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PROTECTION AGAINST INTERFERENCE

SELECTION OF PROTECTIVE DEVICES

ITU-T Recommendation K.36

(Previously "CCITT Recommendation")

FOREWORD

The ITU-T (Telecommunication Standardization Sector) is a permanent organ of the International Telecommunication Union (ITU). The ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

The World Telecommunication Standardization Conference (WTSC), which meets every four years, establishes the topics for study by the ITU-T Study Groups which, in their turn, produce Recommendations on these topics.

The approval of Recommendations by the Members of the ITU-T is covered by the procedure laid down in WTSC Resolution No. 1 (Helsinki, March 1-12, 1993).

ITU-T Recommendation K.36 was prepared by ITU-T Study Group 5 (1993-1996) and was approved under the WTSC Resolution No. 1 procedure on the 8th of May 1996.

NOTES

1. In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

2. The status of annexes and appendices attached to the Series K Recommendations should be interpreted as follows:

- an *annex* to a Recommendation forms an integral part of the Recommendation;
- an *appendix* to a Recommendation does not form part of the Recommendation and only provides some complementary explanation or information specific to that Recommendation.

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SELECTION OF PROTECTIVE DEVICES

(Geneva, 1996)

1 Introduction

The increasing need for protection of telecommunication equipment against overcurrents and overvoltages has resulted in the development of a number of new protective components and elements. Recommendations K.28 for Solid State Arrestors (SSA) and K.30 for self-restoring, current-limiting devices specify the electromagnetic characteristics and test methods for such components. Recommendation K.12 deals with characteristics of Gas Discharge Tubes (GDTs).

The purpose of this Recommendation is to provide information about the application of new devices in the different parts of a telecommunication network. It is intended to guide protection engineers and manufacturers of equipment to select appropriate protection devices for a telecommunication system.

It should be noted that the implementation of protective devices in a communication system is only one of several methods to mitigate transient overvoltages. By using an efficient shielding and bonding technique the need of protective components may be significantly reduced.

2 Scope

This Recommendation gives guidance on the selection of protective components and assemblies in a telecommunication network. It deals with the protection of telecommunication equipment, subscriber's installations and cable plants exposed to overvoltages and overcurrents due to lightning discharges or power faults. Interferences from discharges of static electricity (ESD) and Electrical Fast Transients (EFT) are also considered as far as it may cause permanent damages to equipment.

3 Definitions

For the purposes of this Recommendation, the following definitions apply.

3.1 surge protective device (SPD): A device that is intended to mitigate surge overvoltages and overcurrents of limited durations. It may consist of a single component or have a more complex design, where several functions are integrated. It contains at least one non-linear component.

3.2 primary (or extrinsic) SPD: An SPD capable of diverting or arresting a considerable portion of the surge energy away from the system it is protecting. They are generally installed at the cable entrance to a building, on the MDF or at the equipment/cable interface.

3.3 secondary (or intrinsic) SPD: An SPD capable of handling lower energy surges than a primary SPD, that may be used without a primary SPD in less vulnerable situations, but acts in such a way as to remove residual surge energy that the primary let through. In the majority of cases they are part of the equipment being protected (intrinsic), but can be incorporated as part of a protection module (secondary).

For further definitions about SPD characteristics, see Recommendations K.12, K.28 and K.30.

4 Characteristics of protective components

Protective devices are usually divided into overvoltage and overcurrent elements. They may consist of single components or more complex devices, where several functions are integrated.

There are basically two types of overvoltage components: voltage switching and voltage limiting devices.

A switching component has a discontinuous current-voltage characteristic (e.g. a gas discharge tube). A voltage limiting device limits the voltage to a specified level and has a continuous current-voltage characteristic (e.g. a zener diode).

The aim of such components is to protect equipment against surges of short duration by limiting the voltage and diverting the current. They are shunt connected with the equipment to be protected.

Overcurrent protective devices are divided into resettable and non-resettable components. The aim of such components is to protect the equipment against long duration overcurrents. They will open the circuit or attenuate the current by going to high resistance. They are put in series with the equipment or elements to be protected.

Hybrid protective elements comprise different components that are integrated in assemblies, which fulfil more complex protection functions. Depending on their design they may be shunt, series or a combination of the two.

