Overvoltage Protection of Solid-State Subscriber Loop Circuits

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Introduction

Overvoltage stresses have plagued telecommunica-tions systems from the beginning of the industry. The provision of service to subscribers frequently neces-sitates installing long spans of conductors in environments where exposure to lightning or power faults is only a matter of time. The electromechanical compo-nents that comprise the early vintages of telecommu-nications equipment generally tolerated these insults well. Service outages rarely extended beyond the directly affected lines, and safety hazards (fire or electrical shock) were minimal. Modern telecommunications systems demand high space efficiency and that digital services be extended as far into the plant as possible. These needs have conspired to place extremely sensitive electronic components at the most vulnerable positions in newer systems. Further, the multiple power supplies and control signals required by solid-state line interfaces provide many opportunities for hazardous voltages to propagate beyond the point of entry into the system. All the while potential threats to these systems in terms of power distribution networks and lightning conduction facilities continue to grow.

Although telecommunications systems have always employed transient protection devices such as the carbon gap, the gas discharge tube, and the heat coil, these older technologies are not always ade-quate to protect solid-state circuitry. Several devices show promise in providing the extra protection nec-essary for even more reliable telecommunications. This document discusses the threats to which tele-communications systems are exposed, the tests used to assess protection adequacy, and strategies for dealing with both.

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Agencies, Testing Philosophies, and the Customer

In order to make sense of the complex testing demands currently placed on telecommunications equipment, it is helpful to understand the present regu-latory environment. From its inception through divestiture, the Bell System provided the safety and operational requirements for the majority of the U.S. telecommunications network. With the advent of divestiture, a vacuum was created in the role of operational responsibility and, in addition, new issues of fairness and business relationships developed.

The Public Switched Telephone Network (PSTN) refers to the network over which the telephone operating companies and common carriers exercise control. The performance, quality, and safety needs of the PSTN have been addressed by the operating companies, Bellcore, the common carriers, and, to a limited extent, the FCC. Safety-related requirements of equipment installed in the customer premises have been the domain of a loose consortium of independent labo-rato-ries, again with the modest involvement of the FCC. Performance and quality issues for customer premises equipment are left to caveat emptor.

The technical challenge in telecommunications circuit protection is not so much designing systems that pass the pertinent safety related tests, but doing so in a way in which the ultimate customer perceives value. This frequently means that the equipment manufacturer must decide what stresses are so severe that any of the allowed safe failure modes are acceptable and which hazards the customer would expect the equip-ment to survive in good working order or with minimal repair required. For equipment installed in the network, the standards provide minimally acceptable require-ments; there is little guidance for customer premises equipment.

Using worst-case test conditions as design criteria for survival of equipment without damage will certainly result in overengineering of the protection circuitry. Although field data on customer premises events are sparser, a wealth of information on outside plant haz-ards indicates that existing standards overstate the overvoltage stresses that will be encountered in prac-tice [14, 15, 16, 27].

The Federal Communications Commission

The FCC rules that are pertinent to protection of com-munications circuits are contained in CFR47, part 68.

These rules are unique in that they are federal law and are the only regulations directly traceable to law.

The FCC rules are intended to ensure that any equip-ment connected to the network will not adversely affect the network. These rules do not explicitly address questions related to the safety of individuals or the quality of these products. FCC overvoltage hazard tests are designed to ensure that the attached equip-ment responds to these stresses in a way that does not cause harm to the network.

These rules do not apply to the system components that comprise the network, such as central office switches and transmission gear. They also do not apply to customer premises telephone equipment that does not directly connect to the network (e.g., a station set behind a PBX) except as necessary to complete the system for test purposes.

UL and the National Electrical Code

As indicated by its name, *UL* began life as an advocate of insurance underwriters, which meant helping manu-facturers reduce their liability exposure through the use of good design and manufacturing practices. This has translated into a concern for safety of users and ser-vice personnel, which is a distinctly different perspective than that of the FCC.

Even prior to divestiture, there was some *UL* involve-ment in the testing of communications equipment. Modems were classified as data processing equipment and fell under the review of *UL* 114 and *UL* 478. These standards became the basis for *UL* 1459, “Standard for Telephone Equipment” which, in the heavily revised Second Edition, became effective in July 1991. This standard considers safety issues related to all aspects of customer premises telephone equipment, including exposure to overvoltage events.

In order to ensure that telephone products installed into building wiring systems do not present a fire hazard, the 1990 National Electrical Code (NEC), published by the National Fire Protection Association (NFPA), included a provision (Article 800-51) that required list-ing of telephone equipment by a Nationally Recognized Testing Laboratory (NRTL)—effectively to terms of *UL* 1459. Many local governments incorporated the NEC into their building codes, in effect giving it the force of law.

Agencies, Testing Philosophies, and the Customer (continued)

Bellcore and the Network

With divestiture, the Bell Operating Companies (BOCs) chartered Bell Communications Research (Bellcore) to carry on some of the standardization responsibilities previously a function of AT&T Bell Laboratories. Many of the standards documents developed predivestiture were adopted (without change) into and given the "Bell Pub" nomenclature. Newer standards were developed through the cooperation of the BOCs and the telecom-munications industry in a formal review process that resulted in documents referred to as Technical Refer-ences (TRs). Together these standards documents, supplemented by standards issued by the BOCs and independent operating companies, provide the basis to which subsystems within the network are tested. These standards are advisory in that they are not imposed by governmental agencies and the operating companies may waive them as they deem appropriate.

The standards issued by Bellcore for subsystems in the network are generally far more comprehensive than those issued by the foregoing organizations and address quality and performance issues as well as safety. These standards, in general, specify two over-voltage test suites: a set of lower-level stresses which the system should be able to experience without dam-age and a second set where safety is the only issue.

ITU-T (CCITT) [34]

The main international telecommunications body is the International Telecommunication Union (ITU), also known as the Union Internationale des Te‘le‘communi-cation (UIT). Founded in Paris in 1865 as the International Telegraph Union, the ITU took its present name in 1932 and became a specialized agency of the United Nations in 1947.

Article 7 in the constitution of the ITU states that the International Telephone and Telegraph Consultative Committee (CCITT) is a permanent part of the ITU.

Article 13 of the ITU constitution refers to the CCITT and specifically Article 13-1 (2) states the duties of the CCITT are to:

…study technical, operating, and tariff questions and to issue recommendations on them with a view to stan-dardizing telecommunications on a worldwide basis.

Expressly excluded are technical or operating ques-tions relating specifically to radio communications, which come under the purview of the International Radio Consultative (CCIR).

The CCITT must pay "due attention" to the study of questions and formulation of recommendations directly connected with the establishment, development, and improvements of telecommunications in developing countries. The CCITT must conduct its work with due consideration for the work of national and regional standardization bodies, keeping in mind the need for the ITU to maintain its preeminent position in the field of worldwide standardization for telecommunications.

The Plenary Assembly of the CCITT is a nontechnical meeting of the CCITT member organizations, which sets up and maintains, as necessary, study groups to deal with questions to be studied. The recommenda-tions made by the study groups must be approved at either the Plenary Assembly of the CCITT or between agreed procedures before they formally become rec-ommendations. These recommendations are then published in ten volumes which, for the 1984 to 1988 period, are known as the Red Book and are published with bright red covers. The recommendations were published as the Yellow Book for the VIIth Plenary Assembly and would be published as the Blue Book following the IXth Plenary Assembly for the 1988 to 1992 period.

Subscriber Loops

In order to understand the overvoltage protection issues associated with subscriber loops, it is important to consider some of their electrical characteristics. The conventional subscriber loop consists of two asymmet-rical ends; an end that performs the functions normally associated with a central office or PBX and an end ter-minating the circuit which acts like a station set. The terminology for these ends is not very consistent; for these notes, the following conventions will be used:

Station Orientation is used to refer to the end to which a station set could be attached and expected to func-tion. A conventional central office line circuit has station orientation. In addition to coupling the ac speech sig-nals to the subscriber loop, the subscriber loop circuit must also supply dc loop current and source power ringing current. This means that the station-oriented end usually has finite impedances to ground, and hence, requires protection from excessive currents flowing through these paths during fault conditions.

Office Orientation is used to describe the end of the circuit that operates correctly when connected to a Tip and Ring pair from a central office. Station sets, modems, and simple PBX trunks have office orienta-tion.

In the vast majority of cases for residential subscribers, the station-oriented end is within the network, either at a central office or in pair-gain equipment. In PBX and key systems, both ends of the entire subscriber loop are contained (usually) within the customer's premises. Although not quite as obvious, there are also cases where the station-oriented end is on customer pre-mises and the office-oriented end within the network.

