Operation of a thyristor surge suppressor crowbar type protection diode

Introduction

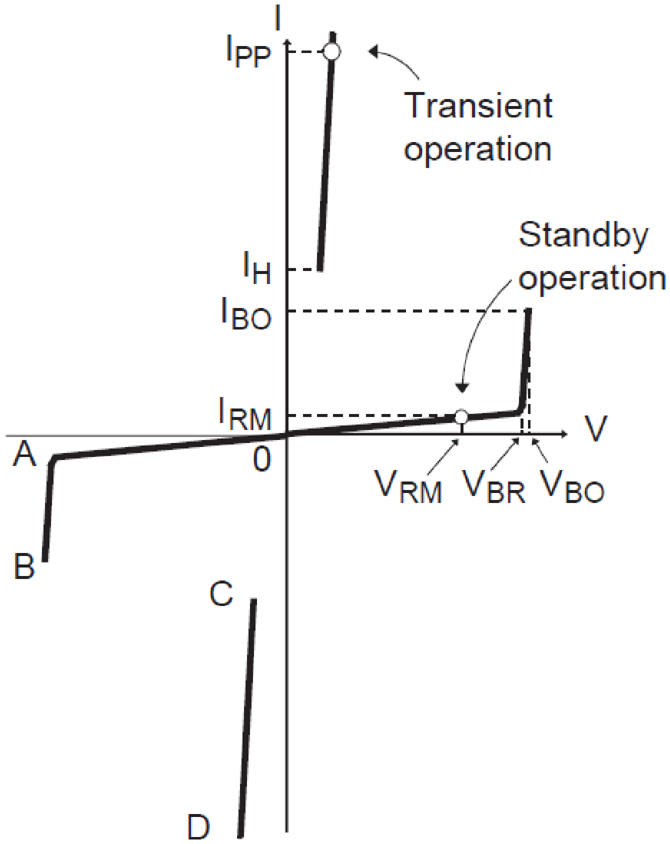
In the field of parallel protection, the devices used have two main functions in transient operation, limit the voltage and divert the surge current.

If the first function is carried out perfectly by an avalanche junction, confirmed by the success of the Transil series, the second is limited by voltage permanently present across the diode terminals.

Use of increasingly sophisticated but fragile electronic components and publication of new standards do not allow the use of Transil diodes in certain applications. This problem is solved by the use of a semiconductor device with two conducting states such as the thyristor (or Triac in the bidirectional version).

This application note describes the operation of the TSS.

Figure 1. I / V characteristic of a thyristor surge suppressor



1 Thyristor surge suppressor (TSS) characteristics (TSS crowbar protection)

1.1 Electrical characteristic

The electrical characteristic of the TSS is similar to a Triac (see Figure 1) except that the component has only two terminals.

Triggering in this case is not done via a gate but by an internal mechanism dependent on the voltage across it and on the current flowing through it.

1.2 TSS operation modes

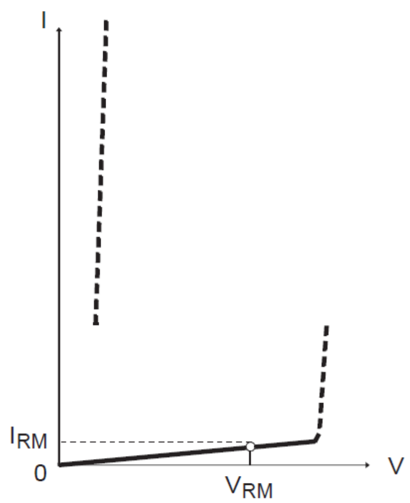
1.2.1 TSS in standby mode

In normal operation, the TSS is biased at a voltage lower than or equal to the standby voltage (V_{RM}). At that point of the characteristic, the leakage current I_{RM} is about 10 nA and the presence of the thyristor surge suppressor connected across the equipment to be protected does not disturb its operation (see Figure 2).

