or overcurrent components are designed to protect a two-wire system and the protector does not have a common connection. As shown in configuration 4a of Figure 6, a current-interrupting device or current limiting device is connected in each conductor of a two-wire circuit.

This current limiting function may be supplemented with an overvoltage component, as shown in configuration 4b of Figure 6, that is electrically connected between the two conductors of the circuit. Redundant, additive, or back-up overcurrent components may be added in series on the output side of the overvoltage component, as shown in configuration 4c and 4d.

4.5.7 Four-terminal theory of operation

The overcurrent protector of configuration 4a of Figure 6 limits abnormal currents in a load in the event of a differential overvoltage condition that has occurred at or within the load. The level of overcurrent protection depends on coordination of a current limiting component and the abnormal current tolerance of the load.

In the case of a differential fault, abnormal current flows through either side of the circuit, connected load, and opposite side. This condition can be controlled by one current limiting component. In the case of a longitudinal fault seeking common through the load, the overcurrent component located in the conductor, experiencing the fault, limits the abnormal current without affecting the condition of the overcurrent component in the opposite line. A longitudinal fault has no effect on an overvoltage protector (configuration 4b) since the overvoltage protector has no connection to common.

Configuration 4b shows the addition of an overvoltage component in parallel with the load to limit overvoltage conditions.

When conduction of the overvoltage component occurs in configuration 4c, excessive current is shunted through the overvoltage component and away from the load. At the same time, the overvoltage condition is distributed along the incoming conductor impedance where the energy is dissipated. In the event of a sustained overcurrent condition, the overcurrent component switches to a current limiting mode when its current rating is exceeded.

Configuration 4d shows two additional overcurrent components for the purpose of redundancy, additive, or back-up features.

4.5.8 Five-terminal basic configuration

Configuration 5a of Figure 6, which is sometimes used as a telephone central office or remote switch protector (but which has other applications as well), has two overvoltage protector elements: one connected between each line and common; and also has two overcurrent protector elements: one connected in series with each line and placed on the protected-equipment side of the overvoltage components. A separate overvoltage protector component may also be connected between the lines for differential overvoltage protection.

Configuration, 5b of Figure 6, which is sometimes used as a telephone station secondary protector (but which has other applications as well), has two overvoltage protector components: one connected between each line and the common terminal, and also has two overcurrent protector components, one connected in series with each line and placed on the surge input side of the overvoltage components. A separate overvoltage protector component may also be connected between the lines for differential overvoltage protection.

Configuration 5c is a six-component protector (or, alternatively, has eight components if X terminal and Y terminal line-to-line overvoltage components are included). Four overvoltage components connect between the four-line terminals and common or ground. Two overcurrent components connect between respective X-line and Y-line terminals, and they separate the overvoltage function components.

If differential overvoltage components are incorporated in the protector, they are connected line-to-line across the X-pair and the Y-pair terminals.

If the configuration 5c protector is intended to have symmetrical capabilities and handle the same surge energy, irrespective of terminal connection, then all the line-to-ground overvoltage components may be of the same type and have the same energy ratings. If the protector is to be applied in non-symmetrical situations because of different surge magnitudes imposed on different terminals, then the overvoltage components for the different terminals may be of different types and energy ratings.

In this latter case, the overcurrent component may also include an impedance to ensure the operation of the overvoltage component. The impedance limits the current conducted by the second overvoltage component and enhances the operation of the first overvoltage component by restoring the voltage across its terminals.

In configuration 5d overvoltage components are each connected between one line and common. Both the first and second overcurrent components typically have a complementary component in the opposite line.

The six components may be mounted within a common enclosure, or they may be configured into modules that plug into one other to form the complete protection package.

4.5.9 FIve-terminal theory of operation

Protectors of this type are intended to interrupt abnormal currents through the lines, which might otherwise damage the protected equipment. The current limiting component should operate before the service wiring or equipment is damaged. Some protectors use a fusible link of wire of finer gauge, having faster fusing characteristics than that of the protected service wire, and the protector is thus said to be coordinated with the wiring.

Overcurrent protection components are selected such that they minimize series resistance and provide adequate overcurrent sensitivity for the application. Shunting-type overcurrent components, such as heat coils or some solid-state limiters, should have sufficient current-carrying ability to shunt the overcurrent that the network can deliver.

If the overcurrent protection component is a fuse, fusible link, or nonresettable heat coil, it or the overall protector will have to be replaced to restore service. If a resettable overcurrent element is used, the service may be restored manually or automatically reset after the overcurrent event has passed. In some cases, sufficient time should be allowed for the protector to cool.

Protectors of this type are also intended to shunt overvoltage surges appearing on lines X_1, X_2, Y_1, and Y_2 to the common reference terminal.

In the event of differential overvoltages appearing at the protector terminals because of unbalanced surges or the operation of only one of the line-to-common overvoltage components, the optional line-to-line overvoltage component provides additional surge protection to the equipment connected to the Y terminals.

If the line-to-line component is designed to limit at a voltage lower than the line-to-common components, it may then operate to protect the equipment from abnormally high differential voltages before the second line-to-common component operates.

Overvoltage component operation, if sustained by a power line contact or similar event, may cause sufficient current to pass through the overcurrent component to cause it to operate. Such intercomponent coordination is designed to prevent damage to the multielement protector.

In the case of configuration 5b, and possibly 5d, it should be noted that if the overcurrent protector components open the line, any high voltage present on the X_1 and X_2 terminals of the protector will remain on the line or the energy will be dissipated by other protectors or impedances of the network. Depending on the application, this condition may or may not be desirable.

In the case of configuration 5a or 5c, if the overcurrent protector components open the line, any high voltage present on the X_1 and X_2 terminal side of the protector will be shunted to ground by the overvoltage protector component.

Some multi component protectors use a thermal overload feature to prevent damage or a fire hazard from excess heat. Sustained overvoltages applied to the network cause the overvoltage component (air gap, gas tube, or solid-state component) to operate and heat. The excess heat is thermally coupled to a mechanical, metallic alloy, or plastic component that melts or operates and allows electrical contacts to close. These contacts then bypass the overvoltage component and connect the lines to common.

Operation of an overvoltage component, if sustained by a power line contact or similar event, may generate sufficient heat in that component to cause the overcurrent component to operate if the latter is thermally coupled to the overvoltage component. For example, if a sustained overvoltage condition is applied to the circuit, the air gap, gas tube, or solid-state overvoltage component will operate and overheat, melting the solder of the heat coil. The heat coil's spring-loaded action then closes a switch that short-circuits the overvoltage component, connecting line to common. The protector then cools to a safe temperature, dissipating the power caused only by contact resistances.

4.6 Protector characteristics: nonsurge performance tests

This subclause gives guidance on the application of the nonsurge performance tests for surge protectors used in low-voltage data, communications, and signaling circuits. The protector is part of a circuit that it should not affect under normal operating conditions; the nonsurge performance tests are intended to help determine that the effect on the circuit is insignificant. The nonsurge performance tests may be used for initial characterization of protectors, and they also may form the basis for assessing a surge protector for damage after the active performance tests from IEEE Std C62.36-1994 have been performed. Before using this subclause, it is important to have an appreciation of the normal operating conditions of the application.

4.6.1 Rated voltage test

For a given application, under normal operating conditions, the maximum operating voltage applied to a protector should be identified, and system performance should not be affected by the use of the surge protector at this maximum voltage. The rated voltage test is applicable when overvoltage (shunt) protection is employed between terminals of a signaling circuit, where excessive leakage current in the protector may affect circuit performance. An example is a telecommunication application where the ringing voltage used for signaling exceeds the voltage used during transmission of data. A surge protector that performs satisfactorily under transmission conditions, may limit or distort the higher ringing voltage. When specifying the maximum voltage across the protector during the ringing interval, any extraneous voltages (e.g., induction from power lines) should be considered.

4.6.2 Rated current test

The rated current should be marked on the protector, or as specified by the application.

While carrying continuous current under normal operating conditions, a surge protector should not

a) Degrade normal circuit functions.
b) Generate temperatures that are excessive for any component in the protector or for any materials in proximity to the protector.

If used at currents that are above the rated current, series overcurrent devices may overheat under continuous current conditions causing degradation of circuit functions (e.g., high impedance, open fuse, tripped PTC) or excessive temperatures on insulating materials.

4.6.3 DC series resistance test

For an application where the surge protector provides overcurrent protection or only provides a through-link function, this test gives a measure of its series resistance. This test is applicable if the type of protector used introduces a resistance in series with the line. The dc series resistance is measured using a continuous current having a value that is appropriate for the application. The current source is applied to the relevant terminals of the surge protector and the voltage across the terminals is measured. The dc resistance is then calculated as the quotient of the two.