Figure 1 simplistically depicts the functional differences between the two ends (and conveniently ignores some operational requirements). The central office provides either loop current or power ringing imposed upon the central office battery to the subscriber loop through cur-rent limiting. In this figure, a transformer is used to couple the differential voice frequency signals to the switching network and to provide electrical isolation from the subscriber side of the circuit. In the past, such transformer-based designs were commonly used in switching systems. These functions are frequently more cost-effectively implemented using integrated cir-cuits in newer equipment.

Strictly speaking, station-oriented circuits, such as the central office line circuit shown in the figure, do not necessarily have battery-feed circuits referenced to a local ground. Loop current can be sourced from an iso-lated supply for each subscriber, which is occasionally done. In general, however, station-oriented circuits have current paths from Tip and Ring to ground and other equipment (e.g., the central office battery) that must be adequately protected, whereas office-oriented circuits do not. This distinction (along with others) makes protection of the station-oriented circuit end from overvoltage events more of a challenge.

System Transients

Overvoltage stresses can occur in either longitudinal or metallic modes. Longitudinal mode is when the over-voltage is impressed on both Tip and Ring relative to ground. Longitudinal stresses result from voltage induction or power crosses where both conductors are exposed to the hazard in the same manner and are the most common type of event. Metallic signals are differ-ential between Tip and Ring and require the unusual set of circumstances where the hazardous voltage is inserted between the two conductors.

System Transients (continued)

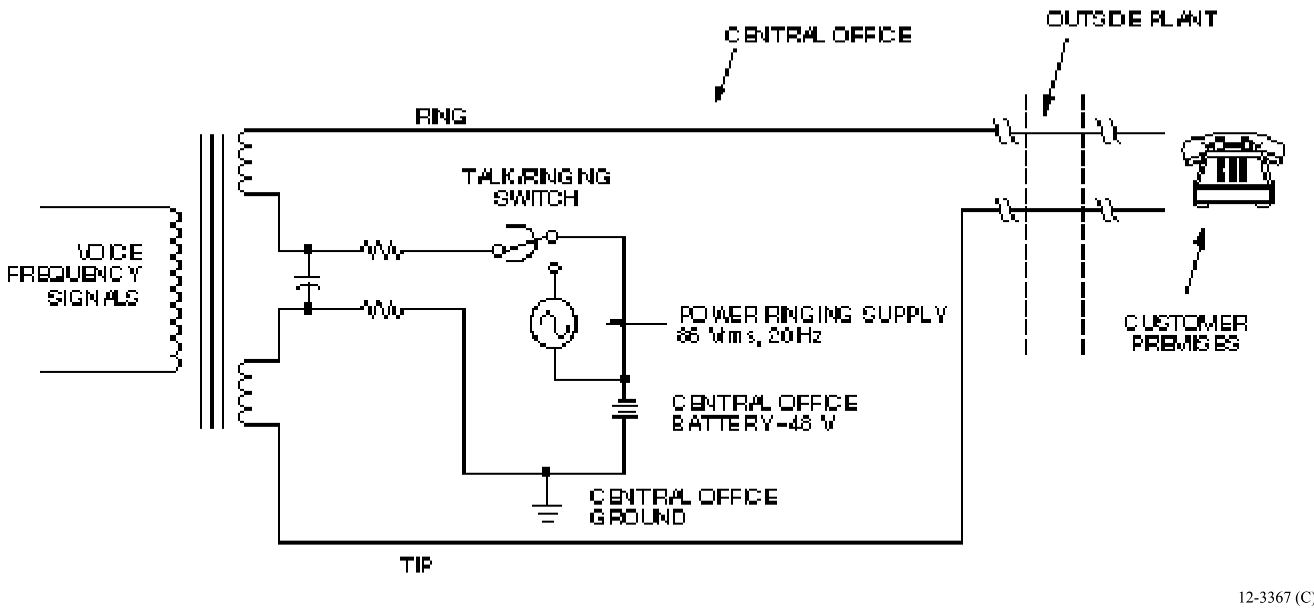

Figure 1. Subscriber Loop

Lightning-Induced Transients

Lightning is the most common source of overvoltage stress in communications systems. Currents may enter the conductive shield of a suspended cable by direct or indirect stroke, or it may enter a cable buried in the ground by ground currents.

Lightning currents are not usually harmful to the shield itself, but they do induce surge voltages on the conduc-tors of the cable which are often imposed on central office, outside plant, and customer premises equip-ment. The surge voltage that appears at the ends of the cable depends upon the distance to the distur-bance, the type of cable, the shield material and its thickness and insulation, as well as the amplitude and waveshape of the lightning current in the shield. Since the current-drive potential along the shield is capaci-tively coupled to the cabled conductors, the waveshape of the surge on the conductors will closely resemble the waveshape of the lightning current.

Lightning-induced currents are always longitudinal in the absence of any imbalance resulting from terminat-ing equipment. In normal operation, great care is taken to balance the impedance seen between Tip to ground and Ring to ground, and conversion of longitudinal cur-rents to metallic currents is highly attenuated. However, overvoltage stresses will frequently cause protectors to operate, shunting current to protection ground. Should these protectors operate simultaneously and similarly, no metallic transients will result. If these protectors are poorly matched or arcing or other abnormal current paths develop, some metallic transients will result. For this reason, lightning test suites generally include metallic as well as longitudinal insults.

Quantitative information on lightning has been accumu-lated from many sources [9]. Using these statistics, a model of induced voltages in various electrical circuits, such as the cable plant of a communications system [21], can be made. These models form the basis of var-ious overvoltage hazard tests.

Power System Induced Transients

Since telephone cables very often share a pole or com-mon-use trench and ground wire with the commercial ac utility power system, some level of inducted longitu-dinal currents are almost always measurable on Tip and Ring. These current is at 50/60 Hz and its odd har-monics and are part of the normal operating milieu.

However, the high currents that accompany power sys-tems faults can induce overvoltages in the telephone cables. Induced overvoltages will be at 50/60 Hz and its odd harmonics and can have long duration (com-pared to the lightning-induced transients) from a minimum of a few milliseconds to effectively indefinite duration.

System Transients (continued)

Power System Induced Transients (continued)

Three fundamental types of overvoltage events occur on telecommunications circuits as a result of power system faults:

- Power Cross

  This is the condition where the power lines make electrical contact with the telephone circuit conductors and is capable of sustaining large currents indef-initely. Power cross can also occur on customer premises where it is usually associated with the actions of service personnel.

- Power Induction

  The electromagnetic coupling between a power sys-tem experiencing heavy fault currents and the telephone cable can produce an overvoltage in the cable.

- Ground Potential Rise

  When the power and telephone systems share a common ground, the high currents resulting from a power fault can result in significant ground potential differences between the point of the fault and the earth ground. This can result in a longitudinal over-voltage condition on the telephone cabling.

Protection Methods

In contrast to lightning events, there is little definitive data available on the severity or frequency of occur-rence of these overvoltages. To understand the problems of protecting exposed telecommunications circuits, a review of the traditional protection layout is useful. Line protection networks are traditionally split into primary, secondary, and sometimes tertiary com-ponents on both ends.

Figure 2 is a very simplified model of a conventional central office subscriber loop highlighting the protec-tion. At the left is a central office switching system, and at the right end is customer provided equipment.

Protection is provided in layers that surround the great-est threat with increasingly stringent protection levels. In this case, the greatest threat is in the outside plant and two layers of protection are in place before encountering sensitive equipment.

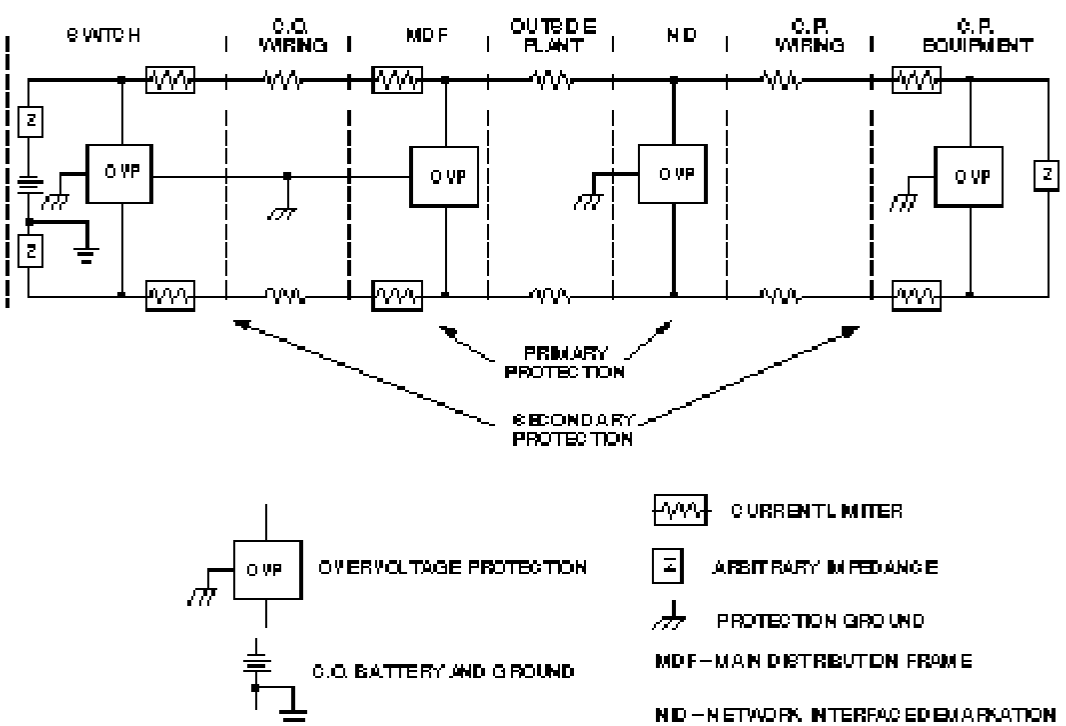

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Figure 2. Central Office Subscriber Loop Protection