The characteristic data at this point includes:

- Leakage current
- Electrical capacitance (C)
- Reliability of the component in blocking mode

Figure 2. Standby characteristic

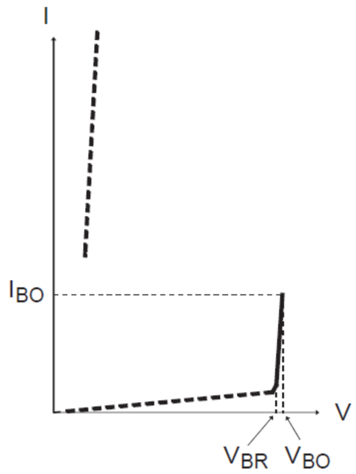


1.2.2 TSS in avalanche mode

As the voltage increases beyond V_{BR} breakdown voltage, the thyristor surge suppressor impedance drops. The TSS remains biased at its avalanche voltage and its operation is then identical to that of a Transil diode (see Figure 3).

The characteristic parameters at this level are the limiting voltage (breakover voltage of the component, V_{BO}) and the time for switching between the blocked and conducting states.

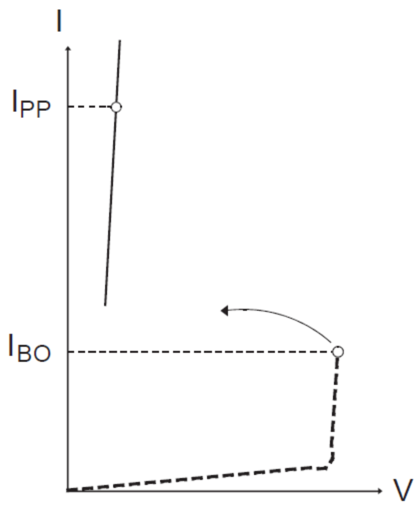
Figure 3. **Avalanche characteristic of the TSS**



1.2.3 Thyristor surge suppressor in triggering mode

For voltage values higher than V_{BO} and current values higher than I_{BO}, the voltage across the TSS drops to a few volts and the high currents permitted without damage are possible due to the low value of this voltage, since the physical limit is dependent on the dissipated power (see Figure 4).

Figure 4. **Triggering, and on-state characteristics**



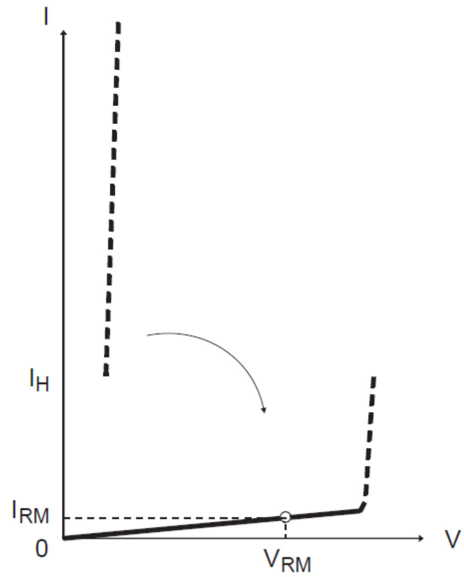
The characteristic parameter is then the possibility of withstanding surge currents (peakpoint current, I_{PP}).

Another electrical parameter is I_{FS} (fail-safe current): it is the maximum current for which the TSS acts as a short-circuit and then well protects the down stream equipment.

1.2.4 Switching-off of the thyristor surge suppressor

Return to standby operation by turning off the TSS takes place when the current flowing through it drops below IH(holding current). This is the characteristic parameter for switching from the conducting to the blocked state (see Figure 5).

Figure 5. Return to standby operation



1.3 Thyristor surge suppressor (TSS crowbar protection) benefit versus avalanche diode

The temperature rise within the semiconductor is the parameter which defines the behavior of the component and its capacity to withstand current surges.It is given by Eq. (1):