4.6.4 Standby current and insulation resistance test

Standby current is the continuous current that is conducted between specified terminals of a surge protector when applying a specified dc voltage across these terminals. The insulation resistance is the calculated result of dividing the applied voltage by the measured standby current. This test usually applies across terminals that are intended to be a high resistance such as on a voltage limiter or insulation. All protector terminals not being measured should be left completely disconnected during the measurement, so that other current leakage paths, if present, are not inserted into the measurement circuit. The standby current can also be measured between the external surface of the protector housing (sometimes wrapped in metallic foil) and the terminals. The results of this test indicate whether the protector contains an undesirable leakage current path, which would interfere with normal circuit operation or pose a safety hazard. The standby current of a surge protector may depend on the magnitude of the applied voltage, polarity of the applied voltage, ambient temperature, and humidity.

This test is meant to be a steady-state measurement, so the capacitance of the surge protector should be allowed to charge to the applied voltage before the current is measured. Any additional capacitance from the test circuit wiring and components may require even longer settling times. For some devices, such as spark-gap devices, up to 100 ms may be needed for the gap to stabilize and reach steady-state.

As the applied voltage approaches the rated voltage of the device, the standby current of the device tends to increase. When measuring the standby current, the magnitude of the applied voltage should not exceed the rated voltage of the protector (4.6.1), since the protector may be significantly conductive at or above its rated voltage. The magnitude of any system dc bias voltage used during normal circuit operation should be considered as at least one of the voltages used to measure the standby current of a protector.

With some solid-state surge protective devices, the standby current is relatively constant over a large part of the applied voltage from zero to the rated voltage. Therefore, the calculated insulation resistance increases as the applied dc voltage increases or, conversely, the calculated insulation resistance decreases as the voltage decreases, even though the leakage current is not changing. The needs of the protected circuit should be considered when determining whether to specify either standby current or insulation resistance of the protector.

The standby current can also be affected by ambient temperature and humidity, and different types of protection devices react differently to these conditions. In particular, the standby current of solid-state surge protective devices increases as the device temperature increases. On the other hand, the standby current of surge protectors incorporating air gaps (carbon blocks or gas tubes having back-up air gaps) can increase as the relative humidity of the nearby atmosphere rises. Moisture condensation inside these types of protectors can actually bridge the gap, thereby providing a leakage path for current.

The standby current of a protector can also be dependent on the polarity of the applied test voltage. This can be particularly true of solid-state bidirectional thyristor surge protective devices.

The standby current of the device is sometimes used as an indication of the condition of the device, especially as the device ages. The standby current can change with time, temperature, environment, bias, and exposure to repeated electrical surges. For instance, the electrodes of spark-gap devices (carbon blocks or gas tubes) can melt from the high temperatures produced by the spark formed during the overvoltage condition. The spark can then spray the molten electrode material onto the surfaces surrounding the gap, eventually depositing enough material to form a current-leakage path across the gap. Some solid-state devices may also deteriorate with repeated surges; some may be sensitive to surges having a very steep current slope (di/dt).

Finally, any protector can contain internal contaminants or can collect surface contamination, possibly leading to the formation of a current leakage path. For this reason, protector housings are often designed to have convoluted surface paths between their terminals, so as to minimize the risk of leakage path formation over time. Because of concern about contamination, consideration should be given to using a voltage source of specified limited short-circuit current capacity. Current is limited to levels available in the application in order to avoid possible disturbance of any contaminants on or in the device under test. The intention of this testing method is to detect the contamination, and not to remove it unless the available current in the application would have done so.

4.6.5 Capacitance test

For a given application, under normal operating conditions, the capacitance of the surge protector should not have a significant effect on signal transmission. Excessive capacitance may introduce problems such as signal attenuation, particularly at higher frequencies, pulse-shape distortion (e.g., in digital transmission systems) or crosstalk between terminals. Because the capacitance may vary with applied voltage and frequency, the dc bias voltage, signal voltage, and signal frequency used in the measurement should be determined by the application.

4.6.6 Inductance test

For a given application, under normal operating conditions, the inductance of the surge protector should not have a significant effect on signal transmission. Excessive inductance may introduce noise into the signal path from surrounding electric and magnetic fields, cause pulse shape distortion (e.g., digital current loop), or cause a voltage drop at higher frequency currents in the signal. Because the inductance may vary with the applied current and frequency, the dc bias current and signal frequency used in the measurement should be determined by the application.

4.6.7 Analog insertion loss test

The analog insertion loss test measures the amount of operating voltage loss, if any, caused by the presence of a surge protector in a matched transmission line. The analog insertion loss should be measured over the entire frequency range of operation appropriate to the application, or at selected frequencies within this range. The insertion loss, in dB, is found by calculating the base 10 logarithm of the ratio between the load voltage measured with the surge protector in place to the load voltage measured with no surge protector in place, and multiplying by 20. Factors affecting analog insertion loss are ambient temperature, signal frequency, and the magnitude of bias voltage or bias current.

Current limiting protection devices can cause analog insertion loss, since they are usually placed in series with the load and may have some resistance, inductance, or both. However, voltage limiting protection devices, which usually are connected from a signal terminal to the common terminal, may also cause analog insertion loss because of their capacitance.

Many protection device parameters change with temperature, so the analog insertion loss should be measured at the expected ambient temperature, as well as at extremes of the application. In particular, current limiting protection devices tend to increase in resistance as their temperature rises, so more analog insertion loss can be expected at higher ambient temperatures. Furthermore, the standby current of voltage limiting protection devices (4.6.4) tends to increase as their temperature rises, which also increases the analog insertion loss at higher ambient temperatures. Of course, any other factors that may contribute to higher ambient temperatures may also increase analog insertion loss, such as functioning nearby protection devices or functioning adjacent surge protector units.

In addition, some types of current limiting protection devices (see ceramic PTC devices, 4.1) will increase in resistance as their temperature drops, thereby increasing analog insertion loss at lower ambient temperatures.

Signal frequency may also contribute to analog insertion loss, because of the frequency dependence of a current limiting protection device's inductance (see 4.6.6) and a voltage limiting protection device's capacitance (see 4.6.5). In addition, the self-inductance of heat coils (see 4.3) may cause significant analog insertion loss at higher frequencies. Solid-state voltage limiting protection devices have a larger parasitic capacitance than spark-gap devices (gas tubes and carbon gaps), so these devices have higher analog insertion loss than spark-gap devices. The added series impedance of some current limiting protection devices at higher frequencies, and the lower shunt impedance of some voltage limiting protection devices at higher frequencies increases the analog insertion loss at these higher frequencies.

Some applications provide a bias voltage or bias current, or both, to the load, and therefore to the inserted surge protector. Bias voltage may increase the standby current of voltage limiting protection devices, and bias current may cause current limiting protection devices to self-heat, raising their temperature and, therefore, their resistance. Thus, the magnitude of any operating bias voltage or current may affect the analog insertion loss. Of course, high-bias voltages or currents, in combination with high-signal voltages or currents, may actually activate a voltage limiting or current limiting protection device, resulting in severe amounts of analog insertion loss.

4.6.8 Phase shift test

The phase shift test measures the presence of constant phase intercept distortion, momentary phase hits, and phase jitter on balanced transmission lines, caused by insertion of a surge protector into the signal path. The time difference between the two voltage waveshapes as they pass through the zero reference line is converted into degrees or radians according to formulas specified in the test.

Phase intercept distortion, a constant phase shift to all frequencies present in a particular band, will affect any signal in which preservation of the phase relationship in the transmitted waveshape is important. With phase shift keyed modems, the phase change introduced by a carrier system or associated surge protectors may affect the ability of the receiving modem to perceive the phase changes from the transmitting modem that contains data transmission information.

Phase hits are sudden changes in phase of the transmitted signal. Characterization often includes determination of magnitude in degrees, duration, and number in a fixed period of time. Momentary phase changes greater than 20 degrees are typically of concern in the operation of telephone systems. Measurement of phase shifts is complicated by the effect impulse noise spikes have on most phase shift detectors. Hence, use of an oscilloscope (as required in the test) is of paramount importance in determining whether a surge protector introduces phase hits.

Various sources cause the instantaneous zero crossings of a signal to oscillate: ripple in the dc power supply associated with long haul carriers, incomplete filtering of image sidebands in short haul carriers, 20 Hz ringing currents. Phase jitter in excess of 10 degrees is typically of concern in the operation of telephone systems.

It is important to adjust the voltage level and frequency of the signal as required for the application. Some applications provide a bias voltage or bias current, or both, to the load, and, therefore, to the surge protector. The magnitude of any applied bias voltage or current can contribute to additional phase intercept distortion, momentary phase hits, or phase jitter.

4.6.9 Return loss test

The return loss test measures the extent of impedance mismatch in a communications channel, causing power to be reflected back to the signal source when a surge protector is inserted in a matched transmission line.

During testing it is important to adjust the voltage level and frequency of the signal as required for the application. Some applications provide a bias voltage or bias current, or both, to the load, and, therefore, to the surge protector. The magnitude of any applied bias voltage or current may contribute to additional return loss.