Protection Methods (continued)

Figure 3 is an equivalent diagram showing a subscriber circuit originating on a PBX and remaining entirely within the customer's premises. Here the threat is posed by the wiring within the building, in particular power cross events, and is generally less significant than faults originating in the outside plant. Conse-quently, only one layer of protection is provided.

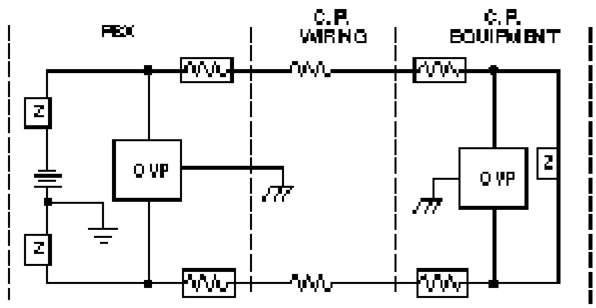

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Figure 3. PBX Station Circuit on Customer Premises

Primary Protection

The primary components provide the first level of pro-tection from an overvoltage event occurring in the out-side plant. These devices typically reside in the main distribution frame (MDF) for central office equipment and at the network interface demarcation (NID) at the customer premises end of the subscriber loop. The pri-mary protection is intended to divert fault currents away from the protected equipment and into a reliable earth ground. Primary protection is generally the property of the operating company, and specifications for primary protectors provide the minimum level of protection that the TELCO guarantees its customers. Traditionally, primary protection has been implemented by using 3-mil carbon blocks with or without gas discharge tubes (GDT) and occasionally supplemented with 350 mA heat coils for current limiting. When heat coils are not provided at the central office end, a fuse is provided outside of the central office for conductors of 24 AWG or 26 AWG. It is the equipment manufacturer's respon-sibility to prescribe the use of heat coils based on the recommendations of the pertinent standards docu-ment.

Because of aging and reliability problems, there has been a move towards use of solid-state devices and away from the traditional primary protection devices in these applications [27].

Secondary Protection

The secondary protection components are usually located on the equipment to be protected and are the responsibility of the equipment manufacturer. The requirements for the secondary protection are deter-mined by the regulatory standards and the customer's expectations.

Secondary protection must deal with the residual fault current passed from the primary protection without cre-ating a fire or electrical shock hazard either in the equipment or in associated wiring including the wiring between the primary and secondary protection. Sec-ondary protection, therefore, usually entails both voltage and current limiting. Overvoltage protection is necessary to prevent damage to the equipment and
shock hazards. Current limiting is necessary to prevent damage to wiring and the voltage limiters themselves. Furthermore, some current limiting is desirable to coor-dinate the actions of the primary and secondary volt-age limiters since the secondary protectors usually operate at a lower potential than the primary and it is undesirable to shunt these currents away from the pri-mary protection ground.

The secondary protection on office-oriented equipment normally does not involve an additional protection ground path. These protection components are placed in series with Tip and Ring and shunt across them, as shown on the right side of Figure 3.

Station-oriented equipment will usually have additional current paths. See, for example, the left side of Figure 3. In low-threat environments, such as customer premises, fault currents may be diverted through talk battery and ground by steering diodes. This scheme is incompatible with most power fusing arrangements and is frequently reserved for tertiary protection. Regard-less of whether a separate protection ground or the talk battery and its ground are used, the potential differ-ences between the primary and secondary protection grounds that result from current flow must be consid-ered.

Standards, Regulations, and Recommendations

These regulations apply to equipment on protected wir-ing. That is, these regulations/standards assume that primary pro-tection is in place. In the following sections, the existing standards for overvoltage testing in the United States will be reviewed. It should be remem-bered that only the sections related to voltage stress on Tip and Ring are discussed and that all standards include other considerations for accep-tance.

FCC Part 68

Specifically, Subpart D Section 302 spells out the haz-ardous voltages for testing Tip and Ring interfaces. These tests take place after the equipment under test has been subjected to relatively rigorous environmental testing which includes temperature/humidity cycling, drop tests, and vibration.

- Metallic Voltage Surge Test:

  10 x 560 µs current pulse, 800 V max, 100 A current lim-ited source pulse of each polarity

- Longitudinal Voltage Surge Test:

  10 x 160 µs current pulse, 1500 V max, 200 A cur-rent limited source pulse of each polarity

  The metallic voltage surge test and the longitudinal surge test should be conducted with the equipment in operating states that can affect compliance.

Note that the equipment does not have to operate or meet longitudinal balance requirements after the test. But, the equipment must fail in an appropriate failure mode; that is, one that causes the user to take action. If such a failure state is reached, the equipment must be “substantially and notice-ably unusable by the user,” in order that the equipment can be immediately discon-nected or repaired.

Electrical stresses are also applied to other interfaces; for example, exposed metal and ac power connections which may affect compliance with the Tip and Ring requirements. Other sections of FCC Part 68 prescribe the basic design and performance characteristics (lon-gitudinal balance, ringer equivalence, etc.).

UL 1459

Specifically, Section 50A details a series of overvoltage safety tests. Of particular interest is Type 1 equipment that contains a device for the purpose of limiting current in the telecommunications wiring to an acceptable level. There are two criteria for passing these test suites:

- Equipment Fire Safety

  The equipment passes this criterion if during or after a surge test it does not burn or char a piece of cheese cloth that has been placed around/on the equipment.

- Wiring Fire Safety

  If during the fault condition, the impedance of the equip-ment is reduced to the point that excessive cur-rent results in exposed wiring, a fire hazard may exist. The Consumer Product Safety Commission has attributed a number of building fires in the U.S. to this cause. To investigate this potential, a 1.6 A slow-blow fuse is placed in series with the surge gen-erator which simulates the internal building wiring and must not open during any of these tests.

The potential for electrical shock hazard can be evalu-ated by repeating the pertinent dielectric withstand (Hi-Pot) tests after the overvoltage tests so that any circuit damage that results in reduced isolation will be discov-ered.

The tests are similar in nature to the FCC tests in that volt-ages are applied metallically and longitudinally, and that the equipment does not have to operate after the test. But they differ in that there are a series of safety or hazard tests designed to investigate the regions of greatest susceptibility of the particular equipment under test. That is, the current limiters are disabled and the output impedance of the surge generator is adjusted to source current at the maximum level the current limiter would permit. These sneak-under tests are designed to deliver the maximum sustained current stress that the system could experience.

Standards, Regulations, and Recommendations (continued)

UL 1459 (continued)

In Tables 1 and 2, the term Ih is used to represent the maximum current that an internal current limiter will allow and Vh is the voltage at which internal voltage limiters operate. All surges are at either 50 Hz or 60 Hz. Figure 4 shows the test configuration for metallic testing and Figure 5 shows that for longitudinal testing.

