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Characteristics of metal oxide varistors for the protection of telecommunication installations

Recommendation ITU-T K.77

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Characteristics of metal oxide varistors for the protection of telecommunication installations

Summary

Recommendation ITU-T K.77 gives the basic requirements to be met by metal oxide varistors (MOVs) for the protection of power circuits and signal circuits of telecommunication installations from surges.

The purpose of this Recommendation is to provide technical guidelines for purchasers and manufacturers of MOVs to ensure their satisfactory operation in the applications for which they are intended.

This Recommendation is intended to be used for the harmonization of existing or future specifications issued by MOV manufactures, telecommunication equipment manufactures, administrations or network operators.

History

Edition	Recommendation	Approval	Study Group	Unique ID*
1.0	ITU-T K.77	2009-01-13	5	11.1002/1000/9659
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Keywords

Metal oxide varistors (MOV), electrical characteristics and test methods.

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Introduction

Two types of metal oxide varistor (MOV) may be differentiated by their constructions: leadless surface mounting device (SMD)-type MOVs and leaded disc-type MOVs (including wire-terminations and strap terminations), while by their application fields the MOV may be divided into MOVs for power circuit use and MOVs for signal circuit use. Table 1 gives the applicable test items for various type MOVs.

Recommendation ITU-T K.77

Characteristics of metal oxide varistors for the protection of telecommunication installations

1 Scope

This Recommendation:

– gives the characteristics of metal oxide varistors (MOVs) used in accordance with [b-ITU-T K.11] for the protection of power supply circuits and signal circuits of telecommunication installations against overvoltages;

– does not deal with combinations of MOV with other over voltage protective component such as gas discharge tube (GDT), avalanche breakdown diode (ABD), etc.;

– does not deal with mountings and their effect on MOV characteristics, the characteristics apply to MOV as a component, mounted only in the ways described for the tests;

– does not deal with mechanical dimensions;

– does not deal with quality assurance requirements.

2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[IEC 60060-1] IEC 60060-1:2010, *High-voltage test techniques – Part 1: General definitions and test requirements.*

[IEC 60060-2] IEC 60060-2:2010, *High voltage test techniques – Part 2: Measuring systems.*

[IEC 60068-1] IEC 60068-1:2013, *Environmental testing – Part 1: General and guidance.*

[IEC 60068-2-1] IEC 60068-2-1:2007, *Environmental testing – Part 2-1: Tests – Test A: Cold.*

[IEC 60068-2-2] IEC 60068-2-2:2007, *Environmental testing – Part 2-2: Tests – Test B: Dry heat.*

[IEC 60068-2-6] IEC 60068-2-6:2007, *Environmental testing – Part 2-6: Tests – Test Fc: Vibration (sinusoidal).*

[IEC 60068-2-13] IEC 60068-2-13:1983, *Environmental testing – Part 2: Tests – Test M: Low air pressure.*

[IEC 60068-2-14] IEC 60068-2-14:1984, *Environmental testing – Part 2: Tests – Test N: Change of temperature.*

[IEC 60068-2-20] IEC 60068-2-20:2008, *Environmental testing –Part 2-20: Tests – Test T: Test methods for solderability and resistance to soldering heat of devices with leads*.

[IEC 60068-2-21] IEC 60068-2-21:2006, *Environmental testing – Part 2-21: Tests – Test U: Robustness of terminations and integral mounting devices.*

[IEC 60068-2-27] IEC 60068-2-27:2008, *Environmental testing – Part 2: Tests – Test Ea and guidance: Shock.*

[IEC 60068-2-30] IEC 60068-2-30:2005, *Environmental testing – Part 2-30: Tests – Test Db: Damp heat, cyclic (12 h + 12 h cycle).*

[IEC 60068-2-45] IEC 60068-2-45:1980, *Environmental testing – Part 2: Tests – Test XA and guidance: Immersion in cleaning solvents.*

[IEC 60068-2-58] IEC 60068-2-58:2015, *Environmental testing – Part 2-58: Tests – Test Td: Test methods for solderability, resistance to dissolution of metallization and to soldering heat of surface mounting devices (SMD).*

[IEC 60068-2-69] IEC 60068-2-69:2017, *Environmental testing – Part 2-69: Tests – Test Te: Solderability testing of electronic components for surface mounting devices (SMD) by the wetting balance method.*

[IEC 60068-2-78] IEC 60068-2-78:2012, *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, stead state.*

[IEC 60099-4] IEC 60099-4:2014, *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems.*

[IEC 60695-11-5] IEC 60695-11-5:2016, *Fire hazard testing – Part 11-5: Test flames – Needle flame test method – Apparatus, confirmatory test arrangement and guidance.*

[IEC 61000-4-2] IEC 61000-4-2:2008, *Electromagnetic compatibility (EMC) Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test.*

[IEC 61000-4-5] IEC 61000-4-5:2014, *Electromagnetic compatibility (EMC) Part 4-5: Testing and measurement techniques – Surge immunity test.*

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

[IEC 61643-11] 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 61643-21] IEC 61643-21:2000, *Low voltage surge protective devices – Part 21: Surge protective devices connected to telecommunications and signalling networks – Performance requirements and testing methods.*

[IEC 61643-331] IEC 61643-331:2017, *Components for low-voltage surge protective devices – Part 331: Performance requirements and test methods for metal oxide varistors (MOV).*

3 Definitions

3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

3.1.1 type [IEC 61051-1]: Group of components having similar design features and the similarity of whose manufacturing techniques enables them to be grouped together either for qualification approval or for quality conformance inspection.

3.1.2 leaded varistors [IEC 61051-1]: Varistors connected to electric circuits via lead wire, or conductive plate, or screw terminations.

3.1.3 surface mount device (SMD) [b-IEC 60749-20-1]: Plastic-encapsulated surface-mount devices made with moisture-permeable materials.

3.1.4 surface mount varistors (SMV) [IEC 61051-1]: Leadless varistors mounted on electric circuits by use of surface mount technology.

3.1.5 varistor voltage (*U_V*) [IEC 61051-1]: Voltage, at specified DC current (also named as DC reference current), used as a reference point in the component characteristic.

3.1.6 temperature derating curve [IEC 61051-1]: Graph showing the parameters' derating of varistors with ambient temperature increasing.

3.1.7 abnormal overvoltage withstanding duration [IEC 61051-1]: Time during which the varistor can withstand an abnormal overvoltage across it without irreversible breakdown.

3.1.8 rated average dissipation power (*P_M*) [IEC 61051-1]: Maximum average dissipation power of repetitive pulses allowed to be applied to the varistors at ambient temperature of 25°C.

3.1.9 rated energy (*E_M*) [IEC 61051-1]: Maximum pulse energy that the varistor is able to withstand one time when it is exposed to 10/1000 current pulse or 2 ms rectangular wave pulse, at an ambient temperature of 25°C.

3.1.10 category temperature range [IEC 61051-1]: Range of ambient temperatures defined by the temperature limits of its appropriate climatic category for which the varistor is designed to operate continuously.

3.1.11 upper category temperature [IEC 61051-1]: Maximum ambient temperature for which a varistor has been designed to operate continuously.

3.1.12 lower category temperature [IEC 61051-1]: Minimum ambient temperature at which a varistor has been designed to operate continuously.

3.1.13 electrostatic discharge (ESD) [IEC 61051-1]: (for surface mount electrostatic protective varistors) Transfer of electric charge between bodies of different electrostatic potential in proximity or through direct contact.

3.1.14 ESD clamping voltage [IEC 61051-1]: (for surface mount electrostatic varistors) Peak voltage developed across the varistor terminations measured at 30 ns after initiation of pulse of 30 A/8 kV defined in Table 3 and Figure 2 of IEC 61000-4-2.

3.1.15 equivalent rectangular pulse duration (*τ*) [IEC 61051-1]: Normalized unidirectional pulse duration that is equal to the ratio of area of the pulse wave to the pulse peak.

3.1.16 isolation voltage (*U_{ISO}*) [IEC 61051-1]: (insulated varistors) maximum peak voltage that can be applied under continuous operating conditions between the varistor terminations and any conducting mounting surface.

3.1.17 capacitance (*C_v*) [IEC 61643-331]: Capacitance across the MOV measured at a specified frequency, voltage and time.

3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 style (based on IEC 61051-1): Subdivision of a type, generally based on dimensional factors and the voltage gradient that may include several variants, generally of a mechanical order.

3.2.2 clamping voltage (*U_{cla}*): Highest peak voltage value among the population when the nominal discharge current (I_n) to be applied to the MOV.

NOTE – For an individual MOV, peak voltages shall be measured in two directions, and the larger value of the two is considered as the clamping voltage of this MOV.

SOURCE: IEC 61643-11:2011, clause 3.1.15 modified: "SPD" has been changed as "MOV", "impulses of specified waveshape and amplitude" has been changed as "nominal discharge current".

3.2.3 maximum impulse voltage (U_{max}): Highest peak voltage value among the population when the maximum impulse current (I_{max}) to be applied to the MOV. U_{max} is used for clearance determination.

SOURCE: IEC 61643-11:2011. 3.1.47, modified: the original expression was "highest measured voltage during surge applications according 8.3.3 for clearance determination".