4.6.10 Longitudinal balance test

The longitudinal balance test measures the degree of unbalance that the protector introduces on a balanced circuit (e.g., telecommunications lines). Any unbalance introduced by the protector could influence the susceptibility of the protected circuit to sources of induced noise. Typical noise sources include power lines, power conductors for electric railroads, etc. Currents that travel in the same direction on both conductors are referred to as longitudinal (i.e., common mode) currents. As these identical currents enter the protector, any difference in the series (i.e., between the input and output terminals) or shunt (i.e., between the input terminals and the ground or common terminal) impedances in the protector will cause the currents appearing on the output of the protector to be unbalanced. If the currents are unbalanced, a metallic (i.e., normal mode) voltage occurs across the pair at the terminating equipment.

The test is a measurement of the effect of the asymmetry of the impedances in series with the conductors or to ground at the input signal terminals. Thus, the resistance, capacitance, and inductance in series with the input and output terminals or between the signal terminals and ground should not differ substantially from one other. If these parameters change over the life of the protector, noise may be introduced as the difference increases. The level of the unbalance that can be tolerated depends on the power influence and the operating voltage and current levels of the circuit across the frequency range of concern.

4.6.11 Digital insertion loss test

The insertion of a surge protector into a circuit that is intended to transmit digital signals may result in a reduction of the signal voltage. Data errors may occur at the receiver if the attenuation is excessive. Data errors may also result from other factors such as waveform distortion resulting from excessive inductance or capacitance. However, this test addresses only possible loss of data caused by signal attenuation.

The test is a matched source and load insertion loss test, in which the source is a bit error rate generator, or a square wave generator. In this test, both the source and the load impedance are set equal to that of the application. Since the digital insertion loss is generally a function of baud rate (frequency), the baud rate of the bit error rate generator, or the frequency of the square wave generator, is set equal to the baud rate of the application. Because the application, the surge protector, or both, may contain elements whose behavior varies nonlinearly with voltage, the source voltage should be set equal to that actually used in the application. The application, the surge protector, or both, may also contain elements with values that vary nonlinearly with current; however, the current is controlled by specifying a matched impedance system and by specifying the applied voltage.

Since device parameters may change with temperature, the digital insertion loss should be measured at the expected ambient temperature, as well as at the temperature extremes of the application. Particularly, overcurrent protection devices tend to increase in resistance as their temperature rises, so more insertion loss can be expected at higher ambient temperatures. Furthermore, the standby current of an overvoltage protection device (see 4.6.4) tends to increase as its temperature rises, which also increases the digital insertion loss at higher ambient temperatures.

Signal baud rate (frequency) may contribute to the digital insertion loss because of the baud rate dependence of an overcurrent protection device's inductance (see 4.6.6) and an overvoltage protection device's capacitance (see 4.6.5). The self-inductance of heat coils (see 4.3) may cause significant digital insertion loss at high baud rates. Solid-state overvoltage protection devices have a larger capacitance than spark-gap devices (gas tubes and carbon gaps), so these devices will have higher digital insertion loss than the spark-gap devices. The added series impedance of overcurrent protection devices at high baud rates, and the lower shunt impedance of overvoltage protection devices at high baud rates increases the digital insertion losses at these high baud rates.

Some applications provide a bias voltage, a bias current, or both, to the load, and therefore to the inserted surge protector. Bias voltage may increase the standby current of overvoltage protection devices, and bias current may cause overcurrent protection devices to self-heat, raising their temperature, and, therefore, their resistance. Thus, the magnitude of any operating bias voltage or current can affect digital insertion loss. Of course, high-bias voltages or currents, in combination with high-signal voltages or currents, may activate an overvoltage or overcurrent protection device, resulting in extremely high-digital insertion loss.

4.6.12 Rise and decay time test

Insertion of a surge protector in a digital transmission system may change the signal's rise time, decay time, or both. This change in the signal-wave shape may result in errors in signal reception.

The change in rise and decay time that can be tolerated is a function of the signal level at the surge protector input, the characteristics of the transmission line connecting the surge protector output to the receiver input, and the characteristics of the receiver. The change in rise and decay time is caused by the series and parallel reactances or nonlinearities of components that constitute the surge protector.

4.6.13 Bit error rate test

In certain applications, the effect on the bit error rate of the insertion of a surge protector needs to be determined over a specified time interval. The test is also useful for situations where the receiver characteristics are not known quantitatively.

Any change in bit error rate introduced by the protector may be a function of many factors, including the series and parallel impedances or nonlinearities of the components that constitute the surge protector.

The allowable change in bit error rate is a function of the requirements of the system in which the protector is used.

4.7 Protector characteristics: active performance tests

This subclause gives guidance on the application of the active performance tests for surge protectors used in low-voltage data, communications, and signaling circuits. These tests characterize the ability of a surge protector to perform its intended function.

Before using this subclause, it is important to have an appreciation of the surge protection requirements of the application.

4.7.1 DC limiting voltage test

DC limiting voltage is the highest protector voltage reached by a slowly rising applied input voltage at any current up to, and including, a specified current. Unless otherwise specified, a rate of rise not exceeding 2 kV/s is used for this test. Limiting voltages of many surge protectors will only vary slightly when the rate of rise is less than 2 kV/s.

In general, dc limiting voltage should be high enough so as not to interfere with the normal operation of equipment to be protected. If the dc limiting voltage is too high, the protector will not protect the circuit. DC limiting voltage should be low enough so that limiting will occur before a low-frequency voltage can rise to destructive magnitudes.

Low dc limiting voltage is of concern when 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 limiting value of the protector. Should the crest value exceed the dc limiting voltage, interruption of the transmission or signaling on the circuit will occur.

During its life, a surge protector may be exposed to a sufficient number of transients and disturbances to cause deterioration in a manner whereby the dc limiting voltage changes (typically, the limiting voltage is reduced). This may be accompanied by a degradation of other parameters, such as insulation resistance and impulse voltage.

4.7.2 Impulse limiting voltage test

The impulse limiting voltage characterizes the ability of a surge protector to limit fast-rising voltage transients. The limiting voltage must be less, by a suitable margin, than the withstand peak voltage capability of the component or circuit that is to be protected. The impulse limiting voltage should not be set so low that either it or the dc limiting voltage, which is normally lower, interferes with system operation.

Because of a time lag between the presence of voltage high enough to cause limiting and actual limiting, faster rates of rise can cause initial overshoots or higher limiting voltages. In the absence of special test requirements, the rate of rise for applied voltage during the impulse limiting voltage test 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 C62.36-1994 for test waveform requirements.) The impulse limiting voltage for protectors using some technologies may also be affected by the rate-of-rise of current.

4.7.3 Transition current test

Current limiting devices are used to protect against relatively long excursions of abnormal current that are driven by voltages below the activation voltage of the voltage limiting devices.

The transition current test measures the sensitivity of the current limiting device(s) in a surge protector. The transition current is the point at which the current flowing through the current limiting device is sufficient to cause it to change to its tripped state. Depending on the type of device used, the tripped state can be either high resistance, open circuit, or grounded circuit. In addition, depending upon the technology employed, the devices may be designed to operate only once or repeatedly. Devices that are resettable are designed to return to their quiescent state after tripping. It is desirable, therefore, to compare the parameters of resettable devices that have been tripped with those that have not experienced excursions into their tripped state.

In all applications using current limiters, care should be taken to ensure that the transition current of the device in the application environment is above the maximum normal current of the circuit.

Care should also be exercised to ensure that a current limiting device has, in fact, tripped. In the absence of specific requirements, it is suggested that a device is considered to be in its tripped state when its resistance has increased at least 40 times. An exception would be any device that operates to ground a circuit such as a heat coil. It is recommended that the onset of transition for these devices be defined when a 10 mΩ impedance to ground is measured.

The transition current threshold of current limiting devices is temperature sensitive. The transition current tests, therefore, should be conducted at the extremes of the ambient temperatures expected in the application. Also, resettable current limiters should be allowed to stabilize in their quiescent state between repeated applications of transient current.

Certain application configurations will require special considerations when testing the transition current of current limiting devices. Multidevice packages and multiple protector applications such as those found in telephone central office distributing frames will influence a surge protector's transition current. Testing should take into account the ambient temperature increases of a device due to the thermal interaction of adjacent devices and protectors, and air flow restrictions due to the tight spacing of multiple protector blocks—especially when blocks are enclosed in cabinets.

4.7.4 Current response time test

The current response time test measures the time required for a surge protector's current limiting protective device(s) to reduce the current passing through protected equipment to a specified level during an overcurrent condition. (Current response time is sometimes called trip time.) Factors that may affect the current response time are the overcurrent magnitude, method of mounting the device, and the environment immediately surrounding the device (including ambient temperature, nearby heat sources, and nearby heat sinks). Note that this test is not necessary for all surge protectors, particularly those known not to contain current limiting protective devices.

In thermally-activated devices, the current response time is inversely proportional to the square of the current passing through the current limiting protective device. The power dissipated in the device (I^2R) increases as the conducted current increases, causing the device's temperature to rise (i.e., *self-heat*). If the conducted current is large enough, the temperature of the device will reach the critical value at which it is designed to change state, and reduce, divert, or interrupt the conducted current in the device itself. Since these current limiting protective devices are usually placed in series with the equipment being protected, this state change also protects the equipment.