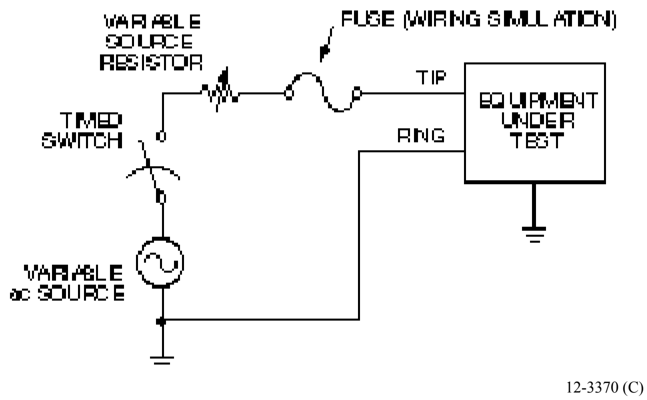

Figure 4. *UL* 1459 Metallic Overvoltage Test Configuration

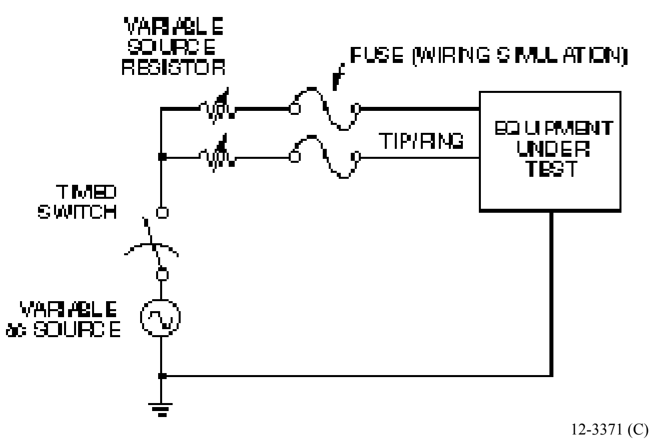

Figure 5. *UL* 1459 Longitudinal Overvoltage Test Configuration

Table 1. Metallic Voltage Surge Test

Test	Vrms	Time	Source Res. (Ω)	Current (A)
M1	600	1.5 s	15	40
M2	600	5 s	85.7	7
M3A	600	30 min	273	2.2
M3B	600	30 min	—	Ih
M4	200 or Vh	30 min	—	Ih

Table 2. Longitudinal Voltage Surge Test

Test	Vrms	Time	Source Res. (Ω)	Current (A)
L1	600	1.5 s	15	40
L2	600	5 s	85.7	7
L3A	600	30 min	273	2.2
L3B	600	30 min	—	Ih
L4	200 or Vh	—	—	Ih
L5	120	30 min	4.8	25

Bellcore Administered Standards

Bellcore maintains an extensive collection of standards documents which cover the performance and safety requirements for every subsystem within the network. The overvoltage stress test requirements for subscriber loops are contained within several documents pertain-ing to individual equipment which interfaces with the subscriber loop. These requirements are generally sim-ilar in nature although they may differ in specifics.

For example, the Bellcore LATA Switching System Generic Requirements (LSSGR) [10], which is the standard for BOC central office switches, specifies two sets of overvoltage tests. These stress tests are classi-fied as first-level and the more severe second-level tests for both ac power cross and lightning. After expo-sure to first-level events, the system should continue to operate within the specified performance parameters when the stress is removed. To pass a second-level test, equipment damage is permitted as long as no electrical shock or fire hazards are created. For refer-ence, the LSSGR standards per TR 515 are tabulated below. An additional set of requirements can be found in TR 1089. Note that the LSSGR categorizes stan-dards as requirements and objectives. Requirements are the minimum acceptable performance levels while objectives represent the direction in which require-ments are expected to migrate.

These tests include both longitudinal and metallic events. The method for applying the stresses is the same as in Figures 4 and 5 except as noted.

Standards, Regulations, and Recommendations (continued)

Bellcore Administered Standards (continued)

Table 3. LSSGR Lightning Test, First Level

Vpk, V	Pulse	Ipeak (A)	Reps.	Comments
±600	10 x 1000	100	50	Met. & Long.
±1000	10 x 360	100	50	Met. & Long.
±1000	10 x 1000	100	50	Met. & Long. replaces 1 & 2
±2500	2 x 10	500	50	Long. Objective

Note: In the first-level test, the primary protection is removed. Voltages may be reduced if protection other than carbon blocks is used. See LSSGR.

Table 4. LSSGR Lightning Test, Second Level

Vpk, V	Pulse	Ipeak (A)	Reps.	Comments
±1000	10 x 2500	200	10	Met. & Long.
±1000	10 x 2500	200	10	Met. & Long.
±1000	10 x 2500	200	10	Met. & Long.
±5000	2 x 10	500	1	Long.

Note: In the second-level test, the primary protection is removed.

LSSGR ac Power Cross Test Suites

The ac power cross test scenarios are similar in princi-ple to those required by *UL* 1459 in that the source impedances and exposure times are used to modify severity. In addition, a novel high-impedance induction test is introduced to test response to high-voltage longi-tudinals resulting from induction. The test apparatus for this test is illustrated in Figure 6, and the level one and level two requirements are given in the notes accompanying the tables. The 60 Hz source for this test should have a minimum power rating of 50 VA, and the turns ratio for the transformer is arbitrary.

Table 5. LSSGR ac Power Cross Test, First Level

Vrms	Res. (Ω)	Duration	1 ° Pro.	Comments
0—50	150	15 min	removed	Met. & Long.
50—100	600	15 min	removed	Met. & Long. Obj.
100—600	600	60 x 1 s	removed	Met. & Long. Obj.
1000	1000	60 x 1 s	operative	Long. Obj.
*	—	60 x 5 s	removed	Long. High Z Obj.

* V1 is increased from 0 to the maximum voltage resulting in either the voltage at V or V’ exceeding 600 Vrms or the voltage at Tip or Ring exceeding the dc breakdown.

Notes:
All sources are 60 Hz.

Voltages may be reduced if protection other than carbon blocks is used. See LSSGR.

1 ° Pro. refers to the status of the primary protection.

Table 6. LSSGR ac Power Cross Test, Second Level

Vrms	Res. (Ω)	Duration	1 ° Pro.	Comments
0—300	<3	15 min	removed	Met. & Long.
300—100	<3	5 s	removed	Met. & Long.
100—600	600	60 x 1 s	removed	Met. & Long.
*	—	15 min	removed	Long. High Z

* V1 is increased from 0 to the maximum voltage, resulting in either the voltage at V, V', VT, or VR exceeding 600 Vrms.

Notes:
All sources are 60 Hz.

Voltages may be reduced if protection other than carbon blocks is used. See LSSGR.

Equipment requiring heat coils may use them.

1 ° Pro. refers to the status of the primary protection.

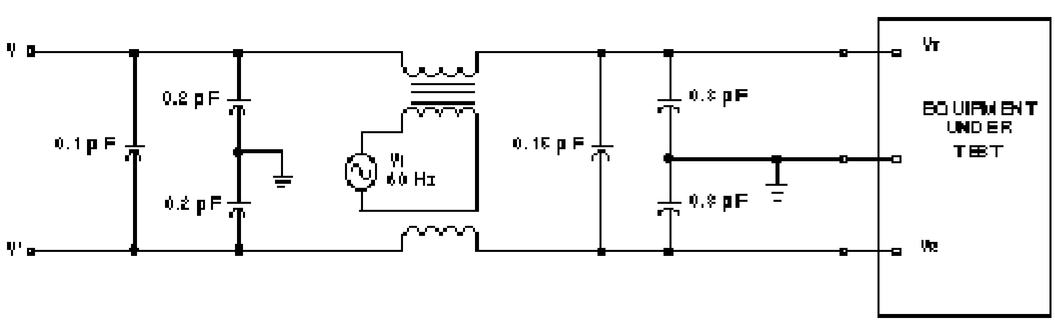

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Figure 6. LSSGR High-Impedance Inductive Test

Standards, Regulations, and Recommendations (continued)

CCITT Recommendations [31]

The following information was extracted from the CCITT Blue Book, Vol. IX, Series K Recommendations (pages 20—24).

CCITT recommendations K.17, K.20, K.21, and K.22 establish testing methods and criteria for resistibility for telecommunications equipment to overvoltage and overcurrent faults.

CCITT K.17 — Establishes criteria for telecom repeaters.

CCITT K.20 — Establishes criteria for central office or switching equipment powered by a central battery.

CCITT K.21 — Establishes criteria for subscriber termi-nals or equipment that is metallically connected directly to balanced pairs.

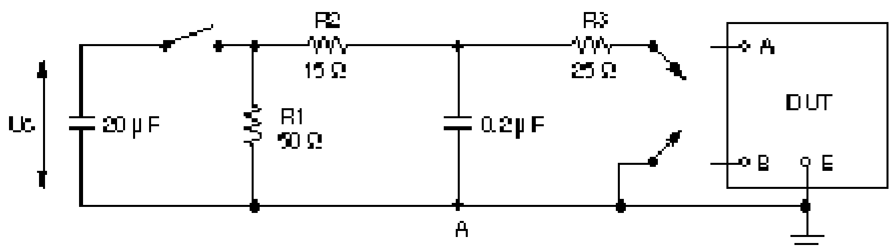
CCITT K.22 — Establishes criteria for local restricted telecommunications equipment.