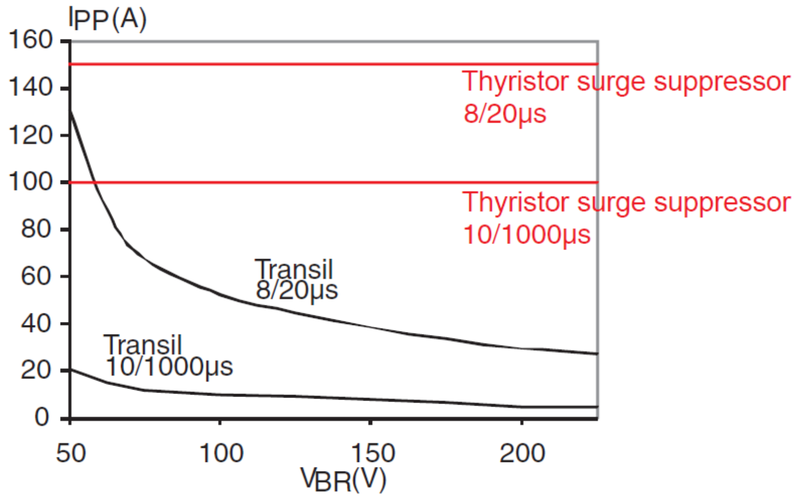
$$T_J = T_A + Z_{TH} \times V_{ON} \times I_{RS} \tag{1}$$

With:

- T_j: instant temperature at the junction level
- T_A: ambient temperature
- Z_{TH}: transient thermal impedance (as a function of the duration of the pulse)
- V_{ON}: voltage across the terminals of the component in the conducting state
- I_{RS}: transient current flowing through the component

This Eq. (1) clearly shows the advantage of the TSS. A voltage decrease across its terminals enables it to conduct a much higher current than the avalanche diode for the same junction temperature. Since the voltage to be taken into consideration for the calculation is the one in the conducting state, the permitted current levels in transient operation are independent of the avalanche voltage and the guaranteed values are identical for all the types of a given series (see Figure 6).

Figure 6. **Comparison of the limited transient currents for a Transil and a thyristor surge suppressor in the similar cases (SMB)**



This high current capacity can be applied in AC operation at the 50 Hz industrial frequency,which is particularly interesting in telephony where equipment should be protected against overvoltages resulting from accidental coupling of the telephone line with the power distribution network. This type of protection is required by certain standards used in telecommunications.

While I_{PP} specifies the current capability of the TSS for short duration surges (8/20 µs,10/1000 µs pulses), the I_{TSM} parameter corresponds to its current capability for surges longer than 10 ms.

1.4 Operation within the avalanche area

This section concerns the segment V_{BR} - V_{BO} (see Figure 3) of the TSS characteristic between the blocked state and the conducting state at low V_{ON}.

This portion of the characteristic is the same one as an avalanche diode. The currents are limited depending on the possibilities of junction to ambient air heat dissipation. The maximum current is defined by the following:

$$\mathrm{T_J} = \mathrm{T}_A + R_{TH} \times V_{BO} \times I_{MAX} \leq T_J \mathrm{max.} = 150°C \tag{2}$$

The condition when the TSS is not triggered is defined as follows:

$$I_{MAX} < I_{BO} \tag{3}$$

The main differences from Eq. (1) are:

- Maximum junction temperature which is the T_j max. value, i.e. 150 °C
- Voltage in the avalanche mode
- R_{TH} (i.e. in steady state) replaces Z_{TH} (i.e. in transient state)

In AC operation, the voltage-current diagram as a function of time is shown in Figure 7.

The value of the breakover current (I_{BO}) plays an important part in the capacity of the device in avalanche operation. If this value is high (see Figure 8,case A), the current in the component must be limited by a suitable series resistor. For lower values, avalanche operation takes place without destruction whatever the external circuit.

