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**Components for low-voltage surge protection –
Part 332: Selection and application principles for metal oxide varistors (MOV)**

**Composants pour parafoudres basse tension –
Partie 332: Choix et principes d'application des varistances à oxyde métallique
(MOV)**



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IEC Secretariat
3, rue de Varembe
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

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The text of this International Standard is based on the following documents:

Draft	Report on voting
37B/243/FDIS	37B/245/RVD

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

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COMPONENTS FOR LOW-VOLTAGE SURGE PROTECTION –

Part 332: Selection and application principles for metal oxide varistors (MOV)

1 Scope

This part of IEC 61643 describes the theory of operation, principles for the selection and application of MOVs to be connected to power lines or telecommunication or signalling circuits, up to 1 000 V AC or 1 500 V DC. These SPCs are designed to protect apparatus or personnel, or both, from high transient voltages.

This document applies to MOVs having two electrodes and voltage dependent elements with or without disconnectors. It does not apply to assemblies that include MOVs and their influence on the MOV's characteristics.

This standard specifically discusses the zinc-oxide type of MOVs.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60664-1:2020, *Insulation coordination for equipment within low-voltage supply systems – Part 1: Principles, requirements and tests*

IEC 61051-1:2018, *Varistors for use in electronic equipment – Part 1: Generic specification*

IEC 61051-2:2021, *Varistors for use in electronic equipment – Part 2: Sectional specification for surge suppression varistors*

IEC 61643-11:2011, *Low-voltage surge protective devices – Part 11: Surge protective devices connected to low-voltage power systems – Requirements and test methods*

IEC 61643-331:2020, *Components for low-voltage surge protection – Part 331: Performance requirements and test methods for metal oxide varistors (MOV)*

IEC 62368-1:2023, *Audio/video, information and communication technology equipment – Part 1: Safety requirements*

3 Terms, definitions, symbols and abbreviated terms

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at <https://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

3.1 Terms and definitions

3.1.1 Ratings

3.1.1.1

rating

limiting capability or limiting condition beyond which damage to the MOV may occur

Note 1 to entry: A limiting condition may be either a maximum or a minimum.

3.1.1.2

single-impulse [transient] maximum current

I_{TM}

rated maximum value of current which may be applied for a single impulse of specified waveform

Note 1 to entry: For power distribution SPDs, IEC 61643-11, Maximum Discharge Current I_{max} is used.

[SOURCE: IEC 61643-331:2020, 3.1.1.2]

3.1.1.3

nominal discharge current

I_n

crest value of the current through the MOV having a current waveshape of 8/20

[SOURCE: IEC 61643-331:2020, 3.1.1.3]

3.1.1.4

maximum continuous voltage

V_M

maximum voltage that may be applied continuously at a specified temperature

Note 1 to entry: May also be called U_C or MCOV (Maximum continuous operating voltage).

Note 2 to entry: See Figure 1.

[SOURCE: IEC 61643-331:2020, 3.1.1.7, modified (addition of "Maximum continuous operating voltage" to Note 1 to entry)]

3.1.1.5

maximum continuous AC voltage

$V_{M(AC)}$

maximum value of RMS power frequency voltage (less than 5 % total harmonic distortion) that may be applied continuously at a specified temperature

[SOURCE: IEC 61643-331:2020, 3.1.1.8]

3.1.1.6

maximum continuous DC voltage

$V_{M(DC)}$

maximum value of DC voltage that may be applied continuously at a specified temperature

[SOURCE: IEC 61643-331:2020, 3.1.1.9]

3.1.1.7**maximum discharge current** $I_{\max}$

crest value of a current through the SPD having an 8/20 waveshape and magnitude according to the manufacturer's specification.

Note 1 to entry: $I_{\max}$ is equal to or greater than I_n .

[SOURCE: IEC 61643-11:2011, 3.1.48]

3.1.1.8**impulse discharge current for class I test** I_{imp}

crest value of a discharge current through the SPD with specified charge transfer Q and specified energy W/R in the specified time

[SOURCE: IEC 61643-11:2011, 3.1.10]

3.1.1.9**rated average dissipation power** P_M

maximum average dissipation power of repetitive pulses allowed to be applied to the varistors at ambient temperature of 25 °C

[SOURCE: IEC 61051-1:2018, 3.23]

3.1.2 Characteristics**3.1.2.1****characteristics**

inherent and measurable properties of an MOV

[SOURCE: IEC 61643-331:2020, 3.1.2.1]

3.1.2.2**standby current** I_D

current passing through MOV at maximum continuous voltage V_M

Note 1 to entry: The current passing through the MOV at less than V_M is called leakage current.

[SOURCE: IEC 61643-331:2020, 3.1.2.2]

3.1.2.3**varistor voltage** V_V

voltage across the MOV measured at a specified current (typically 1 mA) for a specific duration

Note 1 to entry: The MOV manufacturer specifies the current. Otherwise, 1 mA DC for a duration of 20 to 100 ms is normally used.

Note 2 to entry: See Figure 1.

[SOURCE: IEC 61643-331:2020, 3.1.2.3]

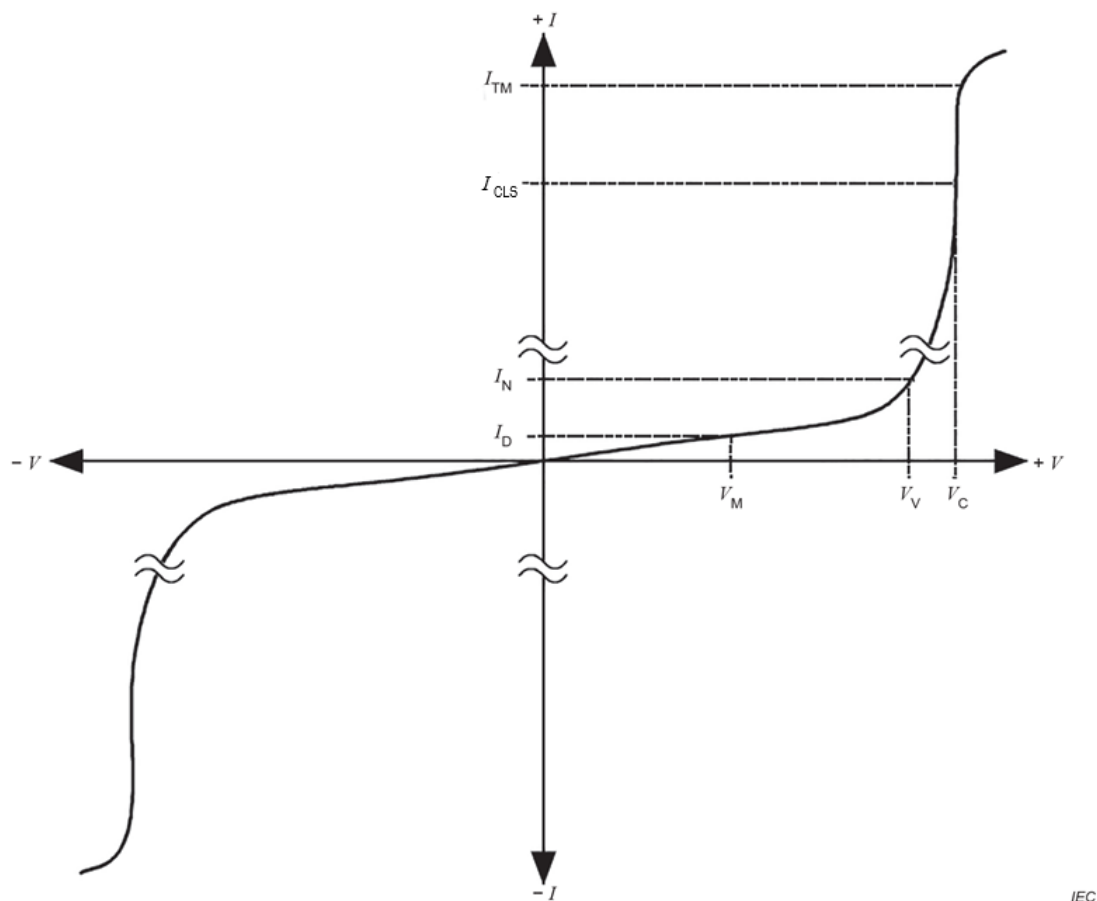


Figure 1 – V - I characteristic of an MOV

3.1.2.4

Clamping voltage

V_C

peak voltage across the MOV measured under conditions of a class current (I_{CLS}) and specified waveform

3.1.2.5

class current

I_{CLS}

peak value of current, which is 1/10 of the maximum peak current for 100 pulses for the 8/20 current pulse with a time interval of 30 s

[SOURCE: IEC 61051-1:2018, 3.21]

3.1.2.6

Capacitance

C_V

capacitance across the MOV measured at a specified frequency, voltage and time

[SOURCE: IEC 61643-331:2020, 3.1.2.6]

3.1.2.7**SPD**

device that contains at least one nonlinear component that is intended to limit surge voltages and divert surge currents

[SOURCE: IEC 61643-11 Clause 3.1.1]

3.1.2.8**SPC**

discrete component whose primary function is to divert or limit excessive voltage and current surges to protect sensitive equipment and circuits from potential damage. Examples of SPCs are MOVs, GDTs, SITs, ABDs, and thyristors.

3.1.2.9**metal oxide varistor (MOV)**

non-linear resistor made of a sintered mixture of metal oxides whose conductance, at a given temperature, increases rapidly with voltage

Note 1 to entry: This is also known as a voltage dependant resistor (VDR).

[SOURCE: IEC 61643-331:2020, 3.1.2.7]

3.1.2.10**thermally protected metal oxide varistor**

varistor which includes a series non-resettable element that will disconnect the MOV when it is overheated due to excessive dissipation

[SOURCE: IEC 61643-331:2020, 3.1.2.8]

3.1.2.11**nonlinearity current index**

β

starting from Formula (1) of 3.3, it is defined by the formula

$$\beta = \frac{I}{U} \times \frac{dU}{dI} \quad (1)$$

Note 1 to entry: For the convenience of calculation, the following formula may be used:

$$\beta = \frac{\log_{10}(U_1/U_2)}{\log_{10}(I_1/I_2)} \quad (2)$$

β is always less than 1.

[SOURCE: IEC 61051-1:2018, 3.4]

3.1.2.12 non-linearity voltage index

γ
reciprocal of non-linearity current index β

Note 1 to entry: γ is always greater than 1.

Note 2 to entry: In varistor industry and literature, the non-linearity voltage index is usually denoted by α rather than γ .

[SOURCE: IEC 61051-1:2018, 3.5]

3.1.2.13 AC standby current

I_{AC}
current passing through MOV at maximum continuous voltage AC $V_{M(AC)}$

3.1.2.14 DC standby current

I_{DC}
current passing through MOV at maximum continuous voltage DC $V_{M(DC)}$

[SOURCE: IEC 61643-331:2020, 3.1.2.9]

3.2 Symbols and abbreviated terms

3.2.1 Symbols

Figure 2 and Figure 3 show the symbols for an MOV and a thermally protected MOV, respectively.