Like the LSSGR specifications, CCITT standards establish two levels of testing for lightning and power-cross/induction-fault conditions. Criterion A states, "Equipment shall withstand the test without damage or other disturbance and shall properly operate within the specified limits after the test. If specifically approved by the Administration, the test may cause the operation of fuses or other devices that have to be replaced or reset before normal operation is restored." Criterion B states, "A fire hazard should not arise in the equipment as a result of the tests. Any damage or permanent malfunction occurring should be confined to a small number of external line-interface circuits."

CCITT K.20 and K.21 requirements are specified below.

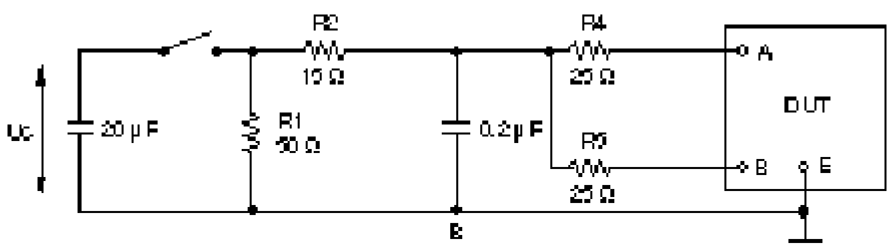
Tests [32]

The test circuits for the overvoltage or overcurrent conditions specified in K.20 are shown in Figures 7, 8, 9, and 10. The test specifications for equipment in an unexposed environment are outlined in Table 7. The test specifications for equipment used in an exposed environment are outlined in Table 8.



12-3100 (C)

Figure 7. Lightning Surge Test (A)



12-3100 (C)

Figure 8. Lightning Surge Test (B)

Standards, Regulations, and Recommendations (continued)

Tests [32] (continued)

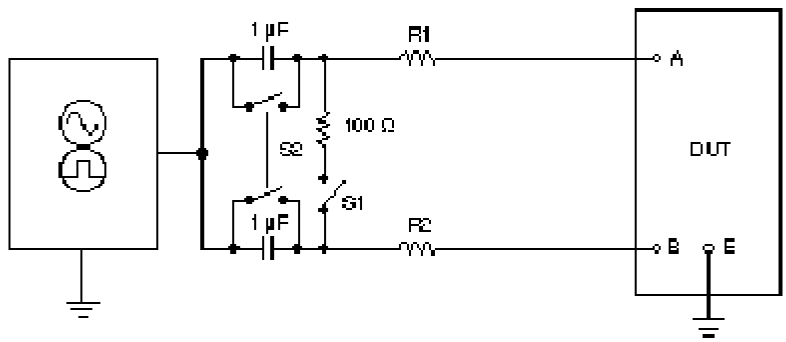


Figure 9. Power Induction Test

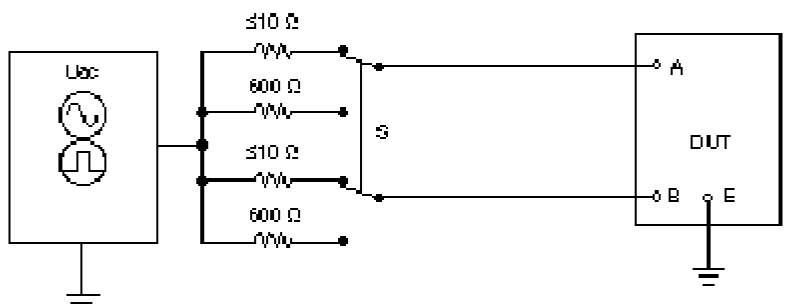


Figure 10. Power Contact Test

Table 7. Test Conditions and Voltages for Unexposed Environments.

Test	DUT Conditions	Test Circuit	Maximum Test Voltage and Duration	Number of Tests	Acceptance Criteria
Lightning Surge	A and E with B at Ground	Figure 7	U_c (max) = 1 kV*	10	Criterion A
	B and E with A at Ground	Figure 7	U_c (max) = 1 kV*	10	
	A + B and E	Figure 8	U_c (max) = 1 kV*	10	
Power Induction	A + B and E	Figure 9 R1 = R2 = 600 Ω Tested with S1 operating and not operating. S2 not operated	U_{ac} (max) = 300 Vrms 200 ms†	5 for each position of S1	Criterion A
Power Contact	A + B and E	Figure 10 Test made with switch in each position‡	U_{ac} (max) = 220 Vrms 15 minutes†	1 for each position of S	Criterion B

* Administration may specify a lower value of Uc (max).
† Administration may specify a lower value of Uac (max) and may vary the duration of the test to meet local requirements (e.g., local mains volt-age).
‡ Heat coils, fuses, fuse cables, etc. may be left in the circuit during these tests.

Standards, Regulations, and Recommendations (continued)

Tests [32] (continued)

Table 8. Test Conditions and Voltages for Exposed Environments

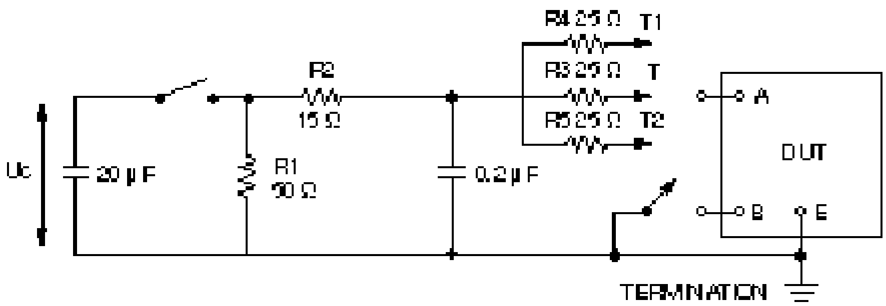
Test	DUT Conditions	Test Circuit	Maximum Test Voltage and Duration	Number of Tests	Added Protection	Acceptance Criteria
Lightning Surge	A and E with B at Ground	Figure 7	U_c (max) = 1 kV*	10	None	Criterion A
	B and E with A at Ground	Figure 7	U_c (max) = 1 kV*	10	None	
	A + B and E	Figure 8	U_c (max) = 1 kV*	10	None	
Lightning Surge	A and E with B at Ground	Figure 8	U_c (max) = 4 kV†	10	Agreed primary protection	Criterion A
	B and E with A at Ground	Figure 7	U_c (max) = 4 kV†	10	Agreed primary protection	
	A + B and E	Figure 8	U_c (max) = 4 kV†	10	Agreed primary protection	
Power Induction	A + B and E	Figure 9 R1 = R2 = 600 Ω S2 operated	U_{ac} (max) = 300 Vrms 200 ms‡	5	Agreed primary protection	Criterion A
Power Contact	A + B and E	Figure 9 R1 = R2 = 200 Ω S2 operated	§	1	Agreed primary protection	Criterion B

* Where the maximum impulse spark-over voltage of the agreed primary protection is less than 1 kV, the Administrations may choose to reduce Uc (max).
† Administrations may vary Uc (max) to meet local requirements.
‡ Administrations may lower values of Uac and vary the period of application.
§ Voltages and durations should be in accordance with CCITT Directives or such other limits that Administrations may set.

Standards, Regulations, and Recommendations (continued)

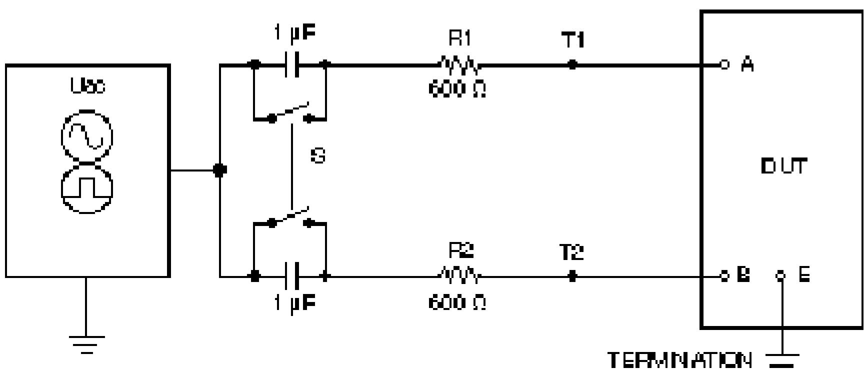
Tests [32] (continued)

The test circuits for the overvoltage or overcurrent conditions specified in K.21 are shown in Figures 11, 12, and 13. The equipment should be tested in accordance with the parameters outlined in Table 9.



