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SERIES K: PROTECTION AGAINST INTERFERENCE

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.

Source

Recommendation ITU-T K.77 was approved on 13 January 2009 by ITU-T Study Group 5 (2009-2012) under Recommendation ITU-T A.8 procedures. This version includes the corrections agreed upon by ITU-T Study Group 5 (2009-2012) on 29 May 2009.

FOREWORD

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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 several MOVs connected in series and/or in parallel, nor combinations of MOV with other components;

– 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 (1989), *High-voltage test techniques – Part 1: General definitions and test requirements*.

[IEC 60060-2] IEC 60060-2 (1994), *High voltage test techniques – Part 2: Measuring systems*.

[IEC 60068-1] IEC 60068-1 (1988), *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 (1995), *Environmental testing – Part 2-6: Tests – Test Fc and guidance: 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 (1979), *Environmental testing – Part 2: Tests – Test T: Soldering*.

[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 (1987), *Environmental testing – Part 2: Tests – Test Ea and guidance: Shock*.

[IEC 60068-2-29] IEC 60068-2-29 (1987), *Environmental testing – Part 2: Tests – Test Eb and guidance: Bump*.

[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 60068-2-54] IEC 60068-2-54 (2006), *Environmental testing – Part 2-54: Tests – Test Ta: Solderability testing of electronic components by the wetting balance method*.

[IEC 60068-2-58] IEC 60068-2-58 (2004), *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 (2007), *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 (2001), *Environmental testing – Part 2-78: Tests – Test Cab: Damp heat, stead state*.

[IEC 60099-4] IEC 60099-4 (2006), *Surge arresters – Part 4: Metal-oxide surge arresters without gaps for a.c. systems*.

[IEC 60695-11-5] IEC 60695-11-5 (2004), *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 (2001), *Electromagnetic compatibility (EMC) Part 4-2: Testing and measurement techniques −Electrostatic discharge immunity test*.

[IEC 61000-4-5] IEC 61000-4-5 (2005), *Electromagnetic compatibility (EMC) Part 4-5: Testing and measurement techniques −Surge immunity test*.

[IEC 61051-1] IEC 61051-1 (2007), *Varistors for use in electronic equipment –Part 1: Generic specification*.

[IEC 61643-1] IEC 61643-1 (2005), *Low-voltage surge protective devices – Part 1: Surge protective devices connected to low-voltage power distribution systems – Requirements and tests*.

[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 (2003), *Components for low-voltage surge protective devices – Part 331: Specification for metal oxide varistors (MOV)*.

3 Definitions

This Recommendation defines the following terms:

3.1 applied voltage ratio (R_{ap}): Ratio of d.c. voltage or peak of a.c. voltage applied on the MOV to the varistor voltage U_N.

3.2 clamping voltage (U_{cla}): Maximum peak voltage across the MOV measured under conditions of a specified waveform impulse with current peak I_P. If there is both a front peak and rear peak on the voltage waveform, the rear peak voltage is defined as the clamping voltage.

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

3.3 clamping voltage ratio (R_{cla}): Ratio of the clamping voltage U_{cla} to the varistor voltage U_N ($R_{cla} = U_{cla}/U_N$).

3.4 combination impulse (1.2/50-8/20): Impulse with open-circuit voltage of 1.2/50 µs (T_1/T_2) and short-circuit current of 8/20 µs (T_1/T_2), which is expressed by "voltage peak/current peak".

NOTE – Unless otherwise specified, the effective impedance shall be 2 Ω, which is the quotient of the open-circuit voltage peak U_P and the short-circuit current peak I_P.

3.5 current peak de-rating curve: Curves expressing the relationship of the three variables of I_P, n, τ, where I_P is impulse current peak, τ is the impulse width, and n is average application numbers of the impulse that the MOV can withstand in terms of specified pass criterion. The current I_P shall be de-rated with the increasing of τ and/or n, that may be represented by equations 3-1 and 3-2.

$$\lg I_g = A - a \lg n \ (\tau = \text{constant}) \tag{3-1}$$

$$\lg I_g = B - b \lg \tau \ (n = \text{constant}) \tag{3-2}$$

Where A, a, B and b are four constants which depend on the type and manufacturing of the MOV, also A and a depend on τ values, B and b depend on n values.

NOTE – Equations 3-1 and 3-2 agree well with the actual characteristics of MOV when $n \geq 10$, while for n less than 10, I_P deviated from these equations.

3.6 current de-rating fraction (F_I): Ratio of impulse current peak I_P (n, τ) to the maximum discharge current $I_{\max}$.

$$F_I = I_P(n,\tau) / I_{\max}$$

3.7 effective resistance: Ratio of the rear peak voltage to the applied impulse current peak of the specified waveform, unless otherwise specified, 8/20 impulse current shall be used.

3.8 effective linear resistance (R_V): Linear component of the effective resistance determined by the high-impulse-current method.

NOTE – The linear resistance of the MOV may be determined by the high-frequency-signal method, infrared method and high-impulse-current method, but they may give different results.

3.9 effective non-linear resistance (R_Z): Non-linear component of the effective resistance which can be expressed by equation 3-3

$$R_Z = A_1 \cdot I_P^{(\beta-1)} \tag{3-3}$$

Where: A_1 is the virtual clamping voltage at 1 A of specified impulse;

β is the non-linearity current index.

3.10 endurance at maximum operating temperature: Property to operate at maximum operating temperature and maximum continuous operating voltage (MCOV) for 1000 h.

NOTE – Unless otherwise specified, the maximum operating temperature shall be 85°C.

3.11 front peak voltage (U_F): Maximum voltage across the MOV occurring at the initial time of an applied impulse current of specified waveform and peak value. The front peak voltage represents a time-dependent modification of the highly non-linear conduction process responsible for varistor action.

3.12 high (low) voltage varistors: The varistors of varistor voltage $U_N \geq 82$ V are called high voltage varistors, and those of varistor voltage smaller than 82 V are named low voltage varistors.

3.13 impulse: Unidirectional wave of voltage or current without appreciable oscillation.

Six impulses are used in this Recommendation: current impulse 8/20, 10/350, 10/1000, 2-ms rectangular wave, electrostatic discharge, and 1.2/50-8/20 combination impulse.

3.14 impulse current peak ((I_P (n,τ)): Repetitive impulse current peak which can be applied for application numbers (n) with impulse width τ.

3.15 impulse width (τ): Normalized impulse duration which is the ratio of the waveform area to the impulse peak, by means of τ any waveform of impulse can be converted into an equivalent rectangular wave.

3.16 informative characteristics: Characteristics of a metal oxide varistor (MOV) which are of significance for applications and should be provided by manufactures, but they are not covered by an acceptance inspection programme, for example: V-I characteristics, V-I characteristics of low field region, current peak de-rating curve, temperature de-rating curve.

3.17 leakage current a.c. (I_{La}): Current passing through the metal oxide varistor (MOV) with the maximum a.c. voltage U_C applied on it, and at a specified temperature, it may be r.m.s value or peak value.

3.18 leakage current d.c. (I_{Ld}): Current passing through the metal oxide varistor (MOV) with the maximum d.c. voltage U_{DC} applied on it, and at a specified temperature.

3.19 long (short) duration impulse: An impulse with an impulse width $\tau \geq 100$ µs is called a long duration impulse, in contrast, an impulse of $\tau < 100$ µs is called a short duration impulse.

NOTE – In this Recommendation, a long (short) duration impulse is denoted by the letter "L" ("S")

3.20 maximum continuous operating voltage (MCOV) (U_C (U_{DC})): Maximum a.c. r.m.s. voltage U_C or maximum d.c. voltage U_{DC} which can be applied continuously at a temperature of 25°C. U_C shall be a substantially sinusoidal voltage (less than 5% total harmonic distortion).

3.21 maximum discharge current ($I_{\max}$): The maximum allowable crest value of impulse current with 8/20 waveform for two applications.

3.22 metal oxide varistor (MOV): Component made of ZnO and a few additives whose conductance, at a given temperature, increases rapidly with the voltage increasing over a certain voltage range. It is also known as a voltage-dependent resistor (VDR).

3.23 nominal discharge current (I_n): The crest value of impulse current with 8/20 waveform that is intended for clamping voltage measurement of the metal oxide varistors (MOVs) for power circuit use.

3.24 non-linearity current index (β): Slope of the volt-ampere characteristic when the effective linear resistance is much smaller than the effective non-linear resistance. It is always less than 1. For the convenience of calculation, equation 3-4 may be used.

$$\beta = \frac{\lg(U_{cla1}/U_{cla2})}{\lg(I_{P1}/I_{P2})} \tag{3-4}$$

NOTE – For most commercially available metal oxide varistors (MOVs), it is considered that the effective linear resistance is much smaller than the effective non-linear resistance when the 8/20 current density J_P is less than 320 A/cm^2.

3.25 rated dissipation power (P_m): Maximum allowable average power dissipation when subjected to the stress of successive impulses and at the temperature of 25°C.

3.26 rated impulse energy (W_{tm}): Maximum single impulse energy which can be absorbed by the metal oxide varistor (MOV) for a specified waveform. Unless otherwise specified, a 2 ms rectangular current impulse or 10/1000 current impulse shall be used.

3.27 rear peak voltage (U_R): Maximum voltage across the metal oxide varistor (MOV) occurring at the time behind the front peak with an application of impulse current of specified waveform and sufficient peak values.

3.28 temperature de-rating curve: Graphical representation of parameters de-rating against temperature.

NOTE – Typical parameters are maximum continuous operating voltage U_C (U_{DC}), maximum discharge current I_{max}, nominal discharge current I_n, impulse current peak $I_P(n,\tau)$, rated dissipation P_m, and rated impulse energy W_{tm}.

3.29 temporary overvoltage (TOV) (U_T): a.c. voltage (r.m.s) or d.c. voltage that the metal oxide varistor (MOV) can withstand; U_T exceeds the maximum continuous operating voltage U_C or U_{DC}.

3.30 temporary overvoltage (TOV) withstanding capability: The specified TOV stress that a metal oxide varistor (MOV) should be capable of withstanding, and evaluated by the energy absorbed by the MOV and element temperature of the MOV under this stress.