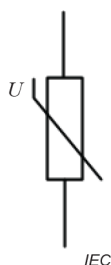


Figure 2 – Symbol for an MOV

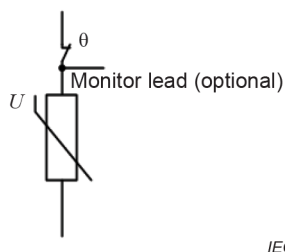


Figure 3 – Symbol for a thermally protected MOV

NOTE IEC 60027 recommends the letters V and v only as reserve symbols for voltage; however, in the field of MOV components, these are so widely used that in this publication they are preferred to U and u .

3.2.2 Abbreviated terms

ESD	Electrostatic Discharge
GDT	Gas Discharge Tube
IC	Integrated Circuit
IT	Information Technology
IT	Isole-Terre (French for Isolated-Earth)
MCOV	Maximum Continuous Operating Voltage
MOV	Metal Oxide Varistor
SMD	Surface Mount Device
SPC	Surge Protective Component
SPD	Surge Protective Device
TCO	Thermal Cut off
TOV	Temporary Overvoltage
TN	Terre-Neutre (French for Earth-Neutral)
TT	Terre-Terre (French for Earth-Earth)

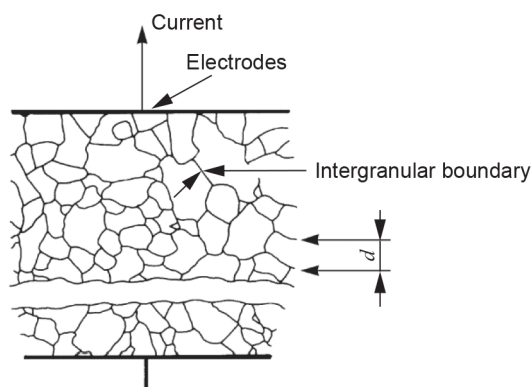
4 General

Due to the high complexity of the ceramics on which the functioning of the MOV is based, the performance of the MOV depends on the technology and processes used. Thus, the electrical properties and characteristics (tolerances, impulse withstand capability, etc.) may vary among manufacturers. The explanations of terms related to electrical properties and characteristics are described in Annex A.

5 Construction

Typically, MOVs consist of a round disc-shaped body of sintered zinc-oxide with suitable additives. Other types in use include rectangular and tubular shapes and multilayer structures. MOVs have metal particle electrodes consisting of a silver alloy or other metal. The electrodes may have been applied to the body by screen printing and firing or by other processes depending on the metal used. MOVs also often have wire leads or some other type of termination that may have been soldered to the electrode.

The basic conduction mechanism of MOVs results from semiconductor barriers at the boundary of the zinc-oxide grains formed during a sintering process. The MOV may be considered a multi-barrier component with many grains acting in series-parallel combination between the terminals. A schematic cross-sectional view of a typical MOV is shown in Figure 4.



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Figure 4 – Schematic depiction of microstructure of MOV



6 Function

6.1 Theory of operation

MOVs have the property of maintaining a relatively small voltage change across their terminals while the surge current flowing through them varies over several decades. This non-linear action allows them to divert the current of a surge when connected in shunt across the line, and hold the voltage across the line to values that protect the equipment connected to that line. Since the voltage across the MOV is held at some level higher than the normal circuit voltage (but still protecting) while surge current flows, there will be energy dissipated in the MOV during its surge diversion function.

The MOV material consists of zinc-oxide grains separated by a thin intergranular material. Bismuth oxide and other metal oxides comprise the boundary between grains, and these form semiconducting barriers with the grains. A fundamental property of the material is that the voltage drop across a single interface between the grains is nearly constant, and is independent of the grain size. Figure 5 shows a typical V - I characteristic of an MOV in one direction of conduction, and the opposite direction would be similar.

The voltage and current values of the curve in Figure 5 were measured by using DC current when the current being less than 10^{-2} A, or by using 8/20 current when the current being greater than 100 A.

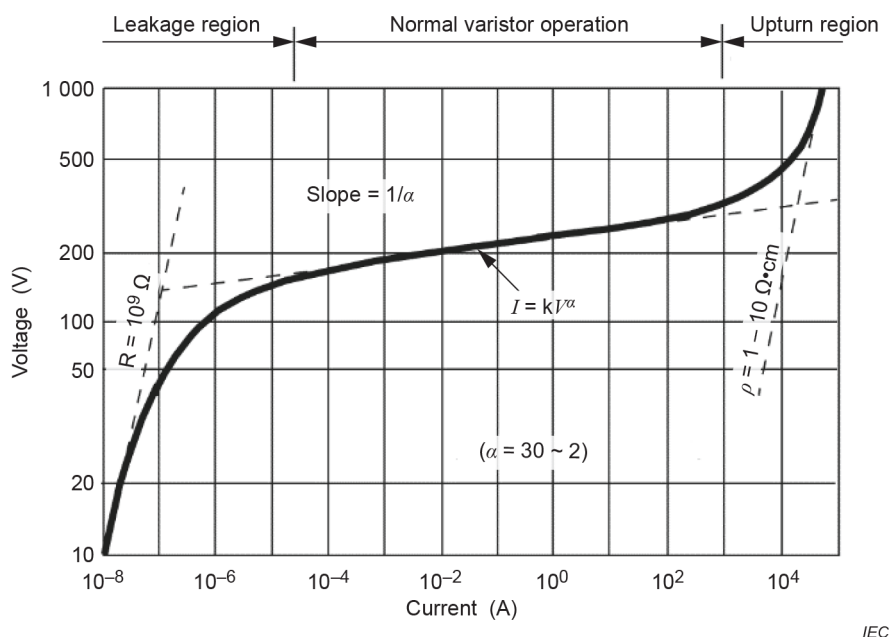


Figure 5 – Typical varistor V - I curve plotted log-log scale

The electrical behaviour of an MOV can be understood by reference to the V - I characteristic of Figure 5 and the equivalent circuit components of Figure 6 as follows:

- 1) Leakage Region: When the voltage across the MOV is below its varistor voltage (V_V), the non-linear resistance R_x approaches a high ohmic state and can be disregarded, hence the parallel resistance R_{off} is the prevailing component. In the example of Figure 6, R_{off} is such a high value that the MOV is essentially in a nearly open-circuit state.

- 2) Normal Varistor Operation Region: The non-linear resistance R_x becomes so small that it is much lower than the linear leakage resistance R_{off} , so that the R_{off} is ignored but R_x remains larger than R_{on} . The variable resistance R_x takes on continuously decreasing values, according to the power law relating current and voltage. In this region, current increases in several orders of magnitude as V_V remains rather constant.
- 3) Upturn Region: At large currents, the series resistance R_{on} becomes a significant part of the total device resistance, causing an upturn with the value of R_{on} as an asymptote. The MOV is essentially in a short-circuit state during this region.

The parametric values given in Figure 5 and Figure 6 are shown for illustration purposes only.

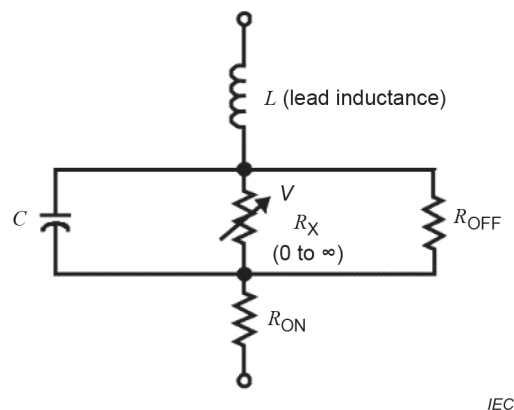


Figure 6 – MOV equivalent circuit model

Under AC or signal operating conditions as well as under surge conditions the reactive components (L and C) of Figure 6 may significantly affect the behaviour of the MOV. The parallel capacitance C can pass a current that may be larger than the DC standby current. The series inductance L , resulting from the leads can increase the voltage appearing across the component terminals when it passes surge currents with steep wave fronts. This inductive voltage drop may appear as an overshoot on the voltage waveform and appear to be a delay in MOV response.

Ambient temperature, and/or the temperature rise caused in the MOV by operating conditions or by a surge, produces little effect on the clamping voltage. However, the standby current will increase with increasing temperature. Therefore, if conditions result in temperatures that may exceed the component rating, consideration will have to be given to thermal design in the application.

6.2 Thermal protection of MOVs

Thermal protection can be effective in cases where current through an MOV might be so low as to not result in the operation of the overcurrent protection, and where currents could be high enough to cause an MOV to reach extremely high temperatures sufficient to result in extreme overheating. The following examples describe how thermal protection means could be applied to disconnect the MOV:

- 1) If a power frequency overvoltage occurs, AC standby power dissipation will rise. This could result in heating of an MOV.
- 2) If an MOV is exposed to stresses beyond its rating, it could be subject to a degradation failure mode. With severe degradation of an MOV, standby power dissipation could rise enough to cause heating.
- 3) If the power source impedance is relatively high, and the fault current available is too low to operate an overcurrent means, an MOV failed in the short-circuit mode could cause heating.

Further work also needs to be done to evaluate the effect of surge transients on their operating characteristics of thermal protections.

6.3 Failure modes

6.3.1 General

The case shall be considered in which power frequency overvoltages or extreme surge values could occur, exceeding the predictions of limited-base statistics, and in which excess energy might be dissipated in the MOV. Like any other component over stressed in this manner, an MOV is subject to failure. The mode of failure will depend on the kind and degree of stress. The failure modes discussed in this subclause are short-circuit, degradation, and open-circuit and high clamping voltage.

The use of "safe failure mode" to describe a failure mode of an MOV is discouraged, since the consequences of failure, if not mitigated, may present a hazard to equipment or personnel. Some users may consider that the most desirable condition of a failed MOV is a low resistance, where the protective function is maintained. Others may prefer failure into a high resistance condition, so that the failed MOV does not induce a short circuit. Because "safe failure mode" means opposite things to different users, the recommended practice is to describe MOV failure only by the terms given in 6.3.2, 6.3.3 and 6.3.4.

High current flowing in a failed MOV can melt soldered connections or shatter the component. Since these ultimate failure modes are not generally desirable, the common practice is to provide a thermal or overcurrent protective means, or both, in order to disconnect the MOV and clear the fault from the circuit.

6.3.2 Short-circuit failure mode

In this failure mode an MOV may exhibit mechanical damage due to overheating by electrical current. The MOV element may have a punch-through hole between the electrodes, and some of the zinc-oxide material may have been reduced to metallic form. Outside of the damaged region, the MOV may have normal V - I characteristics. Hence, in terms of the equivalent electrical circuit of Figure 6 the parallel resistance component R_{off} has a much lower value in failed MOVs. When the failed MOV is measured out of its circuit and at room temperature, the non-linear exponent will be between 1 and 2. Typical values may be on the order of 10 Ω or more. The value could be lower at higher temperature at the time of failure.