3.2.4 leakage current (I_L): Current passing through the MOV with the maximum continuous operating voltage U_M applied on it, and measured at a specified temperature. It is DC current under $U_{M(DC)}$, or RMS value of the current under $U_{M(AC)}$ or $U_{M(SP)}$.

NOTE – Some manufacturers test DC leakage current under $0.75U_v$ or $0.83U_V$, where U_v refers to practical varistor voltage of the tested unit.

SOURCE: IEC 61051-1: 2018, clause3.17, revised.

3.2.5 maximum continuous operating voltage (U_M): Maximum voltage which can be applied continuously on MOV at a temperature of 25°C. It may be DC voltage (with ripple less than 5%) $U_{M(DC)}$, or AC voltage in rms value (total harmonic less than 5% $U_{M(AC)}$), or specified waveform voltage in rms value $U_{M(SP)}$.

NOTE 1 – Manufacturer's data sheet specified that $U_{M(AC)} \approx 0.7U_N$, $U_{M(DC)} \approx 1.3U_{M(AC)}$, provided the tolerance of varistor voltage is ±10%, where U_N refers to nominal varistor voltage.

NOTE 2 – U_M is not a measurable parameter, its conformity is verified by service life test under U_M and maximum operation temperature.

SOURCE: combined IEC 61051-1: 2018, clause 3.8 and 3.9.

3.2.6 maximum discharge current (I_{max}): Crest value of a current through the MOV for once, having an 8/20 waveshape and magnitude according to the manufacturers specification. I_{max} is equal to or greater than I_n.

SOURCE: IEC 61643-11:2011, clause 3.1.48, modified: "SPD" has been changed as "MOV", adding a remark "for once", and "equal to or" deleted

3.2.7 metal oxide varistor (MOV): Non-linear resistor made of a sintered mixture of zinc oxide and other metal oxides whose resistance (R), at a given temperature, decreases rapidly with current (I), and increases with current rate ($\mathrm{d}I/\mathrm{d}t$), i.e. $R = f(I, \mathrm{d}I/\mathrm{d}t)$.

NOTE – This property is expressed by either 2-order polynomial formula (1) or power law formula (2):

$$U = 10^{A_0} \times I^B \quad (1)$$

$$\text{or} \quad U = a + b \times I^C \quad (2)$$

where:

$$B = 1 + A_1 + A_2 \times \lg I$$

I is the applied current flowing through the MOV;

U is the voltage developed across the MOV;

A_0, A_1, A_2 are 2-order polynomial formula constants;

a, b, c : are power law formula constants.

SOURCE: IEC 61643-331

3.2.8 nominal discharge current (I_n): The crest value of impulse current with 8/20 waveform that is intended for clamping voltage measurement.

NOTE – The I_n specified by the most manufacturers is (1500~2000)A/cm^2, and the test current used for clamping (limiting) voltage measurement which are specified by previous manufacturer's data sheets is (30~50)A/cm^2.

SOURCE: IEC 61643-11: 2011, clause 3.1.9, revised.

3.2.9 voltage nonlinear index (α): A physical variable to describe the nonlinearity of MOV over a given current range of (I_1, I_2), expressed by the ratio of $\log(I_2/I_1)$ to $\log(U_2/U_1)$:

$$\alpha = \frac{\log(I_2/I_1)}{\log(U_2/U_1)} \quad (3)$$

Unless otherwise stated, the current range is I_2 = 1 mA, I_1 = 0.1 mA for d.c. property, and $I_2 = 2I_1$ for impulse property. The impulse α is expressed as following formula:

$$\alpha = \frac{1}{1+A_1+0.301A_2+2A_2\cdot\log I} \quad (4)$$

SOURCE: IEC 61051-1: 2018, clause 3.5, revised.

3.2.10 impulse life characteristic ($n = f(I_p, \tau)$): A set of graphs or equations that express the quantitative relations of a population between the number (n) of life-times and the impulse stresses of current peak I_p and current duration τ.

NOTE 1 – Impulse life refers usually to median life $n_{0.5}$ of the population, the specification or contract may specify minimum life $n_{\min}$ of the population.

NOTE 2 – Unless otherwise specified, the range of impulse duration τ is from 20 μs to 10 ms, the range of life n is from 10^1 to 10^6 times.

SOURCE: IEC 61643.331-2017

3.2.11 mean time to failure (MTTF): Basic measure of reliability for non-repairable items, for the purposes of this document, the MTTF refers to the number of failed MOVs per 10^6 unit-hours of the life test, undergoing maximum continuous operating voltage and maximum operation temperature.

SOURCE: IEC 61643-331: 2017

3.2.12 rated repetitive impulse current $I_{R(\tau)}$: Impulse current peak of specified duration τ, under which the MOV's minimum impulse life is 10 times.

NOTE – To determine impulse life, $I_{R(20)}$, $I_{R(200)}$, and $I_{R(2k)}$ are usually specified.

SOURCE: IEC 1051-2:1991 Table 1, item 4.5, modified, original remark was "Pulse current, 10 pulses, 8/20 μs, in one direction, 2 per min" and "10 pulses, 10/1000 μs or 2 ms square wave in one direction, 1 every 2 min".

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

DUT Device Under Test

ESD Electrostatic Discharge

LPF Low Pass Filter

MOV Metal Oxide Varistor

MTTF Mean Time To Failure

PS Power Source

SMD Surface Mounting Device

SMV Surface Mount Varistors

SPD Surge Protective Device

TOV Temporary Overvoltage

VDR Voltage-Dependent Resistor

5 Service conditions and storage conditions

5.1 Service conditions

This standard is for components mounted in stationary equipment and device installations that are weather-protected, see [b-IEC 60721-3-3].

– Temperature: normal range: –5°C to + 55°C
  extended range: –40°C to + 85°C
– Humidity: normal range: 5% to 95%
– Air pressure and altitude: air pressure is 86 kPa to 106 kPa.

5.2 Storage conditions

MOVs of encapsulated types shall be capable of withstanding the following storage conditions without damage:

– Temperature: normal range: –40°C to +85°C
  extended range: –40°C to + 125°C
– Relative humidity: up to 95%.

MOVs which are to be soldered after shipment from the manufacturer should be left in the original packing and kept in the following conditions during the storage period:

– Temperature: –25°C to +45°C
– Relative humidity (without condensation): less than 70% annual average, and less than 90% on a maximum of 30 days per annum.

6 Electrical requirements

6.1 Varistor voltage

When tested according to clause 7.1, varistor voltage should be within the specified limits.

6.2 Maximum continuous operating voltage

MOVs shall have a maximum continuous operating voltage $U_{M(AC)}$, and/or $U_{M(DC)}$, $U_{M(SP)}$, whose conformity shall be evaluated according to clause 7.2.

6.3 Leakage current

When tested according to clause 7.3, the leakage current, under maximum DC continuous voltage, shall be within the specified limit, and there shall be no upward drifting during the application of the test voltage.

6.4 Capacitance

When tested according to clause 7.4, the measured value of capacitance shall be within the specified limit.

6.5 Maximum clamping voltage

The maximum value of clamping voltage of the population that is available according to clause 7.5, shall be within the specified limit.

6.6 ESD impulse test

The surface mount varistors (SMV) shall be subjected to electrostatic discharge (ESD) tests by two methods according to clause 7.6:

–	contact discharge method at 8 kV for 10 applications with interval of 1 second; and

–	air discharge method at 15 kV for 10 applications with interval of 1 second.

During the tests, there shall be no evidence of flashover or puncture of the samples, and the varistor voltage and clamping voltage of the samples shall be tested prior to and after the tests, the change of which shall not exceed ±10%.

6.7 Rated energy

The MOV shall be capable of absorbing the impulse energy specified by the manufacturer when subjected to one impulse current of 2 ms or 10/1000 wave and tested according to clause 7.7.

6.8 Impulse life characteristic

The impulse life characteristic $n = f(I_p,\tau)$ of an MOV population is available according to clause 7.8.

6.9 Service life under voltage-temperature stress

The MOV used for power supply circuitry shall be subjected to and pass an endurance test under the conditions of maximum operating temperature and maximum continuous operating voltage for 1000 h and tested according to clause 7.9.

6.10 TOV- withstanding duration

The minimum temporary overvoltage (TOV) withstanding duration of an MOV shall be not less than the specified value when tested according to clause 7.10.

6.11 TOV-withstand characteristic

This test item is carried out by using the same test set and the same test method as defined in clause 7.10, but at several test current values, which are suggested in Table 1, and the current rating of the voltage source shall be not less than 5A.

Table 1 – Test values for TOV-withstand characteristic

Test current I,A	20 m	50 m	100 m	200 m	500 m	1	2	5	10
R_{XL}, Ω	5 K	2 K	1 K	500	200	100	50	20	10
Test result, t_{BR}									

NOTE – R_{XL} is the current limiting resistor.

After completion of the test, the polynomial fitting equation of $t_{\mathrm{BR}} = f(I)$ shall be calculated by use of the data listed in the Table 1.