Isolating devices are divided into optical insulators and electrical insulators. The aim is to create a total galvanic separation between two parts of a circuit to provide a full electrical immunity for highly exposed equipment.

Tables 1 and 2 summarize the characteristics of typical overvoltage and overcurrent protective components.

TABLE 1/K.36

Characteristics of overvoltage protective components

Devices (operating mode)	Time to operate	Accuracy, voltage	Current impulse capability	Stability of limiting voltage	Max. di/dt	Capa-citance	Normal failure mode	Life time at rated pulse current
GDT (switching)	0.1 µs	20%	Very large	Medium	kA/µs	1 pF	Open circuit	High
Thyristordiode (switching)	0.1 µs	2%	Large	Good	30 A/µs	100 pF	Short circuit	High
MOV (limiting)	1 ns	20%	Large	Medium	kA/µs	500 pF	Short circuit	Low
Zener (limiting)	100 ps	2%	Small	Good	30 A/µs	1 nF	Short circuit	High

TABLE 2/K.36

Characteristics of overcurrent protective devices

Devices (operating mode)	Resistance	Response time at 1 A	Voltage withstand-ability	Resistance stability	Current capability 1 second	Capa-citance	Normal failure mode	Life time
Ceramic PTC (reset)	5-50 ohm	2 s	650 V	Medium	3 A	500 pF	Open circuit	High
Polymer PTC (reset)	2-20 ohm	2 s	650 V	Low	10 A	1 pF	Open circuit	High
Fuse (no reset)	100 mohm	5 s (350 mA fuse)	Not applicable	Good	As specified	–	Open circuit	–
Heat coil (no reset)	1-20 ohm	10 s	650 V	Good	5 A	–	Short circuit	–

For definitions of different components, see Recommendations K.12, K.28 and K.30.

5 Origin of overvoltages and overcurrents

Recommendation K.11 classifies the sources of electrical stress as being:

- direct lightning strikes;
- nearby lightning discharges;
- induction from fault currents in power networks including traction lines;
- direct contacts with mains distribution networks;
- rise of earth potential.

In addition to the above-mentioned threats, there are sources like:

- transients with extreme rate of rise due to electrostatic discharges and bursts related to current switching;
- composite surges combining lightning and a.c. follow-on currents.

6 Strategies for protection of telecommunication systems

It is important for manufacturers and operators of telecommunication systems to consider the level of overvoltage protection in an early state of the design. Disregarding the need of surge protective devices will normally cause excessive costs for additional protection measure, when new equipment has been implemented.

There are different strategies for selection of protective devices depending on the prospective electromagnetic environment for the installation but also on aspects of practicality. It may be convenient for both equipment installers and users to have mobile desktop equipment provided with a complete built-in protection system, able to resist severe interference from lightning discharges. This ensures that the equipment will be independent of any protection measures that may or may not exist at the building or equipment-cable interface.

Permanent installations of telecommunication equipment should be provided with, or at least have the option to be provided with, protective elements at the cable entrance of a building or cabinet. Primary SPDs, installed at the MDF or separate terminal blocks, shall divert surges of high peak current, charge and specific energy. They may consist of single components or more complex hybrid or two-port devices.

Protection against Electrical Fast Transients (EFT) and Electrostatic Discharges (ESD) should always be remembered.

With respect of surges on incoming lines, the resistibility of switching centres, remote sites, etc., might in certain environment rely on high quality primary SPDs with well-specified protection levels, only provided that the telecommunication equipment is placed inside a volume, well-shielded from external fields, and without any internal sources of interference. An advantage with this concept is that future generations of the equipment, or parts thereof in such cabinets, may not require additional test procedures.

Recommendations K.20, K.21 and K.22, for equipment in switching centres and subscriber premises, assume a certain inherent resistibility of the equipment itself. The equipment resistibility level is chosen to meet requirements as defined in Recommendations K.20, K.21 and K.22. In such areas, the need for primary SPDs can be disregarded. However, the electronic circuits should be provided with protection coordinating elements on the line side. This gives the user a flexibility to use the equipment in a harsher EM environment requiring primary protection. See also Recommendation K.11. Recommendations K.20 and K.21 give detailed information of the coordination of protective components.