NOTE – This property of the MOV is intended to match the operation of thermal disconnectors of the surge protective devices (SPDs) that use the MOV.

3.31 unit thickness voltage: Ratio of varistor voltage U_N to the thickness of the metal oxide varistor MOV element, expressed in "V/mm".

NOTE – The peak values of long duration impulse and impulse energy that the MOV is able to withstand depend strongly on the unit thickness voltage of the MOV.

3.32 varistor voltage (U_N): Voltage, at specified d.c. current, used as a reference point in the component characteristic, unless otherwise specified, 1 mA d.c. current shall be used.

3.33 virtual clamping voltage at 1 A (A_1): A constant in the V-I characteristic equation which is a deduced clamping voltage at current peak of 1 A.

3.34 volt-ampere characteristic (V-I characteristic): A description of the voltage limiting property of the metal oxide varistor (MOV) which is described by the relationship between clamping voltage U_{cla} and 8/20 current peak I_P over a specified range of I_P. Unless otherwise specified, the 8/20 current peak I_P shall cover the range from the current peak density J_P of about 32 A/cm^2 to the maximum discharge current. For this range of the 8/20 current, the V-I characteristic is expressed by equations 3-5 or 3-6.

$$U_{cla} = A_1 \cdot I_P{}^{\beta} + R_V \cdot I_P = I_P(R_Z + R_V) \tag{3-5}$$

Where: A_1 is the virtual clamping voltage at 1 A, β is the non-linearity current index, R_Z is the effective non-linear resistance, and R_V is the effective linear resistance.

$$U_{cla} = a_1 \cdot U_N \cdot I_P{}^{\beta} + R_V \cdot I_P \tag{3-6}$$

Where: U_N is the varistor voltage, $a_1 = A_1 / U_N$.

NOTE – For a production lot of the MOV, the varistor voltage of the individual product may vary within an allowable tolerance, but the a_1 and the R_V do not depend on the varistor voltage.

3.35 volt-ampere characteristic of low field region: Relationship between d.c. currents through the metal oxide varistor (MOV) and the voltages across the MOV over a specified operating temperature range, usually the test current is below 1 mA/cm^2 d.c.

NOTE – The volt-ampere characteristic of the low field region is expressed as equation 3-7, by means of which the leakage current is easily obtained at a given applied voltage and temperature.

$$I = I_0 \exp\left(-\frac{E_g - \beta\sqrt{U}}{kT} \right) \tag{3-7}$$

Where:

I (μA)	is the d.c. current through the MOV with the d.c. voltage U (V) applied on it, and at the temperature T (K).
k =	1.38×10^{-23} J/K, Boltzmann constant.
I_0, E_g and β	are three constants that depend on the part number of the MOV, and being determined by laboratory test.

4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

ESD Electrostatic Discharge

LPF Low Pass Filter

MCOV Maximum Continuous Operating Voltage

MOV Metal Oxide Varistor

PS Power Source

SMD Surface Mounting Device

SPD Surge Protective Device

TOV Temporary Overvoltage

VDR Voltage-Dependent Resistor

5 Storage conditions

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

– Temperature: –40°C to +115°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

MOVs of various types should have the characteristics listed in Table 1 when tested in accordance with clause 7.

6.1 Varistor voltage

When tested according to clause 7.1, varistor voltage should be within the specified limits. Tables 2a and 2b show the nominal varistor voltages of high voltage and low voltage disc types that are commonly used; their allowable tolerances are ±10%.

The nominal varistor voltages and tolerances listed in Table 2c are typical for SMD types.

6.2 Maximum a.c. (d.c.) continuous operating voltage

Unless otherwise specified, MOVs shall have a maximum a.c. (d.c.) continuous operating voltage U_C (U_{DC}) as given in Tables 2a, 2b and 2c, the conformity shall be evaluated according to clause 7.2.

6.3 Leakage current d.c.

When tested according to clause 7.3, the leakage current, d.c., under maximum continuous d.c. voltage U_{DC}, shall be less than the maximum value specified by the manufacturer and there shall be no upward drifting during the application of the test voltage U_{DC}.

6.4 Leakage current a.c.

When tested according to clause 7.4, the leakage current, a.c., under maximum continuous a.c. voltage U_C, shall be less than the maximum value specified by the manufacturer.

6.5 Capacitance

When tested according to clause 7.5, the measured value of capacitance shall not exceed the value specified by the manufacturer.

6.6 Clamping voltage

When tested according to clause 7.6, the measured clamping voltage at a specified impulse current shall be no more than the specified values or the values indicated in Tables 2a, 2b and 2c. Unless otherwise specified, 8/20 impulse current having the peak as specified in Tables 2a.1, 2b.1 and 2c shall be used.

Table 1 − MOV characteristics summary

Test item	Clause number		MOV types		
	Requirement	Test method	For power circuits		For signal circuits
			a.c.	d.c.	
Electrical characteristics					
Varistor voltage	6.1	7.1	○	○	○
Max. continuous voltage	6.2	7.2	○	○	○
Leakage current, d.c.	6.3	7.3		○	○
Leakage current, a.c.	6.4	7.4	○		
Capacitance	6.5	7.5	○	○	○
Clamping voltage	6.6	7.6	○	○	○
Max. discharge current	6.7	7.7	○	○	○
ESD impulse test	6.8	7.8			
Rated dissipation	6.9	7.9	○	○	○
Rated impulse energy	6.10	7.10	○	○	○
Impulse durability	6.11	7.11	○	○	○
Endurance at maximum operation temperature	6.12	7.12	○	○	
TOV withstanding capability	6.13	7.13	○		

Table 1 − MOV characteristics summary

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<tr><th rowspan="3">Test item</th><th colspan="2">Clause number</th><th colspan="3">MOV types</th></tr>
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<tr><td colspan="6">NOTE – For insulated MOV only.</td></tr>
</table>

Table 2a – Voltage ratings of high voltage disc types

Nominal varistor voltage U_N (V)	Max. continuous voltage (V)		Clamping voltage (Note), U_{cla} (V)	
	a.c. (r.m.s) U_C	d.c. U_{DC}	8/20, I_{Pl}	8/20, I_n
82	50	65	135	
100	60	85	165	
120	75	100	200	
150	95	125	250	
180	115	150	300	
200	130	170	340	520
220	140	180	360	550
240	150	200	395	605
275	175	225	455	695

Table 2a – Voltage ratings of high voltage disc types

Nominal varistor voltage U_N (V)	Max. continuous voltage (V)		Clamping voltage (Note), U_{cla} (V)	
	a.c. (r.m.s) U_C	d.c. U_{DC}	8/20, I_{P1}	8/20, I_n
300	195	250	505	770
330	210	270	545	835
360	230	300	595	910
390	250	320	650	985
430	275	350	710	1090
470	300	385	775	1190
510	320	410	845	1290
560	350	450	930	1420
620	385	505	1025	1570
680	420	560	1120	1720
750	460	615	1240	1900
820	510	670	1355	2070
910	550	745	1500	2300
1000	625	825	1650	2530
1100	680	895	1815	2780
1200	750	1060	2000	3040
NOTE – The clamping voltages listed represent the clamping voltages of the MOVs having varistor voltages of 10% higher than the nominal values. The test currents shall be 8/20 impulse with the peaks listed in Table 2a.1. The I_n is used for MOVs for power distribution system applications, while the I_{P1} is used for MOVs for other applications.				

Table 2a.1 – Test current peaks for clamping voltages of high voltage disc types

MOV diameter (mm)	5	7	10	14	20	25	32	40	53
Current peak I_{P1}, A	5	10	25	50	100	150	200	300	450
Current peak I_n, A						8 k	12.5 k	20 k	30 k

Table 2b – Voltage ratings of low voltage disc types

Nominal varistor voltage U_N (V)	Maximum continuous voltage (V)		Clamping voltage (Note) U_{cla} (V)
	a.c. (r.m.s) U_C	d.c. U_{DC}	
18	11	14	36
22	14	18	43
27	17	22	53
33	20	26	65
39	25	31	77

Table 2b – Voltage ratings of low voltage disc types

Nominal varistor voltage U_N (V)	Maximum continuous voltage (V)		Clamping voltage (Note) U_{cla} (V)
	a.c. (r.m.s) U_C	d.c. U_{DC}	
47	30	38	93
56	35	45	110
68	40	56	135
NOTE – The clamping voltages listed represent the clamping voltages of the MOVs having varistor voltages of 10% higher than the nominal values.			

The test currents shall be 8/20 impulse with the peaks listed in Table 2b.1.

Table 2b.1 – Test current peaks for low voltage disc types

MOV diameter (mm)	5	7	10	14	20
Current peak, A	1	2.5	5	10	20

Table 2c – Typical voltage ratings of SMD types

Nominal varistor voltage U_N (V)	Maximum continuous voltage (V)		Clamping voltage at 8/20, 1 A U_{cla} (V)
	a.c. (r.m.s) U_C	d.c. U_{DC}	
5 ± 20%	2.5	3.3	14~9
8 ± 20%	4.0	5.6	15~15
12 ± 20%	5.7	8	26~20
16 ± 15%	7.5	11	30~24
20 ± 10%	10	14	40~32
25 ± 10%	12.5	18	46~37
30 ± 10%	15.6	22	54~43
36 ± 10%	18.4	26	58~53
42 ± 10%	21.2	30	65
47 ± 10%	26	33	72
54 ± 10%	30	42	86
62 ± 10%	40	48	100
68 ± 10%	40	56	110
75 ± 10%	50	60	120
85 ± 10%	50	68	130

6.7 Maximum discharge current

MOVs shall be subjected to the maximum discharge current tests of 8/20 and 10/350 waves. Unless otherwise specified, the current peaks shall be as specified in Tables 3a, 3b and 3c.

During the tests, there shall be no flashover or puncture of the samples, 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%, when tested according to clause 7.7.

NOTE – According to the impulse current capability, the MOVs of high voltage disc types may be divided into two grades: standard grade (S-grade) and high grade (H-grade), as indicated in Table 3a.