6.12 Insulation resistance (for insulated MOV only)

Insulation resistance shall be not less than 1000 MΩ under normal conditions, and not less than 100 MΩ after tests of climatic sequence and damp heat, steady state, when tested according to clause 7.11.

6.13 Voltage proof (for insulated MOV only)

The insulated MOV shall be subjected to a voltage proof test at a specified voltage as in the detail specification for 1 min when tested according to clause 7.12.

6.14 ESD clampling voltage

This test is carried out following the test 7.13 on the same specimens; the allowable maximum limiting voltage should be within the specified limits.

6.15 Maximum impulse voltage

This test is carried out following the test method outlined in clause 7.14 on the same specimens; the allowable maximum impulse voltage is the prescribed U_{max}.

7 Test methods

General

Unless otherwise specified, all tests and measurements shall be made under standard atmospheric conditions for testing as below:

Temperature:	15°C to 35°C
Relative humidity:	25% to 75%
Air pressure:	86 kPa to 106 kPa.

The waveform of the impulses used in this Recommendation shall meet the requirements of Annex A.

7.1 Varistor voltage

MOVs shall be kept in prescribed ambient temperature prescribed for not less than 1hr before the measurement is made. Test source shall be constant current source at DC 1 mA (tolerance deviation ±10%) with ripple voltage less than 1%. The voltage shall be read off at 20 ms ~ 100 ms after the application of the test current. Accuracy of the voltmeter shall be ±0.5%. The measured varistor voltage shall be within the limits prescribed.

NOTE 1 – The varistor voltage measurement shall be made in both positive and negative current direction.

NOTE 2 – Two successive measurements may give slightly different outcomes, usually the first is less than the second. Unless otherwise specified, the first is taken.

7.2 Maximum continuous operating voltage

The U_M is not a measurable parameter, its conformity with the specified value is evaluated via 1000 hrs-endurance test and mean time to failure (MTTF) test.

NOTE 1 – The varistor voltage measurement shall be made in both positive and negative current direction.

NOTE 2 – Two successive measurements may give slightly different outcomes, usually the first is less than the second, unless otherwise specified, the first is taken.

7.3 Leakage current d.c.

7.3.1 A test circuit such as shown in Figure 1a or Figure 1b shall be used for d.c. leakage current measurement. The voltage source PS shall be set to the specified value, deviation within ±0.5%. As for DC test, the ripple of the test voltage shall be less than 1%, and for AC test, the total harmonic of the test voltage shall be less than 1%.

To measure the leakage current, a resistor Ry is connected with the MOV in series (Figure 1a), but its resistance should be small enough that the voltage across it is less than 0.5% of the test voltage.

Figure 1b is an alternative test circuit which is suitable for low voltage MOVs. In this circuit, the leakage current is converted to voltage by operational amplifier A and resistor Ry.

The accuracy of voltmeters V1 and V2, and resistor Ry shall be 1%.

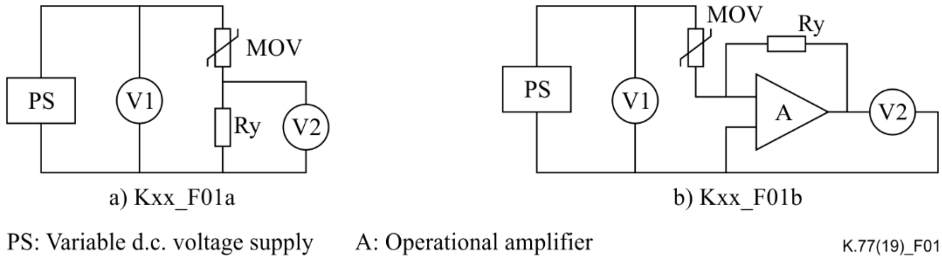


Figure 1 – Test circuits for leakage current measurement

7.3.2 MOVs shall be kept in prescribed ambient temperature for not less than 1 hour before the measurement is made.

7.3.3 The applied time of test voltage shall be within 100 ms to 400 ms prior to taking the leakage current readings. The readings should show no drifting upward, while drifting downward is permitted.

NOTE – The measurement shall be made in two directions.

7.4 Capacitance

The capacitance measurements shall be made by using the test voltage specified by the component manufacturer. Unless otherwise specified, the voltage is 1 kHz, 0.5 V r.m.s for SMV type, or 1 kHz, 1 V r.m.s. for disk type.

NOTE – Measurements of capacitance shall be made on specimens which have not been subjected to other electrical tests in the past 48 hours, or the specimens should be treated at 85°C for 4 hours and kept at room temperature for 2 hours before capacitance measurements are made.

7.5 Clamping voltage

7.5.1 Three samples, randomly selected from the product lot concerned, shall be subjected to the clamping voltage test.

7.5.2 The test impulse shall be 8/20 current with the peak of (1 ± 5%) of the specified value, and the virtual front time of 7 µs to 9 µs, while the time to half value may have any tolerance.

7.5.3 Measure varistor voltages in two directions for an individual sample, resulting in two values U_{N+} and U_{N-}.

7.5.4 Measure voltage peaks (rear peaks) across an individual sample when the pulse current specified in clause 7.5.2 passes through it. Measurement shall be made in two directions, resulting in two values U_{cla+} and U_{cla-}.The tolerance of the clamping voltage measurement shall be within ±3%.

7.5.5 Calculate clamping voltage ratio $R_{cla+} = U_{cla+} / U_{N+}$ and $R_{cla-} = U_{cla-} / U_{N-}$ of each sample, the greater value of R_{cla+} and R_{cla-} is considered to be the sample's clamping voltage ratio. Averaging three samples' clamping voltage ratios, giving $R_{cla}(\text{av})$ that is considered as the clamping voltage ratio of the lot.

7.5.6 The maximum clamping voltage of the lot $U_{cla}(\max)$ is determined by equation (7-1):

$$U_{cla}(\max) = U_{N\max} \times R_{cla}(\text{av}) \tag{7-1}$$

where:

$U_{N\max}$ is the upper limit of the varistor voltage tolerance of the lot.

$U_{cla}(\max)$ shall not exceed the specified limit.

NOTE – The impulse current may induce appreciable interference voltage in the clamping voltage measuring circuit.

7.6 ESD impulse test (for surface mount electrostatic protective varistors only)

7.6.1 Six samples shall be randomly selected from the lot concerned.

7.6.2 Initial measurements: varistor voltage and clamping voltage.

7.6.3 Three samples shall be subjected to the test using the contact discharge method at 8 kV (tolerance deviation ± 5%) for 10 applications, and another three samples shall be subjected to the test using the air discharge method at 15 kV (tolerance deviation ± 5%) for 10 applications; the discharges shall be made in the same direction, and the time between successive applications is 1 second.

During and after the test, there shall be no evidence of flashover or puncture of the samples.

7.6.4 Repeating measurements shall be made as specified in clause 7.6.2. After recovery to room temperature, the varistor voltage and clamping voltage shall not deviate by more than 10% from the initial values measured.

7.7 Rated energy

7.7.1 Three samples shall be randomly selected from the lot concerned, one of them is used for a trial, while the other three samples are used for the formal test.

7.7.2 Initial measurements: varistor voltage and clamping voltage; and the sample of the lowest varistor voltage is used for a trial.

7.7.3 In order to determine appropriate peak value I_P of the test current of 2 ms impulse or 10/1000 impulse, applying the test current I_{trial} calculated by equation (7-4) on the trial sample, at the same time the energy W_{trial} absorbed by the trial shall be measured.

$$I_{trial} = \mathrm{k_W} \cdot W_{tm} /(1.5 U_{Ntrial}) \tag{7-4}$$

where:

$\mathrm{k_W}$= 500 for 2 ms wave, or $\mathrm{k_W}$ = 694 for 10/1000 wave.

W_{tm} is the rated impulse energy of the MOV, in joules.

U_{Ntrial} is the varistor voltage of the trial sample.

1.5 is the approximate value of the clamping voltage ratio.

The current peak I_P used for the rated impulse energy test is computed by equation 7-5:

$$I_P = I_{trial} \frac{W_{tm}}{W_{trial}} \tag{7-5}$$

7.7.4 The test current of 2 ms wave or 10/1000 wave with the peak value determined by equation 7-5 shall be applied once to each of the three samples, after 0.5~1 h recovery at room temperature, visual examination shall show no evidence of flashover on mechanical damage to the samples.

7.7.5 Repeating measurements shall be done as specified in clause 7.7.2. The varistor voltage and clamping voltage shall not deviate by more than 10% from the initial values measured.

7.8 Impulse life characteristic

Test methods for impulse life characteristics are described in Annex B.

7.9 Service life under voltage-temperature stress

Test methods for endurance under voltage/temperature stress are described in Annex C.

7.10 TOV-withstand duration

7.10.1 Description

The MOV TOV withstand duration, t_{BR} is the withstand time duration measured from the application of a specified over-load current to when MOV voltage collapse occurs. It has been shown that the equation of cumulative failure rate F(t_{BR}) versus withstand duration t_{BR} follows a Weibull distribution. Using Weibull analysis, the minimum duration $t_{BR\ (min)}$ of a population can be predicted, giving the minimum TOV withstand time or a given model of MOV.