6.3.3 Degradation failure mode

Overvoltage stresses that do not result in functional failure may nonetheless cause an observable change in V - I characteristics. In the degradation failure mode, an MOV has a V_V of less than 90 % of the initial value.

A degradation of V_V is likely to be associated with an increase in the MOV's DC standby current and AC standby power dissipation. Continuing degradation could lead to overheating and premature failure. For the reference, V_V changes in MOV durability evaluation under DC bias conditions are shown in Annex B. Consequently, users are cautioned against selecting MOVs with inadequate voltage ratings.

Degradation may be explained as due to a reduction in the value of parallel resistance R_{off} in the equivalent circuit of Figure 6. It is important to note that such a change would affect only the low-current extremity of the V - I characteristics, and the MOV would continue to perform its surge-protective function.

The outcome of evaluation for this failure mode is sensitive to the current density at which the test is conducted. Specifically, if the current selected is too low, serviceable MOVs could be unnecessarily rejected. Typically a test current of 1 mA is applied to all MOVs regardless of size. However, a more ideal value should be based on current density rather than current. It should be noted that V_V may shift upward without implication that clamping voltage has shifted upward in correlation. Instead, clamping voltage should be measured independently.

6.3.4 Open-circuit and high clamping voltage failure mode

The V - I characteristics of MOVs used in AC mains applications typically are very stable in the region of protective operation. However, if the electrodes, leads, solder or other connections become damaged, or the MOV is shattered, the MOV may become open circuited because of an increase in the effective value of series resistance component R_{on} in the equivalent circuit of Figure 6. External mechanical damage is evident in this failure mode almost invariably, and an open-circuit voltage condition can be identified in position by visual inspection. The recommended definition of failure is: 1) clamping voltage exceeding 120 % of initial value, or 2) open-circuit voltage condition.

7 Application

7.1 MOVs basic application

7.1.1 Application circuit

The application of MOVs to limit voltages at the terminals of electronic and electrical equipment requires the selection of an MOV with suitable characteristics, and then the proper physical arrangement of the MOV in the electrical circuit. In addition, electrical components downstream of the MOV shall be rated suitably for the clamping voltage provided by the MOV. Typically, an MOV with proper clamping voltage is selected in accordance with the downstream component's acceptable voltage limits.

The electrical configurations of the most common applications in low-voltage AC power systems are illustrated in Figure 7. If a single MOV is employed, the usual connection is line-to-neutral (see (1) in Figure 7) to limit overvoltage surges in that mode. Surges also can occur between neutral-to-earth (see (3) in Figure 7) and line-to-earth (see (2) in Figure 7), together or independently. In some applications MOVs may be installed between all three lines, as illustrated. Overcurrent protection means or thermal protection means or both should be added as appropriate.

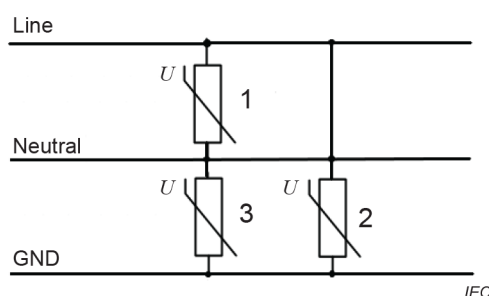


Figure 7 – Possible connection of MOVs (simplified)

NOTE Overcurrent and/or thermal protection means which are not shown in figures can be used.

Examples of MOV specifications and their circuit in specific applications are described in Annex C, Annex D and Annex E.

7.1.2 Operational compatibility

MOVs may be connected between the AC line unearthed conductor and the equipment earthing conductor, earthing path or earthed metal parts. The purpose is to protect insulation against damage by surge voltages or to prevent flashover between clearances. However, safety concerns related to leakage paths through the MOV shall be considered for the particular application. One of these concerns has to do with standby current.

As a result of the capacitance associated with the internal semiconducting barriers of an MOV, and also its internal resistance, an MOV will contribute to the standby current described above. With DC circuits only, the resistive portion will contribute to standby current. With AC power circuits, the internal capacitance and resistance both contribute. The standby current will vary with temperature and also is related to the size and energy handling capability of the MOV.

Standby current through MOVs along with other standby currents in the system can increase the risk of electric shock, or risk personal injury related to reaction levels of electric current, depending on the standby current levels and other conditions related to the specific MOV application.

IEC 61643-331 describes test procedures for measuring standby current through the MOV.

7.1.3 Voltage limiting

The expected clamping voltage of MOVs can be found by constructing a V - I graph similar to Figure 1. Load lines can be drawn representing all possible output combinations of a test surge generator under the conditions of this example; i.e., 6 kV open-circuit voltage, and 0,5 kA and 3 kA short-circuit currents. Maximum clamping voltage curves for MOVs can be obtained from manufacturer's specifications. The intersections of load lines and clamping curves represent peak operating point predictions for each combination of test condition and MOV size. Predicted values should be verified by testing.

At the same specified current and same voltage rating, larger diameter MOVs tend to clamp at lower voltages than smaller ones. The user should select the size that best fits the space and performance goals of the application.

7.1.4 Selection of MOVs

7.1.4.1 General

MOVs are selected by a range of performance criteria such as the maximum supply voltage of the system, impulse current rating, operating temperature and clamping voltage. Annex F describes MOV characteristics as defined by various standards.

For most applications, the selection is a six-step process:

- a) 7.1.4.2: Determine the required maximum continuous voltage of the MOV
- b) 7.1.4.3: Determine the peak transient current for the application
- c) 7.1.4.4: Select an MOV size to provide the required clamping voltage for the application
- d) 7.1.4.5: Assess MOV energy rating – if needed
- e) 7.1.4.6: determine power dissipation– if needed
- f) 7.1.4.7: Determine if a thermal disconnecter is required for the application

Selection of an MOV for a particular application requires balancing several deciding factors. Selecting an MOV with V_V too high may result in an unacceptable clamping voltage that could damage the equipment downstream. Selecting an MOV that has V_V too low may result in an increased level of power dissipation which will cause an increase in standby current and shorten the life of the MOV. The tolerance of the supply system voltage and voltage swell conditions should also be considered.

The user should be cautioned against selecting an MOV with a clamping voltage so low that it would begin to conduct excessively during high AC or DC power line conditions. This might then interfere with normal operation of the equipment being protected, overheat the MOV and shorten its life due to extended operation above its rating.

Typically, MOVs with thermal protection are utilized for applications where temporary overvoltage (TOV) conditions may be present and the performance of these thermally protected MOVs should be also considered.

Besides the above, Subclauses 7.1.4.2, 7.1.4.3, 7.1.4.4, 7.1.4.5, 7.1.4.6 and 7.1.4.7 provide general guidelines and examples, however, these are general guidelines.

Each MOV should be selected according to its specific application and manufacturer's recommendation. Annex G and Annex H show MOV selection flowcharts for equipment and an SPD, respectively.

7.1.4.2 Determine the required maximum continuous operating voltage the MOV

The first parameter to address in selecting an appropriate MOV is its maximum continuous voltage, V_M (may also be called U_C or MCOV). This parameter is largely based on the system's supply voltage where the MOV will be used. To make sure the MOV does not enter the normal varistor operating region (see Figure 5) during normal voltage fluctuations, the selected MOV shall have a maximum continuous voltage that is higher than the system's normal supply voltage. Generally, V_M of 20 % higher than the system's normal supply voltage is a reasonable design approach, however, other voltage requirements arising from industry and safety standards may require higher V_M .

Safety standards may mandate the required continuous voltage of MOVs connected across the AC supply. For example, IEC 62368-1:2018, G.8.1 requires that the MOV has V_M that is at least 1,25 times (125 %) the equipment's rated voltage. For example, selecting the MOV for equipment intended to be connected on a 220 V AC, TT (neutral earthed electrical supply system where the neutral is earthed at the source and the electrical equipment protective earthing is local to the equipment) power system, the safety standards require having an MOV rated at least $230 \text{ VAC} \times 125 \% = 287,5 \text{ VAC}$. When the equipment has an AC voltage range, V_M shall be at least 1,25 times the upper voltage of the rated voltage range. For example, if the equipment is marked with a voltage range of 90 to 250 VAC, the maximum continuous voltage is $250 \text{ VAC} \times 125 \% \approx 313 \text{ VAC}$.

One important item to note for IT equipment designed to meet IEC 62368-1 is that the maximum continuous voltage is based on the equipment's voltage label. For example, consider the difference in V_M of an equipment marked with 120 V/230 V versus equipment marked with a voltage range of 100 V to 240 V. For the equipment marked with 120 V/230 V operating AC voltages, V_M is $230 \text{ VAC} \times 125 \% \approx 288 \text{ VAC}$. For the equipment marked with the 100 V to 240 V AC voltage range, V_M is $240 \text{ VAC} \times 125 \% \approx 300 \text{ VAC}$. Thus, it is important to know how the working voltage of the equipment is expressed. This is further complicated if the marked voltage range includes the typical 10 % voltage fluctuations. For example, if the IT equipment states 90 VAC to 264 VAC then V_M would have to be based 125 % of the 264 VAC voltage.

7.1.4.3 Determine the peak transient current for the application

For equipment energized directly from the AC mains supply, IEC 60664-1 categorises transient voltages as shown in Figure 8:

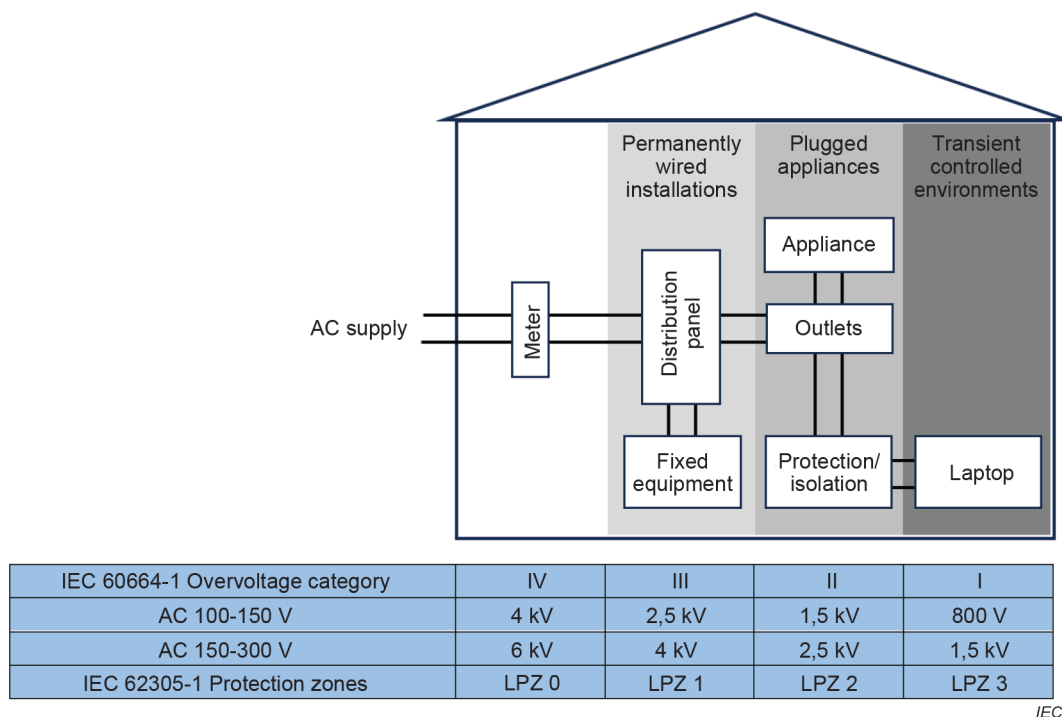


Figure 8 – Overvoltage categories

- Overvoltage category IV is for use at the origin of the installation. For AC mains >150 V and ≤ 300 V the 1,2/50 impulse withstand voltage requirement is 6 kV.