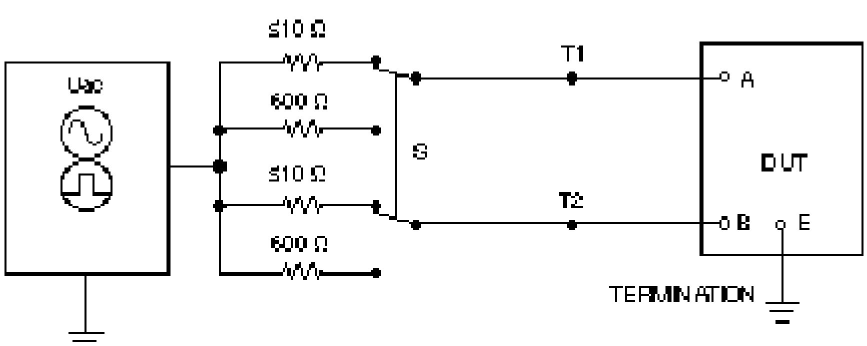
12-3102 (C)

Figure 11. Lightning Surge Test



12-3103 (C)

Figure 12. Power Induction Test



12-3104 (C)

Figure 13. Power Contacts Test

Standards, Regulations, and Recommendations (continued)

Tests [32] (continued)

Table 9. Test Conditions and Voltages for Exposed Environments

Test	DUT Conditions	Test Circuit	Maximum Test Voltage and Duration	Number of Tests	Added Protection	Acceptance Criteria
Lightning Surge	T and A, B, etc. in turn with all other equipment terminals grounded[1]	Figure 11	U_c = 1 kV[2]	10	None	Criterion A
			U_c = 4 kV[3]	10	Agreed primary protection	Criterion A
	T1 and A T2 and B	Figure 11	U_c = 1.5 kV[2]	10	None	Criterion A
			U_c = 4 kV[3]	10	Agreed primary protection	Criterion A
Power Induction	T1 and A T2 and B	Figure 12 S2 not operated	U_{ac} (max) = 300 Vrms 200 ms[4]	5	None	Criterion A
		Figure 12 S2 operated	See Note 5	1	Agreed primary protection	Criterion B
Power Contact	T1 and A T2 and B	Figure 13 Test made with S in each position[6]	U_{ac} (max) = 230 Vrms 15 minutes[4]	1 for each position of S	None	Criterion A

1. An earthed condition may prevent the establishment of normal operation conditions when the test is made. In these cases, alternative testing procedures should be followed to meet the requirements of this test (e.g., a low-voltage spark-gap or other variation in earth connection should be used).
2. Administrations may choose other values of Uc (max) to suit local circumstances, e.g., to avoid the use of protectors or to align with the impulse spark-over voltage of protectors that are normally used.
3. Administrations may vary Uc (max) to meet local requirements.
4. Administrations may specify lower values of Uac (max) and vary the duration of the test to meet their local requirements (e.g., local mains voltages).
5. Voltages and durations should be in accordance with CCITT Directives or such other limits that Administrations may set.
6. Fuses, fuse cables, etc., may be left in the circuit during these tests. The current conducted by wiring shall not constitute a fire hazard within the premises where the equipment is located.

Standards, Regulations, and Recommendations (continued)

Other Standards

Other equipment and telecommunications vendors as well as standards bodies write requirements and suggestions for telecommunications hazard testing. Some standards bodies such as ANSI (American National Standards Institute) and the REA (Rural Electrification Administration) also provide standards for protection devices.

A list of related standards and recommendations for lightning and electrical hazards protection is included in the References section.

Protective Devices

Protection devices fall into two broad categories: cur-rent limiting and overvoltage protection. Current limiting is primarily important in longer duration faults in which ohmic heating can result in a fire hazard or can damage thermally sensitive components. Overvoltage protection is intended to prevent the protected equipment from being exposed to voltages in excess of its dielectric isolation capabilities which could in turn cause high currents, arcing, and other potential hazards.

Current Limiters

A fixed resistor is rarely an acceptable current limiter in telephony applications. Generally, some active element is required which is low resistance in normal operation and high resistance in fault states. The ultimate exam-ple of this is an ideal fuse which is low impedance when the current is below the rated current and infinite when the current exceeds the rating.

Positive Temperature Coefficient (PTC) Devices

PTC devices that are useful for current limiting have a dramatic resistance change with temperature when the operating temperature is exceeded. Most current-limit-ing PTCs can change their resistance several orders of magnitude within a very small temperature gradient. As current increases, the Joule heating increases as the square of the current, thus making the transition to the nonconducting state even more accentuated. Two common variants of protection PTCs are polycrystalline titanate ceramic thermistors (thermal resistors) and conductive-polymer PTC devices.

It should be be noted that unlike varistors and gas discharge tubes (GDT) there are no standards at this time specifically for PTCs used for surge protection. They should applied to make the entire piece of equip-ment comply with the overall performance and hazard protection standards.

Since all PTC devices rely on thermal effects to oper-ate, ambient temperature is a consideration in their use and impacts performance. Furthermore, the trip times in all PTCs are determined by heating of bulk materials and, hence, are relatively long (milliseconds to sec-onds) and related to the amount of thermal energy imparted to the component (i.e., the area under the I versus t curve). Large fault currents cause more rapid transition to the nonconducting state.

PTC Thermistors

PTC thermistors are resistors made of a doped poly-crystalline titanate ($BaTiO_3$) ceramic material which has a very high positive temperature coefficient. Microscop-ically, the material looks like grains of sand held together in a uniform substrate.

The very steep slope in the resistance versus tempera-ture curve results from the interaction of grains of individual crystals within the material. The bulk resistance of the material is a function of the potential gradient which can be developed across the crystal's grains which is, in turn, limited by the dielectric constant of the surrounding material. Below the Curie point, Tc (124 °C in pure $BaTiO_3$), the material has a low dielec-tric constant, Er, which allows only low potentials to develop, resulting in low resistance. Above the Curie point, the dielectric constant rises precipitously, allowing increased potentials and increased resistance. This phenomenon is referred to as Mosote catastrophic depolarization and is described by the Curie-Weiss Law:

$$Er = \left|\frac{Beta}{T - Tc}\right|$$, Beta is the Curie constant.

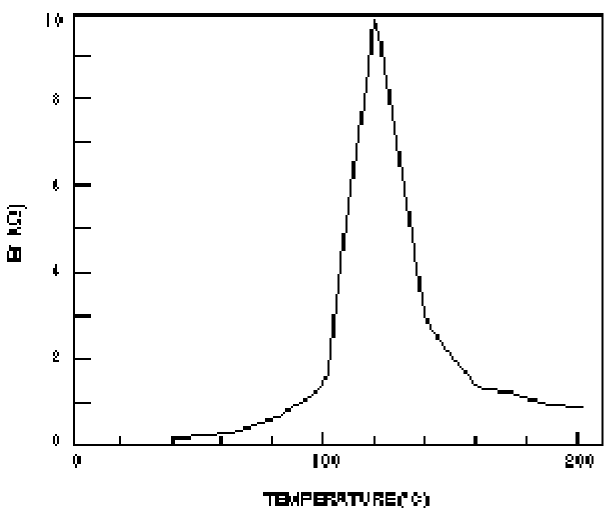
When the overcurrent event subsides, the thermistor will cool and return to the conductive region.

Protective Devices (continued)

Current Limiters (continued)

PTC Thermistors (continued)

Ceramic thermistors have a practical limitation that must be considered. Figure 14 is a plot of the Curie-Weiss expression for a reasonable set of parameters. Above the Curie point, the slope of the Er versus tem-perature curve becomes negative and, consequently, the ceramic thermistor enters a region which exhibits negative temperature coefficient (NTC) behavior. This means that if the stresses are severe enough to result in ohmic heating above the Curie point, the ceramic PTC will return to a conductive state and no longer pro-vide protection and may result in the destruction of the component. These effects are detailed in the thermistor manufacturer's literature.



12-3373 (C)

Figure 14. PTC Dielectric Constant vs. Temperature

PTC Polymer Devices

Polymer PTCs use carbon particles in a nonconducting polymer as the charge carriers. At normal operating temperatures, the carbon particles are physically close and offer only minimal resistance to current flow. As the temperature increases, a state change in the polymer occurs which results in isolation of the particles and resistance increases. When the fault is removed, the normal operating load may not allow the polymer PTC to return to the conductive region. This latching effect is distinctive from thermistors but is generally not an important consideration in subscriber loops since the on-hook state removes all current from the circuit.

A polymer PTC when overstressed will fail by oxidizing the polymer matrix which results in a nonconductive state. Unless contained, this can result in soot being discharged from the device. They do not exhibit an NTC phenomenon.

Heat Coils

Heat coils are very time-honored current-limiting components that find little application in new secondary protection designs. Heat coils are comprised of metals which have a positive temperature coefficient that reach a power-limiting thermal equilibrium when large currents are carried. In this sense, heat coils are very similar to electric lamps.