7.10.2 Test set-up

There are three operation modes in the test set of Figure 2.

(1) By pressing button "Adj", the test voltage applied for 30 ms only. This mode is used to set the test voltage and consequential MOV current.

(2) When switch "SA" is in position "1" a fixed duration TOV test results. Timer TM1 sets the test duration to a time $t_{S.}$ Pressing the "test" button applies the TOV condition to MOV for the duration t_S.

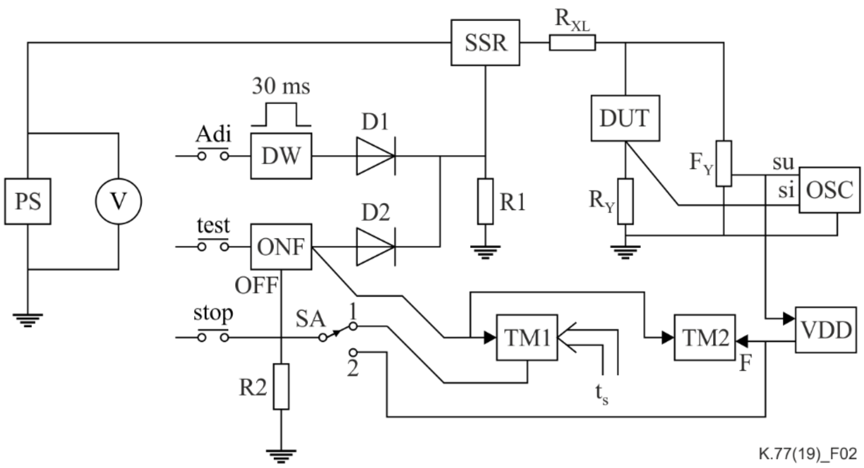
(3) When switch "SA" is in position "2", the TOV test runs until MOV voltage collapse. Pressing button "test" applies the TOV condition to the MOV and starts timer TM2. When MOV voltage collapse occurs, the control circuit turns off the test voltage and stops timer TM2, which reports the TOV test duration t_{BR}.

7.10.3 Test steps

– Set the resistance of RXL to 10 Ω ~ 100 Ω, and the resistance of Ry to such a value that the voltage across it at given test current being less than 0.5% of the test voltage.

– Set the test set to its operation state (1), and adjust the test voltage to such a value that gives a specified current passing through the DUT, via trial for several times.

– Set the test set to its operation state (3), to obtain the value of t_{BR} of the tested piece.



PS: Adjustable voltage source (AC/DC)
DW: Monostable trigger
DUT: Device under test
OSC: Oscilloscope
TM1: Timer started by "test", stopped by ts

V: Voltmeter
ONF: On/off controller
R_Y: Current sensing resistor
VDD: Voltage drop detector
TM2: Timer started by "test" stopped by VDD

SSR: Solid state relay
R_{XL}: Current limiting resistor
F_Y: Voltage divider
t_s: Time setting

Figure 2 – Test set for TOV-test items

7.11 Insulation resistance (for insulated MOV only)

7.11.1 The metal ball method shall be used for insulation resistance measurement. The sample shall be placed in a container holding 1.6 mm ± 0.2 mm diameter metal balls such that only the terminals of the sample are protruding. An electrode shall be inserted between the metal balls.

7.11.2 The insulation resistance shall be measured with a DC voltage of 500 V ± 50 V between both terminations of the sample connected together as one pole and the metallic balls as the other pole. The voltage shall be applied for 1 minute, the insulation resistance being read at the end of that period.

7.11.3 The measured insulation resistance shall be not less than 1000 MΩ under normal conditions, and not less than 100 MΩ after the tests of climatic sequence and damp heat, steady state.

7.12 Voltage proof (for insulated MOV only)

7.12.1 The voltage proof test shall be conducted using the metal ball method described in clauses 7.11.1 and 7.11.2, but the voltage applied shall be the specified a.c. voltage.

7.12.2 The power frequency voltage of 2500 V r.m.s. shall be applied for 60 s ± 5 s between all terminations of the sample connected together as one pole and the metallic balls as the other pole. The voltage shall be applied gradually at a rate of approximately 100 V/s. There shall be no breakdown or flashover.

7.13 ESD clamping voltage

This test item is carried out by using the same methods as described in clause 7.5, except that:

– the 8 kV/30 A ESD impulse is used as test impulse.

– the clamping voltage is measured at 30 ns after the impulse start.

7.14 Maximum impulse voltage

This test item is carried out by using the same methods as described in clause 7.5 except that:

– the maximum impulse voltage is measured at the test current of 8/20 – I_M.

8 Environment tests

8.1 Robustness of terminations

8.1.1 General

Prior to and after the following tests, the varistor voltage shall be measured. Unless otherwise specified, the change from the initially measured value shall not exceed ±5%. Visual examination shall show no evidence of damage, and all markings shall remain legible.

8.1.2 Wire terminations robustness

MOVs with wire terminations shall be subjected to tests U_{a1} and U_b of [IEC 60068-2-21] with the following details:

a) Test U_{a1} – Tensile

The force applied shall be as outlined in Table 2, for 1 minute.

Table 2 – Force for wire terminations

Nominal cross sectional area (mm^2)	Corresponding diameter for circular section wires (mm)	Force (N)
$0.07 < S \leq 0.2$	$0.3 < d \leq 0.5$	5
$0.2 < S \leq 0.5$	$0.5 < d \leq 0.8$	10
$0.5 < S \leq 1.2$	$0.8 < d \leq 1.25$	20

b) Test U_b – Bending

Two consecutive bends shall be applied in each direction.

8.1.3 Strap terminations robustness

MOVs with strap terminations shall be subjected to test U_{a1} of [IEC 60068-2-21] with the following details:

Test U_{a1} – Tensile

The force applied shall be 40 N.

8.1.4 Threaded studs or screw terminations robustness

MOVs with threaded studs or screw terminations shall be subjected to Test U_d of [IEC 60068-2-21] with the following details:

Test U_d – Torque

The torque applied shall be as given in Table 3.

Table 3 – Torque

Thread diameter (mm)	2.5	3	3.5	4	5	6
Torque (Nm)	0.4	0.5	0.8	1.2	2.0	2.5

8.1.5 SMV terminations robustness

a) Force application test

SMV type shall be soldered on to the substrate using the method prescribed by the manufacturer as given in Figure 3. The dimensions of the substrate are as shown in Table 6. A force specified in Table 4 shall be smoothly applied on the sample for 5 s ± 1 second.

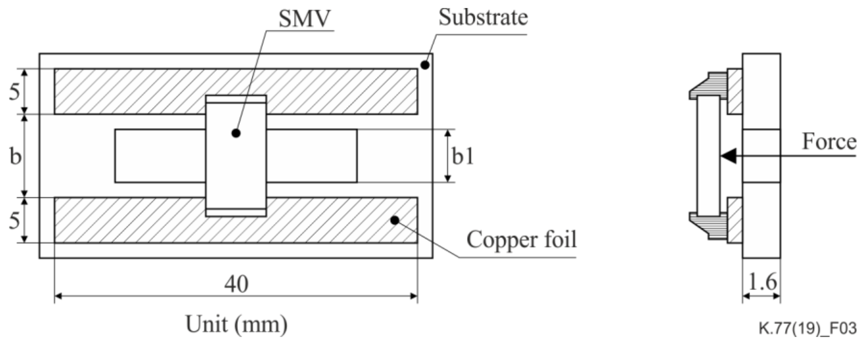


Figure 3 – Test arrangement of terminations of SMV

b) Test U_e of [IEC 60068-2-21]

Bend the substrate by 2 mm 10 times. The change of varistor voltage from the initially measured value shall not exceed ±5%.

Table 4 – Force and dimensions of the substrate

MOV of SMD type	1005 (0402)	1608 (0603)	2012 (0805)	3210 (1206)	3225 (1210)	4532 (1812)	5750 (2220)
Force *P*(N)	5	5	10	10	10	15	15
Dimension b (mm)	0.5	1.0	1.2	2.2	2.2	3.2	4.0
Dimension b_1 (mm)	0.5	1.0	1.0	1.0	1.0	1.0	1.5

8.2 Solderability

8.2.1 Disc type solderability

Tested in accordance with [IEC 60068-2-20], test *Ta*, method 1 (solder bath) with the following details:

Depth of immersion (from component body): 2 mm for wire terminations or 3.5 mm for strap terminations. A thermal insulating screen of 1.5 mm ± 0.5 mm thickness shall be used for wire terminations.

Time of immersion: 2 s ± 0.5 seconds.

Temperature of the solder bath: 235°C ± 3 K, for P_b-Sn solder.
250°C ± 3 K, for lead-less solder.

The terminations shall be examined for good tinning as evidenced by free flowing of the solder with wetting of terminations.

8.2.2 SMV solderability

Tested in accordance with [IEC 60068-2-58], test *Td* with the following details:

Time of soldering: 4 s ± 1 s.

Recovery time: 24 hours ± 2 hours.

Visual examination shall show free flowing of the solder with the wetted area of terminations not less than 80%. A magnifier capable of giving a magnification of (4~10) times may be used when visual examination is carried out.