7 Desirable electrical characteristics

7.1 Normal operation of the system

Under normal operation, SPDs shall have negligible effect on the system transmission, signalling or switching performance.

Voltage SPDs with high capacitance, e.g. varistors, should be carefully matched to avoid unbalance.

The selected SPDs shall be transparent to all relevant signals for transmission, ringing, alarms and for power supply voltage in the telecommunication network.

There should be an operating margin of the protection level with respect to the maximum transmission signals and supply voltage, considering the behaviour of the SPDs within the full temperature range for the equipment to be protected.

At the d.c. voltage of the system, normally –48 V, the SPD shall not load the system at maximum signal and temperature conditions. Some of the special digital services being introduced have d.c. voltages a lot higher than –48 V and account needs to be taken if one protector design is to be used in all situations.

In metallic pair cables the immunity against external interference depends on the balance about earth to the system. This balance must not be disturbed by high and unstable capacitance values of SPDs. The capacitance for varistors and zeners is a function of the applied system d.c. voltage. A good system balance also requires precise and stable values for series resistive components used as coordinating and current limiting devices.

An SPD shall be able to restore to its off-state level after transients or 50/60 Hz overvoltages of limited duration. This parameter is expressed by the holding current of a solid state type SPD or by the hold-over voltage for a gas discharge tube. The holding current level should be chosen for the worst condition at maximum d.c. voltage and different circuit loads. Consideration should also be given as to the maximum current that the equipment can supply to the line.

SPDs shall meet specified climatic requirements for the intended application. Special concern should be given to SPDs placed in cabinets of the outside plant, where the temperature and humidity may vary between extreme values. Bad insulation resistance of SPDs may interrupt or destort the transmission signals.

7.2 SPD operating conditions

SPDs shall have a fast response time. All SPDs respond very fast with negligible time delay. The time delay of gas discharge tubes is generally of less importance for the protection efficiency than its current handling capability.

SPDs used as secondary protective devices shall have a well-defined clamping voltage. The clamping level shall be chosen with respect to the withstandability of the circuits to be protected and to the maximum operating voltage of the system. Generally, there are no advantages to choose the lowest possible clamping voltage. An operating margin to the circuit withstandability will eliminate unnecessary operation of the SPDs, which would repeatedly interrupt the ongoing data transmission.

The SPD shall have a capability to survive the expected single surges without being destroyed. It shall be able to protect circuits against repetitive transients from lightning discharges and induced 50/60 Hz overvoltages for time periods specified in Recommendation K.20.

The selection of suitable characteristics shall also facilitate the coordination with other SPDs upstream or downstream in the system. Coordinating impedances shall resist relevant energy and voltage stresses without degradation.

7.2.1 Voltage switching devices

SPDs used as a primary protection and for the protection of cables in the outside plant are exposed to the highest threat from lightning and from power induction due to earth faults in the power systems. Protective devices containing components with switching characteristics develop less heat during the discharge process than voltage limiting SPDs, due to a low residual voltage.

7.2.1.1 Gas discharge tubes

Gas discharge tubes are the most robust switching component and can survive lightning transients of many kA for a duration of hundreds of μs, and several amperes a.c., for a second or more during a power system fault condition.

The breakdown voltage of gas discharge tubes is sensitive to the voltage rate of rise and may for lightning induced impulses be twice the value for 50/60 Hz overvoltages. A gas tube is, like all spark gaps, a tough SPD with large operating tolerances.

Gas discharge tubes may not be suitable for protection of sensitive circuits inside equipment, due to the weakness mentioned above, but also to its ability to create very fast transients during its breakdown event, that can cause interference in nearby, badly shielded, circuits. They should preferably be used as primary SPDs, especially at highly exposed places like rural installations for subscribers or other remote sites, where their capability to handle large energies is important.

Gas discharge tubes exposed to many greater currents tend to increase their d.c. firing voltage due to electrode erosion, which will increase the gap spacing.

Some gas discharge tubes contain beta-emitting radioactive isotopes in order to minimize the statistical time delay. Such components may conduct extremely fast also at very steep wave fronts. The effect will be reduced after some years depending on the half-life of the radioactive material.