Table 3a – Maximum discharge current of high voltage disc types

<table>
<tr><th colspan="3">Nominal diameter (mm)</th><th>5</th><th>7</th><th>10</th><th>14</th><th>20</th><th>25</th><th>32</th><th>40</th><th>53</th></tr>
<tr><td colspan="2" rowspan="2">8/20, $I_{\max S}$ (kA)</td><td>S</td><td>0.4</td><td>1.2</td><td>2.5</td><td>5</td><td>10</td><td>12</td><td>20</td><td>40</td><td>60</td></tr>
<tr><td>H</td><td>–</td><td>–</td><td>3</td><td>6</td><td>12</td><td>16</td><td>25</td><td>50</td><td>70</td></tr>
<tr><td rowspan="8">10/350
$I_{\max L}$ (A)</td><td rowspan="2">V_O =
210 V/mm</td><td>S</td><td></td><td></td><td></td><td>265</td><td>535</td><td>850</td><td>1375</td><td>2150</td><td>3230</td></tr>
<tr><td>H</td><td></td><td></td><td></td><td>315</td><td>645</td><td>1030</td><td>1630</td><td>2580</td><td>3870</td></tr>
<tr><td rowspan="2">V_O =
180 V/mm</td><td>S</td><td></td><td></td><td></td><td>310</td><td>625</td><td>1000</td><td>1600</td><td>2500</td><td>3750</td></tr>
<tr><td>H</td><td></td><td></td><td></td><td>370</td><td>750</td><td>1200</td><td>1900</td><td>3000</td><td>4500</td></tr>
<tr><td rowspan="2">V_O =
150 V/mm</td><td>S</td><td></td><td></td><td></td><td>370</td><td>750</td><td>1200</td><td>1900</td><td>3000</td><td>4500</td></tr>
<tr><td>H</td><td></td><td></td><td></td><td>440</td><td>900</td><td>1440</td><td>2280</td><td>3600</td><td>5400</td></tr>
<tr><td rowspan="2">V_O =
110 V/mm</td><td>S</td><td></td><td></td><td></td><td>480</td><td>970</td><td>1550</td><td>2450</td><td>3900</td><td>5850</td></tr>
<tr><td>H</td><td></td><td></td><td></td><td>580</td><td>1150</td><td>1850</td><td>2950</td><td>4650</td><td>7020</td></tr>
<tr><td colspan="12">NOTE 1 – The MOV of square shape 34 × 34 mm is considered to have a nominal diameter of 40 mm.
NOTE 2 – The current density for 8/20 impulse is about 3.2 kA/cm^2 for S-grade, or 3.8 kA/cm^2 for H-grade.
NOTE 3 – The energy density for 10/350 impulse is about 350 J/cm^3 for S-grade, or 420 J/cm^3 for H-grade.</td></tr>
</table>

Table 3b – Maximum discharge current of low voltage disc types

MOV diameter (mm)	5	7	10	14	20
8/20, $I_{\max S}$ (A)	100	250	500	1000	2000

Table 3c – Typical maximum discharge current of SMD types

<table>
<tr><th>Dimensions</th><th>1005
(0402)</th><th>1608
(0603)</th><th>2012
(0805)</th><th>3210
(1206)</th><th>3225
(1210)</th><th>4532
(1812)</th><th>5750
(2220)</th></tr>
<tr><td>Current peak, (8/20), A</td><td>10~20</td><td>30</td><td>100~120</td><td>100~200</td><td>250~400</td><td>500~800</td><td>1000~1200</td></tr>
<tr><td colspan="8">NOTE 1 – The dimensions in this table are expressed both in metric, for example "1005" signifies 1.0 mm × 0.5 mm, and in imperial, for example "0402" signifies 0.04 inches × 0.02 inches.
NOTE 2 – The maximum discharge current of the same dimensions may vary from voltage to voltage and from manufacturer to manufacturer. The data given in this table are typical.</td></tr>
</table>

6.8 ESD impulse test

The MOVs of SMD types shall be subjected to electrostatic discharge (ESD) tests by two methods according to clause 7.8:

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

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

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%.

6.9 Rated dissipation (impulse life)

Unless otherwise specified, the rated dissipation of MOVs shall be as specified in Tables 4a, 4b and 4c, and evaluated by an impulse life test with 8/20 current in accordance with clause 7.9. The impulse life test current corresponds roughly to the current for 8/20-10000 impulses of the MOVs.

Table 4a – Rated dissipation and test current of high voltage disc types

MOV diameter (mm)	**5**	**7**	**10**	**14**	**20**	**25**	**32**	**40**	**53**
Rated dissipation (W)	0.10	0.25	0.40	0.60	1.0	1.2	1.3	1.40	1.50
Current fraction, k_F	0.05	0.05	0.05	0.03	0.02	0.015	0.012	0.025	0.012
NOTE – The peaks of test current of 8/20 impulse shall be the product of the maximum discharge current of the MOV multiplied by current fraction k_F.									

Table 4b – Rated dissipation and test current of low voltage disc types

MOV diameter (mm)	**5**	**7**	**10**	**14**	**20**
Rated dissipation (W)	0.01	0.02	0.05	0.10	0.20
Test current (A)	5	15	50	100	150

Table 4c – Rated dissipation and test current of SMD types

Dimensions	**1005 (0402)**	**1608 (0603)**	**2012 (0805)**	**3210 (1206)**	**3225 (1210)**	**4532 (1812)**	**5750 (2220)**
Rated dissipation (W)	–	0.003	0.005	0.008	0.010	0.015	0.020
Test current (A)	–	4	10	15	25	70	80

6.10 Rated impulse 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 7.10.

6.11 Impulse durability

The MOV shall be subjected to 10 applications of impulse currents of 8/20 wave and 10/350 wave with the peak specified by the manufacturer, and tested according to clause 7.11.

6.12 Endurance at maximum operating temperature

The MOV used for power supply circuitry shall be subjected to an endurance test under the conditions of maximum operating temperature and maximum continuous operating voltage for 1000 h and tested according to clause 7.12.

6.13 TOV withstanding capability

The absorbed energy by the MOV, and the surface temperature rise of the MOV element prior to its thermal runaway, shall be not less than the values specified by the manufacturer under specified TOV stress when tested according to clause 7.13.

NOTE – The surface temperature of the sample may vary from point to point, the temperature rise of the point on which the thermal disconnector is fixed after delivery of the MOV, or the lowest temperature rise, shall be tested.

6.14 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 7.14.

6.15 Voltage proof (for insulated MOV only)

The insulated MOV shall be subjected to a voltage proof test at 2500 V r.m.s., for 1 min when tested according to clause 7.15.

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.

When tests are conducted, the MOVs of leaded disc type shall be mounted as for normal use, while the MOVs of SMD types shall be mounted on the substrate in accordance with Appendix I.

7.1 Varistor voltage

A power supply of constant current source of 1 mA d.c. ±10% shall be used. The voltage across the tested MOV should rise from a lower value than that of the varistor voltage measured, rather than declining from the maximum voltage of the current source. The ripple of d.c. voltage shall be no more than 1%. The time of applied test current 1 mA shall be within 20 ms to 100 ms prior to taking the voltage reading. The accuracy of the voltmeter shall be ±0.5%.

NOTE 1 – The measurement shall be made in two directions.

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 a.c. (d.c.) voltage

MOVs are considered to have specified maximum continuous a.c. or d.c. voltage when they pass the leakage current test according to clauses 7.4 or 7.3, and pass the endurance test at maximum operating temperature according to clause 7.12.

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 output voltage of d.c. voltage supply (PS) shall be U_{DC} ± 0.5% (U_{DC} is the maximum continuous d.c. voltage of the MOV). The a.c. ripple of U_{DC} shall be less than 1%.

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

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%.

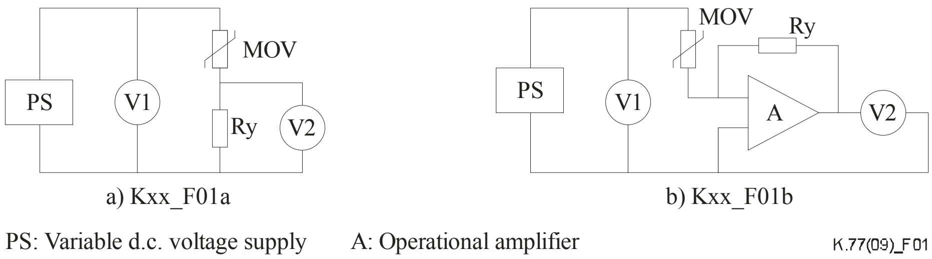


Figure 1 – Test circuits for leakage current d.c.

7.3.2 The samples should remain in the environment of 25°C ± 5 K, or other specified temperatures for 2 hours before the leakage current test is performed.

7.3.3 The applied time of test voltage U_{DC} 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 Leakage current a.c.

7.4.1 A test circuit such as shown in Figure 2a or Figure 2b shall be used for a.c. leakage current measurement.

The power supply (PS) should be an a.c. power frequency source, its output voltage shall be U_C ± 0.5% of the MOV.

A low pass filter (LPF) is often necessary in order to remove parasitic noise on the output voltage of the PS which applies directly onto resistor Ry via capacitance Cv of the MOV, hence resulting in significant error.

A recommended LPF is an R-C filter with R = 1 kΩ and C = 1 μF.

The voltmeters V1 and V2 should give true r.m.s values with accuracy ±1%.

7.4.2 The samples should remain in the environment of 25°C ± 5 K, or other specified temperature, for 2 hours before the leakage current test is made.

7.4.3 The applied time of test voltage U_C shall be within 100 ms to 400 ms prior to taking the leakage current readings.

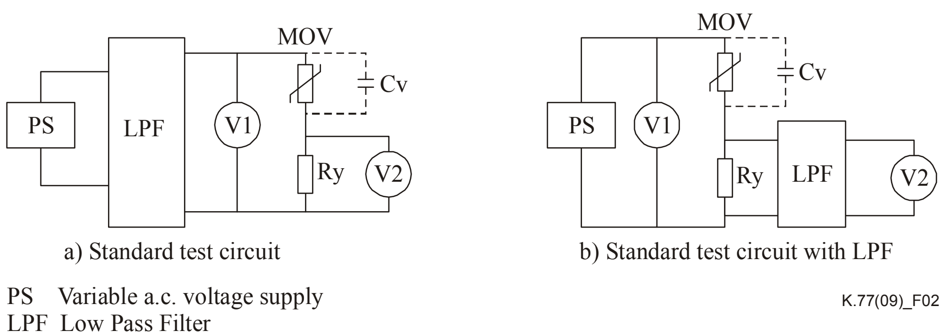


Figure 2 – Test circuit for leakage current a.c.