8.3 Resistance to soldering heat

8.3.1 Disc type resistance to soldering heat

Tested in accordance with [IEC 60068-2-20], test *Tb*, method 1 (solder bath) with the following details:

Initial measurement: varistor voltage.

Depth of immersion (from component body): 2 mm for wire terminations or 3.5 mm for strap terminations.

Time of immersion: 5 s ± 0.5 s.

Temperature of the solder bath: 235°C ± 3 K, for P_b-Sn solder.
250°C ± 3 K, for lead-less solder.

After recovery for 1 hour, visual examination shall show no evidence of damage, and all markings shall remain legible. Varistor voltage shall be measured, the change of which from the initially measured value shall not exceed ±5%.

8.3.2 SMD type resistance to soldering heat

Tested in accordance with [IEC 60068-2-58], test *Td* with the following details:

Initial measurement: varistor voltage.

Time of soldering: 10 s ± 1 s.

Recovery time: 24 hours ± 2 hours.

After recovery for 1 hour, visual examination shall show no evidence of damage and all markings shall remain legible. A magnifier capable of giving a magnification of (4~10) times may be used when the visual examination is carried out.

Varistor voltage shall be measured, the change of which from the initially measured value shall not exceed ±10%.

8.4 Vibration

Tested in accordance with [IEC 60068-2-6], test *Fc*, method B4 with the following details:

Initial measurement: varistor voltage.

Frequency of sine wave: 10~55 Hz for 10 cycles.

Acceleration: 98 m/s^2, or amplitude: 0.75 mm, whichever is the less severe vibration.

Duration: 6 hours (2 hours for each direction).

The change of varistor voltage from the initially measured value shall not exceed ±5%. Visual examination shall show no evidence of damage.

8.5 Shock

Tested in accordance with [IEC 60068-2-27], test *Ea* with the following details:

Initial measurement: varistor voltage.

Pulse: half sine, duration 6 ms.

Maximum acceleration: 400 m/s^2.

Number of bumps: 4000.

The change of varistor voltage from the initially measured value shall not exceed ±5%. Visual examination shall show no evidence of damage.

8.6 Rapid changes of temperature

Tested in accordance with [IEC 60068-2-14], test *Na* with the following details:

Initial measurement: varistor voltage.

The temperature cycle shall be repeated 5 times as outlined in Table 5:

Table 5 – Temperature and period of cycle

Step	Temperature	Period
1	–40°C ± 3 K	(30 ± 3) min
2	(transition time)	<10 s
3	+85°C ± 2 K	(30 ± 3) min
4	(transition time)	<10 s

After completion of 5 cycles, the samples shall be allowed to recover at room temperature for 1~2 hours.

The change of varistor voltage from the initially measured value shall not exceed ±5%. Visual examination shall show no evidence of damage, and all markings shall remain legible.

8.7 Climatic sequence

The MOVs shall be subjected to the following climatic sequence:

Initial measurement: varistor voltage

a) Dry heat, in accordance with [IEC 60068-2-2], test *Ba*, at upper category temperature for 16 hours.

b) Damp heat, cyclic, in accordance with [IEC 60068-2-30], test *Db*, first cycle, at 55°C/25°C, 93% relative humidity for 24 hours.

c) Cold, in accordance with [IEC 60068-2-1], test *Aa*, at lower category temperature for 2 hours.

d) Damp heat, cyclic, in accordance with [IEC 60068-2-30], test *Db*, remaining cycles: the single cycle is 55°C/25°C, 93% relative humidity, 24 hours, that shall be repeated 5 times.

NOTE – An interval of maximum 3 days is permitted between any of the tests during the period of the climatic sequence, except that test b shall be followed immediately by test c.

After completion of the climatic sequence, the samples shall be allowed to recover at room temperature for 1~2 hours.

The change of varistor voltage from the initially measured value shall not exceed ±10%.

Visual examinations shall show no evidence of damage, and all markings shall remain legible.

The insulation resistance shall be not less 100 MΩ.

The voltage proof test shall be performed as prescribed in clause 7.15. There shall be no breakdown or flashover.

8.8 Damp heat, steady state

Tested in accordance with [IEC 60068-2-78], test *Ca* with the following details:

a) Initial measurement: varistor voltage.

b) Tested at +40°C, 90-95% relative humidity for 500 hours. Half of the samples shall be tested without voltage applied, and the other half tested with a voltage applied that is 10% of the maximum continuous d.c. voltage of the MOV.

c) After completion of the damp heat test, the samples shall be allowed to recover at room temperature for 1~2 hours.

d) The change of varistor voltage from the initially measured value shall not exceed ±10%. Visual examination shall show no evidence of damage, and all markings shall remain legible. The insulation resistance shall be not less 100 MΩ.

8.9 Fire hazard

The MOV shall be subjected to the needle-flame test of [IEC 60695-11-5]. The needle-flame application shall be on the side surface of the samples for 5 s. The burning of the sample shall be self-extinguishing within 30 s after removing the needle flame.

8.10 Solvent resistance of marking

Tested in accordance with [IEC 60068-2-45], test *XA* with following details:

a) Solvent to be used: see clause 3.1.1 of [IEC 60068-2-45];

b) Solvent temperature: 23°C ± 5 K.

c) Conditioning: method 1 (with rubbing).

d) Rubbing material: cotton wool.

After the test, all markings shall remain legible.

8.11 Component solvent resistance

Tested in accordance with [IEC 60068-2-45], test *XA* with following details:

a) Initial measurement: varistor voltage;

b) Solvent to be used: see clause 3.1.1 of [IEC 60068-2-45];

c) Solvent temperature: 23°C ± 5 K;

d) Conditioning: method 2 (without rubbing);

e) Recovery time: 4 hours;

f) Post-test inspection: measure varistor voltage, its change from the initially measured value shall not exceed ±5%. Visual examination shall show no evidence of damage.

9 Identification

9.1 Marking

The information given in the marking is normally selected from the following list, the relative importance of each item being indicated by its position in the list:

– maximum continuous a.c. voltage or nominal varistor voltage;

– date of manufacture;

– type reference;

– manufacturer's name or trade mark.

The MOV shall be clearly and permanently marked with the information in item a) above and with as many of the remaining items as is practicable.

The package containing the MOV(s) shall be clearly marked with all the information listed above.

9.2 Documentation

Documents shall be provided to the user so that, from the information in clause 10.1, the user can determine the full characteristics as set out in this Recommendation.

10 Ordering information

The following information should be supplied by the user:

a) drawing giving all dimensions, finishes and termination details;

b) maximum continuous a.c. voltage or nominal varistor voltage;

c) type or model;

d) quantity;

e) quality assurance requirements.

Annex A

Impulses used in this Recommendation

(This annex forms an integral part of this Recommendation.)

In this Recommendation, four types of impulses are used, they are shown by Figures A.1 to A.4.

The differences from an impulse that are accepted between the specified values and those actually recorded shall be within the tolerances listed in this annex, provided that the measuring system meets the requirements of [IEC 60060-2].

A.1 Definition of T_1/T_2 impulse

T_1/T_2 impulse is a combination of two numbers, the first representing the virtual front time (T_1) and the second the virtual time to half value on the tail (T_2).

NOTE – It is written as T_1/T_2, both in microseconds, the sign "/" having no mathematical meaning.

Virtual front time T_1 of a current impulse is 1.25 times the interval between the instants when the impulse is 10% and 90% of its peak value; while virtual front time T_1 of a voltage impulse is 1.67 times the interval between the instants when the impulse is 30% and 90% of its peak value.

Virtual time to half value T_2 of a current impulse or a voltage impulse is the time interval between the virtual origin and the instant on the tail at which the current or the voltage has first decreased to half its peak value.

Virtual origin O_1 of a current impulse is the instant preceding the point at which the current is 10% of its peak value by a time $0.1 \times T_1$; virtual origin O_1 of a voltage impulse is the instant preceding the point at which the voltage is 30% of its peak value by a time $0.3 \times T_1$.

A.2 Tolerances for T_1/T_2 impulse (Figures A.1 and A.2)

Tolerances for T_1/T_2 impulse are listed in Table A.1.

Table A.1 – Tolerances for T_1/T_2 impulse

T_1/T_2 impulse	For 8/20 current	For 10/350 current	For 10/1000 current	For combination wave	
				I_{SC} 8/20	U_{OC} 1.2/50
Peak value, I_P	±10%	±10%	±10%	U_{OC}/2 Ω ± 10%	±3%
Front time, T_1	8 μs ± 0.8 μs	<50 μs	10 μs + 10 μs, –1 μs	8 μs ± 0.8 μs	1.2 μs ± 0.36 μs
Time to half value, T_2	20 μs ± 2 μs	(Note)	1000 μs ± 200 μs	20 μs ± 2 μs	50 μs ± 10 μs
Virtual total duration			(2.5~4) T_2		
NOTE – See "10/350 impulse current" below.					

A small overshoot or oscillations are tolerated provided that their single-peak amplitude in the neighbourhood of the impulse peak is not more than 5% of the peak value. Any polarity reversal after the current has fallen to zero should be not more than 20% of the peak value.