7.2.1.2 Solid state devices (thyristors)

Solid state switching devices are mainly used as secondary protection on printed circuit boards or as part of a hybrid protection unit. SPDs in the thyristor family have lower peak current resistibility compared with gas tubes but can handle some hundreds of amperes for the same surge duration. This current capability may be high enough to accept them as primary protective components at the MDF or elsewhere in rather exposed areas. The development of thyristor type protective devices is proceeding very fast and components also for highly exposed sites like rural subscriber's installations may be available on the market.

Compared with gas discharge tubes, solid state devices have a well-specified breakdown voltage that are independent of the rate of rise of voltage, du/dt.

However, semiconductor SPDs are sensitive to rapidly increasing currents. The simple p-n junctions may develop so-called "hot spots" that increase until they cause burnout of the device.

Thyristor switching devices can be damaged by anode currents with high rate of rise. "Hot spots" may form when the junction area is not given time enough to conduct uniformly.

Thyristor diodes behave in their initial state as a voltage limiting device before switching to a lower limiting voltage takes place. During this transition time, the operating voltage of the thyristor diode is dependent on the di/dt of the surge and can rise to levels significantly above the nominal clamping voltage. This behaviour may be responsible for many unexpected damages on line card circuits. The user of such SPDs should require detailed information from the SPD manufacturer concerning this characteristic.

The switching of thyristors can be initiated in different ways. Thyristors without a gate are self-triggering, i.e. the switching takes place when the anode current is above a threshold value or due to rapidly increasing voltage. The maximum limiting voltage of thyristor overvoltage protectors is set in manufacture: on devices which have a gate terminal the inherent protection level may be lowered by gate control.

Thyristors with a gate can be turned on by applying a pulse created by a voltage drop in a series impedance, often integrated in the SPD.

Thyristors are switched off when the current drops to a value below its holding currents. Too low a holding current will keep the SPD in its on-state causing a latch-up problem.

7.2.2 Voltage limiting devices

Examples of voltage limiting devices are varistors, zener diodes and forward diodes. This type of SPD does not switch to lower voltages in the conducting phase, but limits the overvoltage to a level that is nearly constant for all currents.

7.2.2.1 Varistors

Varistors based on Metal Oxide Material (MOV) are widely used on power supply circuits, where their capability to quench follow-on currents is important. They are also used in telecommunication applications, where some of their characteristics are advantageous, e.g. they do not create short circuits with an excessive di/dt but absorb a high portion of the surge energy at the first moment.

An MOV has an extremely fast response time, below 1 ns, and a very high insulation resistance in its non-conducting state, but tend to have a high capacitance compared to gas discharge tubes.

At excessive current loads, the residual voltage of an MOV increases significantly, which should be considered in the selection of the voltage protection level. However, this character of the SPD also facilitates the coordination with other SPDs and may even eliminate the need for series elements in a protection circuit. In combination with other MOV components, the MOV on the line side of the secondary protection is assumed to divert the major part of a surge, and should have the lower clamping voltage in contradiction with current practices. The lower the clamping voltage the lower the energy developed in a component. This method allows the use of smaller and cheaper varistors for secondary protection.

MOVs should, like other voltage limiting devices, mainly be used as secondary inherent protective components. Used as primary protection the high residual voltage will transfer a large and unspecified part of the surge energy to the secondary protective device. Exposed to excessive currents or a large number of small surges the nominal protection level may decrease. This ageing process must be considered.

7.2.2.2 Zener diodes

Zener diodes are used as secondary SPDs and in applications on printed circuits boards, where its small size and fast response is utilized to protect sensitive integrated circuits. Zeners may operate as a protection element in both forward and backward directions. They are often combined in a back-to-back configuration to create a bidirectional circuit.

Zeners do not degrade in characteristics like varistors and gas discharge tubes but have a much lower capability to handle large surge currents. They have a much more precise voltage threshold than varistors.

7.3 Current-limiting devices

Current-limiting devices shall react to overcurrents of a specified amplitude and duration. They have a slow response time and are not intended to operate on transients, e.g. caused by lightning discharges, since their resetting time may be quite long or even, for fuses, infinite. Their main purpose is to limit failures in the electronic circuits in case of long duration (seconds or more) power induction and contacts with the mains or a d.c. supply bus.

