

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

Copyright © 2000 by the Institute of Electrical and Electronics Engineers, Inc.
All rights reserved. Published 4 May 2000. Printed in the United States of America.

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

No part of this publication may be reproduced in any form, in an electronic retrieval system or otherwise, without the prior written permission of the publisher.

IEEE Standards documents are developed within the IEEE Societies and the Standards Coordinating Committees of the IEEE Standards Association (IEEE-SA) Standards Board. Members of the committees serve voluntarily and without compensation. They are not necessarily members of the Institute. The standards developed within IEEE represent a consensus of the broad expertise on the subject within the Institute as well as those activities outside of IEEE that have expressed an interest in participating in the development of the standard.

Use of an IEEE Standard is wholly voluntary. The existence of an IEEE Standard does not imply that there are no other ways to produce, test, measure, purchase, market, or provide other goods and services related to the scope of the IEEE Standard. Furthermore, the viewpoint expressed at the time a standard is approved and issued is subject to change brought about through developments in the state of the art and comments received from users of the standard. Every IEEE Standard is subjected to review at least every five years for revision or reaffirmation. When a document is more than five years old and has not been reaffirmed, it is reasonable to conclude that its contents, although still of some value, do not wholly reflect the present state of the art. Users are cautioned to check to determine that they have the latest edition of any IEEE Standard.

Comments for revision of IEEE Standards are welcome from any interested party, regardless of membership affiliation with IEEE. Suggestions for changes in documents should be in the form of a proposed change of text, together with appropriate supporting comments.

Interpretations: Occasionally questions may arise regarding the meaning of portions of standards as they relate to specific applications. When the need for interpretations is brought to the attention of IEEE, the Institute will initiate action to prepare appropriate responses. Since IEEE Standards represent a consensus of all concerned interests, it is important to ensure that any interpretation has also received the concurrence of a balance of interests. For this reason, IEEE and the members of its societies and Standards Coordinating Committees are not able to provide an instant response to interpretation requests except in those cases where the matter has previously received formal consideration.

Comments on standards and requests for interpretations should be addressed to:

Secretary, IEEE-SA Standards Board
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08855-1331
USA

Note: Attention is called to the possibility that implementation of this standard may require use of subject matter covered by patent rights. By publication of this standard, no position is taken with respect to the existence or validity of any patent rights in connection therewith. The IEEE shall not be responsible for identifying patents for which a license may be required by an IEEE standard or for conducting inquiries into the legal validity or scope of those patents that are brought to its attention.

Authorization to photocopy portions of any individual standard for internal or personal use is granted by the Institute of Electrical and Electronics Engineers, Inc., provided that the appropriate fee is paid to Copyright Clearance Center. To arrange for payment of licensing fee, please contact Copyright Clearance Center, Customer Service, 222 Rosewood Drive, Danvers, MA 01923 USA; (978) 750-8400. Permission to photocopy portions of any individual standard for educational classroom use can also be obtained through the Copyright Clearance Center.

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
William Greason
Phillip Havens
Andrew Robert Hileman
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

1. Scope.....	1
2. References.....	2
3. Electrical environment	2
4. Description and theory of operation	2
4.1 Positive temperature coefficient devices	3
4.2 Bimetallic devices.....	7
4.3 Heat coils	9
4.4 Fuses	10
4.5 Multiple-component surge protectors	11
4.6 Protector characteristics: nonsurge performance tests.....	19
4.7 Protector characteristics: active performance tests.....	24
4.8 Application of surge protectors used in low-voltage data, communications, and signaling circuits	29
Annex A (informative)—Examples of applications of surge protectors used in low-voltage data, communications, and signaling circuits	33
Annex B (informative)—Bibliography	41

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

¹Information on references can be found in Clause 2.

²The 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

³The 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/>).

⁴ANSI 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/>).

⁵IEEE 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.