NOTE 1 Examples of such equipment are electricity meters, primary overcurrent protection means and ripple control units.

- Overvoltage category III is equipment in fixed installations and for cases where the reliability and the availability of the equipment is subject to special requirements. For AC mains >150 V and ≤ 300 V the 1,2/50 impulse withstand voltage requirement is 4 kV.

NOTE 2 Examples of such equipment are switches in the fixed installation and equipment for industrial use with permanent connection to the fixed installation.

- Overvoltage category II is energy-consuming equipment to be supplied from the fixed installation. If such equipment is subjected to special requirements with regard to reliability and availability, overvoltage category III applies. For AC mains >150 V and ≤ 300 V the 1,2/50 impulse withstand voltage requirement is 2,5 kV.

NOTE 3 Examples of such equipment are appliances, portable tools and other household and similar loads.

- Overvoltage category I is for equipment without a direct connection to a mains supply. For AC mains > 150 V and ≤ 300 V the 1,2/50 impulse withstand voltage requirement is 1,5 kV.

NOTE 4 Unless the circuits are designed to take the temporary overvoltages into account, equipment of overvoltage category I cannot be directly connected to the mains supply.

IEC 61051-2/AMD1 turns these category voltages into currents by specifying a 1,2/50 to 8/20 test generator set to the category voltage with a fictive impedance of 2 Ω. Thus, for AC mains > 150 V and ≤ 300 V.

- Category IV is 8/20 at 3 kA,
- Category III is 8/20 at 2 kA,
- Category II is 8/20 at 1,25 kA, and

- Category I is 8/20 at 750 A.

In testing with a 1,2/50 to 8/20 generator the MOV clamping voltage will reduce the peak current. For an MOV used in AC mains >150 V and ≤ 300 V the generator peak currents are

- Category IV is 8/20 at 2,5 kA,
- Category III is 8/20 at 1,5 kA,
- Category II is 8/20 at 1 kA, and
- Category I is 8/20 at 500 A.

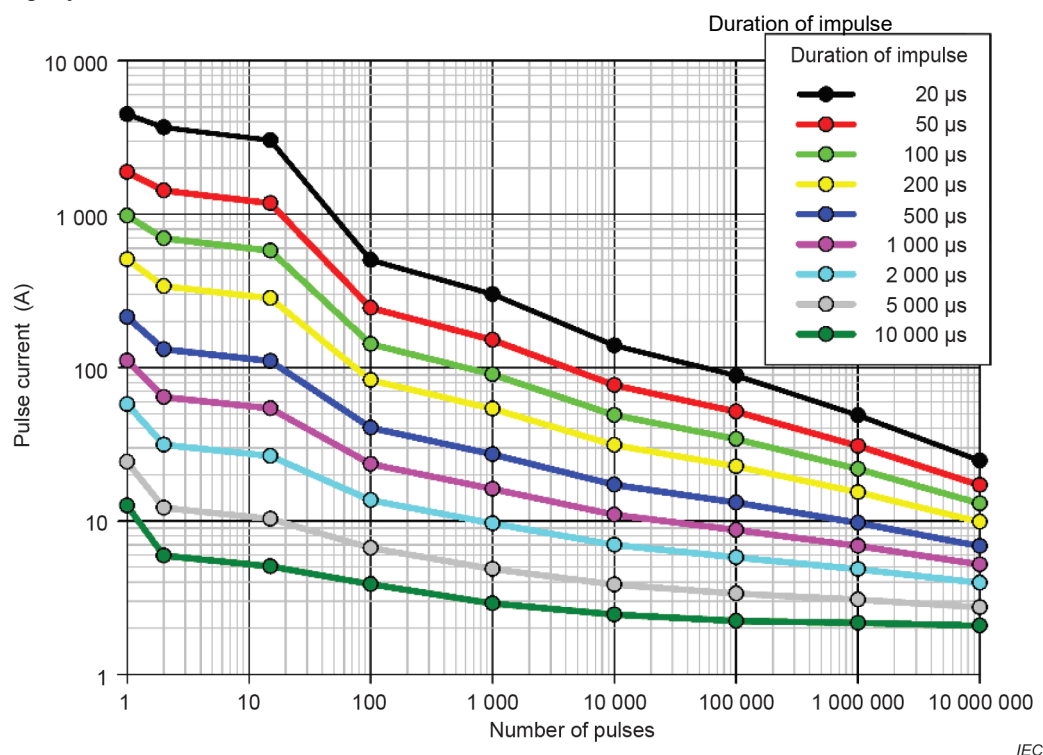


Figure 9 – Test data example of impulse current vs repetitions for 14 mm MOVs

A category transient is not a single event but can happen many times during the equipment life. The repetitive pulse graphs shown in Figure 9 as an example use rectangular pulses of current. Due to the relatively slow front time of the 8/20 current impulse its effects are similar to a 20 μs rectangular current pulse. For the same peak current, impulses, with a much greater difference between the front time and time to half value, have much higher charge and energy values than a pulse having the same duration as the half value.

The impulse current vs repetitions graph is essential in confirming that the selected MOV can withstand the anticipated number of pulses during its lifetime,

For example, let us assume the MOV will be utilized in an equipment connected to AC Mains with an Overvoltage Category of II in a 230 V supply voltage system. IEC 60664-1 requires a 1,2/50 impulse withstand rating of 2,5 kV (for voltage > 150 VAC to ≤ 300 VAC) and IEC 61051-2/AMD1 states that the MOV shall withstand a 1,2/50 to 8/20 combination pulse of 2,5 kV/1,25 kA for voltages ≤ 300 VAC. Since the duration of the current pulse is 20 μs (from the 8/20 current pulse) and the pulse current is 1,25 kA, Figure 9 indicates that the MOV would withstand about 7 to 8 pulses. If the equipment is to withstand more pulses, a different (typically larger size) MOV shall be used.

7.1.4.4 Select an MOV size to provide the required clamping voltage for the application

Having determined the maximum continuous rating and the peak 8/20 current required, the designer can now determine the size of the MOV to determine the clamping voltage of the MOV. If there is an absolute maximum clamping voltage requirement (for example downstream components such as transformer, capacitor, etc have a maximum voltage withstand rating), then increasing the MOV size will reduce the peak voltage at a given current. Figure 10 shows about a 10 % voltage reduction for each size increase.

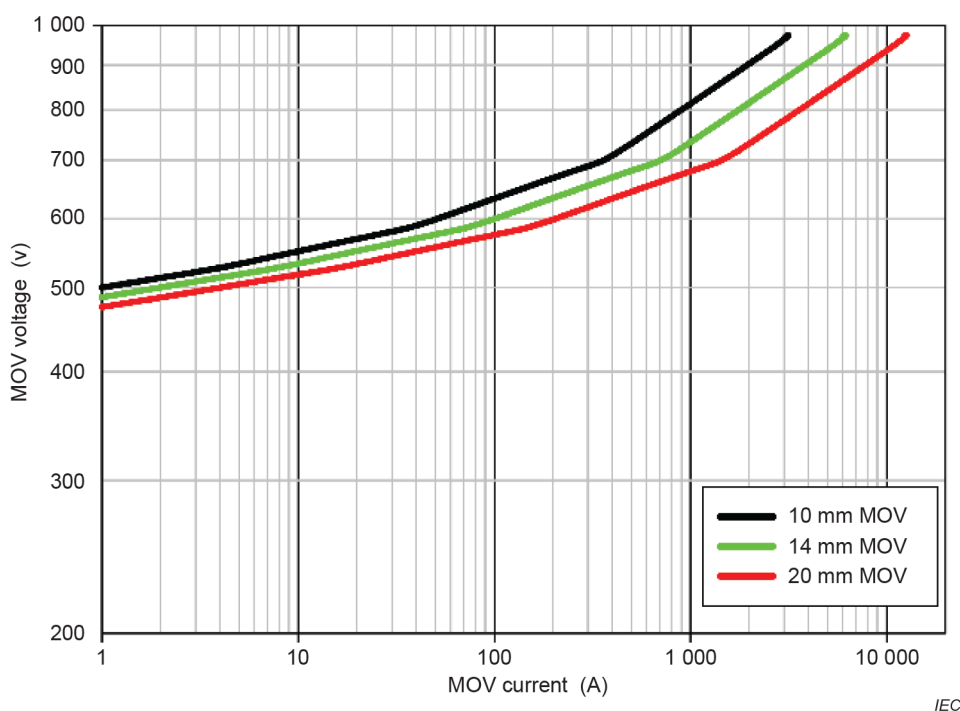


Figure 10 – Example of 10 mm, 14 mm and 20 mm MOV voltage current characteristics

Generally, the MOV size determined from the MCOV and the required peak 8/20 current is sufficient.

For example, if the downstream components cannot exceed 700 V and the maximum current impulse is 1,25 kA (from 7.1.4.3), that would result in a clamping voltage of approximately 680 V to 690 V for the 20 mm MOV while the 10 mm and 14 mm MOVs would result in a clamping voltage of roughly 750 V and 850 V, respectively. The 10 mm and 14 mm would not be suitable for the application as the let through voltage will be too high for the downstream components.

7.1.4.5 Assess MOV energy rating

In most applications, 7.1.4.2, 7.1.4.3 and 7.1.4.4 are sufficient in selecting the MOV; additionally, the rated energy of the MOV can be used to determine suitability. This is done by comparing the rated energy of the MOV versus the energy of the impulse in the end application. In IEC 61051-1, E_M is the rated energy value of the MOV and it is the maximum pulse energy that the varistor is able to withstand one time when it is exposed to a 10/1 000 current pulse or a 2 ms rectangular wave pulse at an ambient of 25 °C. The energy value of the impulse shall be equal to or less than the rated energy value of the MOV.