Figure 7. AC operation in the avalanche mode

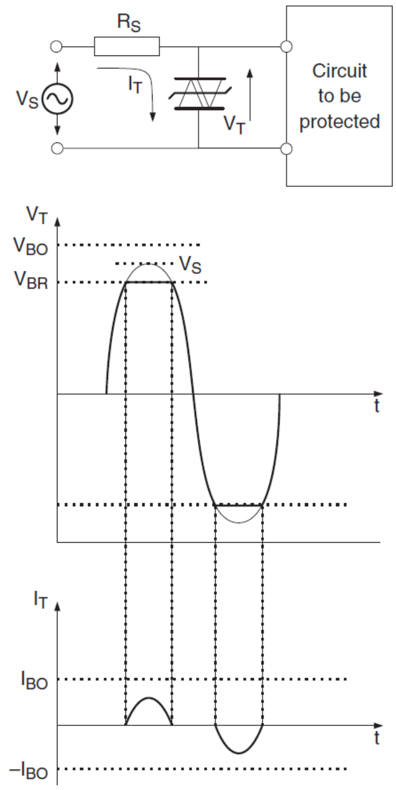
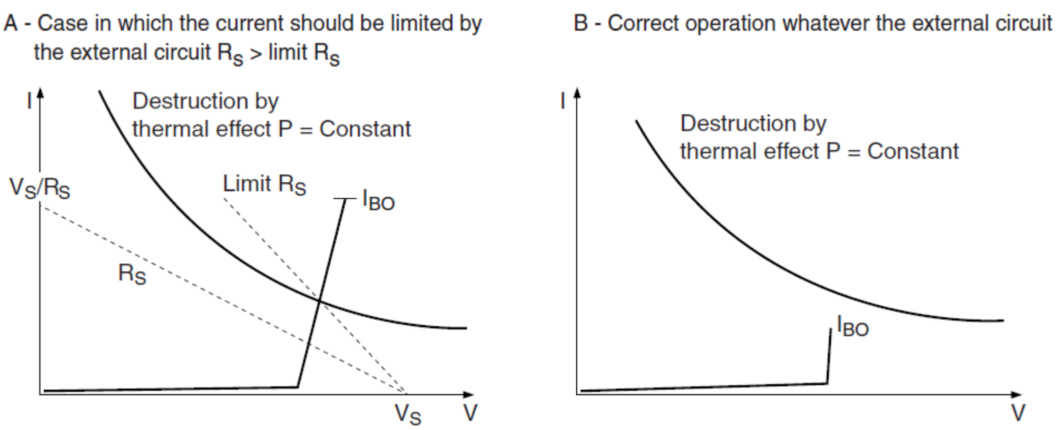


Figure 8. Conditions for non destructive operation in the avalanche mode



1.5 Physical operation

At first level, a TSS can be represented by two thryristors connected back to back. It will suffice to explain the operation of one thyristor. The other operates in the same way if the voltage across the component is reversed.

Figure 9. **Operation in the blocked mode**

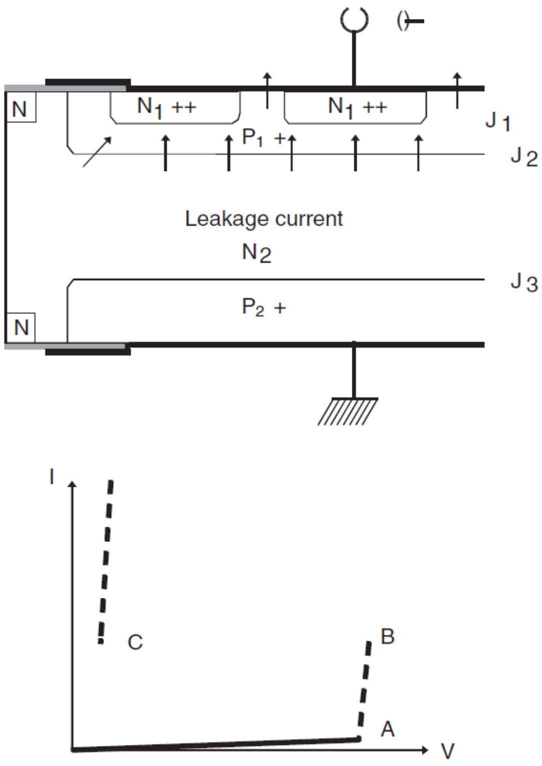
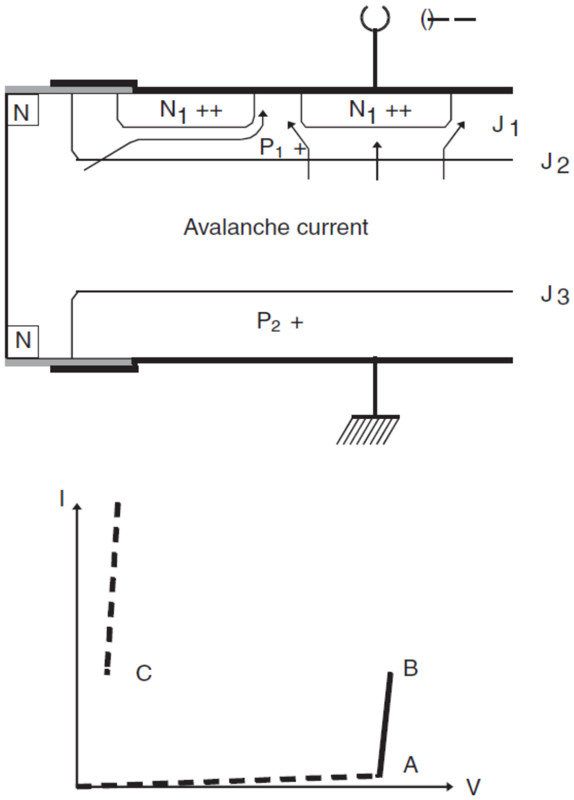