10/350 impulse current

The 10/350 impulse current shall be a unipolar impulse that reaches its peak I_P within 50 µs, the transfer of charge Q shall occur within 10 ms. The tolerances on the 10/350 impulse shall be the following:

Peak value:	$I_P \pm 10\%$
Charge:	$Q = 0.5\ I_P \pm 5\%$, (Q in coulombs, I_P in kA)
Specific energy:	$W/R = \int_0^{\infty} i^2(t)dt = 250\ I_P^2 \pm 10\%$, ($W/R$ in J/Ω, I_P in kA)

NOTE – The virtual time to half value T_2 of current impulse 10/350 may depend greatly on the effective impedance of the tested component, hence the time T_2 is not required, while the requirement of charge $Q = 0.5\ I_P \pm 5\%$ should be met to ensure that sufficient energy is absorbed by the tested component.

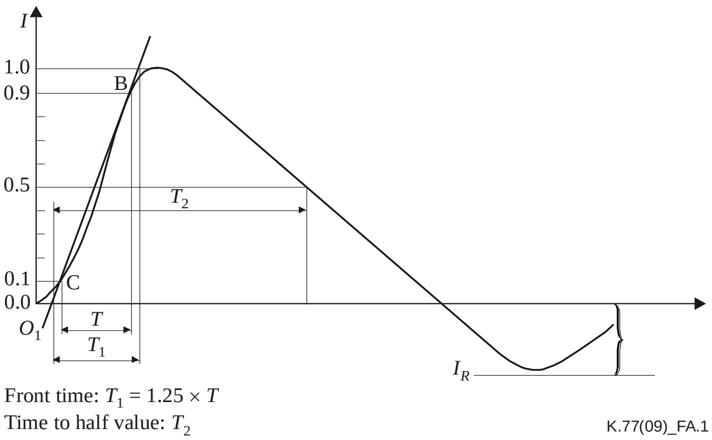


Figure A.1 – T_1/T_2 current impulse

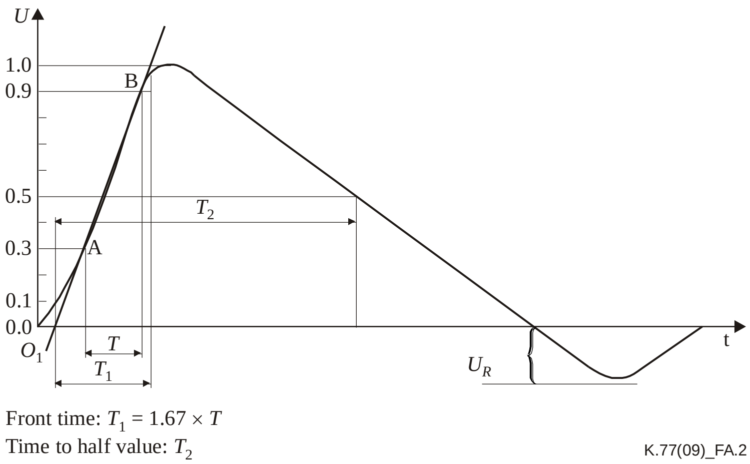


Figure A.2 – T_1/T_2 voltage impulse

A.3 Tolerances for rectangular impulse (Figure A.3)

Peak value I_P :	+20%, –0%
Virtual duration of the peak T_D :	+20%, –0%
Virtual total duration T_T :	$\leq 1.5\ T_D$
Polarity reversal :	$\leq 0.1\ I_P$

An overshoot or oscillations are tolerated provided that its peak amplitude is not more than 10% of the peak value.

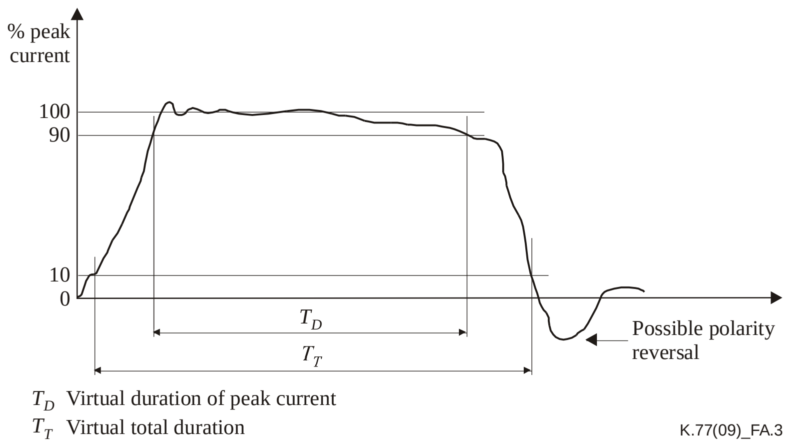


Figure A.3 – Rectangular current impulse

A.4 ESD discharge current impulse (Figure A.4)

Waveform parameters of ESD discharge current shall meet the requirements of Table A.2 and shall be verified according to [IEC 61000-4-2].

Table A.2 – Waveform parameters of ESD discharge current

Test level	Indicated voltage (kV)	First peak current of discharge (A)	Rise time T_r (ns)	Current at 30 ns (A)	Current at 60 ns (A)
1	2	7.5 ± 0.75	0.7~1	4 ± 1.2	2 ± 0.6
2	4	15 ± 1.5	0.7~1	8 ± 2.4	4 ± 1.2
3	6	22.5 ± 2.25	0.7~1	12 ± 3.6	6 ± 1.8
4	8	30 ± 3	0.7~1	16 ± 4.8	8 ± 2.4

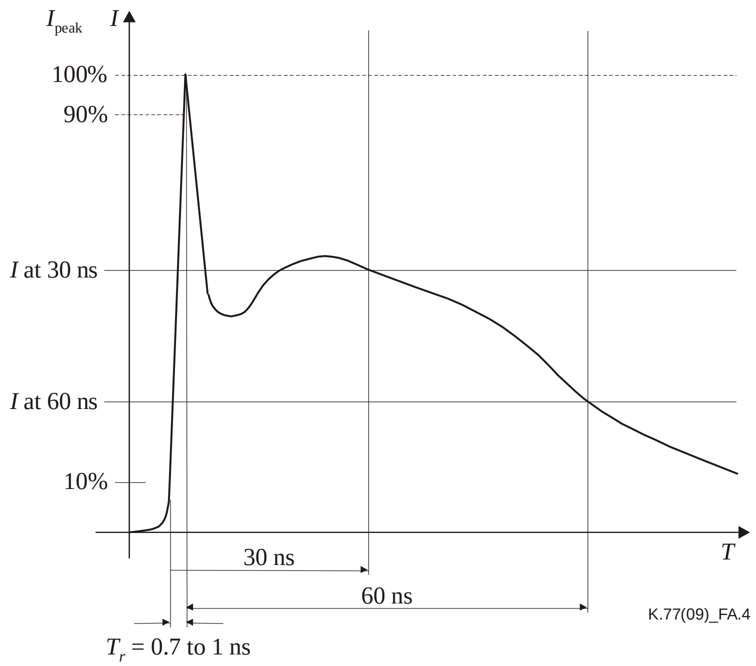


Figure A.4 – ESD discharge current impulse

Annex B

Test methods for impulse life characteristics of MOV

(This annex forms an integral part of this Recommendation.)

B.1 Scope

The impulse life characteristic of a MOV, $n = f(I_p, \tau)$, expresses the quantitative relations between the impulse numbers (n), impulse current peak (I_p), and impulse equivalent duration τ.

This annex provides the test method for the impulse life of an MOV, and the method for establishing a set of impulse life equations by use of the test data, as well as the method for calculating life characteristic by using the equations.

B.2 Method for impulse life characteristics

For the purpose of this annex, the following terms apply:

- Population: A set of all the individuals of interest in a particular assessment.
- Sample: A set of individuals selected from a population, usually intended to represent the population in a particular assessment.
- Individual: A piece of the sample.

B.2.1 Sampling and initial measurement

All individuals should be of the same type code which may include different dimensions and/or nominal varistor voltages, according to the specification, whose voltage gradient difference is no more than 20 V/mm.

The individuals should first pass the reliability test to eliminate the products with potential failure at an early period.

The individuals shall be randomly selected from the population, unless otherwise specified, the total number of individuals is 90 pieces that should be equally assigned to each dimension and/or each nominal varistor voltage. The individuals of 90 pieces are divided into six test groups of 15 pieces each.

Measure and record the initial varistor voltage in two directions of each individual before impulse test.

B.2.2 Test currents

The six test groups of individuals should be subjected to the impulse life tests respectively under short duration impulse, middle duration impulse, and long duration impulse. Unless otherwise specified, the six test currents, as specified in Figure B1, shall be used. The equivalent rectangular width τ are 20µs, 200µs and 2ms, separately. Two current levels of (I_R, I_S) are used for each duration as shown in Figure B.1. The amplitude of current depends on the impulse time, to make sure the samples can pass 10 times the impulse of I_R and 1000 times the impulse of I_S. The interval time between impulse applications shall be determined to make sure the the surface temperature of samples are lower than the specified maximum operating temperature. The direction of the test current remains constant.