To determine the approximate energy absorbed by the MOV, the shape of the impulse, impulse current and clamping voltage are used as follows:

$$E = \int_0^T V_C(t) \times i(t) \times \Delta t \approx K \times V_C \times I \times \tau$$

E = energy rating of MOV, (J)

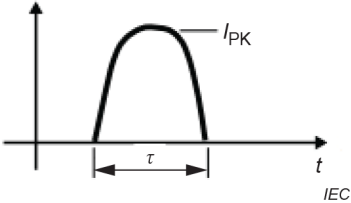
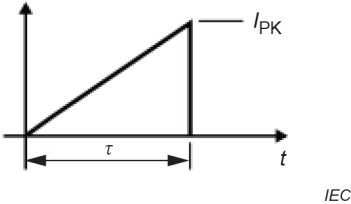
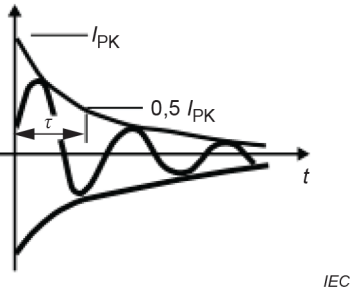
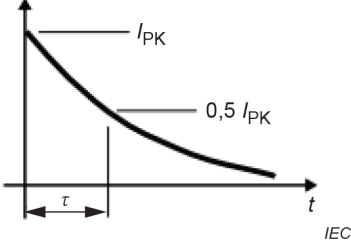
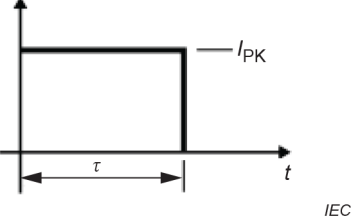
V_C = resulting clamp voltage

I = peak current

K = constant based on waveform

τ = pulse duration

The K value and pulse width correspond to the current waveform only, assuming the varistor voltage waveform is almost constant during the current impulse. The K value is derived for various waveforms as shown in Figure 11 and complex waveforms are divided into segments and then totalled.

Waveshape	Equation	K ^a
	$I_{PK} \sin\left(\frac{\pi}{\tau} t\right)$	0,637
	$I_{PK} \left(\frac{t}{\tau}\right)$	0,5
	$I_{PK} \sin(\pi t) e^{-t/\tau}$	0,86
	$I_{PK} e^{-t/1,44\tau}$	1,4
	I_{PK}	1,0

^a Based upon alpha of 25 to 40

Figure 11 – K value for various waveforms

Let us assume that the impulse is a 100 A 5/50 exponential waveform as shown in Figure 12. The waveform is then divided into two parts: (1) for the 0 μs to 5 μs and (2) for the 5 μs to 50 μs.

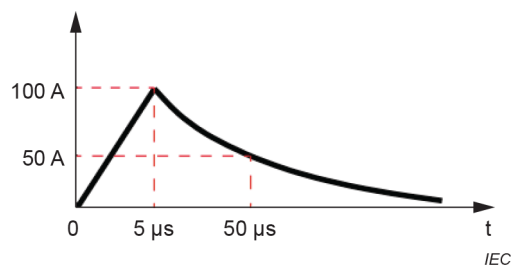


Figure 12 – 5/50 exponential waveform as an example

This would result in the following equation for the overall energy of the 5/50 waveform:

$$E_{\text{Total}} = E_{0-5\mu\text{S}} + E_{5-50\mu\text{S}}$$

$$E_{0-5\mu\text{S}} = K V_c I T = 0,5 \times V_c \times 100 \text{ A} \times 5 \mu\text{S}$$

$$E_{5-50\mu\text{S}} = K V_c I T = 1,4 \times V_c \times 50 \text{ A} \times 45 \mu\text{S}$$

Energy rating is the result of the impulse current capability of the MOV and clamping voltage. The black single impulse energy line shown in Figure 13 is reasonably constant, over a wide pulse width range, and is close to the data sheet 2 ms rated energy value. The graph in Figure 13 is typically not found in manufacturer's data sheet and is shown here for information purposes.

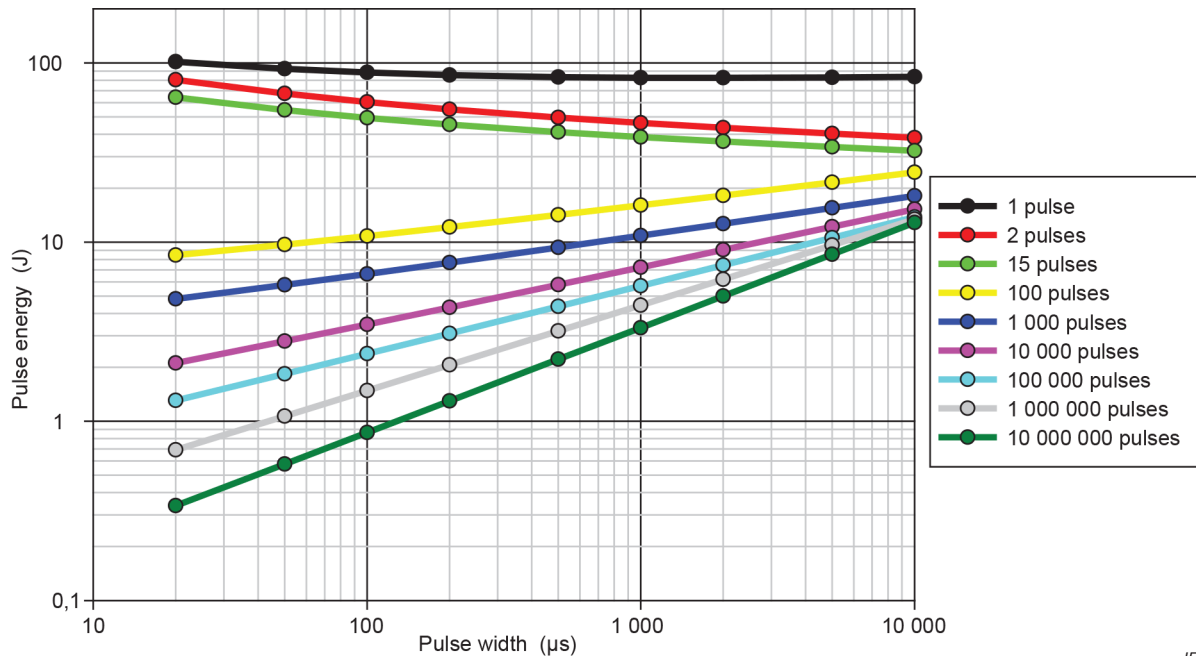


Figure 13 – MOV pulse energy versus pulse width for various pulse repetitions

7.1.4.6 Power dissipation and energy requirements and parameters

7.1.4.6.1 Requirements for impulses

The type of impulse (single or repetitive) and its duration will affect the MOV's capability to dissipate power.

For single impulses, short term events should be assessed by the MOV thermal capacity, which is related to the MOV energy rating in Joules. However, the quoted energy rating is for a single event and it shall be derated for repetitive events.

For example, with cooling in between events, the event energy rating for 10 repetitions is about 30 % of the single event rating. According to CIGRE 549 (Lightning Parameters for Engineering Applications), lightning flashes consisting of multiple strokes and continuing currents should be considered as a single event with the total energy of the constituent parts (multiple rapid events).

Repetitive impulses, with a cooling time between impulses, will have a decreasing current rating as the number of repetitions increase. As the rated current decreases so will the clamping voltage decrease. Increasing impulse duration will also decrease the current rating.

7.1.4.6.2 Requirements for temporary overvoltage

Overheating due to incorrect MOV selection, MOV degradation or a TOV event may result in a fire risk when the MOV is directly connected across a power source. A TOV condition is the result of a fault in the power distribution system that causes the supply voltage to increase above the nominal supply voltage range. IEC 60364-4-44:2007, Clause 442 lists TOV L-N, L-E and N-E ratings based on TN, TT and IT power distribution systems. IEC 61643-11:2011, Annex I, TOV Ratings adds in North American and Japanese TOV test requirements. Because of the number of variables involved there isn't a harmonised set of TOV tests. Worst case TOV voltages for AC 230 V are: nearly AC 1 500 V for 0,2 s, nearly AC 400 V for both 5 s and 120 min.

Connecting a GDT, having a DC sparkover higher than the peak power source voltage, in series with the MOV prevents any continuous MOV power dissipation. For L-E and N-E protection IEC 62368-1 requires a high voltage GDT to be connected in series with the MOV in IT equipment and this avoids the need for IEC 61643-11 TOV testing. Connecting two MOVs in series between L-N is a potential solution to the IEC 62368-1 single fault test. IEC 61643-11 compliant SPDs specify either internal or external disconnectors to open-circuit the connection to a failed SPD when excessive currents flow.

7.1.4.6.3 Parameters

In specific applications where the duration between impulses is a known parameter, the average dissipation power can be used to determine the suitability of an MOV. The actual power dissipation of an MOV is composed of the basic dissipation P_0 (power dissipation during normal operating state (leakage region of Figure 5)) caused by the operating voltage and, possibly, the average of periodic energy absorption. If MOVs are selected from the product specification in agreement with the maximum permissible operating voltages, P_0 will be negligible. Periodic energy absorption produces an average dissipation power of:

$$P = \frac{E}{T}$$

E : energy of single pulse (Joules)

T : time period between two pulses (seconds) if known in application

By solving this equation for T , it is possible to calculate the minimum time, $\tau_{\min}$, that must elapse before energy is applied again without exceeding the rated average dissipation power P_M (this parameter is typically specified by MOV manufacturer).

$$\tau_{\min} = \frac{E}{R_M}$$

Since the energy of a single pulse is affected by the maximum of the impulse current, the designer should take into consideration that the MOV cannot handle multiple impulses at currents close to its maximum capability. For example, Figure 9 indicates that if an MOV is pulsed with a 4 000 A 8/20, it cannot withstand another 4 000 A 8/20 regardless of how long the duration is between these two impulses.

It also should be noted that MOVs are not to be "operated" permanently at P_M . They are not suitable for "static" power dissipation, e.g. voltage stabilization or temporary overvoltages as this may lead to decrease lifespan of the MOVs.

For such long term events over tens of seconds other measures shall be taken to protect the MOV from getting damaged. Either the MOV voltages should be selected accordingly or a high voltage GDT should be connected in series with the MOV. For L-E and N-E protection IEC 62368-1 requires a high voltage GDT to be connected in series with the MOV in IT equipment and this removes any TOV requirements.

7.1.4.7 Thermally protected MOVs

A thermally protected MOV is the series connection of an MOV and a thermally operated link/thermal cut off (TCO), usually supplied as a single, integrated component but sometimes as separate elements. The protection performance is normally shown as a graph of current versus the series thermal link operate time. This arrangement is an open circuit mode function where an end of life MOV is disconnected and becomes an open-circuit. Disconnection of an overheated MOV results in the equipment being left unprotected. Because of this, a short circuit mode function for power SPDs is being developed. Here the SPD is shorted out causing the local fuse or the supply circuit breaker to operate. Which is in favour of the continuity of protection, but against the continuity of supply that some critical applications require. Such a shorting arrangement already exists for telecommunication Gas Discharge Tubes (GDTs) to protect the equipment in the event of a power fault occurring between power distribution and telecommunication lines.