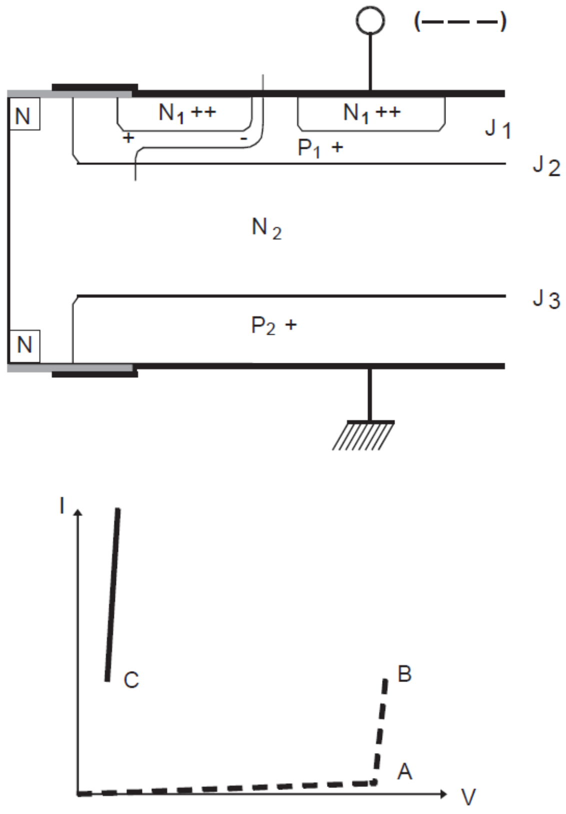
Figure 10. Operation in the avalanche mode



Application of a negative voltage on cathode N_1 ++ results in forward biasing of junctions J_1 and J_3 and reverse biasing of J_2. The current observed is thus the leakage current of junction J_2. When the voltage exceeds a certain value, junction J_2, which is reverse biased, begins to operate in the avalanche mode. The structure up to this current level operates like a diode (junction J_2). The side current biases the P_1 layer next to the N_1 part of the emitter.

The highly doped N_1 layer has the same potential. The P_1 area at the surface is forced to the same potential as the N_1 region by metallization.

Figure 11. Thyristor effect of the TSS



As the avalanche current increases, this difference of potential can reach the threshold of 0.6 V, a value which is sufficient to create injection of electrons from the cathode towards the P_1 area and thus trigger thyristor N_1 P_1 N_2 P_2.

The electrons thus injected into P_1 in fact will reach J_2 by diffusion, and cross it under the effect of the electrical field operating in the space charge of the reverse biased J_2 junction.

In N_2, the electrons help to reduce the potential of this area compared with P_2 and as a result inject holes from P_2 towards N_2. These holes travel in the reverse direction because of their polarity. When they arrive at P_2 they help to increase the potential of P_1 with respect to N_1, this time resulting in the injection of electrons from N_1 to P_1.

The procedure is cumulative. The excess electrons in N_2 and the holes in P_1 will compensate the fixed charges of the space charge and will thus suppress it. Junction J_2 will act as a forward biased junction and the voltage across the component will drop.