7.5 Capacitance

The capacitance measurements are made in normal conditions, at a frequency of 1 kHz and at a signal level ≤ 0.5 V r.m.s. for SMD types, or ≤ 1.0 V r.m.s. for disc types. The measured capacitance shall be within the limits specified by the manufacturer.

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.

7.6 Clamping voltage

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

7.6.2 The test impulse shall be 8/20 current with the peak of ±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.

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

7.6.4 Measure voltage peaks (rear peaks) across an individual sample when the pulse current specified in clause 7.6.2 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%.

7.6.5 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.

7.6.6 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. Clause II.4 describes the methods of avoiding interference.

7.7 Maximum discharge current

7.7.1 Three samples shall be randomly selected from the product lot concerned for the 8/20 current test or for the 10/350 current test.

7.7.2 Initial measurements: varistor voltage and clamping voltage.

7.7.3 The MOVs shall be subjected to a specified maximum discharge current test at 8/20 impulse or 10/350 impulse. Unless otherwise specified, the current peaks shall be as specified in Tables 3a, 3b and 3c. Each test shall be performed in two directions, the interval between them is 25-30 min. During and after the test, there shall be no evidence of flashover or puncture of the samples.

7.7.4 Repeating measurements shall be done as specified in clause 7.7.2. After recovery to room temperature, the varistor voltage and clamping voltage shall not deviate by more than 10% from the initial values measured.

7.8 ESD impulse test (for SMD type MOV only)

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

7.8.2 Initial measurements: varistor voltage and clamping voltage.

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

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

7.8.4 Repeating measurements shall be made as specified in clause 7.8.2. After recovery to room temperature, the varistor voltage and clamping voltage shall not deviate by more than 10% from the initial values measured.

7.9 Rated dissipation (impulse life)

7.9.1 Three samples shall be randomly selected from the lot concerned.

7.9.2 Initial measurements: varistor voltage and clamping voltage.

7.9.3 The generator should be able to deliver 8/20 current into the samples, the peak of which shall be within ±5% of the value specified in Tables 4a, 4b or 4c, that is called I_{PS2}.

7.9.4 To determine the impulse repetition rate r (times per second), the energy W, in joules, absorbed by each sample shall be measured when the test current as specified in clause 7.9.3 passes through it, and then the repetition rate shall be computed by equation 7-2:

$$r = P_m / W_{av} \tag{7-2}$$

where: P_m = rated dissipation of the MOV in watts.

W_{av} = the average value of the measured energy W of three samples.

Note that the energy W shall be measured by an impulse energy metre of ±5%, or the current peak I_P and clamping voltage V_{cla} be measured, then computed by equation 7-3:

$$W = 17.5 \times I_P \times U_{cla} \tag{7-3}$$

where: I_P is in kA, U_{cla} is in kV and W is in joules.

NOTE – The theoretical duration of the equivalent rectangular waveform of 8/20 impulse is 17.5 µs.

7.9.5 The samples of MOVs shall be subjected to repetitive impulse current in compliance with clauses 7.9.3 and 7.9.4; the impulse polarity shall alternate as a minimum after every 50 impulses.

After 10000 impulses have been applied, the samples shall be disconnected from the generator, after 0.5~1 h recovery at room temperature, visual examination shall show no evidence of flashover or mechanical damage to the samples.

7.9.6 Repeating measurements shall be done as specified in clause 7.9.2, the varistor voltage and clamping voltage shall not deviate by more than 10% from the initial values measured.

7.9.7 After 10000 applications, continued applications of 8/20 impulse shall be made, and the measurements as in clause 7.9.6 shall be performed after every 50 applications, until either of the varistor voltage or clamping voltage has deviated by more than 10% from the initial values measured. If total application numbers of the three samples are n_1, n_2 and n_3, respectively, then the average value $n_{S2} = (n_1 + n_2 + \text{d } n_3)/3$ shall be calculated which is intended to be used for calculation of a peak current de-rating curve, see clause 9.2.

NOTE – The MOV has passed the rated dissipation (impulse life) test when the requirements of clauses 7.9.5 and 7.9.6 have been met. This clause is intended to get the data (I_{PS2}, n_{S2}) for calculation of the peak current de-rating curve (see clause 9.2).

7.10 Rated impulse energy

7.10.1 Four 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.

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

7.10.3 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.

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

where:

constant $\mathrm{k_W}$ = 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:

$$I_P = I_{trial} \frac{W_{tm}}{W_{trial}} \qquad (7\text{-}5)$$

7.10.4 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.

7.10.5 Repeating measurements shall be done as specified in clause 7.10.2. The varistor voltage and clamping voltage shall not deviate by more than 10% from the initial values measured.

7.11 Impulse durability

7.11.1 Three samples shall be randomly selected from the product lot concerned, for the 8/20 current test or for the 10/350 current test.

7.11.2 Initial measurements: varistor voltage.

7.11.3 The test current of 8/20 wave (called I_{PS1}) or 10/350 wave (called I_{PL1}), with peak values specified by the manufacturer, shall be applied to each of the three samples for 10 applications, 5 in the positive direction and 5 in the negative direction. The impulses are to be applied 5 min apart. After completion of 10 applications, the samples are allowed to recover for 0.5~1 h at room temperature, visual examination shall show no evidence of flashover or mechanical damage to the samples.

7.11.4 Repeating measurements shall be done as specified in clause 7.11.2, the varistor voltage shall not deviate by more than 10% from the initial values measured.

7.11.5 After 10 applications, continued applications of 8/20-I_{PS1} impulse or 10/350-I_{PL1} impulse shall be made in alternating directions (positive/negative), the varistor voltage shall be measured 5 min after each impulse application, and the next application should be immediately after the measurement, until the varistor voltage has deviated by more than 10% from the initial values measured.

If total application numbers of the three samples are n_1, n_2 and n_3 respectively, then the average value $n = (n_1 + n_2 + n_3)/3$ shall be calculated. The average value from the 8/20 test is called n_{S1}, while the average value from the 10/350 test is called n_{L1}. The data n_{S1} and n_{L1} are intended to be used for calculation of peak current de-rating curve, see clause 9.2.

NOTE – The MOV has passed the impulse durability test when the requirements of clauses 7.11.3 and 7.11.4 have been met. This clause is intended to get the data (I_{PS1}, n_{S1}) for calculation of the peak current de-rating curve, see clause 9.2.

7.12 Endurance at maximum operating temperature

7.12.1 Eight samples shall be randomly selected from the lot concerned, and the varistor voltages U_N of the samples shall not deviate from each other by more than 1%. The average varistor voltage of 8 samples is referred to as U_{NO}.

7.12.2 Test set-up

a) Test chamber

The temperature of the test chamber shall be controlled so that the surface temperature of the samples is 85°C ± 2 K, but it should be 85°C ± 1 K when measurements of the properties of the samples are made.

b) Power supply

For the a.c. voltage test, the voltage shall be $U_{tac} = 0.707\ U_{NO}$ (see clause 7.12.1 for U_{NO}).

For the d.c. voltage test, the voltage shall be $U_{tdc} = U_{DC}$ (U_{DC} is the maximum continuous d.c. voltage of the MOV).

The error of the voltmeter shall be no more than ±0.5%.

The impedance of the power supply shall be such that during the period of the test, the voltage measured at the MOV terminals does not fall below the U_{tac} or U_{tdc} by more than 1%, but the voltage should be set to ±0.2% of the U_{tac} or U_{tdc} when measurements of the properties of the samples are made.

c) For the purpose of measuring the power loss of the samples, an accurate resistor of ±0.1% may be connected in series with each sample, but placed outside the test chamber. The resistance of the resistor shall be such that the voltage across it is no more than 0.5% of the U_{tac} or U_{tdc}. The power loss of each sample shall be measured by means of a power loss meter of ±2% which shall give an indication of the product of the voltage wave multiplied by the current wave of the sample.

7.12.3 Test procedures

a) Initial measurement: clamping voltage in two directions.

b) The samples are placed in the test chamber at 85°C ± 3 K, applying the test voltage U_{tac} or U_{tdc} onto each sample.

c) The power loss P_1 shall be measured at 2-3 h after the test voltage application.

d) The power loss shall be measured once in every 100 h time span after the first measurement. Finally, the power loss P_2 shall be measured after 1000 (+100, –0) h of ageing under the same conditions.

NOTE – Accidental intermediate de-energizing of the test samples, not exceeding a total duration of 24 h during the test period is permissible. The interruption will not be counted in the duration of the test. The final measurement should be performed after no less than 100 h of continuous energizing.

e) After completion of the measurement of the power loss P_2, the samples are de-energized and are allowed to recover for 1~2 h at room temperature.

7.12.4 Pass criteria

The MOV has passed the endurance test if:

a) Visual examination shall show no evidence of mechanical damage to the samples.

b) The minimum power loss value among those measured at least every 100 h time span is called P_3, then P_2 shall be equal to or below 1.1 times P_3 for the a.c. voltage test, or 2 times P_3 for the d.c. voltage test and for low voltage varistors ($U_N \leq 68$ V).

c) Clamping voltage shall be measured in two directions, the values of which shall not deviate from that of clause 7.12.3 item a) by more than 10%.

7.13 TOV withstanding

7.13.1 Three samples shall be randomly selected from the lot concerned, the varistor voltages are measured, which are called U_{N1}, U_{N2} and U_{N3}, respectively. The TOV stresses shall be the values specified by the manufacturer, or 0.95 U_{N1} (for sample 1), 1.0 U_{N2} (for sample 2) and 1.05 U_{N3} (for sample 3).

7.13.2 Test set-up (see Figure 3)

a) Test chamber

The test chamber shall be made of flame-resistant material in which the samples are mounted for testing, for safety reasons.

b) Power frequency source

The source shall be able to apply TOV stress as specified in clause 7.13.1 onto the samples. The rated output capacity of the source shall be not less than 20 A. The accuracy of voltmeter shall be ±0.5%.

c) Interruption means

At the instant the current through the sample exceeds 1.2 times the initial current value, the interruption means shall be able to interrupt the test voltage on the sample immediately. The breaker (6A) shall operate to switch OFF the test voltage at the time of thermal puncture of the sample taking place.