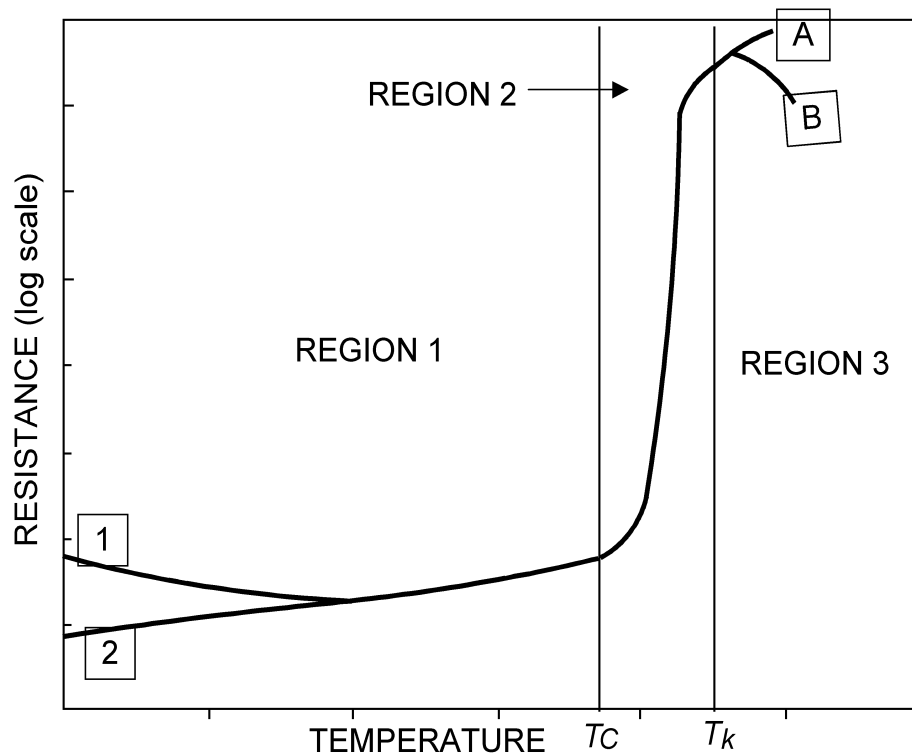


Figure 1—Resistance vs. temperature for a PTC device

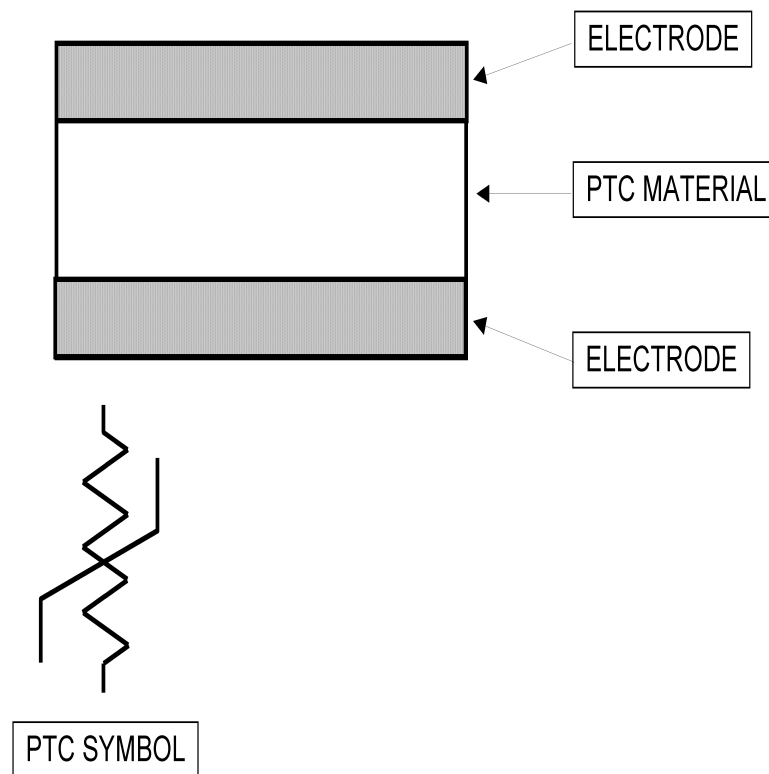


Figure 2—Functional components for PTC devices

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 ($^{\circ}\text{C}$),
- T_A is the ambient temperature ($^{\circ}\text{C}$),
- k is a dissipation constant for the device ($\text{W}/^{\circ}\text{C}$).