2 How to choose the thyristor surge suppressor and the series protection

2.1 Choice of the thyristor surge protection

There are several series of TSS: SMP100LC, SMP100MC, SMP80MC, SMP75, SMP50/SMTPA/TPA and SMP30.

Each series contains several parts, each part having a specific V_R value (V_R = V_{RM} max.) that varies from 8 V to 400 V.

Except for the SMP75 series that only has one device, the SMP75-8.

In order to choose the suitable TSS for a given application, a few considerations have to betaken into account:

Select the TSS series

The designer of the card (analog line card, DSLAM, xDSL modem, Ethernet switch…) has to select the series of TSS that has the current capability (IPP, ITSM) required by his application.

This is determined by the resistibility standard of telecommunication equipment that the card of the designer has to comply with.

The different resistibility standards of telecommunication equipment are the following:

- Telcordia GR-1089-CORE, dedicated to equipment deployed in North America and located on central offices, on customer premises or on outside plant facilities
- TIA-968-A (formerly FCC Part 68), dedicated to equipment deployed in North America and located on customer premises.This standard specifies only lightning tests and is less and less used with the generalization of Telcordia GR-1089-CORE in North America.
- ITU-T K20, dedicated to equipment deployed everywhere in the world except in North America and installed in central offices
- ITU-T K21, dedicated to equipment deployed everywhere in the world except in North America and installed in customer premises
- ITU-T K45, dedicated to equipment deployed everywhere in the world except in NorthAmerica and installed in outside plant facilities

These standards specify two kinds of surge tests: the lightning tests that define the I_{PP} value of the TSS, and the AC power fault tests that define in conjunction with the used series protection the I_{TSM} curve of the TSS.

So, Telcordia GR-1089-CORE standard requires SMP100LC or SMP100MC series, where 100 in the name of the series means 100 A (10/1000 µs) that is a typical lightning test of this standard.

In the same way, TIA-968-A requires SMP80MC series while ITU-T K20/K21/K45 require SMP30 or SMP50 series depending on the series protection used on the card.

Select suitable V_{RM}

Once the designer of the card has selected the series of thyristor surge suppressor with the suitable current capability (I_{PP}, I_{TSM}) for his application, he must choose the V_{RM}: it must be equal or higher than the maximum voltage of the application in normal operation (V_R = V_{RM} max.).

For instance, for an analog line card dedicated to US market, the signal present on the line is generally made up of a battery voltage around -56 V DC and of a superimposed 150 V_{rms} ringing signal, which gives a maximum voltage of about 268 V in normal operating: hence, the designer of this card has to choose a TSS with a V_R = 270 V.

For the same kind of card, but now dedicated to European market, the maximum voltage in normal operating is about 189 V (due to a -48 V DC battery voltage and a superimposed 100 V_{rms} ringing signal): in this case, the suitable V_R is 200 V.

Another example is for ethernet applications where the data signal present on the line is of low amplitude (about ±2 V): here, the V_R to be chosen is 8 V.

Please note that the choice of this V_R value is important. If this value is chosen too low, the TSS will clamp the signal in normal operating.If this value is too high, the protection level will be less efficient (V_{BO} higher) and maybe no more sufficient for the circuit to be protected.

Intrinsic capitance

For digital applications, another parameter to be taken into account for the choice of the TSS is its intrinsic capacitance (C). If the designer has an idea about the max capacitance value that will not disturb its application in normal operating (no degradation of the signal), he has to select a TSS with a capacitance value lower or equal to this max value.

For example, the SMP100MC and SMP80MC series, where MC means micro capacitance, are recommended for ADSL applications.

2.2 Choice of the series protection

Two kinds of series protection are used in telecommunication equipment: fuses and PTCs.

Their goal is to prevent the currents due to long duration AC power fault disturbances from damaging the thyristor surge suppressor and the circuit to be protected.

Fuses are preferred in digital applications (xDSL…) thanks to their low ohmic value (< 1 ohm), which does not deteriorate the signal.

The advantage of PTCs is that they are resettable, and then they don't need to be replaced on the field (lower cost of maintenance for the equipment).