Fusible Conductors

Fusible links operate when sufficient thermal energy has been absorbed by the conductor so that the metal undergoes a change of state (i.e., melts), opening the circuit. Like PTC devices, fuses require bulk heating and their operation time is related to the area under the I^2 versus t curve. These fuses may take the form of conventional metallic fuses or resistors that are designed to open under fault conditions.

All fusible elements have the obvious disadvantage of requiring a service call to replace them. In the case of secondary protection, this is further complicated in that the circuit pack containing the failed fuse may be pro-viding service for a large number of subscribers, all of whom will lose service during the maintenance period.

Overvoltage Protection

Simplistically, components exposed to voltages in excess of their design maximums can fail in one of two ways. They can fail open which increases the terminat-ing impedance and enhances the potential for arcing and igniting any flammable substance. They can also fail short-circuited, allowing large fault currents to flow which presents a fire hazard through ohmic heating in both the equipment and the associated wiring. It is important, then, to provide protection which ensures that the protected components operate within their design limits for safety as well as operational reasons.

There are two responses to overvoltage stress that protection devices commonly take: foldback (crowbar) and foldover (voltage limiters). Foldback overvoltage protectors become very low impedance in the pres-ence of overvoltage, effectively shunting all of the fault current. Foldover protectors pass only the current nec-essary to limit the voltage to the maximum allowed. Foldback devices are typified by PNPN devices and GDTs while foldover devices are commonly metal oxide varistors (MOV) and Zener diodes.

Protective Devices (continued)

Overvoltage Protection (continued)

Varistors

Varistors are symmetrical voltage-dependent resistors in which the resistance decreases as a function of volt-age. The V/I characteristics of a varistor are reasonably well approxi-mated by the following exponential law:

$I = kV^{\alpha}, \alpha > 1$

where k is a constant determined by the geometry of the device and α is constant for a given material. It fol-lows that the resistance and power dissipation are:

$R = V^{(1-\alpha)}/k$

and,

$P = kV^{1+\alpha}$

These three curves are shown in Figure 15.

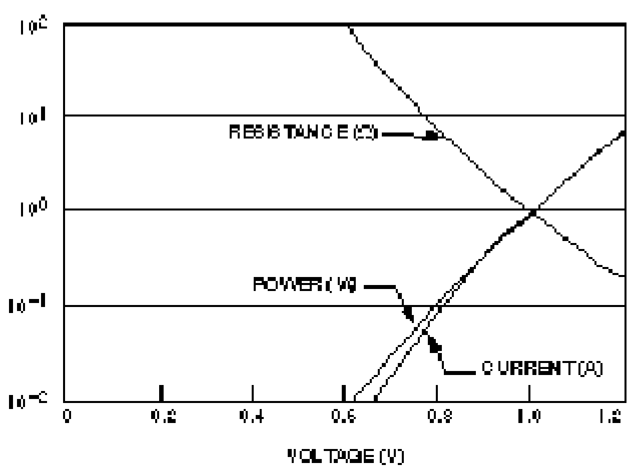


Figure 15. Varistor Characteristics (α = 10)

It is apparent that there is no clearly delineated voltage at which the varistor transitions from a nonconductor into a conductor (plotting on semilog coordinates accentuates this). This lack of a definitive threshold voltage requires that the designer be cognizant of the fact that the varistor is always conducting some amount of current and guard against plac-ing the threshold too low.

A second important observation is that the power the varistor is required to dissipate increases dramatically with voltage. Therefore, during prolonged low-imped-ance fault condi-tions (e.g., power cross) some means of limiting the current to the varistor is generally neces-sary to prevent the destruction of the device.

There are four general categories of varistors, of which only two see much general use: silicon carbide varistor, selenium elements, metal oxide varistors (MOVs), and Zener diodes. Silicon carbide varistors have only mod-est nonlinearity ($\alpha \sim$ 5) which limits their use to only very high voltage; that is, a current rise of 1 mA to 10 A can require a voltage rise of 1000 V. Selenium ele-ments have larger exponents ($\alpha \sim 10$); however, they are asymmetrical necessitating two devices for bilateral protection. Also, the maximum current density of 2.5 A/cm^2 makes the devices physically large.

MOVs have much greater nonlinearity ($30 < \alpha < 70$) which makes them more useful at the lower protection voltages used in telephony and sharpens the knee towards a more ideal characteristic. Zener diodes have an even larger expo-nent ($40 < \alpha < 100$), but somewhat less current carrying capacity, and like selenium ele-ments must be used in pairs for symmetric protection. MOVs and Zener diodes are con-sidered in more detail in the following text.

Metal Oxide Varistors

MOVs are similar in construction to a plate capacitor where the dielectric is replaced with sintered zinc oxide grains mixed with several other metal oxide additives. The ZnO grains are highly conductive while the inter-granular matrix consisting of other oxides is highly resistive. The interfaces between individual ZnO grains form elements comparable to symmetrical Zener diodes ($V_Z \sim 3.8$ V) which are series con-nected between the plates of the MOV. By controlling the size of the grains and the geometry of the matrix, various electrical parameters can be optimized. Controlling the dis-tance between the plates and the size of the grains deter-mines how many of the grains are in series and, therefore, the operational voltage. The statistical spread of the place-ment of these grains softens the knee of the V/I curve. Mak-ing the area of the plates larger increases the number of strings of grains avail-able to carry the current and relates to the resulting maximum power dissipation.

This scattering of the individual microvaristors through-out the body of the MOV also accounts for its high-power han-dling capacity compared to similar semicon-ductors. Whereas the power dissipation of semicon-ductor devices occurs exclusively at the p-n junction, a relatively small por-tion of the active material, MOVs distribute the heat almost uniformly throughout the device.

Protective Devices (continued)

Overvoltage Protection (continued)

Metal Oxide Varistors (continued)

The construction of the MOV, not surprisingly, creates a relatively large parasitic capacitance that is roughly proportional to the power handling capacity of the MOV (i.e., plate area). This capacitance can typically range from 60 pF to 5000 pF and can contribute to high-fre-quency transient suppression but can also affect voice frequency performance.

Two additional nonideal characteristics of MOVs deserve mention: deviation at high and very low cur-rents from the exponential V/I equation and finite response times. At both low- and high-current extremes, the actual V/I curve softens with respect to the exponential curve. That is, the apparent $\propto$ reduces at these currents causing the MOV to change in behav-ior becoming less of an ideal protection device. This results in decreased current flow (and higher voltages) in the protection region and increased current flow (with decreased resistance) in the lower regions of nor-mal operation. In practice, the high voltage/current characteristics of MOVs can limit their use in primary protection where voltage stresses may be very large. Of further practical significance, the low-voltage char-acteristics can present a load at normal operational voltages which needs to be evaluated.

The finite response time of MOVs permits a voltage overshoot in faults with a large dV/dt. This overshoot may significantly impact the protection of sensitive components and requires consideration.

Zener Diode

Every semiconductor diode has a breakdown region in the reverse-voltage characteristic. Diodes which are designed with adequate power dissipation properties in the breakdown region may be operated as voltage-lim-iting devices. There are two physical mechanisms responsible for the breakdown phenomenon which are of practical interest: avalanche multiplication and Zener breakdown.

In avalanche multiplication, a thermally generated car-rier acquires enough energy from the applied potential to disrupt a covalent bond when colliding with a crystal ion. The new hole-electron pair may in turn be acceler-ated sufficiently to displace additional carriers causing a chain reaction resulting in large currents.

Zener breakdown relies on the existence of a suffi-ciently intense electric field at the p-n junction to cause an electron to be torn out of its covalent bond. The resulting hole-electron pair increases the reverse cur-

rent without involving avalanche multiplication. In order to attain the high field gradients (~2 x 10^7 V/m) required for this effect to occur at low voltages, heavy doping is necessary to increase the dielectric isolation. When diodes are lightly doped to increase the breakover voltage, avalanche multiplication may become the predominant mechanism. The term Zener diode is commonly applied to diodes designed to operate in the breakdown region regardless of the actual physical mechanism of action.

When using Zener diodes in protection applications, where power dissipation can be high, temperature-related effects become significant. Temperature coefficients of Zener diodes vary depending on processes used but are generally in the range of ±0.1%/°C. One of the few practical considerations related to the break-down phenomena is that avalanche multiplication results in a positive temperature coefficient while true Zener effects produce a negative temperature coeffi-cient. Hence, for diodes with reference voltages above approximately 6 V (where avalanche multiplication pre-dominates and where there is the greatest interest for protection applications), a positive temperature coeffi-cient of ~0.1%/°C should be expected.