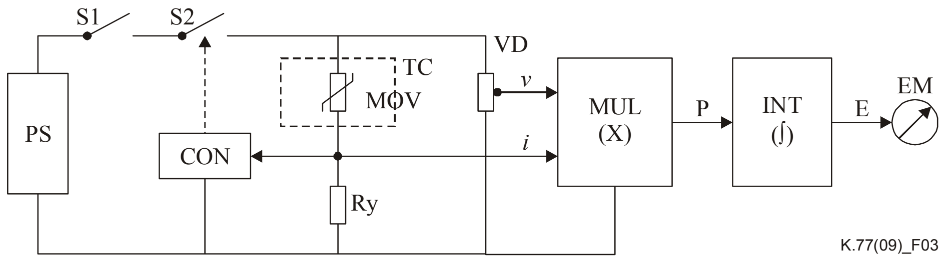
d) Instrumentation

For the purpose of detecting the current through the sample, an accurate resistor of ±0.1% shall be connected in series with the sample. The resistance of the resistor shall be such that the voltage across it is no more than 0.5% of the voltage across the sample.

The voltage divider shall have an accuracy of ±0.5%.

The energy absorbed by the sample shall be measured by the method that gives the definite integration of the product of the voltage wave multiplied by the current wave of the sample over the time span from the instant of test voltage application to the instant at which thermal runaway of the sample occurs. It is assumed to be thermal runaway if the current through the sample exceeds 1.2 times initial current value.

An infrared camera is used to measure the temperature distribution of the sample surface.



PS	Power source	S1	Breaker (6A)
S2	Controlled solid state switch	CON	Control circuit that operates S2
TC	Test chambers	MOV	Tested MOV
Ry	Accurate resistor	VD	Voltage Divider
MUL	Multiplier	INT	Integrator
EM	Energy Meter		

Figure 3 – Test circuit for energy under TOV stress

7.13.3 Test procedures

The sample shall remain at room temperature for at least 1 h, and a record of the room temperature should be kept.

Samples 1, 2 and 3 shall be connected to the test circuit in turn. The open circuit voltage of the power source shall be set at 0.95 U_{N1} (for sample 1), 1.0 U_{N2} (for sample 2) and 1.05 U_{N3} (for sample 3) before it is applied to the sample. Then the test voltage is switched on so that the sample is energized until interruption of the test voltage takes place. The temperature test shall be made immediately after the interruption of the test voltage.

The temperature rise with respect to room temperature on the specified position of the sample surface, or the lowest temperature rise on the sample surface, shall be not less than the specified value.

The measured energy shall be not less than the specified values.

Note that the energy W_{TOV} absorbed by the sample may be determined by equation 7-6,

$$W_{TOV} = N \times Q_1 \cdot U_P \cdot \Delta t \tag{7-6}$$

where:

Q_1 = charge (in coulombs) of each current pulse during the half cycle of the test voltage.

U_P = clamping voltage (in volts) of the sample under the test voltage.

Δt = time period (in seconds) during which the test voltage is applied to the sample.

N = 100 for the test voltage of 50 Hz, or 120 for the test voltage of 60 Hz.

7.14 Insulation resistance

7.14.1 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.

7.14.2 The insulation resistance shall be measured with a d.c. 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 min, the insulation resistance being read at the end of that period.

7.14.3 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.

7.15 Voltage proof

7.15.1 The voltage proof test shall be conducted using the metal ball method described in clauses 7.14.1 and 7.14.2, but the voltage applied shall be the specified a.c. voltage.

7.15.2 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.

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 10 N for wire diameters 0.6 mm and 0.8 mm, or 20 N for wire diameter 1 mm, for 1 min.

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 5.

Table 5 – 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 SMD terminations robustness

a) Force application test

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

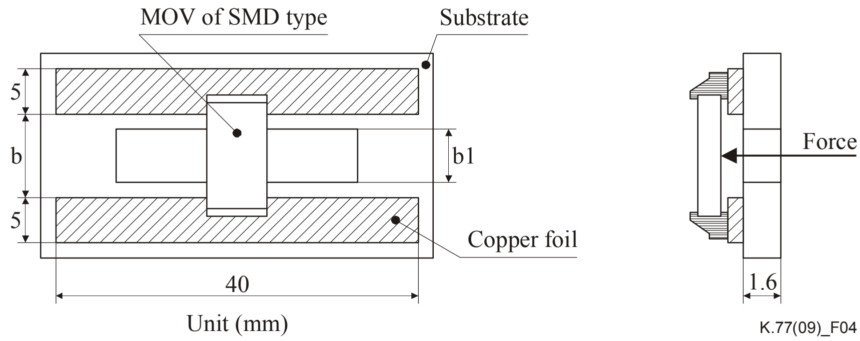


Figure 4 – Test arrangement of terminations of SMD type

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 6 – 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 60068-2-54], 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 s.

Temperature of the solder bath: 235°C ± 5 K, for P_b-Sn solder.

260°C ± 5 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 SMD type 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 h ± 2 h.

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 ± 5 K,	for P_b-Sn solder.
	260°C ± 5 K,	for lead-less solder.

After recovery for 1 h, 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 h ± 2 h.

After recovery for 1 h, 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 h (2 h 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 Bump

Tested in accordance with [IEC 60068-2-29], test *Eb* 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 below:

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 h.

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 +85°C ± 2 K for 16 h.

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 h.

c) Cold, in accordance with [IEC 60068-2-1], test *Aa*, at –40°C ± 3 K for 2 h.

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 h, 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 h.

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 h. 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 h.

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 h.

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 Informative characteristics

9.1 V-I characteristic

a) Three samples shall be randomly selected from the lot concerned. Varistor voltage U_N of each sample shall be measured and recorded into Table 7.

Table 7 – Test record

Sample number	Voltage U_N (V)	Test 1		Test 2		Test 3	
		I_{P1} (A)	U_{cla1} (V)	I_{P2} (A)	U_{cla2} (V)	I_{P3} (A)	U_{cla3} (V)
1							
2							
3							

b) Test the clamping voltages of each sample at 8/20 impulse current with the peak I_{P1}, I_{P2} and I_{P3} as specified by Table 8. The measured values of the current peak and clamping voltage shall be recorded into Table 7. The time gap between two applications of the impulse current shall be sufficient to allow the samples to cool to room temperature.

Table 8 – Current peaks of 8/20 impulse (for high voltage disc type MOV)

Nominal diameter of MOV (mm)		5	7	10	14	20	25	32	40	53
8/20 current peaks (A)	I_{P1}	6.2	12.5	25	50	100	150	250	400	700
	I_{P2}	50	100	200	400	800	1.2 k	2 k	3 k	5 k
	I_{P3}	620	1.25 k	2.5 k	5 k	10 k	15 k	25 k	40 k	70 k
NOTE – The test current peaks for low voltage disc types and SMD types are under consideration.										

c) Complete the calculations described in Table 9 using the data listed in Table 7.

Table 9 – Calculate the average β, a_1 and R_V

Sample number	$\beta = \dfrac{\lg(U_{cla2}/U_{cla1})}{\lg(I_{P2}/I_{P1})}$	$A_1 = \dfrac{U_{cla1}}{I_{P1}^{\beta}}$	$a_1 = \dfrac{A_1}{U_N}$	$R_V = \dfrac{U_{cla3}}{I_{P3}} - A_1 \cdot I_{P3}^{(\beta-1)}$
1				
2				
3				
Average		–		

d) The V-I characteristic of the tested lot is available by putting the average values of β, a_1 and R_V into equation 3-6.

The highest clamping voltages of the tested lot at various current peaks are determined by putting the maximum varistor voltage of the lot into the above equation.

9.2 Current peak de-rating curve

The method of plotting peak current de-rating curve is based on equations 3-1 and 3-2 that includes the following steps:

a) Placing the data from test 7.11 (I_{PS1}, n_{S1}) and from test 7.9 (I_{PS2}, n_{S2}) into equation 3-1 results in equations 9-1 and 9-2.

$$\lg I_{PS1} = A - a \lg n_{S1} \qquad (\tau = 17.5\ \mu s) \tag{9-1}$$

$$\lg I_{PS2} = A - a \lg n_{S2} \qquad (\tau = 17.5\ \mu s) \tag{9-2}$$

The particular values of constants A and a for 8/20 wave can be obtained by solving equations 9-1 and 9-2.

b) Compute the current peaks of 8/20 wave which correspond to $n = 10^1$, 10^2, 10^3, 10^4, 10^5 and 10^6, respectively, by using equation 3-1 and the particular values of constants A and a above.

c) Placing the data from test 7.11 (I_{PL1}, n_{L1}) and the data (I_{PL2}, n_{L2}) into equation 3-1 results in equations 9-3 and 9-4; the data (I_{PL2}, n_{L2}) may be obtained from a special test at 10/350 current with peak of I_{PL2} and $I_{PL2} = 0.1\ I_{PL1}$, which is recommended.

$$\lg I_{PL1} = A - a \lg n_{L1} \qquad (\tau = 500\ \mu s) \tag{9-3}$$

$$\lg I_{PL2} = A - a \lg n_{L2} \qquad (\tau = 500\ \mu s) \tag{9-4}$$

The nominal impulse width τ of 10/350 wave is 500 µs.

NOTE – If the data (I_{PL2}, n_{L2}) are not available, a special test for this pair of data is needed.

The particular values of constants A and a for 10/350 wave can be obtained by solving equations 9-3 and 9-4.

d) Compute the current peaks of 10/350 wave which correspond to $n = 10^1, 10^2, 10^3, 10^4, 10^5$, and 10^6, respectively, by using equation 3-1 and compute the particular values of constants A and a as per item c.

e) The following data shall be plotted into an "$\lg I_P$ versus $\lg\tau$" graph as shown in Figure 5:

– Maximum discharge current $I_{\max S}$ (8/20), and $I_{\max L}$ (10/350), which correspond to the peaks of $n = 2$ (see clause 7.7),

– Peaks of 8/20 wave correspond to $n = 10^1, 10^2, 10^3, 10^4, 10^5$ and 10^6 (see item b),

– Peaks of 50/350 wave correspond to $n = 10^1, 10^2, 10^3, 10^4, 10^5$ and 10^6 (see item d).