For AC SPDs, IEC 61643-11:2011, 8.3.8.1 and 8.3.8.2 require TOV testing. IEC 62368-1 specifies using the same IEC 61643-11 TOV tests for equipment MOV components that are connected across the AC supply. Thermally protected MOVs may be used to terminate current flow during a TOV overload, but the thermally operated link shall be able to open in a harmless manner at the TOV voltage. The IEC 62368-1:2018 Varistor overload test, G.8.2.2, which applies double the AC mains voltage, is an option for thermally protected MOV use.

7.1.5 Mitigating the consequences of failure

7.1.5.1 General

Like any other electronic component, an MOV can fail when subjected to electrical over stress, generally in a short-circuit mode. The consequences of MOV short-circuit failure can vary from violent rupturing of the package to sustained overheating, depending on a number of variables, including the packaging of the MOV in its application and the fault current that flows through it after failure. The latter can depend on the source impedance in the circuit.

Generally, there are three approaches to mitigating the consequences of MOV short-circuit failure. One involves the use of overcurrent protective means that respond directly to current. Examples are fuses and resettable circuit breakers. The second involves the use of thermal protection means that respond to heat produced externally to the MOV itself. Examples are one-shot thermal cut-offs (fusible links), automatically or resettable thermostats, thermistors, etc. The third involves packaging the MOV so that the effect of overheating and/or rupturing of the MOV is contained.

With respect to overcurrent and thermal protection, there are two options for electrically connecting such means as shown in Figure 14. In option (a), the means disconnects both the MOV and the load from the supply, so that the protected equipment is not exposed to further surges. Under option (b), only the MOV is disconnected, and the equipment remains powered and able to function. Depending on the type of equipment and its use, one option may be preferable to the other. For example, in the case of option a), load current requirements can limit how low the rating of an overcurrent protection can be, whereas load current is not a factor in the rating selected for the overcurrent protection in option (b). On the other hand, in any case of option (b), the protective means (overcurrent or thermal) shall be capable of withstanding (i.e. remaining intact) transient surges that the MOV is capable of diverting. If it is not, then the means can needlessly operate, leaving the equipment operating unprotected. In addition, it should be noted that the resistance and inductance of the protective means in circuit (b) will add to the circuit's overall clamping voltage.

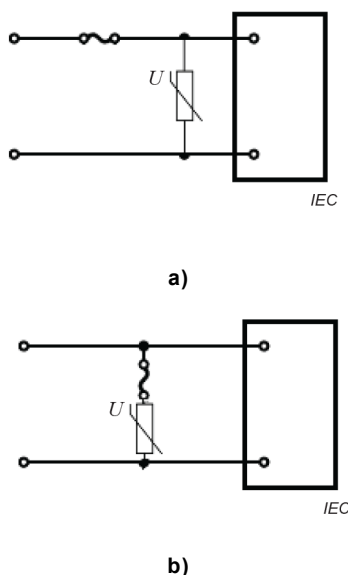


Figure 14 – Options for MOV fuse connection

From the foregoing it is clear that it is not appropriate to describe either option (a) or (b) as being necessarily better than the other. If an indicator is wanted of operation of the overcurrent or thermal protection means, then different approaches are possible.

The choice of rated trip current of an overcurrent protection means will be limited to a lower bound by such factors as load requirements (if the overcurrent protection means is in series with the load), and the need for the means to withstand (i.e., not open) in the presence of expected transient currents. These factors, can limit the usefulness of overcurrent protection means. Thermal protection means might be needed as well.

7.1.5.2 Overcurrent protection

Overcurrent protection interrupts the excessive current flow caused by the MOV developing low impedance.

Overcurrent protection is most effective in the case where the source impedance is relatively low, and therefore the current available to the MOV, if it fails in the short-circuit mode, is relatively high. In this case the overcurrent protection has the advantage of a faster response as compared to thermal protection, because the latter requires time for heat transfer to take place in order to function. It should be noted that fuses generally respond more quickly than some types of circuit breakers, especially the thermal trip type. Regardless of type, the overcurrent protection should be suitable for the fault current available in the circuit.

I^2t rating is typically used to describe the response of overcurrent protection. These ratings are usually based on time events longer than transient surge events, see Figure 15. For example, the melting curve of a 3 A fast-acting fuse shows a melting current of 46 A at 0,01 s, which corresponds to an I^2t of 21 A²s.

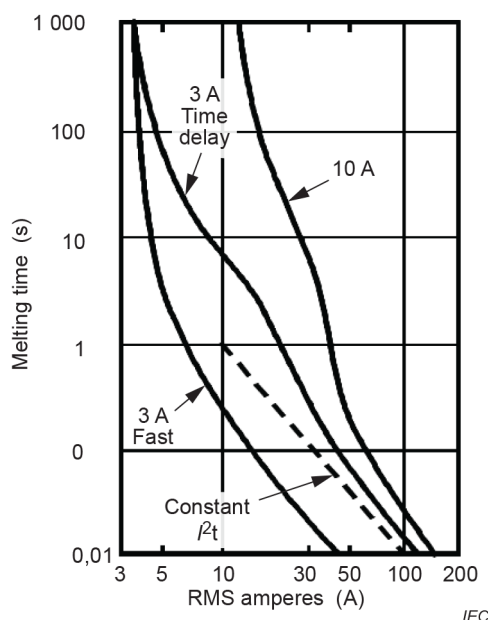


Figure 15 – Time-current characteristic of fast acting and time delay fuse

The applicability of overcurrent protection means ratings to surge currents needs to be established. For example, the standard impulse for characterizing MOVs and other surge-protective components is an 8/20 current waveshape. The I^2t integral for this impulse can be computed. For a 1 000 A crest, the I^2t value of the 8/20 impulse waveshape has been found to be close to 20 A²s.

Empirical tests have shown that the observed I^2t fuse melting current for 8/20 current waveshape can be similar to the I^2t rated value for 0,01 s duration currents. This relationship held for both fast and time delay types. However, the statistical nature of fuse melting should be recognized, and at a given current some fuses from a group of the same type will survive more surge repetitions than others. Further, to avoid premature opening of a fuse after repeated surges, the surge current should not exceed 25 % of the value corresponding to the fuse's I^2t rating. In other words, a fuse selected to withstand a few surges at 3 kA, for example, would be expected to withstand many times more surges at 750 A.

The opening of a current-limiting fuse will take place when there is sufficient fault current to melt the fuse wire. Voltage swells have the potential to overheat SPCs without causing short-circuit failure (users are cautioned against selecting components with inadequate voltage ratings). In the absence of specific requirements, it is recommended that MOVs ratings preferably should have margins of 25 % or more above nominal AC power system voltages.

7.1.5.3 Housing

The consequences of MOV failure and heating may also be mitigated by the way the MOV is encapsulated in the application, such as by isolating the MOV from flammable materials, positioning the MOV away from openings in the enclosure, and/or enclosing the MOV in a substantial non-flammable or flame resistant housing.

The choice of whether to use overcurrent protection, thermal protection, application housing or some combination of the three, as a means of mitigating the consequences of MOV failure will depend on the specific application. Generally, it is desirable to conduct tests that simulate the failure modes of concern on the complete product in order to determine the effectiveness of the means used to mitigate the consequences of MOV failure.

7.1.6 Operations to failure

7.1.6.1 General

The MOV ratings described in this document help the user to estimate the ability of a specific type to function reliably in a particular surge environment. Clearly, the estimate depends on assumptions made about the actual environment from generalized descriptions.

7.1.6.2 Matching MOVs to their surge environment

A procedure for evaluating the cumulative effect of surges on MOVs in their use environments has been devised. That method constructs a model of the surge environment as a basis a set of surges of specific amplitude. This enables calculation of an annual rate of consumption of the rated pulse life of MOVs of specified type and diameter. MOVs then can be selected such that rated life will not be consumed within some time chosen as a design goal.

The procedure was used to calculate the time to consume rated life for SPDs installed at the service entrance and also for SPDs installed in short branch circuits. SPDs at the service entrance were found subject to higher lightning currents than those downstream, because branch circuit wiring tends to limit surge voltage by flashover and to limit surge current through higher impedance. Consequently, MOVs near the service entrance need greater surge current handling capacity than those in branch circuits.

Users of the procedure should note that the expected annual rate of surge occurrence versus voltage level includes all wave shapes. When constructing a model of annual surges, it is necessary to assume a value for the fraction of surges that have the effect of 8/20 impulses. This assumption is very significant because the other surges, represented by 100 kHz wave shape, consume little of a typical MOV's rated life. Also, it is necessary to assume an exposure level, such as medium exposure. By contrast, the exposure and actual rate of surge occurrence in service can vary over a very wide range. Clearly, although the procedure is valid, the accuracy of the estimates obtained is limited by possible inaccuracy in assumptions about the environment.

The procedure is not intended as a substitute for conformance to MOV performance standards where applicable, but can be useful additional MOV selection criteria. In the absence of specific requirements, the procedure represents a reasonable and conservative approach to selecting MOV ratings for reliable operation, and to comparing MOVs of different sizes.

7.1.7 Earthing and bonding

7.1.7.1 General

SPCs may be connected between AC power circuit conductors and the equipment earthing conductor, or to accessible metal parts of the equipment that are connected to the earthing conductor. These SPCs serve to protect insulation from surge voltages. In turn, the insulation reduces the risk of electric shock to personnel under normal line voltage conditions. But, when SPDs are so connected, an increased risk of electric shock might arise as a result of the injection of surge current into paths, under the following conditions:

- a) The magnitude, duration and source impedance of a surge are such that the surge itself poses a risk of electric shock.
- b) The accessible metal parts of the equipment are not reliably or positively earthed.
- c) SPCs conduct high surge current into the earth return paths including the earthed power conductor and the equipment conductor.

- d) The earthed power conductor, neutral, does not carry enough of the surge current, and a high surge current is injected into the earthing conductor.
- e) The impedance of the combined earth return paths at the surge current frequency is sufficiently high to cause significant peak surge voltage to develop between accessible metal equipment surfaces and surrounding conductive surfaces possibly in contact with personnel.

7.1.7.2 Reliability of earthing

The reliability of earthing of accessible metal equipment surfaces can be affected by numerous factors. In general, the earthing of permanently wired equipment is more reliable than the earthing of equipment that is connected to a branch circuit outlet receptacle by cord and plug means. The latter may be adversely affected by an improperly wired or unearthed receptacle or a mis-wired attachment plug or cord. Users are cautioned to make sure that a properly earthed outlet has been provided when using cord connected equipment intended to be earthed, in which SPCs may have been effectively connected between line and accessible metal surfaces.

7.1.7.3 Earth path impedance

Although the impedance of a properly installed earthing system may be sufficiently low at AC power frequencies so as not to be of concern, the impedance may play an important role at surge pulse frequencies. The extent of its importance will be strongly influenced by the specific conditions at the installation site. Discussion of factors affecting those conditions is beyond the scope of this clause, and users should refer to appropriate sources.