For self-resetting devices the reset time to the original series impedance value of PTC components may be overcome by using a low ohmic value device in series with a wirewound, or similar, resistor to give the necessary total series resistance.

The reset time of an PTC depends on:

- ambient conditions;
- proximity to other components with high temperature;
- time the overcurrent has been applied;
- physical size of the PTC;
- coating material on the PTC.

Due to their sensitivity to heat, PTC resistors can be integrated with an other component to form a hybrid. In those hybrids, the PTC resistors have a strong thermal coupling to the other component. Two such hybrids exist today:

a) Resistor and PTC mounted in series providing:

- faster time to trip for the PTC element;
- better longitudinal balance by using adjustable resistance;
- smaller time to reset.

b) MOV (in parallel) and PTC (in series) providing:

- faster time to trip the PTC element;
- elimination of the heat dissipated in the MOV.

In its high-ohmic state, the device shall be able to withstand overvoltages specified in Table 1/K.20.

PTCs are mounted in series with the line and may, if they are connected upstream of the secondary protection, fulfil the task of coordinating resistances during incoming surges. However, it should be observed that some PTCs have quite high capacitance, which will reduce the impedance for fast transients. PTCs used as coordinating resistances should be stable during a lightning current impulse.

Compared with a normal line fuse, the PTCs have the advantage of being resettable after an excessive voltage event. However, it is important that the components reset to values not differing too much from those measured before the loading. The deteriorated balance in the loop depends on the difference $\Delta R = R_a - R_b$, where R_a and R_b are the values of PTC resistances in the branches a and b. To limit the longitudinal conversion loss the selected PTCs should always be matched. Modern switching equipment may have an ability to automatically compensate for the changed values of the PTCs but usually limited to only a few ohms.

How to calculate the requirements of PTCs thermistors is described in detail in Recommendation K.30, "PTC-thermistors".

7.4 Isolating devices

Isolating devices are used to protect equipment from common mode overvoltages. They are not formally defined as SPDs but may efficiently prevent damages from overvoltages.

Special designed transformers on signal lines can be used to isolate the communication equipment from a network exposed to a potential rise due to faults in high voltage power plants. With an insulation breakdown voltage between the windings of tens of kV such transformers may also resist the majority of lightning induced transients.

Such electrical isolating devices can easily be installed at subscriber installations near power stations or in rural areas with high keraunic levels.

Optical isolating devices provide an insulation of a few kV. Optical isolators and some electrical isolators may have the ability to transfer d.c. signals. Specially designed transformers and optical isolating devices can be used to mitigate low level interferences.

Some electrical isolators have the advantage to be remote powered while optical isolators require mains supply.

8 Failure modes

8.1 Clamping devices

When an SPD is loaded with excessive surges it should always fail safe. An SPD that fails in a transition mode, i.e. with some series resistance, may develop enough heat to cause a fire on a printed circuit board or other surrounding materiel.

Most solid state components fail in a short circuit mode but can change to open circuit mode for long duration currents. This is also the case for MOVs.

There are on the market both gas discharge tubes that fail open and those that fail short circuit. The latter type is intentionally made sensitive to heating that will cause a special metal or insulating compound to melt and bring the electrodes together.

The selection of failure mode depends on the application. Primary SPDs with low surge current capability should fail short circuit to divert subsequent surges and thus protect the equipment or its inherent protective components. The majority of gas tubes, used at an MDF, will resist nearly any short duration current but can be overloaded by continuous currents if signalling lines are in direct contact with the mains. An advantage with the short circuit mode device is that the damage is self-indicating. A disadvantage is a possible need for back-up fusing elements.

Some subscriber equipment, like answering machines or smaller PABXs, are provided with built-in protection, gas tubes or varistors, on signalling circuits. To limit the common mode overvoltage with respect to the low voltage network, the SPDs are bonded to the protective earth inside the equipment. If the SPDs are bonded to the mains live conductors, the short circuit mode shall be avoided, as such failure will jeopardize the personal safety for the user and the telecom personnel working in the outside plant or switching centres.