The most important factor affecting current response time is the magnitude of the current passing through the sensing devices. Higher currents cause more self-heating, which increases the device temperature at a faster rate. Adequate characterization of a protector's current response time may require measurements at many different current levels.

Because of the thermal nature of operation of some current limiting protective devices, ambient temperature also affects the current response time. In general, the current response time decreases as the surrounding temperature increases. Devices that are already warm do not need as much time to reach their thermal transition point. Therefore, it is recommended that a surge protector's current response time be measured at the expected ambient temperature, as well as at extremes of the application.

For many applications, surge protectors contain two or more current limiting protective devices in a single housing (e.g., a telecommunications line protector). In addition, some applications have several protectors installed in a still larger enclosure, sometimes located quite closely together. Therefore, it may be appropriate to measure the current response time when one, some, or all of the current limiting protective devices are energized simultaneously. Adjacent devices or protectors may interact with each other; energized units (individual devices or complete protectors) may increase the surrounding temperature, which shortens the current response time, and unenergized units may lengthen the current response time by absorbing more of the heat generated by the energized current limiting protective device.

In order to conserve test effort, the current response time test can be performed with the transition current test (see 4.7.3), and before the current reset test (see 4.7.6).

4.7.5 Impulse reset test

The impulse reset test serves to verify that a voltage limiting surge protector, when connected to a circuit simulating the actual application, returns to its normal operating mode after an impulse of specified open-circuit voltage and short-circuit current of specified waveshape has been applied to it. It is usually desirable that this return to the normal operating mode occur automatically so there is no interruption of service of the protected equipment, i.e., the surge protector should self-reset within a specified time period. A protector that does not self-reset, a condition sometimes called latch-up, usually shorts out the power and signal source it is connected to and requires a means to temporarily disconnect the power source so that the protector can reset. Latch-up could result in long-term interruption of transmission, the destruction of the protector, or both.

The ability of a protector to self-reset depends mainly on the type of surge-suppressive components employed, on the ambient temperature conditions, on the characteristics of the dc power source, and on the magnitude and waveshape of the current impulse the protector conducts. The magnitude and waveshape of the conducted current are influenced by the open-circuit voltage of the impulse generator and by the characteristics of the device itself.

In general, if the voltage level of the power source connected to a protector is lower than the clamping or on-state voltage of the surge protective device employed, the protector will self-reset after limiting an impulse. If the voltage level of the source is higher than the clamping or on-state voltage of the surge protective device, then device characteristics, temperature conditions, and power source parameters have to be well understood.

Voltage limiting protective devices can be divided into two main groups: clamping devices and crowbar devices. Clamping devices limit applied surge voltages to a certain specified voltage level and conduct the associated surge current at the clamping voltage. Avalanche junction semiconductors, Zener diodes, and metal oxide varistors are clamping devices. In general, a clamping device self-resets if the sum of the power source voltage and signal voltage is lower than its clamping voltage. Crowbar devices limit applied surge voltages to certain specified voltage levels, but once turned on with sufficient current, they enter a low impedance on-state and therefore have a low on-state voltage. It is important to understand the characteristics of crowbar devices, the nature of the circuit they are connected to, and the type of impulses they are expected to pass in order to achieve reliable self-reset performance. Gas tubes and thyristor diodes are typical crowbar devices.

Gas tubes are manufactured in many variations, the main differences being the fill gas, the gas pressure, the electrode spacing, and the electrode coating, all of which affect the ability of the spark gap to self-reset. Spark gaps are not as temperature dependent as thyristor diodes.

A thyristor diode's ability to self-reset is, to a great extent, a function of its junction temperature and the value of the holding current. Therefore, the ambient temperature, the I^2t of the current surge, and the follow current of the power source and signal source are critical self-reset parameters. In general, a thyristor diode self-resets if the current conducted by the device is reduced to a level that is less than its holding current. The instantaneous holding current is reduced by the heating produced by the applied impulse. Protectors containing thyristor diodes should be tested for impulse reset at the expected ambient temperature, as well as at extremes of the application.

Isolating devices of the test circuit that serve to isolate the impulse generator from the power source should be carefully chosen, since they may affect the self-reset behavior of the surge protective device. If the power source consists of a dc source, one or several blocking diodes of sufficiently high peak inverse voltage rating can be employed. It is important to know that certain spark gaps will shorten, or *chop* the wavetail of an impulse and not pass all of the surge energy through the protective device of the protector.

4.7.6 Current reset test

The current reset test is done to verify that surge protectors intended to provide self-resetting overcurrent protection actually return to their quiescent operating state after they have properly limited or diverted the transition current (see 4.7.3). In order for a self-resetting overcurrent protection device to reset, the device should be allowed to cool once the overcurrent condition has been removed. Factors such as ambient temperature, heat transfer conditions, magnitude of current after removal of the overcurrent, and the overcurrent magnitude and duration determine whether a particular device returns to its quiescent operating condition.

Self-resetting overcurrent protection devices are sensitive to ambient temperature, and higher ambient temperatures make it more difficult for these devices to reset. This occurs because the change in state of the device in response to an overcurrent is caused by thermal accumulation in the device (self-heating) caused by the overcurrent. Once the overcurrent is removed, the self-heating of the device is greatly reduced, but not completely eliminated. There may still be enough device self-heating present, in combination with a high ambient temperature, to prevent a change back to the quiescent state. Therefore, the current reset test should be done at the maximum expected ambient temperature for the application. (Of course, this test may also provide useful information at other temperatures.)

Some self-resetting overcurrent protection devices do not actually reset unless the current conducted by an already-activated device is reduced to well below the quiescent operating current level for a short period of time. In some cases, this reduction may be accomplished only by temporarily disconnecting the device from the circuit. Therefore, these types of self-resetting overcurrent protection devices may not be appropriate for some applications, particularly those that are continuously energized before, during, and after an overcurrent surge.

The higher the temperature reached by a self-resetting overcurrent protection device, the more difficult it becomes for it to reset. The longer a device is allowed to self-heat, the hotter it will become, until thermal equilibrium with the surroundings is reached. Therefore, the protector being tested should be allowed to reach a steady-state condition before the transition current is removed. In addition, larger currents will cause more self-heating, and a hotter device. So, the transition current level used for the current reset test should be the highest expected for the application.

It may be interesting, or even necessary for some applications, to measure the time required for the self-resetting overcurrent protection device to return to its quiescent state. If so, it should be noted that the reset time of the device is affected by ambient temperature and heat transfer conditions. Since the device reset depends on whether the device can adequately cool, higher ambient temperatures result in longer reset times and lower ambient temperatures result in shorter reset times.

In order to conserve test effort, the current reset test can be done after the transition current test (see 4.7.3) and the current response time test (see 4.7.4).

4.7.7 AC life test

Under normal operating conditions, surge protectors usually do not encounter ac voltage of the magnitude that would originate from power lines. However, since telephone and other signal cables often share a pole and ground wire with the commercial ac power system, high currents associated with the power system can induce overvoltages in telephone and signal cables. Under real-world field conditions, accidents do occur, so a low-voltage surge protector should be able to withstand abnormal ac voltage.

Abnormal ac voltages can arise from contact between power, data, communications, or signaling lines (sometimes referred to as *power cross*) caused by storms (i.e., a branch or tree falls on overhead lines strung between poles, causing various lines to contact each other), motor vehicle accidents with traffic lights or telephone poles, or construction equipment digging into underground lines.

Another source of abnormal ac voltage is power induction, which is electromagnetic coupling between power lines and signaling lines during power system fault conditions, or as a result of long runs with the lines in close proximity.

In general, power system-induced transients have a long duration (when compared to lightning-induced transients), lasting from a few milliseconds to several cycles of the power system frequency. There is little definitive data on the magnitude of these transients, but usually power contact is the most severe. In addition, steady-state currents from a few hundred milliamps to several amps can exist from inductive coupling of long runs.

Typical test conditions are listed in Table 5 of IEEE Std C62.36-1994 and represent both high-current modes (as might occur during power contacts) and low-current modes (such as from induction). It may not be necessary to test all the conditions listed; a high-current and a low-current test may be sufficient.

The user should consider what failure criteria are appropriate. For example, it may be desirable for a protector not to fail, but to provide continuous protection under mild conditions (to avoid being a nuisance); but under high-current conditions, fail in a mode that will still protect equipment connected to the protector's output, without becoming a fire hazard.

4.7.8 Impulse life test

A measure of the durability of surge protectors is the impulse life test. IEEE Std C62.36-1994, suggests waveforms and currents to be used, as well as the maximum time between test impulses. The individual application will determine the extent of life test requirements necessary.

The useful life of the protector is ended when degradation results in interference with transmission of signaling, or when the protector arrester fails to protect. The purpose of the impulse life test is to determine the end-point of life caused by either occurrence.

Applications in areas of high lightning or switching incidence, or severe exposure, may justify the use of surge protectors with high-impulse life characteristics.