7.1.8 Location of MOVs

MOVs are components intended to be installed within complete electrical or electronic equipment by the complete equipment manufacturer. Generally, MOVs are not "stand alone" type components suitable for direct installation in the field. At a minimum, a suitable housing and means for making electrical connections in the field are needed.

Consequently, the suitability of an MOV, from the standpoint of safety, in a specific application will entail an investigation of the MOV in combination with the actual end-use equipment. The safe operation of an MOV in the end-use equipment will depend upon a number of factors, including, but not limited to, the following:

- a) The intended use of the equipment
- b) The function of the MOV and its location in the equipment circuitry
- c) The equipment environment (surge environment, power frequency voltage, temperature, humidity, etc).
- d) The enclosure of the equipment (flammability characteristics; number, location and size of openings, etc.)
- e) The presence of overcurrent and/or thermal protective means within the equipment
- f) Voltage regulation within the equipment

These and other factors are the purview of standards that cover the specific end-use equipment.

7.1.9 Applications for MOVs

There are two broad categories of end-use equipment applications for MOVs.

One category is SPDs for low-voltage AC or DC power circuits. These SPDs may contain MOVs packaged along with other components. Their intended function is to provide some measure of protection for electrical and electronic equipment against the adverse effects of transient surges. Examples of such SPDs are wall outlet receptacles, cord and plug connected power outlet strips, service panel-mounted SPDs, and outdoor mast-mounted secondary surge arresters.

The second category involves the direct installation of MOVs into the circuitry of utilization equipment, such as TV receivers, computers, and appliances. When MOVs are included in such equipment, the combination of the MOV and the equipment should be evaluated to an appropriate standard covering the specific equipment.

7.1.10 Parallel connections

MOVs in parallel can be used to increase total impulse current rating and/or reduce the clamping voltage for a given total impulse current. The ideal condition is to install MOVs that have identical varistor voltage, however, in volume production, to make products having identical characteristics is unrealistic. Figure 16 is an equivalent circuit representing MOVs connected in parallel. Though the surge current flows into both MOVs, the current divides and flows according to the resistance of the two MOVs. This is because of the difference of V - I characteristics between the MOVs.

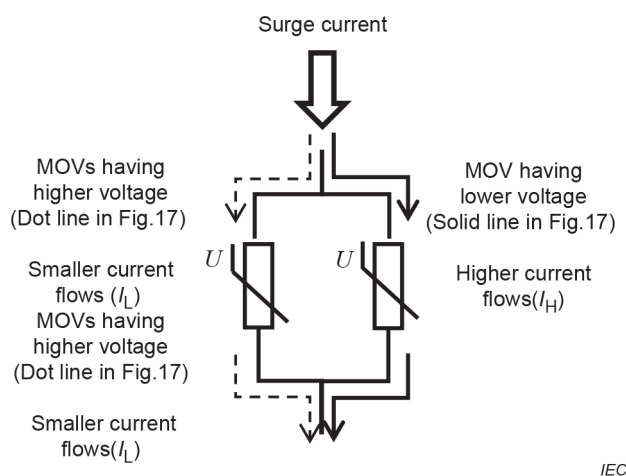


Figure 16 – Parallel connection of MOVs

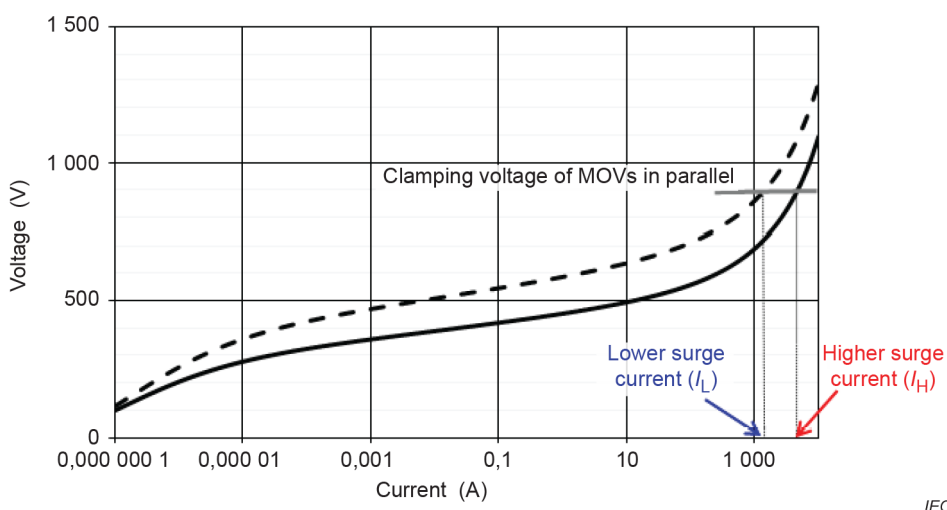


Figure 17 – Example of V - I characteristics for two parallel MOVs

Figure 17 shows that V_V for each MOV is different. This mismatch is the reason for the varied current flows through the MOVs. The length of wires connecting the MOVs influences the sharing of the current as well. So, if several MOVs are connected together in parallel, it most likely results in creating unbalanced conditions due to different impedance paths.

To estimate the maximum impulse capability of a set of two MOVs in parallel, a ratio of 0,8 may be applied as a typical value. As an example, if using two MOVs rated 10 kA maximum impulse current, the maximum impulse current capability of the paralleled set is estimated to $(10+10) \times 0,8 = 16$ kA. However, the user should confirm the impulse withstand capability by testing. For more than two parallel MOVs, no coefficient is provided.

If MOVs can be sorted to achieve a closer match of $V-I$ characteristics, alternative coefficient values may be used. This ratio may be discussed with MOV manufacturers and depends on the sorting or the manufacturing process; it will never equal 1. This ratio may be precisely determined by testing.

In consideration of the above discussion, users may achieve a parallel MOV combination that meets the requirement. To avoid using parallel MOVs, the user may employ a single MOV with a larger diameter.

7.1.11 Series connections

When MOVs are connected in series, the resultant clamping voltage is the summation of the individual MOV clamping voltages. MOVs in series decrease capacitance and also increase both energy capability and power dissipation of the whole assembly.

7.2 Thermally protected metal oxide varistor

7.2.1 Introduction

MOVs have traditionally been used to protect equipment from all types of surges. The surges are usually short in duration and an MOV can adequately clamp the voltage to a level that will not damage the equipment downstream. Surges can be generated from many different sources, including lightning, the switching of various loads and other types of switching.

Frequently however, electrical transients of a longer duration can occur. These longer duration transients are referred to in the industry as a temporary overvoltage. Temporary overvoltages can be caused by a loss of neutral, or an instable line voltage. In either event, the AC line voltage can temporarily increase beyond the MCOV (AC) specified for the MOV. As a result, the MOV could be forced into a continuous clamping condition. In this state, the MOV is driven into thermal runaway and generally fails to a very low resistance. Most of the available fault current would flow through the MOV which would cause the MOV to overheat, generate smoke and possibly catch fire.

Thermally protected MOVs have a thermal link in series with the MOV so that in the event of a temporary overvoltage, the increased current through the MOV would open the thermal link and prevent the MOV from catching fire or exploding due to an excess amount of fault current flowing through the SPD. Figure 3 is the symbol of a thermally protected MOV.

Available fault currents at the power source can be anywhere between 0 and 200 000 A or more. During an abnormal overvoltage when the MOV portion is in constant clamping mode, thermally protected MOVs are designed to manage the low level currents of 10 A or less. Other types of overcurrent protection coordinated with the thermally protected MOV should be used to manage the higher levels of current beyond 10 A. Because thermally protected MOV have to manage fault currents anywhere between 0 and 10 A, the larger sized thermally protected MOVs are tested at short-circuit currents of 10 A, 5 A, 2,5 A and 0,5 A. With regards to the low level currents of 0,5 A or less, there might not be sufficient current to open the fuse. In such cases, the thermally protected MOVs should not show any visible damage. At the larger currents once the fuse opens, a dielectric test across the thermal link is performed for verification. A dielectric test is also measured between foil wrapped around the case and all of the leads tied together to ensure that there is sufficient insulation between the leads and case once the MOV is damaged.

7.2.2 Selection of thermally protected MOV

The selection of a thermally protected MOV in actual application is based on several criteria. If the thermally protected MOV is going to be used in a permanently connected application, then a 25 mm or larger thermally protected MOV is used because it will have to be capable of passing the 10 A limited current temporary overvoltage test. Also, the permanently connected application will be regarded as Type 1 or Type 2 according to UL 1449, will have to pass the 10 kA or 20 kA nominal discharge current test.

On the other hand, if the thermally protected MOV is going to be used in a cord connected application, then generally speaking, a size of 14 mm, 18 mm or 20 mm is used. These shall in turn be able to pass the 5 A limited current temporary overvoltage test and shall be able to withstand a minimum of 15 impulses at 3 kA.

These are general guidelines. However, each MOV shall be selected according to its specific application. Annex G and Annex H show MOVs and thermally protected MOVs selection flowcharts for equipment and an SPD.

7.2.3 Time to open characteristics

Figure 18 shows typical clearing times for a thermally protected MOV. The thermal disconnect takes much longer to open at the lower current levels because the heating of the disk is much slower.

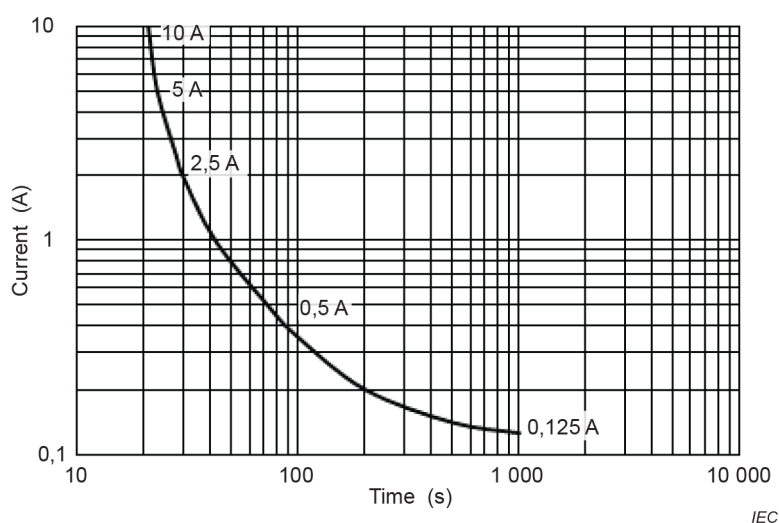


Figure 18 – Operating Time

7.3 ESD

7.3.1 Background

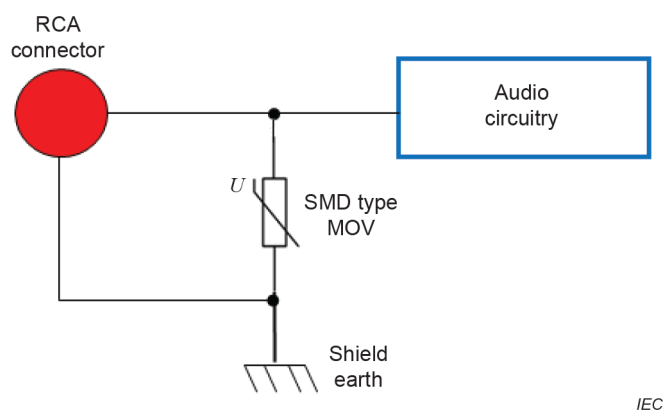
Electronic systems are sensitive to both internal and external sources of overvoltage transients. One source of these transients is electrostatic discharge, ESD. Typically, integrated circuits (ICs) are used as the "brains" of many pieces of equipment such as microprocessors, USB transceiver chips, IEEE 1394 controllers and video graphics chips. Generally the ICs are designed with some ESD protection built in. A common value for this built in protection is 2 000 volts at the waveform according to IEC 61000-4-2. However the end product will likely see several times this value. This means that the ESD shall be prevented from getting to the chip or other sensitive component to prevent damage. One solution to this problem is to use MOVs for ESD application.