The d.c. clamping voltage of such SPDs should be set above the maximum peak voltage value of the mains power supply for safety purposes (see clause 10).

8.2 Current-limiting device

Current-limiting devices like fuses, PTCs or resistors that are connected in series with the line, preferably fail in open circuit mode to ensure that the currents are interrupted. It may be necessary in some cases to integrate an alarm indication for vital circuits or to warn of possible dangerous voltages on the line.

9 Location and mounting of SPDs

The efficiency of protective measures depends to a large extent on the location and mounting technique of SPDs.

Generally, short lead lengths are of greatest importance for all SPDs intended to mitigate transients with high rate of rise. Large inductive voltage drops in SPDs connections may easily exceed the breakdown or residual voltage of the protective device itself.

Switching equipment should always be able to tolerate interference in the cable plant of the building induced by internal or external sources such as nearby lightning discharges.

Transients internally created by ESD or activated GDTs are extremely fast. To mitigate such interference the secondary SPDs must possess a fast response time and be well-bonded to an effective screening at the equipment interface. Without a possibility to bond the SPDs to a good screen, the SPDs will have a very limited effect at high frequencies.

Substantial transient overcurrents originating from the external plant should be diverted to earth via the local reference plane by primary SPDs, which should be installed at the outer boundary of the volume to be protected.

SPDs at cable entrances have the task to prevent excessive overvoltages and overcurrents reaching the electronic equipment but also to limit overvoltages inside incoming cables. Thus it is important that cable shields be bonded to the common earth of the SPDs with a wire as short as possible.

10 Safety aspects

SPDs bonded to a low voltage network at the entrance of subscriber’s building or inherent to a customer equipment shall meet electrical requirements given in IEC publication 950 or by national regulations. The aim of the requirements is to prevent injuries caused by unintentional contacts between the a.c. low voltage installation and the circuits in the telecom equipment. Such SPDs shall have a specified minimum d.c./a.c. breakdown voltage to keep the isolation at a safe level.

In the selection of the nominal breakdown voltage, the tolerances of the mains voltage as well as the tolerances of the SPD shall be taken into account. See Figure 1.

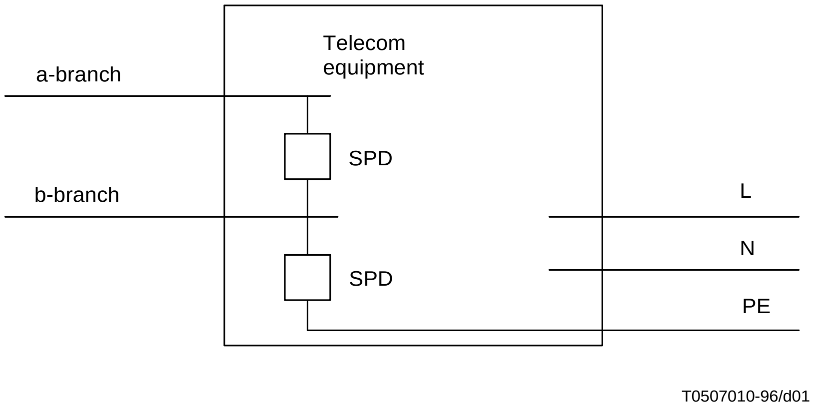

FIGURE 1/K.36

Equipment with inherent protective devices bonded to the internal protective earth (PE)

11 General aspects on costs for installation and maintenance

The need of protective measures should be based on a risk assessment, where the environmental conditions of the particular telecommunication plant are carefully analysed. It should be remembered that the use of SPDs is only one part of the protection and must be properly coordinated with filtering, shielding, earthing and bonding measures.

Maximum accepted costs for total protective measures depend to a large extent on what losses of service can be tolerated, and less on the value of destroyed equipment. However, the costs for the installation of SPDs should be minimized, and include costs for maintenance or replacement.

SPDs mounted in the MDF or at terminal blocks in the outside plant are assumed to be installed for at least a decade and will often survive the equipment to be protected, which may be replaced due to the fast development of transmission techniques. A high product quality of the SPDs will always pay, as the maintenance and control of cheap low-quality devices may be very expensive, especially at remote sites and subscriber installations.