Isokeraunic maps provide the mean annual number of thunderstorm days. Statistical data have 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, desired reliability of service, and the exposure to lightning, in addition to knowledge regarding nearby power switching operations, a determination can be made of the protector's life requirements.

Although lightning flashes occur in multiple strokes, usually averaging two to six strokes within a few tenths of a second, a standardized life test method has been accepted. Test results can be used to compare cost/performance tradeoffs and to indicate the durability of surge protectors. Failure criteria for this test are usually defined in terms of specified degradation in protector parameters such as standby current or insulation resistance, dc limiting voltage, and impulse limiting voltage.

4.7.9 Maximum single impulse discharge test

The maximum single impulse discharge test is a measure of the capability of a surge protector to withstand a single large current surge. Nearby lightning strikes can produce such surges. In the absence of specified requirements, IEEE Std C62.36-1994 suggests waveforms of 8/20 μs or 10/1000 μs. Peak current magnitude of the single test impulse is determined by the possibility of exposure to a severe impulse. The test is of the greatest importance in applications involving exposed facilities, located in areas of high thunderstorm activity or high soil resistivity.

4.8 Application of surge protectors used in low-voltage data, communications, and signaling circuits

The application of surge protectors to limit voltages and/or current to electrical apparatus requires the selection of a protector with suitable characteristics, and the proper physical arrangement of the protector in the electrical circuit. It also requires the selection or design of equipment that will withstand the voltages, currents, and/or energy that bypasses the selected protector in the circuit configuration. An overall economic choice of both equipment and protectors should be made.

The basic electrical configurations of the most common protectors is illustrated in Figure 5. Depending upon the type and arrangement of the internal components of the protector as shown in Figure 6 and the manner in which the protector is connected in the circuit, as shown in Figure 5, the protector may limit current, longitudinal (common mode) surge voltages, and/or metallic (transverse mode) surge voltages as discussed in 4.5.

This clause discusses some of the general principles involved in the application of surge protectors, using the example of a three-terminal voltage limiting protector (Figure 5, configuration 3b), which is shown connected between a transmission line and the protected circuit in Figure 8. More detailed examples involving this and other configurations are given in Annex A.

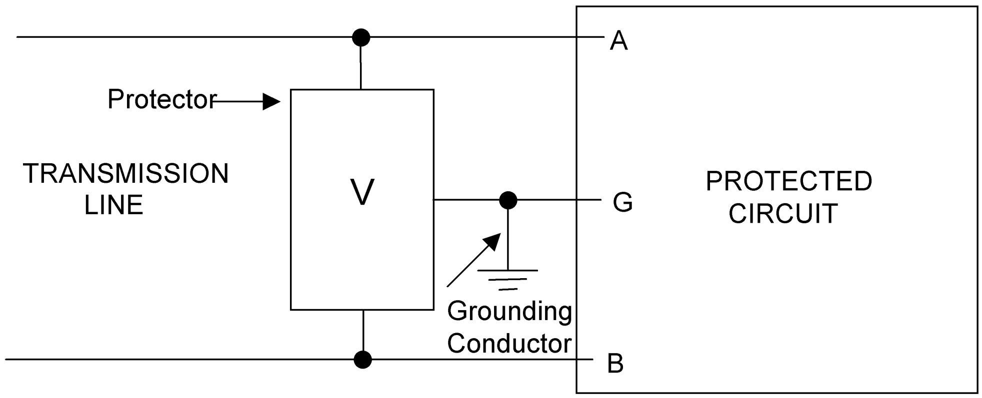


Figure 8—Protection of circuit composed of two signaling leads and a ground terminal

4.8.1 Operational compatibility

In the quiescent state, an unoperated surge protector should not interfere with transmission of information, control, or test signals. For example, the insulation resistance (see 4.6.4), measured between terminals A-G, B-G, and A-B of the protector at the voltages applied by the system, should be sufficiently high so as not to have a significant effect on signal transmission. Likewise, the capacitance (see 4.6.5) measured between these terminals should be sufficiently low so as not to have a significant effect on signal transmission at the expected transmission frequencies involved in the application.

Unwanted clipping of signals is avoided by specifying the minimum dc limiting voltage (see 4.7.1) and impulse limiting voltage (see 4.7.2) to be greater than the largest signal level, including any superimposed dc bias or any acceptable induced ac interference voltage, at the protected terminals. Unnecessary interruption of service of the protected equipment following the intended operation of a protector can be avoided by the use of a protector that self-resets within a specified time period (see 4.7.5).

4.8.2 Voltage limiting

The protector 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).

In the case of the protector shown in Figure 8, protection of the apparatus or circuit 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 impulse limiting voltage (see 4.7.2) of the protector between A-G or B-G. Accordingly, any of the three-terminal protector configurations of Figure 7 may be sufficient to protect all three terminals. If the application is such that metallic transients can occur without a longitudinal component, then the 3b1 three-terminal protector of Figure 7 may permit metallic voltages as high as the sum of the two limiting voltages. In this situation, a 3b2 or 3b3 three-terminal protector of Figure 7 may be necessary to limit metallic transients to lower values.

4.8.3 Grounding and bonding

In Figure 8, 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 flowing through the protector to ground, 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 8 and other systems connected to the same electrode. If the protector is a 3b1 configuration (Figure 7), and the two voltage limiting components of the protector operate, the difference in potential between terminals A-B-G will be the conducting voltage of the protector components, 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 9.14 m (30 ft) 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 voltage limiting components is 200 A, with a rise time of 100 A per μs, the resistive component of voltage will be 16 V and the inductive will be 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.

4.8.4 Location of protectors

The physical location of protectors should be such as to 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 70-1999, 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 9a) illustrates the hazard that can result if this requirement of ANSI/NFPA 70-1999, 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 create 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, create a fire hazard. If a secondary protector is installed, as illustrated in Figure 9b), 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 70-1999, 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 of and incorporate means for limiting 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.

4.8.5 Codes and standards

Protectors used for protection of communications circuits should comply with the provisions of ANSI/NFPA 70-1999, Articles 800, 830, and/or ASC C2-1997, where these are applicable. These standards address the requirement for the provision of protectors. In addition, ANSI/NFPA 70-1999 addresses the location and grounding requirements for protectors on communications circuits and network powered broadband communications systems. Typical safety test requirements are described in UL 497 [B1] for communications circuit protectors and in UL 497A [B2] for secondary protectors.

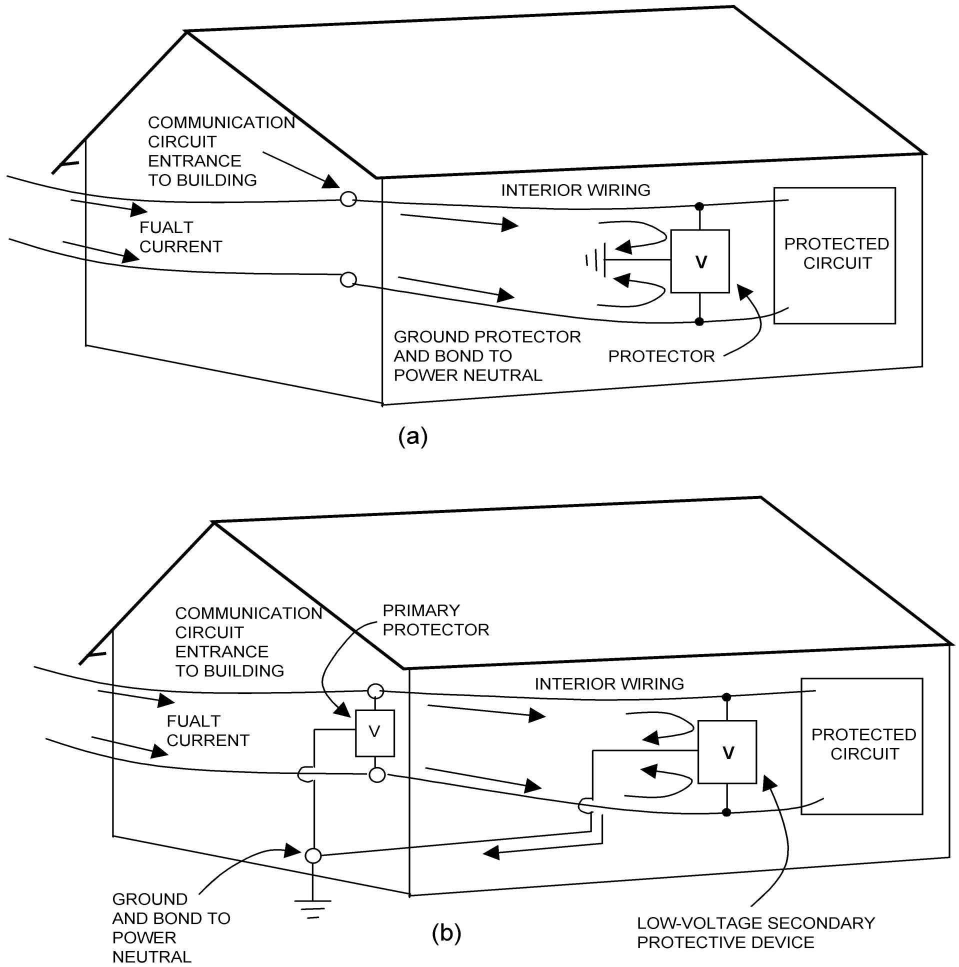


Figure 9—Possible overheating of interior wiring
a) When protector is located remotely from building entrance
b) When secondary protector without current limiting is used

Annex A

(informative)

Examples of applications of surge protectors used in low-voltage data, communications, and signaling circuits

The following are examples of considerations in the selection and application of surge protectors intended for use in low-voltage data, communications, and signaling circuits. These examples are intended for illustrative purposes only. Since the purpose of each example is limited, each may be incomplete in some respects. Therefore, these examples are not intended to be used as the sole basis of selecting and using protectors in actual applications, nor should they be viewed as the only approach that can be taken for surge protection.