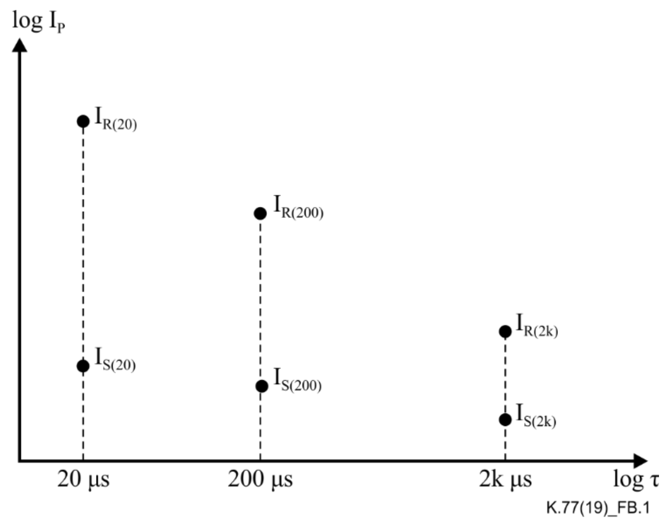


Figure B.1 – Six types of impulse

B.2.3 Failure criterion

The individual is considered failure when one or more of the following defects occurred:

– Varistor voltage of specimen deviates by more than 10% from the initial values;

– Breakdown of the ceramic body;

– Cracking of the ceramic body;

– Flashover on the side of ceramic body.

B.2.4 Weibull distribution (Weibull distribution function):

A distribution function that describes the characteristics of the number of impulse life that can be expressed as equation (B-1):

$$\mathrm{F}(n) = \frac{S_{nt}}{S_T} \qquad \text{(B-1)}$$

$$\mathrm{F}(n) = 1 - \mathrm{e}^{\left(-\frac{(n-n_{min})^m}{n_o}\right)} \qquad \text{(B-2)}$$

where:

n: number of impulse life

S_T: total number of specimens of a sample

S_{nt}: accumulated number of specimens, whose impulse life is not more than n

n_{min}: minimum number of impulse life among the population that is obtained via calculation of the Weibull distribution of the sample. It is also named "guarantee impulse life".

n_0: scale parameter of the Weibull distribution function

m: shape parameter of the Weibull distribution function.

A straight-line of Weibull distribution that is a conversion expression of Weibull distribution as equation (B-3):

$$Y = m \cdot X - b \qquad \text{(B-3)}$$

where:

$Y = \ln\ln\left(\frac{1}{1-\mathrm{F}(n)}\right)$;

$X = n - n_{min}$;

$$b = \ln(n_0).$$

For a group of samples whose failure distribution conforms to Weibull function, the cumulative failure probability F(n) is equal to 0.5, while Y is equal to –0.3665 correspondingly. The formula of medium life can be expressed by equations (B-4) and (B-5).

$$X_{0.5} = \frac{b-0.3665}{m} \quad \text{(B-4)}$$

$$n_{0.5} = 2.71828^{X_{0.5}} + n_{min} \quad \text{(B-5)}$$

where:

$X_{0.5}$: the value of X at F(n) = 0.5.

An instance of the calculations is given in Table B.1. However, it should be noted that the total number of the specimens are 15 pieces.

Sample information as:

– 14D-561, 210V/mm;

– Impulse current: $I_{R(200)}$=451 A;

– Interval time of discharge: 100 s;

– Surface temperature of specimen: 78°C~80°C.

Table B.1 – An instance of Weibull distribution calculation of a sample

Impulse time n_i	Number of failures	Impulse Life[1] n_{ind}	Cumulative numbers of failures S_{nt}	Cumulative failure probability[2] F(n)	Y	ln(n_{ind}-n_{min})at assumed n_{min}		
						n_{min}= 17	n_{min}= 16	n_{min}= 15
17	1	16	1	0.033333	–3.38429		0	0.693147
20	1	19	2	0.1	–2.25037	1.098612	1.386294	1.609438
21	1	20	3	0.166667	–1.70198	1.386294	1.609438	1.791759
22	1	21	4	0.233333	–1.32538	1.609438	1.791759	1.94591
23	2	22	6	0.366667	–0.7836	1.791759	1.94591	2.079442
24	1	23	7	0.433333	–0.56566	1.94591	2.079442	2.197225
25	1	24	8	0.5	–0.36651	2.079442	2.197225	2.302585
26	2	25	10	0.633333	0.003297	2.197225	2.302585	2.397895
35	1	34	11	0.7	0.185627	2.890372	2.944439	2.995732
37	1	36	12	0.766667	0.375203	2.995732	3.044522	3.091042
45	1	44	13	0.833333	0.583198	3.332205	3.367296	3.401197
62	1	61	14	0.9	0.834032	3.806662	3.828641	3.850148
78	1	77	15	0.966667	1.224128	4.110874	4.127134	4.143135

NOTE 1 – $n_{ind} = n_i - 1$

NOTE 2 – F(n) $= \frac{S_{nt}-0.5}{S_T}$, when $S_T < 20$.

NOTE 3 – Calculation for minimum life: The minimum life n_{min} cannot be available from direct calculation, it can only be obtained by a method of trial and error according to the rule of making the straight-line of Weibull distribution, equation (B-3), the best linearity. For this instance, the tested minimum life was 17, hence the population's minimum life n_{min} must be ≤ 17. Assume that n_{min} = 17, 16, 15, then calculate the slope errors of the straight- line equations by use of software of Origin or the like, resulting in the following calculations:

$Y = \mathrm{F}(\ln(n_{ind} - 17))$ slope error = 9.76%

$Y = \mathrm{F}(\ln(n_{ind} - 16))$ slope error = 7.77%

$$Y = \text{F}(\ln(n_{ind} - 15)) \qquad \text{slope error} = 9.21\%$$

It is noted that the linearity of the life straight- line equation is the best when assuming n_{min}= 16. That is to say the minimum life n_{min}= 16 for this instance.

NOTE 4– Calculation for median life: The median life $n_{0.5}$ can be obtained by fomula (B-5), where the value of $X_{0.5}$ is calculated by fomula (B-4) as n_{min} is equal to 16. As a result, the median life $n_{0.5}$ is 26 for this instance.

B.3 Expressions of MOV impulse life characteristics

B.3.1 Basic impulse life equations

An MOV has different impulse life characteristics for short-duration impulses or long-duration impulses. The former typically refers to τ = 20 μs ~ 2 ms. In order to describe the impulse life characteristics of a MOV population, the basic impulse life equations as shown in equation (B-6) and (B-7) are needed for τ =17.5 μs ~ 200 μs, and equations (B-6) and (B-7) for τ =200 μs ~ 15 ms. It is noted from equations (B-6) and (B-7) that to determine impulse life equations means to determine the two pairs of parameters of (A_τ, a_τ) and (B_n, b_n).

$$\log I_P = A_\tau - a_\tau \cdot \log n \quad (\tau = \text{constant}) \tag{B-6}$$

$$\log I_P = B_n - b_n \cdot \log \tau \quad (n = \text{constant}) \tag{B-7}$$

B.3.2 Graphical expressions of the impulse life characteristics

Using the log values for the peak current I_P, number of impulses n and impulse duration τ, the constants in equations (B-6) and (B-7) can be determined. Figure B.2 shows equation (B-6) results for τ values of 20 μs, 200 μs and 2 ms. The three versions of equation (B-6) for the example τ values are shown in equations (B-8) to (B-10). The impulse life *n* values are classified as minimum, n_{min} or medium, $n_{0.5}$.

$$\log I_{P(20)} = A_{20} - a_{20} \cdot \log n \tag{B-8}$$

$$\log I_{P(200)} = A_{200} - a_{200} \cdot \log n \tag{B-9}$$

$$\log I_{P(2k)} = A_{2k} - a_{2k} \cdot \log n \tag{B-10}$$

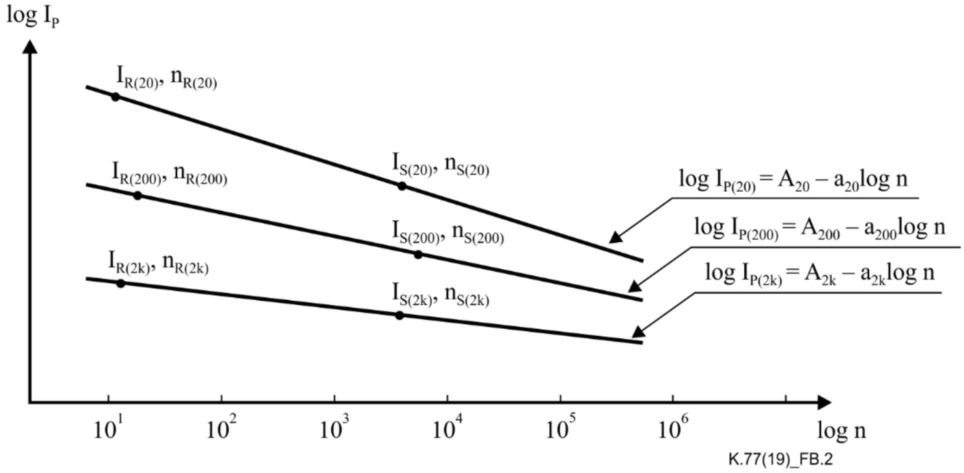


Figure B.2 – Test results of six groups of samples and three basic life characteristic equations

Annex C

Test methods for service life under voltage-temperature stresses

(This annex forms an integral part of this Recommendation.)