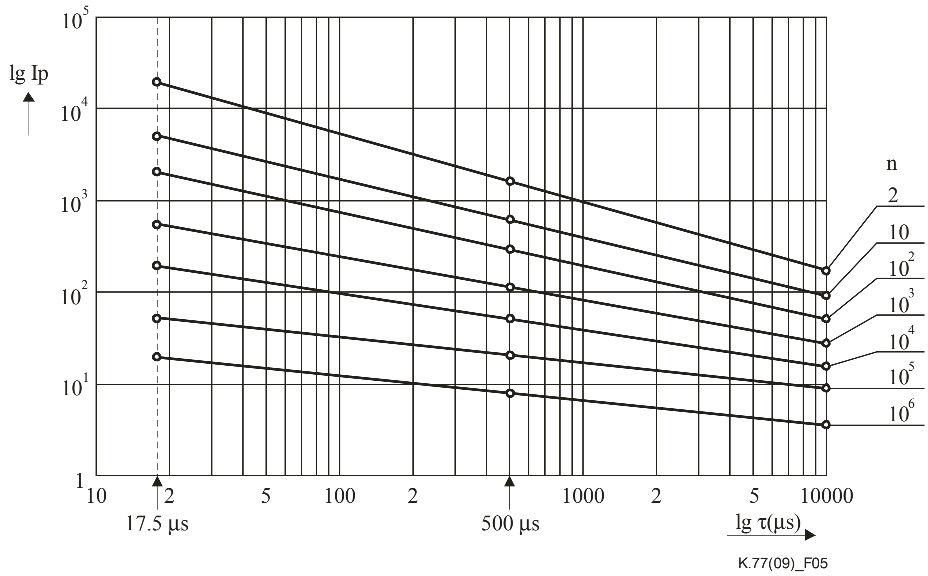


Figure 5 – Method of plotting peak current de-rating curve

f) Draw a straight line through the two points of 8/20 wave (τ = 17.5 µs) and 10/350 wave (τ = 500 µs) that have the same n values, as is depicted in Figure 5.

g) Each straight line shown by Figure 5 may be represented by equation 3-2.

$$\lg I_P = B - b \lg \tau \qquad \text{(n = constant)}$$

The particular values of B and b relating to a given n are obtained by solving the pair of equations 9-5 and 9-6.

$$\lg I_{PS} = B - b \lg 17.5 \qquad (9\text{-}5)$$

$$\lg I_{PL} = B - b \lg 500 \qquad (9\text{-}6)$$

where the data I_{PS} and I_{PL} are the peaks of 8/20 current and 10/350 current with the same n as shown in Figure 5.

By use of equation 3-2 with the particular values of B and b, the I_P can be computed for a given impulse width τ.

9.3 Volt-ampere characteristics of low field region

9.3.1 Volt-ampere characteristics of the low field region are expressed by equation 3-7. The leakage current of the MOV at given temperature T and applied d.c. voltage U can be calculated by using this equation. The equation has three constants I_0, E_g and β that need to be determined by three tests as below.

9.3.2 Three samples (a, b and c) shall be randomly selected from the lot concerned. Varistor voltages of U_{Na}, U_{Nb} and U_{Nc} shall be measured and placed into Table 10.

Three tests shall be carried out at the voltages and temperatures as specified by Table 10. For each test, the samples shall be un-energized and kept in an oven of specified temperature for at least 1 h, and then the leakage currents are measured at the specified voltage. The measured leakage currents are placed into Table 10.

Table 10 – Test records for volt-ampere characteristics

Sample	Measured U_N	Test 1, T_1 = 40°C		Test 2, T_1 = 40°C		Test 3, T_2 = 115°C	
		U_1	I_1	U_2	I_2	U_2	I_3
a	U_{Na}	1.0 U_{Na}		0.9 U_{Na}		0.9 U_{Na}	
b	U_{Nb}	1.0 U_{Nb}		0.9 U_{Nb}		0.9 U_{Nb}	
c	U_{Nc}	1.0 U_{Nc}		0.9 U_{Nc}		0.9 U_{Nc}	

9.3.3 Calculate the three constants I_0, E_g and β for each sample by using the data listed in Table 10 and the following equations:

$$\beta = \frac{0.432 \times 10^{-20}}{\sqrt{U_1} - \sqrt{U_2}} (\ln I_1 / I_2)$$

$$E_g = \beta\sqrt{U_2} + 2.24 \times 10^{-20} \times \ln(I_3 / I_2)$$

$$I_0 = \ln^{-1}[\ln I_1 + 2.32 \times 10^{20}(E_g - \beta\sqrt{U_1})]$$

9.3.4 Calculate the average values of three samples for the three constants I_0, E_g and β, which are considered as the constants representing the production lot concerned.

10 Identification

10.1 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.

10.2 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.

11 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 $0.3 \times \mathrm{T}_1$.

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%	$U_{OC}/2\ \Omega \pm 10\%$	±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.

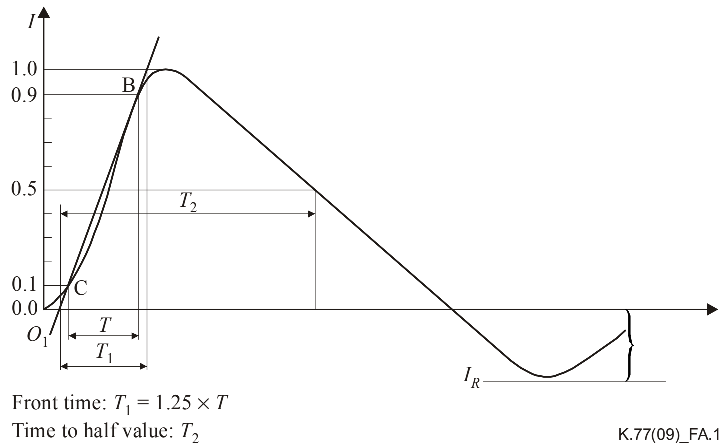


Figure A.1 – T_1/T_2 current impulse

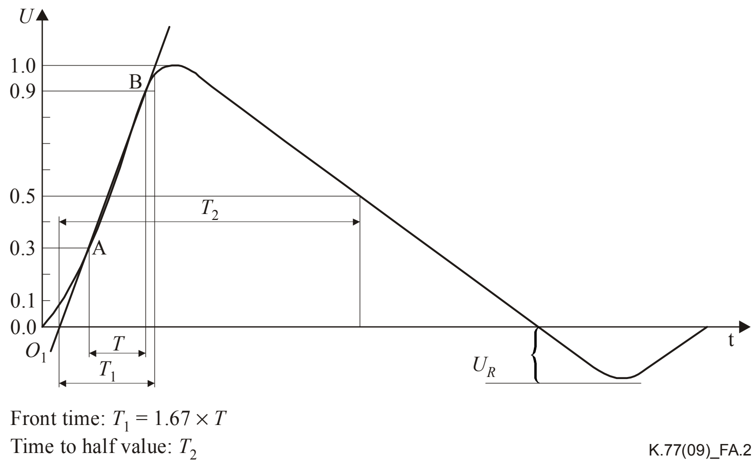


Figure A.2 – T_1/T_2 voltage impulse

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:	≤1.5 T_D
Polarity reversal:	≤0.1 I_P

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

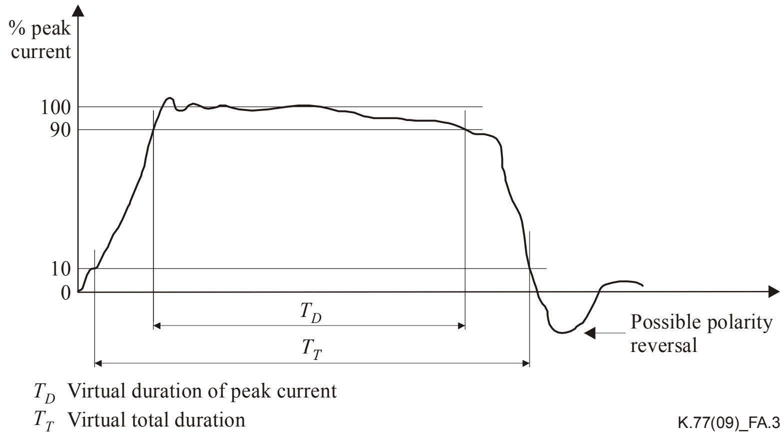


Figure A.3 – Rectangular current impulse

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

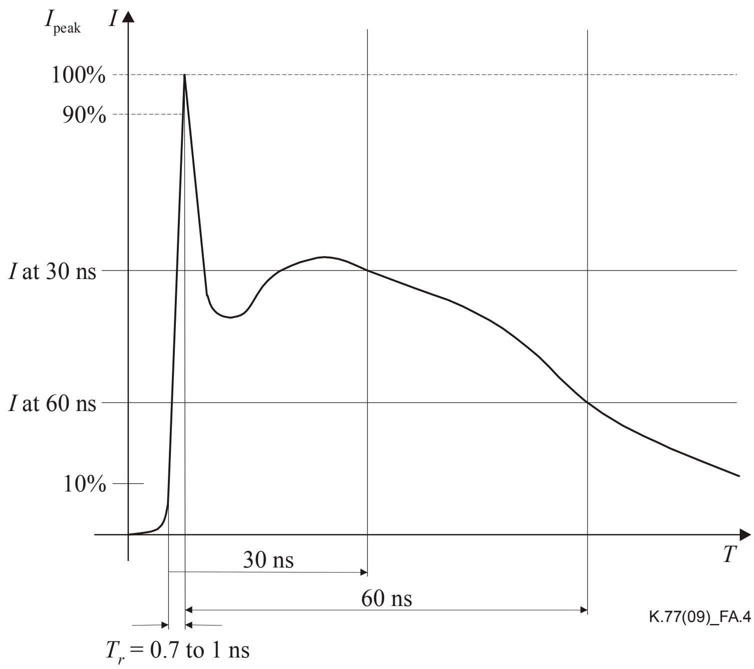


Figure A.4 – ESD discharge current impulse

Appendix I

Mounting method for measurement of SMD type

(This appendix does not form an integral part of this Recommendation)

I.1 Recommended mounting method

SMD-MOVs shall be soldered onto a substrate, the method of mounting depending on the MOV's construction. The substrate material shall normally be a 1.6-mm thick epoxide woven glass fabric laminated printed board (as defined in [b-IEC 61249-2-7], IEC-EP-GC-CU) or a 0.635 mm alumina substrate and shall not affect the result of any test or measurement. The manufacturer shall indicate which material is to be used for the electrical measurements.