A.1 Protectors on outdoor lines

This clause provides an example of a common application of surge protectors on lines that terminate inside a building but are connected to data, communications, or signaling circuits that extend to the outdoors. This example is not intended to apply to protection of all video equipment connected to outdoor lines. Higher surge currents, or different types of equipment or lines, with different withstand capabilities, may require other considerations.

A.1.1 Example of protection of video camera on coaxial line

Video cameras are frequently mounted on the outside of a building to provide security against intruders. Their elevated location and long connecting cable make them susceptible to lightning-related disturbances and possible damage. Protection is applied on the signal line at the camera and building interfaces.

A.1.1.1 Circuit configuration

In this example, a four-terminal surge protective device (SPD) is selected for protection because of the high level of lightning impulse current and the requirement for low-voltage clamping at the camera and video monitor locations. SPDs are placed on a single coaxial cable line in which the cable shielding is also the return path and ground connection. The protector is placed directly at the connection to the outdoor equipment. A two-stage SPD is required that employs, as a minimum, a primary protection element (V_x) for diverting the lightning impulse current and a secondary protection element (V_y) to provide the low clamping voltage (Figure A.1).

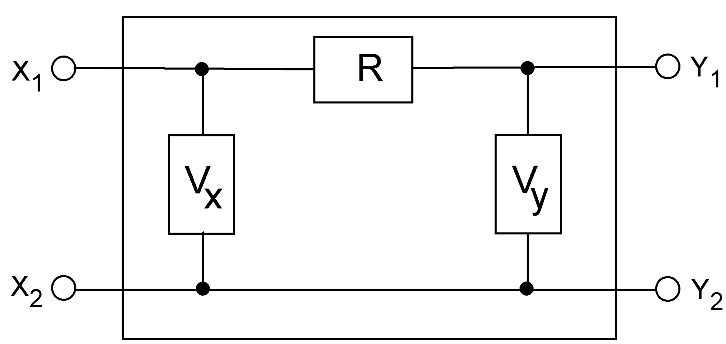


Figure A.1—Example of protector used on outside coaxial line

A.1.1.2 Discussion

The primary protection element of the SPD should have sufficient impulse life to divert up to 2000 A of transient current of an 8/20 μs waveform. The secondary protection element should provide an impulse limiting voltage below the failure threshold voltage of the sensitive component, in this example, 40 V. Between the protection elements is an in-line series resistor (R). This resistor provides the necessary impedance between the two protection elements to ensure activation of the primary element during a transient event. The voltage across the second protection element (V_y) plus the voltage drop across the resistor (R) causes a voltage difference across the primary protection element (V_x) enabling it to conduct some of the transient current. For this example, the SPD uses a sealed metallic package with a BNC-type connector at each end so that the SPD can be easily inserted in the line at either end of the data transmission line. The insertion loss and return loss of the protector should be acceptable for the application.

A.1.2 Secondary protectors

This subclause provides an example of a common application of surge protectors in communication circuits (Figure A.2) that extend an outdoor line to circuits within a building.

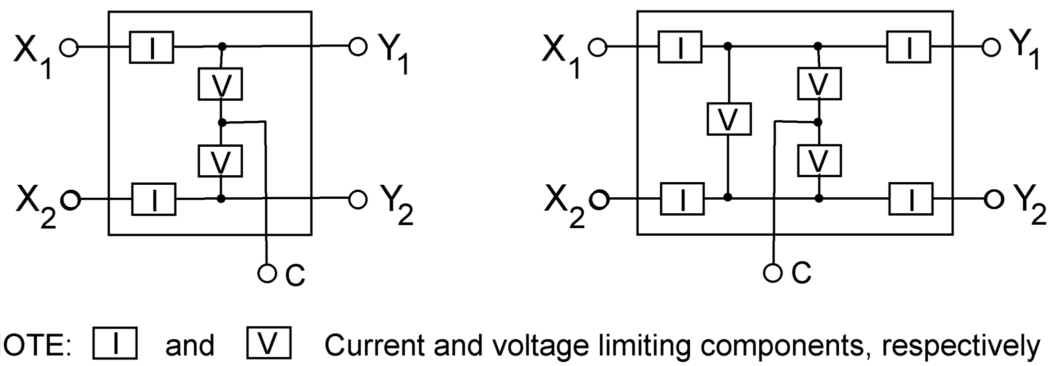


Figure A.2—Examples of secondary protectors used on communication circuits

A.1.2.1 Description

Secondary protectors are intended for use on internal building communication circuits that enter from an exposed outside plant. The secondary protector is typically listed or classified for indoor use. In many cases, the protection device is sealed to prevent moisture from entering the device. In cases where a secondary protector is used outdoors, the circuitry and related hardware is housed within an environmentally suitable enclosure.

The secondary protector is typically located within, or just before, the protected equipment on the communications circuit that connects the equipment to the outside plant. The secondary protector is required to be located on the equipment side of a primary communication protector. In those applications not equipped with a primary protector (e.g., intrabuilding cabling), the secondary protector may be used by itself.

The user is typically an equipment manufacturer, installer, or equipment-owner concerned with fast-rising transients that are not limited by the primary protector. The secondary protector is designed to suppress these types of transients, which are caused by coupling from lightning or other electrical disturbances. The secondary protector also helps protect against above-normal currents that are conducted to ground within the protected equipment. In such cases, a low-impedance path to ground may result in the bypassing of the primary communications protector, so the secondary protector should limit currents to values that are below the current-carrying capability of the on-premises wire and equipment to be protected.

A.1.3 Five-terminal protector on outside lines

This subclause describes an application for five-terminal protectors on lines that run from one building to another within a particular factory, campus, or job site.

A.1.3.1 Example of PBX protection using PTC current limiting devices

Many companies require more telephone sets than outside plant telephone lines. This situation necessitates an interface between many telephone sets and few telephone lines. This interface, called a PBX, may be located in one building on a large site and connected to many telephone sets located in various buildings around the site. Since the lines connecting these telephone sets may extend up to several miles, they can make the PBX susceptible to damage from power line contacts or lightning. Voltage limiting devices are placed between each input terminal and the grounded terminal to limit voltage surges. Current limiting devices in series with each input terminal can be used to help avoid damage and overheating from excess currents.

This example demonstrates the use of PTC devices for current limiting; other devices are available. Because a PBX has two output terminals for each telephone set and also has a ground terminal, a five-terminal protector can be placed at each output to help protect the PBX from damage.

A.1.3.2 Circuit configuration

Figure A.3 shows the circuit configuration for the five-terminal protector. It includes V_x, which is a primary overvoltage protection device that is normally an open circuit, and becomes a low impedance when a particular voltage level is reached. V_y is a secondary overvoltage protection device that becomes a low impedance at some particular voltage that is lower than the breakdown voltage of the primary device. The PTC devices are normally low impedance. Because of their PTC characteristics, they become a high impedance if a fault current is conducted, and they, therefore, limit the current. The resistors R1 also act as current limiters and may or may not be necessary depending on the characteristics of the other components and the type of surges expected.