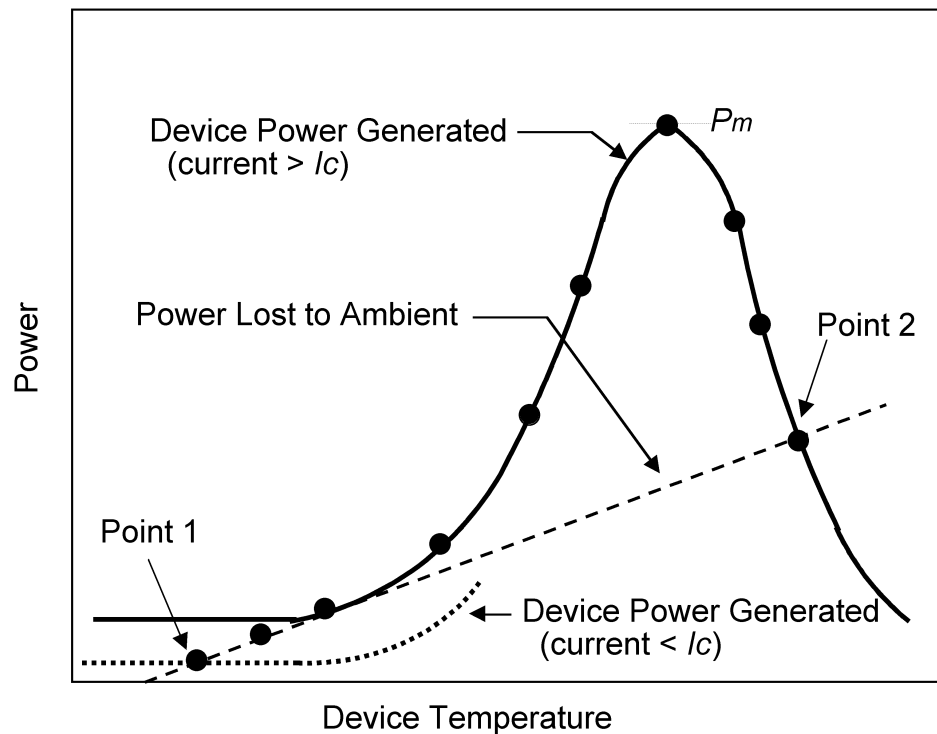


Figure 3—Power generated in the device and power lost by the device to ambient, as a function of temperature

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 T_a' 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.

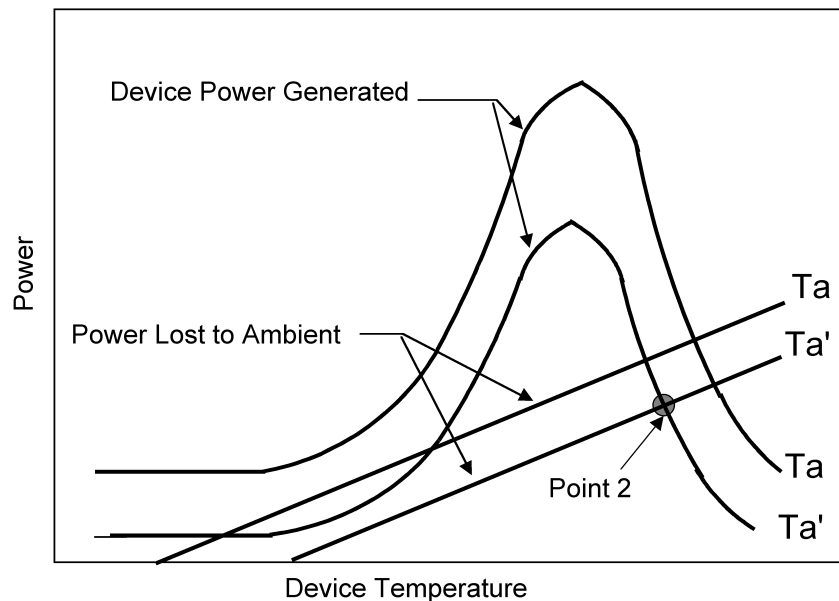


Figure 4—Power generated in the device and power lost by the device to ambient, as a function of temperature. T_a and T_a' are ambient temperatures where $T_a' > T_a$

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 through 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.