C.1 Scope

This annex establishes failure rate sampling test method and failure distribution function for MOV service life under voltage-temperature (U-T) stresses.

The failure rate sampling test method is used when the service life of MOV samples are too long to figure out. The mean time to failure (MTTF) is obtained as a result. Since the failure rate $\lambda(t)$, of MOV under U-T stress is roughly a constant, the methods of "failure rate sampling plans and procedures" defined by MIL-STD-690D can be used for the purpose of this annex.

The failure distribution function is used if all the samples or more than half of the samples failed during test. The minimum service life t_{min} and medium service life $t_{0.5}$ are determined.

C.2 Initial qualification approval test

C.2.1 Sampling plans

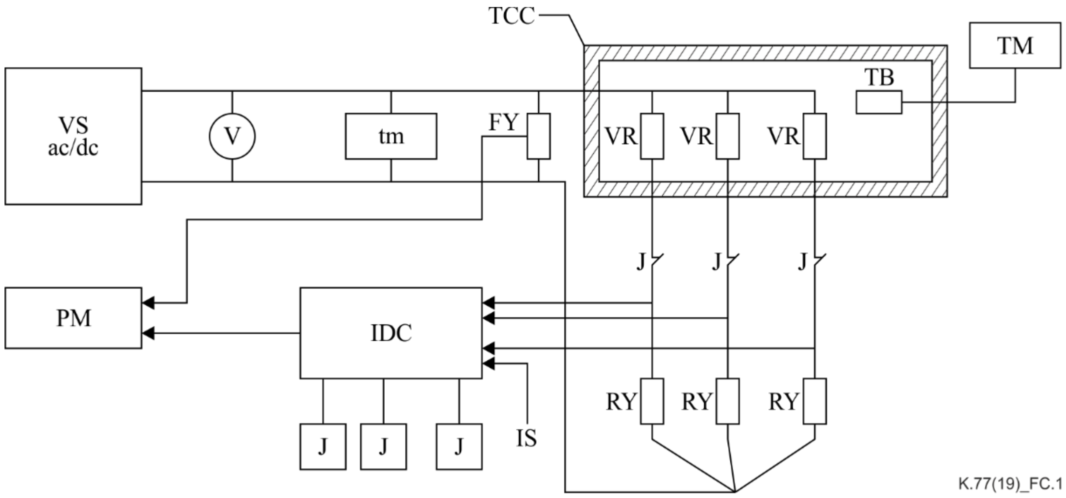
Six sampling plans are provided for choice, see Table C.1, which are based on the confidence level of 60% and 90%, and the permitted number of failures C = 0, C = 1 and C=2.

Table C.1 – Sampling plans for qualification approval test

Life time in years			**5**	**10**	**15**	**20**	**30**
Life time in khrs			44	88	132	176	264
MTTF (failure number/10^6hrs)			22.7	11.4	7.57	5.7	3.8
Symbol of failure rate (FR) level			L-2.27	L-1.14	M-0.76	M-0.57	M-0.38
Confidence Level (%)	Permitted Number of failures C	Cumulative [UH] of M-level	Cumulative unit-hours[UH] (×10^6) of the test				
60	0	0.0916	0.0404	0.0804	0.1205	0.1607	0.2411
60	1	0.202	0.089	0.1772	0.2658	0.3544	0.5316
60	2	0.311	0.137	0.273	0.409	0.546	0.818
90	0	0.230	0.1013	0.2018	0.3026	0.4035	0.6053
90	1	0.389	0.1714	0.3412	0.5118	0.6825	1.0237
90	2	0.532	0.234	0.467	0.794	0.933	1.4

C.2.2 Test set-up

The test set-up shown in Figure C.1 is used for the testing described in this annex.



VS: Variable voltage source (ac/dc)
V: Voltmeter
tm: test time accumulator
FY: Voltage divider
TCC: Thermostatic chamber
TB: Temperature sensor
TM: Thermometer
VR: Varistor
RY: Current measuring resistance
IDC: Current measurement/overcurrent controller
PM: Power meter
IS: Upper current setting
J: Relay

Figure C.1 – Voltage – temperature stress test equipment

C.2.3 Test hours

Test hours of 2000 hours is specified which is a common practice for this kind of test.

C.2.4 Number of samples (N)

There is a choice between a) and b) as follows:

a) All samples are tested under normal U-T stress, in this situation the N shall be [NH]/2000, where the [NH] is the required cumulative unit-hours [NH] ($\times 10^6$) of the test obtained from Table C.1.

b) Generally, (1/3) [NH] is tested under normal U-T stress, and (2/3) [NH] is tested under accelerated U-T stress of acceleration factor AF, in this situation the N shall be as equation (C-1):

$$N = \frac{1}{3} \times \frac{[NH]}{2000} + \frac{2}{3} \times \frac{[NH]}{2000 \times AF} \qquad (C\text{-}1)$$

C.3 Test procedures

C.3.1 Sampling and initial measurement of the samples

Samples shall be randomly selected from the interested MOV population, their varistor voltages shall be measured, and shall differ by not more than 1% from each other, the average varistor voltage is denoted as U_{av}.

C.3.2 Installation of the samples in the test chamber

The samples shall be installed in the test chamber in such a way that the distance between two adjacent samples is not less than three times the major dimension of their body.

There shall be no undue draught over the specimens, only natural convection resulting from the hot body of the specimens.

The temperature of the test chamber shall be maintained at the specified value (tolerance deviation ± 2 K).

The test voltage applied on the specimens shall be equal to the specified voltage applied ratio (AVR) multiplied by the U_{av} with a tolerance of ± 0.5%. The rated output current of the source shall be not less than 1 A. The a.c. voltage shall be of a substantially sinusoidal waveform (total harmonic distortion less than 5%).

The resistance of the current sensing resistor RY shall be such that the voltage on the RY at 1 mA shall be less than 0.5% of the test voltage.

Unless otherwise specified, the control circuit is set in such a way that the relay operates to disconnect the MOV from the test voltage as the current passing through the RY is greater than 2 mA.

C.3.3 Measurement during the test

The current or the power loss of each specimen shall be measured at the test hours of 1, 4, 24, 96, 200, 500, 750, 1000, 1250, 1500, 1750, 2000. If an increasing trend in current or power loss is found, then a tracking measurement should be made. The specimen is treated as failed when the measured current or power loss is greater than the specified value, which is, unless otherwise specified, 1.5 times the value measured at 1-hour test.

Accidental break of the test voltage is allowed if the total duration is not more than 50 hours and does not happened during the period of 1900 hours ~ 2000 hours.

C.3.4 Restoration and measurement after 2000 hours

After 2000 hours, turn off the test voltage and the power of the chamber, open the door of the chamber, and allow the specimens to cool for (1~2) hours.

Measure the varistor voltage of each specimen in both directions, which shall be greater than 0.9 times the initial value.

C.3.5 Conformance criterion for qualification approval test

The total number of failures, including judgement during and after the test, shall be equal to or less than the specified value "C".

C.4 Maintenance of qualified failure rate (FR) level

C.4.1 Sampling plans for qualification maintenance test

Sampling plans for qualification maintenance test are shown in Table C.2 based on a confidence level of 10%.

Table C.2 – Sampling plans for qualification maintenance test (10% confidence level)

Life in years	05	10	15	20	30
Life in khrs	44	88	132	176	264
MTTF (failure number/10^6hrs)	22.7	11.4	7.57	5.7	3.8
Symbol of failure rate (FR) level	L-2.27	L-1.14	M-0.76	M-0.57	M-0.38
Permitted number of failures C	Cumulative unit-hours [UH] ($\times 10^6$) of the test				
C=1	0.0235	0.0467	0.07	0.0943	0.14
C=2	0.0485	0.0965	0.145	0.193	0.29

C.4.2 Requirements

Qualification shall be maintained periodically. The maintenance period shall be 6, 9 or 12 months, or each production batch, as specified in the specification, which is not an option to be selected by the manufacture.

At the beginning of each qualification maintenance period, the manufacturer shall elect and record the unit-hours that shall be met within the qualification maintenance period specified, and notify the qualifying activity.

The maintenance period in effect shall not be changed, regardless of the unit-hours accumulated. Unit-hours that exceeded those required for the maintenance period shall be at the manufacture's risk (within the original "C" number). However these unit-hours may be used for failure rate extension.

Each type of the initial qualification approval (combination of life in years, confidence, permitted number of failures C) shall be maintained separately.

C.5 Failure distribution function of service life

The method of Weibull distribution function used for impulse life characteristics in Annex B is also suitable for evaluating the service life, as long as service time *t* is used instead of impulse life *n*.

Bibliography

[b-ITU-T K.11] Recommendation ITU-T K.11 (2009), *Principles of protection against overvoltages and overcurrents.*

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