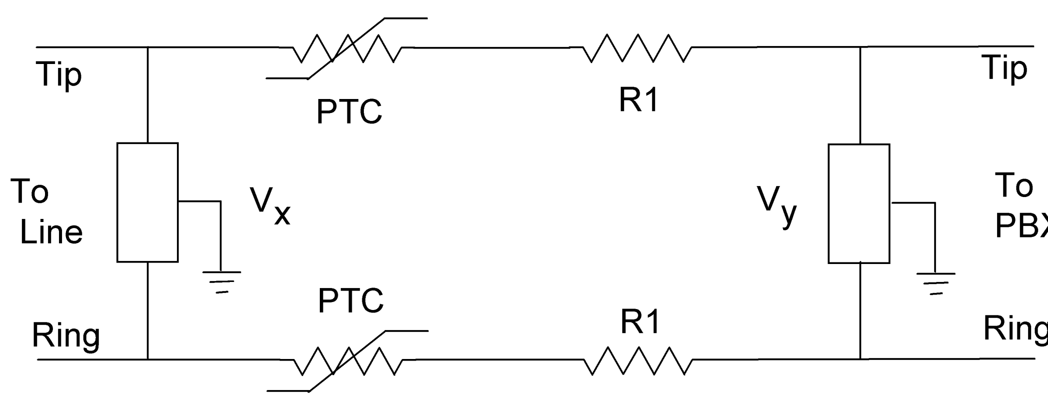


Figure A.3—Example of a protector used on a PBX

A.1.3.3 Discussion

The primary overvoltage protection element, V_x, should be robust enough to take the current from the worst fault expected. It should have a high enough limiting voltage so that the highest voltage expected under normal conditions, (i.e., ringing voltage), will not trigger it. The secondary over-voltage protection element, V_y, should have a low enough limiting voltage to protect the PBX, and like V_x, it should have a high enough limiting voltage so that it does not trigger from routine operating voltages. If this is an impossible compromise, switches can be used to make sure that the PBX and V_y are disconnected whenever ringing voltage is applied. Another consideration is the time V_x takes to trigger relative to V_y. Since V_y is not as robust as V_x, a situation in which V_y triggers first and conducts a large amount of current while waiting for V_x to trigger can result in damage to V_y.

The purpose of the PTC devices is to interrupt any abnormally high current that may be conducted to ground via the PBX or V_y. They interrupt the current in a *sneak under* situation in which the fault voltage is not high enough to trigger V_x. The sneak under current represents a significant threat, particularly when a power line fault occurs far away from the PBX so that the line resistance to the fault is large. This fault may result in a relatively low voltage at the protector, and a relatively low-fault current, which will not instantly fuse a wire or component, but instead slowly heats a wire or component, creating a fire hazard.

In cases where the fault voltage is greater than the limiting voltage of V_x, the resistor may be needed to ensure that when fault current is conducted, a high enough voltage is sensed by V_x that it triggers quickly. In some cases, the increase in PTC resistance caused by the fault current is all that is necessary to ensure that V_x triggers, and the resistors are not needed. In lightning-induced faults, the resistors may be needed to limit current that has too fast a rise time for V_x, V_y, and the PTCs to limit.

A.1.4 Single-wire protection, RS-423

This subclause describes the application of a three-terminal SPD to be used on an RS-423 unbalanced data line that extends outside a building.

A.1.4.1 Example of data line transmission protection

When data transmission lines are extended outside a building, they may be exposed to lightning-induced transient threats. Because of the high level of voltage and current transients, an external protection network is often required to protect sensitive interface components. Protection is best at the building interface using an SPD that is connected to the ground return path of the circuit. A multistage, three-terminal SPD is useful for this application.

A.1.4.2 Circuit configuration

A three-terminal SPD can be used for this application because of the single point ground of the multistage unit. The example SPD is composed of a gas tube, resistor, and avalanche junction semiconductor surge protective device (Figure A.4). The packaging can be kept small enough to be located on the data input line of the equipment, or it can be inserted in the line at its entrance to the building. If placed at the building entrance, an additional SPD may be required at the equipment interface to suppress transients from sources generated within the building.

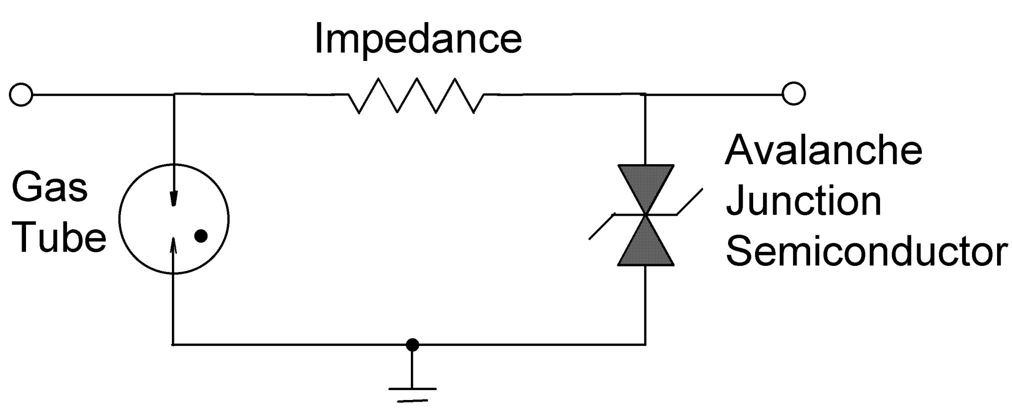


Figure A.4—Example of protector used on RS-423 unbalanced data line

A.1.4.3 Discussion

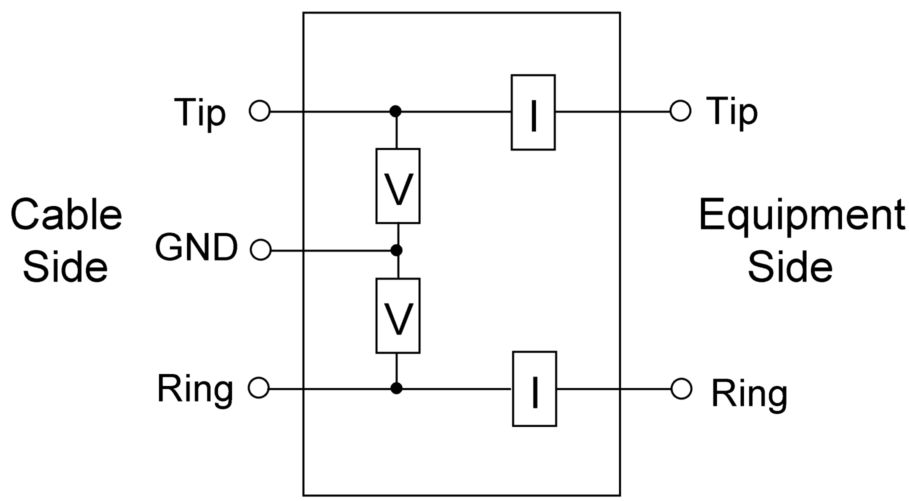
A two-stage SPD is used because of the high-energy transient environment that can cause large currents to be conducted to the input pins of the serial port. The gas tube is used to divert the major portion of the transient current to ground. The avalanche junction semiconductor surge protective device is the secondary protection element that provides the low-voltage clamping for protection of sensitive components. In this application, it is not only important to have a low-resistance ground connection, but to provide the shortest possible connection to a low-impedance earth ground. Installation is best at the building interface where a short wire can be connected to the nearest accessible grounding electrode (e.g., building steel, ground rod, or other good earth ground).

A.2 Telecommunication line five-terminal protector module

Persons using telecommunications equipment need protection against injury or damage from electrical surges that can occur on the two-wire line that delivers telephone service to the customer. These surges can originate from lightning or ac power lines. The purpose of the protector is to divert these surges to ground and to return to its quiescent state when the surge has dissipated.

The protector commonly used in a local telephone company central office is the telecommunications line five-terminal protector module. In addition to its protection function, the five-terminal module also connects the outside cable pair to the telecommunications equipment inside the central office.

Typically, five-terminal modules contain both overvoltage and overcurrent protection devices, where the overvoltage devices are placed between each cable side terminal and the ground terminal, and the overcurrent devices are placed between the outside cable terminals and the equipment terminals. A schematic of one possible configuration is shown in Figure A.5.



NOTE: I and V Current and voltage limiting components, respectively

Figure A.5—Telecommunication line five-terminal protector module

Five-terminal protector modules are used in central offices, but because of their wide availability and relatively compact size, they are also being used in outdoor applications such as remote terminals and building entrances. The outdoor environment, being mostly uncontrolled, exposes the modules to a wide range of temperature and humidity conditions, compared to the much more benign environment of a central office. Most types of protection modules are significantly affected by temperature, humidity, or both. Therefore, the five-terminal module selection process should anticipate, among other things, the final installation location (indoors, outdoors, or both).

A.2.1 Service-affecting considerations

While five-terminal modules are intended to help protect people and equipment during a surge, they should not disturb telephone service under normal conditions. The nonsurge performance tests of IEEE Std C62.36-1994 help determine whether or not a particular five-terminal module will interfere with normal telephone service.

A telecommunications circuit's rated voltage and rated current indicate the maximum continuous voltage and current levels, respectively, expected during normal circuit operation. Normal operation should include some unwanted steady-state voltages, such as low-level induction from ac power lines near the outside plant cable. The circuit's rated voltage determines a protector's minimum allowable dc limiting voltage, while the circuit's rated current determines a protector's minimum allowable transition current.