The dynamic resistance (also called Zener impedance) is the inverse of the slope of the I/V curve in the break-down region or,

$$rz = \frac{(dVz)}{dIz}$$

The ability of the Zener diode to limit the overvoltage condition to the reference voltage is strongly depen-dent on the size of the dynamic resistance. When ana-lyzing the response to pulse overvoltage stresses, it is sometimes convenient to combine the complementary effects of dynamic resistance and temperature coeffi-cient into a single factor. The so-called clamping factor is used to estimate the peak voltage resulting from pulses of arbitrary duration of similar energy
(Watt-sec). That is,

$$Vpeak = Fc \bullet Vz$$

This approximation relies on the observation that in high-power, short duration pulses, the Izrz voltage rise predominates while in longer, lower-power pulses, the temperature-induced increase in the reference voltage is more significant. A reasonable value for Fc for refer-ence voltages greater than 12 V is about 1.25.

The capacitance across a Zener diode varies as the inverse of some power of the voltage. Furthermore, the capacitance generally increases with power ratings due to the larger cross-sectional areas required. Practi-cal protection Zeners have capacitance in the 100 pF to 10,000 pF range.

Protective Devices (continued)

Overvoltage Protection (continued)

Zener Diode (continued)

Zener diodes are asymmetrical varistors and must be used with additional circuitry to provide complete pro-tection. This may be accomplished by using two devices back to back which may be physically pack-aged together, or by placing a single Zener diode in a diode bridge to provide bilateral protection.

Foldback Overvoltage Protection

Foldback devices (also referred to as crowbar devices) bring the point of protection to a low voltage when an overvoltage event occurs. These devices are the tradi-tional network protection and (at least in theory) increase the stress on overcurrent protection by increasing the voltage across these components. The components discussed below are gas discharge tubes, carbon blocks, and thyristor-type devices.

Gas Discharge Tubes

Gas discharge tubes (GDTs) use an electric arc to shunt current from overvoltage conditions. An arc will ignite in a gas whenever the electric field intensity is great enough to ionize the gas to provide charge carri-ers. This phenomenon allows the sudden transition of the gas from an exceptional insulator (>10 G¾) to a very low resistance conductor (<0.1 ¾) in the span of a few volts and nanoseconds. Lightning is a common example of these principles in practice within the atmosphere. The construction of GDTs is such that the envi-ronment within the tube is well controlled to produce highly predictable operation. The GDT is typically a small cylinder which rigidly holds a pair of insulated parallel electrodes less than 1 mm apart. The atmo-sphere between the electrodes is a rare gas (usually neon or argon). The electrodes are treated with an acti-vating compound which enhances the ability of the GDT to discharge and reduces electrode damage resulting from operation. An ignition aid on the insulator can be used to cause field distortions which improve the response times. The striking voltage and current carrying capabilities of the GDT can be controlled by electrode geometrics, gas pressure, and activating compound chemistries; however, the arc voltage (after ignition) is nearly independent of these parameters.

The voltage at which ignition occurs (the striking volt-age) is a strong function of the rate of change of the voltage waveform. For example, a GDT which ignites at 100 V with a 500 V/ms dV/dt may not ignite until 400 V in the presence of a 100 V/ms transient. In prac-tical terms, this means that a GDT will perform dramatically differently in response to lightning versus power cross hazards.

After ignition, the GDT provides a very high current path (>500 A) at the arc voltage which is generally less than 30 V. The GDT will remain in this state until the applied voltage is reduced below the minimum arc volt-age or the current is limited below the extinction value. This latching effect means that consideration must be given to the extinction characteristics when a GDT is used for circuit protection. That is, if a voltage transient results in the ignition of the device and the normal operating voltages and impedances prevent extinction, the GDT will not recover from the fault condition and may ultimately fail. Especially in the power cross set-ting, current limiting is usually necessary to protect the GDT from currents in excess of its maximum follow-on current which is frequently much less than the maxi-mum permitted surge current.

Capacitance of GDTs is generally in the low picofarad range, and leakage currents are insignificant. A com-mon concern in the use of GDTs is that they can be expected to fail after a finite number of surges have been absorbed. Furthermore, failure generally causes an elevation of the ignition voltage resulting in expo-sure of the protected circuit to higher voltage stresses with attendant hazards.

Carbon Block Overvoltage Protection

Carbon block overvoltage protectors have been in the network practically from the first installations. Carbon blocks have traditionally been the primary protection, with and without heat coils and GDTs, at the network interface (NI) and at the main distribution frame (MDF) in the central office. For this reason, many of the over-voltage attenuation characteristics on which secondary protection stress models are predicated result from field experience with carbon blocks.

The physical principles by which carbon blocks operate and their inherent limitations are very similar to those of GDTs. The standard 3-mil carbon block, so called because of its 0.003" (0.076 mm) interelectrode gap, is the prevalent primary protection in the network. These protectors are relatively unpredictable in breakdown voltage distribution, requiring that the design break-down voltage be somewhat higher than other protectors to prevent distortion of ringing. As would be expected, ignition voltages at power frequencies are lower.

A sample of unused carbon block protectors exposed to a 1200 V (open circuit), 10/1000 µs sawtooth wave-form [9] resulted in an approximately normal distribution of breakdown voltages with a peak voltage of 1200 V, a median of 700 V, and 3 σ points of 400 V

Protective Devices (continued)

Overvoltage Protection (continued)

Carbon Block Overvoltage Protection (continued)

and 1000 V. A similar study using a 60 Hz generator produced a distribution with a median of 500 Vpeak, 3 σ points of 240 Vpeak, and 800 Vpeak.

As with GDTs, carbon blocks incur some physical dam-age from arresting surges resulting in an increase in their breakover voltages with age. Carbon blocks like-wise can fail in the open-circuit state, leaving the circuit effectively unprotected.

Thyristor-Type Overvoltage Protection

As the capabilities to implement sophisticated line interface features in integrated circuit technology have evolved, so has the ability to address the more strin-gent protection requirements. Solid-state protectors have provided an important alternative to overvoltage protection. These components are available from multi-ple vendors under various trade names but with little in the way of consistent generic terminology.

Trade names include *Surgectar**, *Sidactor*†, and LB1201 SLIC Protector (Zarlink). These monolithic protection devices consist of one or more SCR-type thyristors where the gate region contains an additional diffused section which acts like a Zener diode. This voltage reference on the gate provides the trigger voltage at which the thyristor fires to provide a low-impedance path for fault currents. While the pro-tected circuit is within the normal operating range, the thyristor allows virtually no leakage current. These devices are available with unidirectional and symmetri-cal operation as well as with multiple devices per pack-age. Symmetrical operation is more useful in telephony where the polarity of the overvoltage insult is arbitrary. A single symmetrical component across Tip and Ring can be used to protect telephone equipment which is isolated from ground (e.g., station sets and modems). In line circuits where the battery feed has a path to ground, a three-terminal version is useful. In these, there are effectively three independent devices in a Y configuration, each with a protection voltage at 1/2 of the design maximum. The three terminals connect to Tip, Ring, and protection ground. Therefore, a metallic overvoltage surge will cause at least the two protectors between Tip and Ring to foldback, controlling the differ-ential voltage. Overvoltages impressed longitudinally will be shunted by the device in the ground leg in com-bination with one or both of the others, thus protecting the battery feed circuits.

Like the GDT, the thyristor-type protector remains in the conducting state as long as current flows in excess of the holding current, typically less than 300 mA. The holding current has a strong temperature dependence; when normalized to 20 °C, holding current at –40 °C may be 1.7 nominal, while at 80 °C it may fall to 0.7 nominal. When the device is conductive, the volt-age across it is determined by the saturation voltage of two or more p-n junctions and is hence extremely low compared with the ignition voltage of a GDT and is generally less than 2 V. This, in turn, allows the protec-tor to pass very large currents with little thermal stress. Thyristor-type protectors have the additional advantage of very fast response times (a few nanoseconds) with minimal dV/dt sensitivity. In the range of 100 V/µs to 10,000 V/µs, the breakover will typically increase by 10%—15%. Breakover voltage has a positive tempera-ture coefficient reflecting the characteristics of the Zener diode voltage reference and is in the range of 0.14%/ °C.

Capacitance is approximately negatively exponential with respect to voltage. At low voltages, the capaci-tance may be 200 pF while at 200 V, falling to 30 pF. The capacitance at any voltage tends to be greater for higher breakover voltage ratings.

In contradistinction to GDTs, thyristor-type protectors do not demonstrate any significant aging or damage from repetitive surges that are within the design param-eters. Also overstress causes the protector to usually fail in a low-impedance state rather than open, as is typical of GDTs. This fail safe mode offers three distinct advantages: overvoltage hazards cannot propagate further into the equipment, overcurrent will cause oper-ation of fuses or similar protection removing the threat, and the operation of the telephone equipment will fail causing a maintenance action and making part 68 compliance easier.

* *Surgectar* is a trademark of Harris, Inc.
† *Sidactor* is a trademark of Teccor, Inc.

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