The substrate shall have metalized land areas of proper spacing to permit mounting of the SMD-MOV and shall provide electrical connection to the SMD-MOV terminals. The details shall be specified by the manufacturer.

I.2 Wave soldering method

When wave soldering is used, suitable glue specified by the manufacturer shall be used to fasten the component to the substrate before soldering is performed.

Small dots of the glue shall be applied between the conductors of the substrate by means of a suitable device securing repeatable results.

The SMD-MOV shall be placed on the dots using tweezers. To ensure that no glue is applied to the conductors, The SMD-MOV shall not be moved about.

The substrate with the SMD-MOV shall be heat-treated in an oven at 100°C for 15 min.

The substrate shall be soldered in a wave soldering apparatus. The apparatus shall be adjusted to have a pre-heating temperature of 80°C to 130°C, a solder bath at 260°C ± 5K, and a soldering time of 5 s ± 0.5 s.

The soldering operation shall be repeated once more (two cycles in total).

The substrate shall be cleaned for 3 min in a suitable solvent (see clause 3.1.2 of [IEC 60068-2-45]).

I.3 Reflow soldering method

When reflow soldering is used, the following mounting procedure applies:

a) The solder used in preformed or paste form shall be silver bearing (2% minimum) eutectic Sn/Pb solder together with a non-activated flux as stated in [IEC 60068-2-20]. Alternative solders such as 60/40 or 63/37 may be used on SMD-MOVs whose construction includes solder leach barriers. The Pb-free solder used in preformed or paste form shall be Sn96.5-Ag3.0-Cu0.5 or derivative solder together with a flux as stated in [IEC 60068-2-58].

b) The SMD-MOV shall then be placed across the metalized land areas of the test substrate so as to make contact between the MOV and substrate land areas.

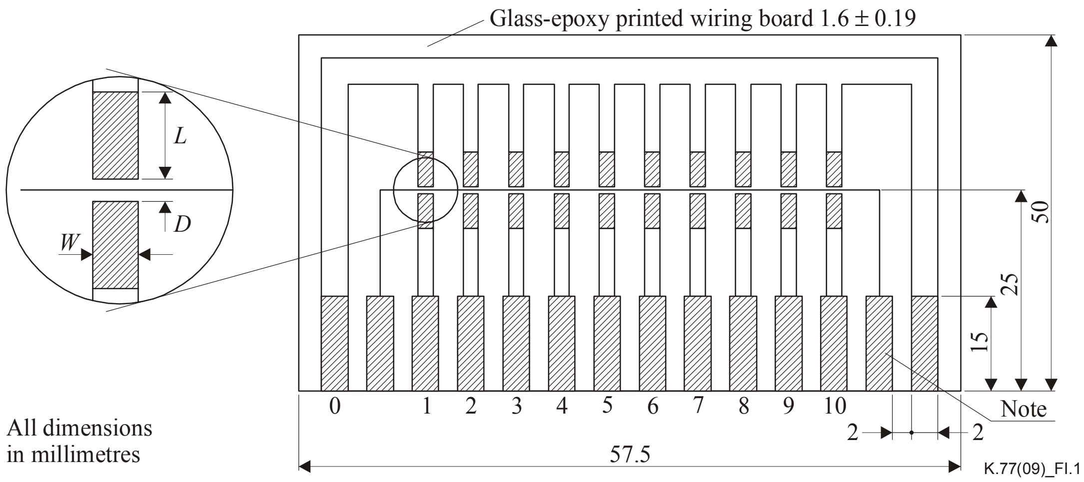
c) The substrate shall then be placed in or on a suitable heating system (molten solder, hot plate, tunnel oven, etc.). The temperature of the unit shall be maintained between 215°C and 260°C until the solder melts and reflows forming a homogeneous solder bond, but for not longer than 10 s.

NOTE 1 – Flux should be removed by a suitable solvent (see clause 3.1.2 of [IEC 60068-2-45]).

All subsequent handling should be performed such as to avoid contamination. Care should be taken to maintain cleanliness in test chambers and during post-test measurements.

NOTE 2 – A more restrictive temperature range may be required by the manufacturer.

NOTE 3 – If vapour phase soldering is applied, the same method may be used with the temperatures adapted.



NOTE – This conductor may be omitted or used as a guard electrode.

Figure I.1 – Mounting method for measurement of SMD type

Appendix II

Response of MOV to 8/20 impulse current and clamping voltage test

(This appendix does not form an integral part of this Recommendation)

The 8/20 impulse current has been widely used for MOV testing to measure clamping voltage, determine the volt-ampere characteristic and impulse current withstanding capabilities. In this appendix, four subjects are described as follows:

– double peaks on the voltage waveform of the MOV responding to 8/20 impulse current;

– instantaneous volt-ampere characteristic;

– volt-ampere characteristic (voltage limiting characteristic);

– methods for avoiding interference during clamping voltage measurement.

II.1 Double peaks on the voltage waveform

Experiments have shown that there is a voltage peak on the voltage waveform during the initial period (about 0.1 µs to 1 µs from the origin of the current) when the MOV responds to an 8/20 impulse current. This peak is termed as the "front peak" U_F in this appendix. An MOV is a non-linear resistor whose resistance decreases rapidly with increasing current passing through it; however, the decrease cannot take place instantaneously, rather it is time-dependent. This property of the MOV results in the front peak voltage. With the increasing of the current peak, the time at which the front peak occurs shifts towards the origin of the current, while the magnitude of the U_F increases, but at much higher current peaks, the U_F does not increase further and may even decrease.

If the 8/20 current density J_P is less than 32 A/cm^2, the voltage waveform of the MOV declines steadily after the front peak time as is shown in Figure II.1. It is noted that the time scale is 1 µs/division for the left waveform plot of Figure II.1, but 10 µs/division for the right one. The former shows the variation in voltage passing through the MOV during the period in which the 8/20 current increases from zero to its peak, and the latter shows the whole voltage waveform.

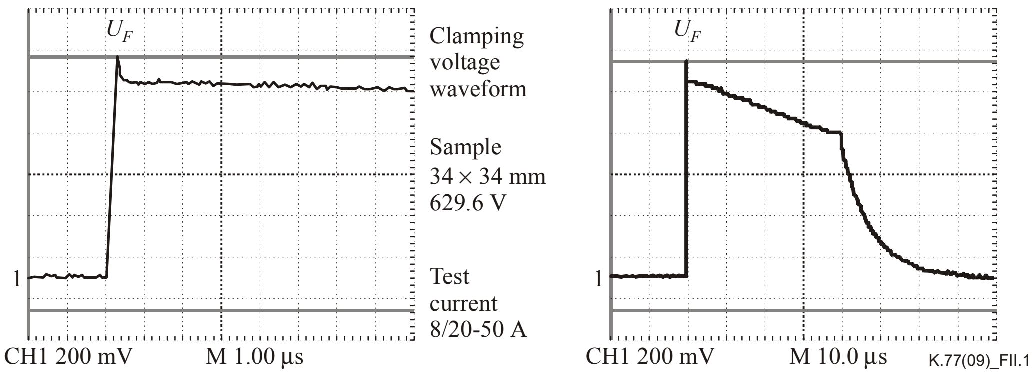


Figure II.1 – Front peak U_F on voltage waveform at low impulse current (1 µs/division for left plot, 10 µs/division for right plot)

If the 8/20 current density J_P is greater than about 32 A/cm^2, the magnitude of the voltage increases after the front peak time with the current impulse increasing towards its peak as shown by the left plot of Figure II.2. It implies that the rising rate of the current has become greater than the declining rate of the non-linear resistance of the MOV, and the current rising effect associated with the declining effect of the non-linear resistance of the MOV results in a second voltage peak an instant behind the front peak, as shown by the right plot of Figure II.2. This second voltage peak is termed the "rear peak U_R" in this appendix. It is found that as the 8/20 current density J_P is slightly greater than 32 A/cm^2, the magnitude of U_R is smaller than that of U_F, but that U_R increases more rapidly than that of U_F as J_P increases. At the nominal discharge current, U_R is much greater than U_F, as shown by Figure II.3.