7.3.2 Standards

While there are many ESD standards the most common is IEC 61000-4-2 which has various levels and discharge voltages. This standard has values up to 15 kV (see Table 1 of IEC 61000-4-2:2008) which is many times higher than the typical IC can withstand.

7.3.3 Application example 1

To protect a standard audio port (e.g. RCA-type jack) used in Audio/Video equipment, a single channel SPC is recommended. As shown in Figure 19, the ESD suppressor is installed between the signal line and earth shield to shunt the transient from the signal line to earth.

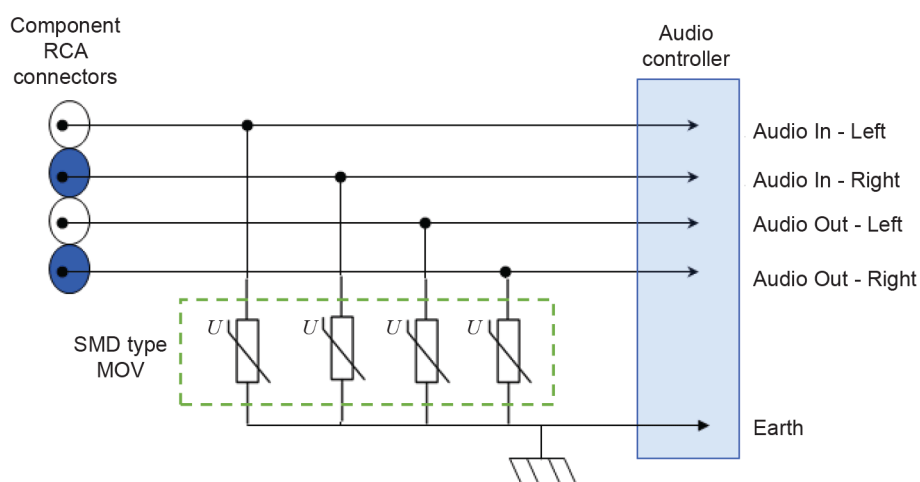


IEC

Figure 19 – Example of MOV application for ESD

7.3.4 Application example 2

To protect 4 port application covering audio in/out left and right channels. As shown in Figure 20, a single SMD type MOV may be used to protect all four channels.



IEC

Figure 20 – Example of 4 ports application using MOVs for ESD

7.4 Consideration for TOV

7.4.1 Failure of the low-voltage power supply circuit

A fault in the low-voltage power supply circuit can produce a TOV of, for example, 330 V between the charging phase and the neutral conductor. It is assumed that this voltage is applied to the MOV for a long time. Therefore, it is necessary to select a product with V_V exceeding 480 Vdc for the MOV installed in the low-voltage power supply circuit.

7.4.2 Failure of high voltage or medium voltage power supply circuit

A voltage of 1 200 V is assumed to occur between the charging phase and ground in the event of a fault in the high and medium voltage circuits. In such a case, if the V_V is increased, it is assumed that the withstand voltage of the protected equipment will be exceeded. Therefore, consider using it in combination with GDT as shown in Figure 21. At this time, by selecting a GDT operating voltage higher than the TOV, it is possible to prevent the MOV from operating and the MOV from burning out.

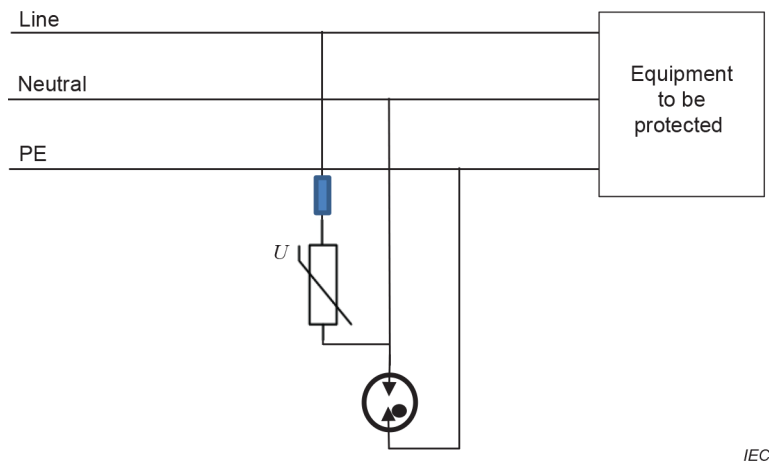


Figure 21 – Combination an MOV with a GDT

8 Safety and hazard information for MOVs

8.1 Overview

8.1.1 General

MOV users shall design the suitable circuit for MOVs based on the following precaution statement because there are fire risks and electric shock risks for human being if MOVs are used in case of abnormal situations due to the surrounding conditions (materials in final equipment design, environment, power conditions, circuit conditions or accidents of distribution system, etc.).

8.1.2 Confirmation of rated performance

MOVs shall be used within the range of rated performance (V_M , impulse withstand capability, energy withstand capability, impulse life and operating temperature)

If MOVs are used beyond the rated performance, the performance of the MOV may degrade or puncture, resulting in smoke or ignition.

8.2 Fire risks

8.2.1 General

The following measures should be taken to avoid fire risks.

8.2.2 Use between lines

Normal current fuses or circuit breakers may be used in series with MOVs. The fuses shall have the current rating appropriate for respective circuits. However, it is also necessary to consider the impulse withstand capability of the fuses or circuit breakers at the same time (refer to 7.1.)

8.2.3 Use between line and earth

Even if the MOV fails shortly, the current fuse may not operate due to earthing resistance. In this case, the resin as MOV insulation may smoke or ignite finally.

In order to prevent this risk, a leakage breaker may be installed on the power supply side from the location of the MOV. If the earth leakage circuit breaker is not installed, current fuses and thermal fuses are used in series with the MOVs.

8.2.4 Shatter-proof

Since the MOV may scatter by its punctures, use it in the case box of the set product or cover it to take measures to prevent the scattering.

8.2.5 Prevention of burning

MOVs shall not be installed near combustibles (vinyl wires, resin mouldings, etc.) because the MOVs may generate heat. In difficult cases, non-flammable covers may be used.

8.2.6 Environmental condition

MOVs shall not be used in the following environment.

- Water or salt water is directly irrigated
- Dew condensing
- Filled with corrosive gas (hydrogen sulphide, sulphurous acid, chlorine, ammonia, etc.)
- Environment that deviates from operating temperature range
- Vibration or impact exceeds the specified range

8.3 Electrical shock risks

In case that MOVs are used between live parts and metal enclosures, short failure of MOVs may cause electrical shocks. In order to avoid them, metal enclosures should connect to the earth and not touch the human being.

In addition, it is also important to reduce MOV standby currents. However, reducing of standby current may cause the increase of clamping voltage.

Using residual current operated protective devices (RCDs) is an option to prevent human beings from electrical shocks.

8.4 Typical precaution statement for the use of MOVs

8.4.1 Information related to degradation and failures of MOVs

Strictly observe the following items, as it may cause degradation of MOV performance and its puncture, resulting in smoke and fire.

- a) Do not use MOVs in temperatures exceeding the operating temperature range such as in direct sunlight or near heat generation.
- b) Do not use in places with high humidity such as direct exposure to wind and rain or where steam is generated.
- c) Do not use MOVs in a dusty place, a salty place, or an atmosphere contaminated with corrosive gas.
- d) Do not wash MOVs with a solvent (such as thinner or acetone) that dissolves or degrades the exterior resin.

- e) Do not apply strong vibration, impact (dropping, etc.) or pressure that may cause cracks in the exterior resin or sintered body to MOVs.
- f) MOVs shall not be used at the voltage exceeding the maximum allowable circuit voltage. If the DC voltage is irregular, MOVs shall not be used at the peak voltage exceeding the maximum allowable circuit voltage.
- g) A surge exceeding the energy withstand capacity shall not be applied to MOVs.
- h) If surges are applied repeatedly, MOVs shall not be used beyond the specified surge life.
- i) When surges are applied intermittently at short intervals, MOVs shall be used under the rated pulse power.
- j) MOVs shall not be used in high frequency circuits exceeding 1 kHz because the element may be punctured by heat generated by dielectric loss.
- k) When MOVs have coating insulation with resin (including mold), do not use resin that will deteriorate the MOV.
- l) MOVs shall not be installed near flammable materials.

8.4.2 Information related to scattering of MOVs

Strictly observe the following items, as MOVs may scatter and cause injury.

- a) MOVs shall not be used in circuits where a surge exceeding the specified surge current is applied.
- b) MOVs shall not be used over the maximum allowable circuit voltage.

8.4.3 Information related to equipment damage or malfunction

Strictly observe the following items because there is a risk of equipment damage or malfunction due to lack of MOV function

- a) Do not bend the lead wire more than necessary.
- b) Do not apply excessive force to the lead wire of MOVs.
- c) Do not bend the lead wire in the vicinity of the insulation coating of MOVs or apply external force to these areas.
- d) The lead wire near MOVs shall be fixed when bending or cutting lead wires
- e) The lead wire shall be connected to the external terminal in the condition kept the area clean and free from dirt and rust. It may be one of the contact failures.
- f) When soldering the lead wires, do not melt the solder and insulation coating as structures of MOVs.
- g) Molten solder or a soldering iron shall not contact to the insulation coating of the MOVs or lead wires

8.4.4 Information related to accidents caused by unexpected phenomena

Take the following measures to avoid accidents caused by unexpected phenomena.

- a) When MOVs are installed between lines, use a circuit breaker or current fuse in series with the MOVs.
- b) When MOVs are installed between line and earth, use earth leakage breakers, current fuses and thermal fuses in series with the MOVs. Also, since an excessive voltage is applied due to an earth fault, use MOVs having higher V_V than this excessive voltage.