Consider a voice communication circuit, which uses an oscillating signal superimposed on the central office battery to alert the receiver (i.e., rings the telephone set). This circuit's operating voltage would typically be a maximum of 200 V peak. The peak value of the unwanted steady-state voltage should be added. A five-terminal module having a dc limiting voltage below this sum would interfere with the circuit's normal operation. While a voice circuit also has its own rated current, five-terminal modules used on voice circuits are also used on other circuits, which have a higher rated current. For instance, a digital carrier circuit requiring a loop extender (because of the extreme length of the cable) may have a continuous operating current (i.e., rated current) of 140 mA. The transition current of a five-terminal module's overcurrent protection devices should exceed this circuit's rated current (140 mA) plus an allowance for unwanted steady-state currents, or the circuit's normal operation will be affected.

In addition to these severe effects, consideration should be given to lesser amounts of signal change likely to be introduced by a five-terminal module. For instance, a module's dc series resistance, inductance, and capacitance each contribute to a module's analog or digital insertion loss and longitudinal balance. The dc series resistance and inductance is associated, most often, with overcurrent protection devices, and the capacitance is associated with overvoltage protection devices. A module's dc series resistance changes with temperature, and its inductive and capacitive reactance will change with frequency. Furthermore, the presence of a continuous current or voltage may affect the dc series resistance or capacitance, respectively, of a module.

A five-terminal module in the circuit introduces a path to ground that is used by the protector to divert surge energy to ground. However, this path may also reduce the signal amplitude reaching the receiver if there is excessive current leakage in the protector. The standby current and insulation resistance of the protector indicates how much of the signal current is inadvertently diverted to ground. Temperature, humidity, signal frequency, signal amplitude, and bias voltage all can affect standby current and insulation resistance of a module.

Digital circuits, in particular, are not only sensitive to signal amplitude changes, but also to signal shape changes, such as phase shift, or rise time and decay time deterioration. Furthermore, these effects, and excessive insertion loss can result in an unacceptably high bit error rate. Requirements for dc series resistance, inductance, and capacitance, should be carefully matched to the type of circuits being protected, and should be specified over appropriate ranges of temperature, frequency, and bias levels, so that the five-terminal module causes the least amount of signal degradation.

A.2.2 Surge performance considerations

The active performance tests of IEEE Std C62.36-1994 describe those tests that determine a protector's performance during and after a surge, and a protector's ability to withstand repeated surges without affecting service. In addition, and of particular importance for five-terminal protector modules, these tests characterize the failure modes of the protector.

Impulse limiting voltage measures the peak voltage allowed by the five-terminal module during a simulated surge condition. In general, the impulse limiting voltage for a particular set of conditions should be lower than the maximum voltage level that the protected equipment can withstand. This level may be different for different types of surges.

The impulse limiting voltage of overvoltage protection devices used in five-terminal modules can be affected by ambient temperature, voltage rate-of-rise, and current rate-of-rise. For example, the impulse limiting voltage of gas tubes and carbon gaps increases as the voltage rate-of rise increases. The impulse limiting voltage of solid state devices increases as ambient temperature increases; compared to gas tubes and carbon gaps, the dependence on rate-of-rise is much less.

Once the five-terminal module has diverted the surge to ground, it should return to its quiescent condition in order that normal circuit operation be restored. The purpose of the impulse reset test is to verify that the overvoltage protective devices return to their high-impedance state after a surge is applied. In order to simulate actual circuit conditions after the surge, a dc source (simulating the central office battery) is connected to the module as it is surged. The short-circuit output current of the dc source is limited with a resistor.

For gap-type overvoltage protection devices, the ability to reset is influenced by the magnitude of the open circuit voltage and short-circuit current of the dc source, as well as the source regulation characteristics and the system's reactive components. A gap-type protector should be specified that can reset under the specified circuit conditions. For thyristor diode overvoltage protective devices, the ability to reset is influenced by the short-circuit current of the dc source and by the ambient temperature at the protector. A thyristor diode should be specified with its holding current greater than the short-circuit current of the dc source at the maximum anticipated application temperature in order to assure that normal circuit operation is restored after the surge has passed.

There are some surge conditions that will not activate the overvoltage protection devices, but can still damage equipment. These surges are sometimes referred to as sneak currents, since they are low-voltage surges that are said to sneak by the overvoltage protection device. While sneak currents are low voltage and (usually) low current, they can have long durations. Sneak currents can cause small electronic components and wiring to overheat, which could interrupt service or start a fire.

Unlike overvoltage protection devices, the overcurrent protection devices used in five-terminal modules can take longer to respond to a surge. For overcurrent protection devices, surge rates-of-rise are not as important as surge magnitude and surge duration. The performance of a five-terminal module's overcurrent protection devices during and after a surge is evaluated using the transition current and current response time tests. Modules containing or requiring self-resetting overcurrent devices are further evaluated by the current reset test.

Since the typical overcurrent protection device depends on thermal accumulation to activate, its performance is dependent on temperature, the relative proximity of heat sinking material, and its own size. Therefore, it is important that an operating temperature range is specified for applications using five-terminal modules with overcurrent protection devices. It is also important that designers consider not only the device itself, but the connections to the device, and even the connections to the module. Air flow around the module will also affect performance of an overcurrent protection device.

Some types of overcurrent protection devices, such as heat coils, do not reset once activated. Other types, such as a PTC thermistor, can reset automatically. A heat coil diverts the sneak current to ground by releasing a so-called *fail-safe* mechanism that permanently short-circuits the protected conductor to ground. On the other hand, a PTC thermistor actually reduces current (i.e., limits) by accumulating heat, which increases its resistance. When the voltage across the activated thermistor is substantially reduced, the thermistor cools down and returns to a low-resistance condition, allowing normal circuit operation to resume. PTC thermistors may not be suitable for some circuits, particularly carrier systems, because the operating current of the system is continuous, even after a surge, and is high enough in magnitude to prevent the PTC thermistor from resetting.

AC life and impulse life tests are meant to simulate the surge conditions five-terminal modules might experience once installed. Studies of surges on telecommunications cables show that, in general, lower magnitude surges occur more frequently than higher magnitude surges. However, in order to better characterize a particular five-terminal module, and to better simulate the wide variety of surges that actually occur, a number of different surge types, magnitudes, waveshapes, and occurrences are used for surge life testing.

Note that some device degradation can be expected to occur during surge life testing. However, the protection devices used should properly anticipate this degradation, so as to extend the useful life of the five-terminal module. For instance, the dc limiting voltage of gas tubes and carbon gaps has a tendency to decrease as the number of applied surges increases. Therefore, these devices typically have an initial dc limiting voltage that is higher than the rated voltage of the protected circuit. In this way, these devices can withstand many surges before their dc limiting voltage falls below the rated voltage of the circuit. Other parameters may also be affected during surge life tests, and it is common that the limits on these parameters during surge life testing differ from initial (*out-of-box*) limits.

Because of this change in operating parameters of gas tubes and carbon gaps with surge life discharges, the user sometimes makes compromises in performance of these protector types in order to achieve a desired *lifespan*. For instance, the dc limiting voltage situation described above results in higher impulse limiting voltages. In this case, a compromise is made to allow higher peak voltages to reach equipment, in order for the modules to last longer. Note that such a compromise may not cause any problems because the protected equipment may be able to withstand the higher peak voltages.

The thyristor diode protective device, when used within ratings, typically does not exhibit a degradation in dc or impulse limiting voltage with applied life surges. Therefore, its specified limiting voltage can be closer to the rated voltage of the protected circuit, significantly reducing its surge vulnerability without interfering with normal circuit operation.

The surge current amplitude that a thyristor diode can survive decreases when applied at lower temperature extremes. The minimum operating temperature for a particular application should be determined when thyristor diode surge protector devices are being specified. In this case, the user may have to compromise on the five-terminal module's lifespan according to the probability of surges occurring at low temperatures.

Life testing has two purposes. The first is to determine whether the modules survive a sufficient number and variety of surges, thereby suggesting they will not affect service for an adequate period of time. The second is to cause device failure, to determine that the modules reach their end-of-life in an acceptable manner. If a module cannot recover from the applied surge and allow normal circuit operation to resume (i.e., it reaches the end-of-life), the module should still provide protection.

A five-terminal module is considered to have met the intended failure mode requirement if it has either high standby current (low insulation resistance), low dc limiting voltage, or has shorted one or both conductors to ground. The module's inability to return to its quiescent condition during the impulse reset test may also be an appropriate failure mode. Unacceptable failure modes include: module ejects molten material, catches fire or overheats, or if the overvoltage protection device(s) has open-circuited. (The latter condition leaves the circuit functional, but unprotected.) Once a module reaches one of the designated failure modes, surge life testing can be stopped.

The maximum single-impulse discharge test can be considered as a special case of the impulse life tests. A five-terminal module subjected to this test would be expected to recover from such a test, but, at the very least, it would have to fail in an acceptable mode if it did not recover.

Annex B

(informative)

Bibliography

[B1] UL 497, Standard for safety, Protectors for paired conductor communication circuits (6th Edition, Underwriters Laboratories Inc.).

[B2] UL 497A, Standard for safety, Secondary protectors for communication circuits (2nd Edition, Underwriters Laboratories Inc.).

[B3] IEEE Std 100-1996, *The IEEE Standard Dictionary of Electrical and Electronics Terms,* Sixth Edition.