The choice of the series protection depends on the standard of resistibility of telecommunication equipment that the card of the designer has to comply with, and also on the TSS required by his application.

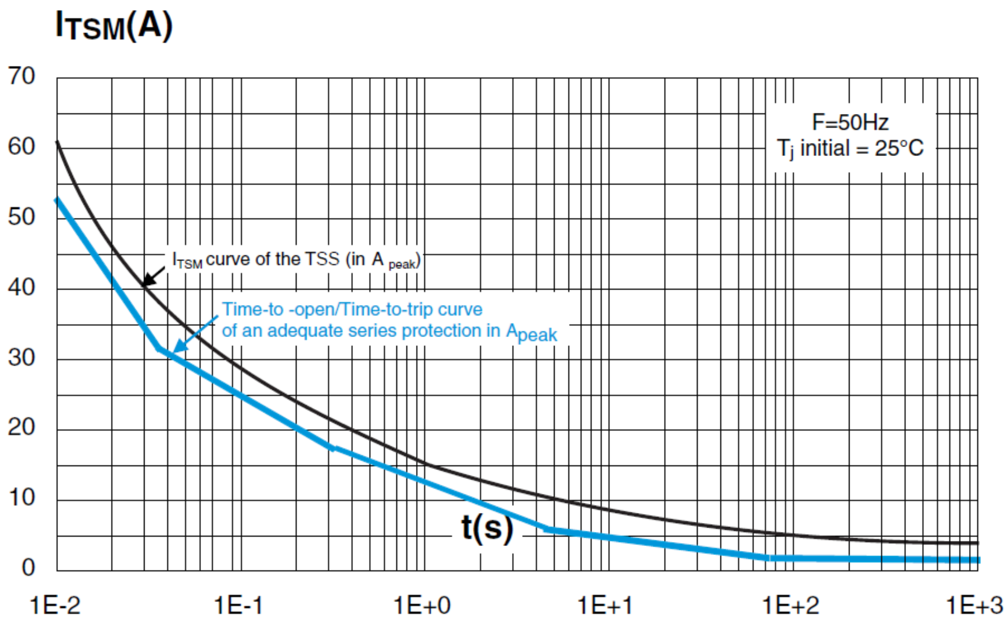
Indeed, the standards of resistibility of telecommunication equipment have two acceptance criteria: First level (or A criterion) that requires the equipment to remain functional after the test, second level (or B criterion) that doesn't require the equipment to be functional after the test but to be damaged in a safe manner (i.e. no fire, no fragmentation in the equipment).

So, the suitable fuse must not open for first level surge tests and must open for second level surge tests.

While the right PTC has to withstand the peak voltage of the lightning tests and the rms voltage of the AC power fault tests specified in the standard.

Finally, the time-to-open or time-to-trip curve of the series protection (respectively for the fuse or the PTC) must be below the I_{TSM} curve of the TSS (as shown on Figure 12), so that the series protection well protects the TSS and the circuit to be protected from long duration AC power fault disturbances.

Figure 12. **Comparison of ITSM and time-to-open/time-to-trip curves**



Note that the time-to-open/time-to-trip curve of the fuse/PTC is given in A rms in the specification. Hence, the designer has first to convert this curve in Apeak before comparing it to the I_{TSM} curve of the TSS.

An example of choice of series protection is the fuse TCP1.25A from Cooper-Bussmann that we recommend for use with the series of TSS SMP100LC and SMP100MC in order to get a protection kit compliant with the Telcordia GR-1089-CORE standard.

If the choice of the TSS (parallel protection) and the series protection is correct for a given application, then we have a good coordination between both series and parallel protection.

The TSS protecting the downstream circuit from short duration disturbances while the series protection from long duration disturbances.

Revision history

Table 1. Document revision history

Date	Version	Changes
February-1998	1	First issue.
10-May-2004	2	Stylesheet update. No content change.
05-Jul-2010	3	Updated trademark statements.
08-Dec-2011	4	Updated for current products. Added Section 2.
09-Jul-2021	5	Updated Trisil with thyristor surge suppessor (TSS). Minor text changes.

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