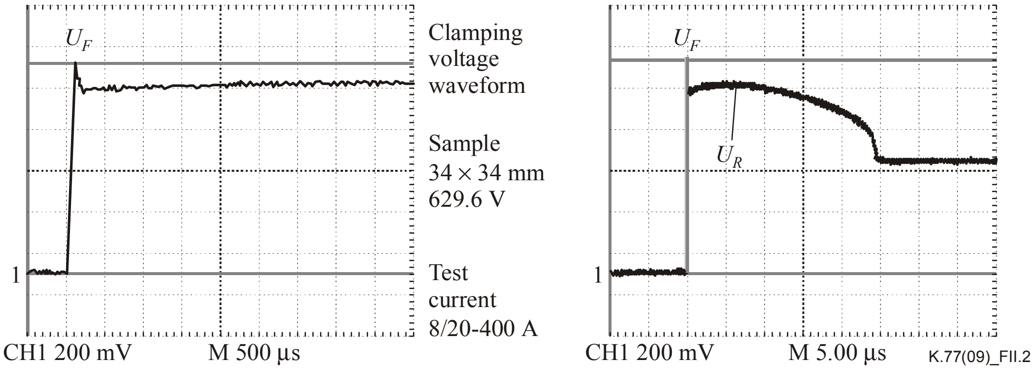


Figure II.2 – Double peaks (U_F and U_R) on voltage waveform at medium impulse current (0.5 µs/division for left plot, 5 µs/division for right plot)

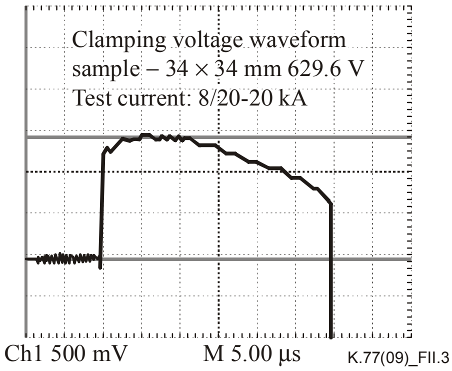


Figure II.3 – Rear peak voltage is much greater than front peak voltage at nominal discharge current of the MOV

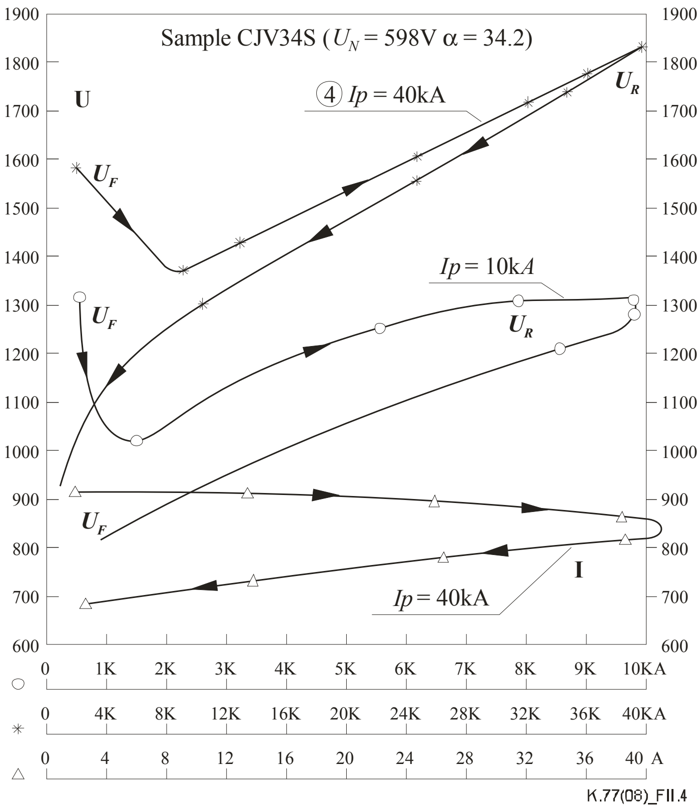
II.2 Instantaneous volt-ampere characteristic

The instantaneous volt-ampere characteristic expresses the relationship between the magnitudes of voltage and current at the same instant when an impulse current is applied to a component, while the V-I characteristic expresses the relationship between the magnitudes of impulse current peak and the associated voltage peak which are, in most cases, not coincident in time.

Instantaneous volt-ampere characteristics can be obtained by plotting the current value and the voltage value, at the same instant, as the current waveform and associated voltage waveform into a volt-ampere plot. Figure II.4 is an example that gives three instantaneous volt-ampere curves tested from the same MOV sample (34 × 34 mm, 598 V). The three curves correspond to the applied 8/20 current peaks of 40.8 A (≈40 A), 9.92 kA (≈10 kA) and 39.2 kA (≈40 kA), respectively.

1) With a short duration impulse current 8/20 applied, the instantaneous volt-ampere characteristics of the MOV exhibits a hysteresis property. If the curve branch corresponding to the current rising from zero to its peak is termed "rising phase branch", and the branch corresponding to the current falling from the peak to zero is termed "falling phase branch", then the rising phase branch is always higher than the falling phase branch. This property of the MOV implies that both the voltage and the resistance on the rising phase branch are always higher than that on the falling phase branch at the same current values. The differences between the two branches become smaller when long duration impulse is

applied. This is further evidence of the time-dependent property of the non-linear resistance of the MOV.



Sample: 34 × 34 mm, 598 V.
At 8/20-40 A, there is front peak U_F only.
At 8/20-10 kA, there are both front peak U_F and rear peak U_R; they are similar in magnitude.
At 8/20-40 kA, U_R is much greater than U_F.

Figure II.4 – Example of instantaneous volt-ampere characteristics of the MOV showing hysteresis property

2) The differences between the rising phase branch and falling phase branch become smaller in the vicinity of the current peak point where the current rate di/dt = 0, therefore the resistance of the MOV at this point is considered to be stable.

3) At low impulse currents, there is a front peak U_F only on the rising phase branch, the magnitude of the voltage and resistance falling steadily with time, the rising phase branch has negative resistance.

At medium and high impulse currents, there is both front peak U_F and rear peak U_R on the rising phase branch that forms a valley between the two peaks. The resistance from the peak point to the valley point is negative, therefore an oscillation is often seen in the vicinity of this part of voltage waveform.

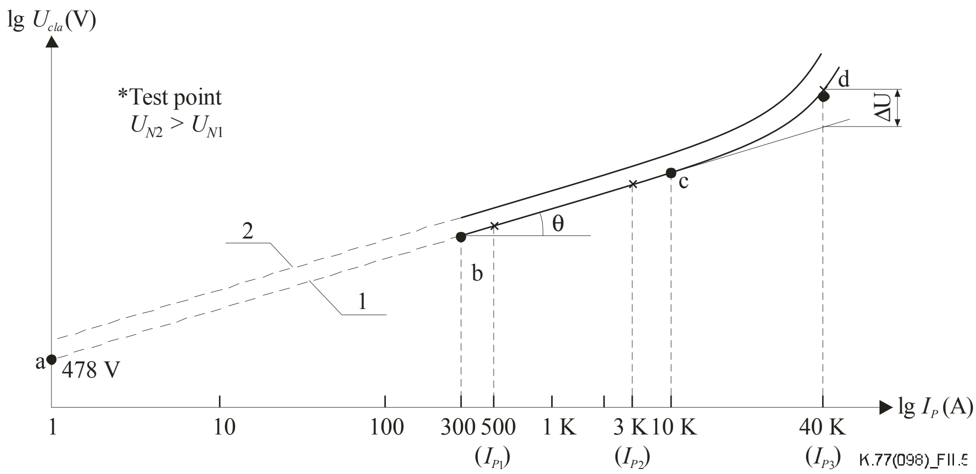
With the increasing of the current peak, the magnitudes of both U_F and U_R increase, but the U_R increases faster than U_F and the time at which the rear peak occurs shifts approaching the current peak time. Experiments show that the rear peak is almost coincident in time with the current peak as the 8/20 current peak ranges from the nominal discharge current to the maximum discharge current.

II.3 Voltage limiting characteristics

The voltage limiting property of an MOV is usually described by the characteristic of clamping voltage ~ applied impulse current peak in log ~ log plot (lg U_{cla} ~ lg I_P) which is named the volt-ampere characteristic (V-I characteristic) in the MOV specifications.

According to the current data sheet of the MOV, the V-I characteristic is given for each part number of the MOV product with the varistor voltage of +10% higher than the nominal varistor voltage, and such a characteristic is described by a continuous curve covering a current peak range from 1 mA to the maximum discharge current, no mathematical expression corresponding to the curve is available.

In this Recommendation, the V-I characteristic is described by both the curve, for example Figure II.5, and equation 3-5 or 3-6, that covers a current peak range from the current density $J_P = 32$ A/cm^2 to the maximum discharge current. Taking the fact into consideration that the V-I characteristic of a given part number may vary from lot to lot, therefore the manufacturers of the MOV should provide the V-I characteristic of each lot of MOV production, see clause 9.1 for the method to determine the V-I characteristic. A further discussion on the V-I curve and V-I equation is given below.



Sample: 34 x 34 mm, U_N=629.6 V.

Test points: 500 A/912 V, 3 kA/1100 V, 40 kA/1800 V.

V-I formula: $U_{cla} = 478\ I_P^{\ 0.104} + 0.0091\ I_P$.

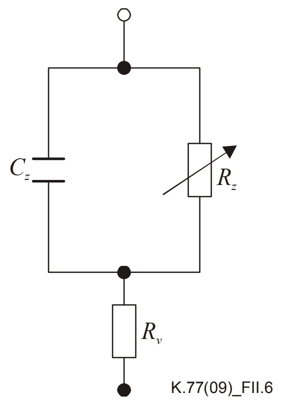
Figure II.5 – An example of V-I characteristic

$$U_{cla} = A_1 \cdot I_P^{\ \beta} + R_V \cdot I_P = I_P(R_Z + R_V) \tag{3-5}$$

$$U_{cla} = a_1 \cdot U_N \cdot I_P^{\ \beta} + R_V \cdot I_P\ (a_1 = A_1 / U_N) \tag{3-6}$$

The MOV behaviour of responding to an applied impulse current can be well understood by its equivalent circuit (Figure II.6), where C_Z is the capacitance, R_V is the effective linear resistance including ZnO grain resistance, silver-electrode and terminal resistance, contact resistances between the ceramic body~silver-electrode and silver-electrode~terminal. R_V is independent of the current through the MOV. R_Z is the effective non-linear resistance which decreases with the current increasing in accordance with equation 3-3. It should be noted that the non-linear current index β is always less than 1, so the power of I_P in equation 3-3 is negative.

$$R_Z = A_1 \cdot I_P^{\ (\beta - 1)} \tag{3-3}$$



C_Z Capacitance
R_Z Effective non-linear resistance
R_V Effective linear resistance

Figure II.6 – MOV equivalent circuit

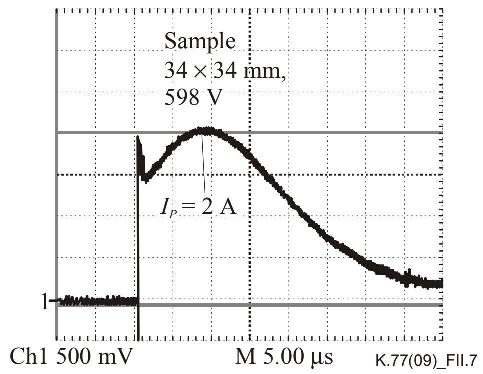


Figure II.7 – Deformed current waveform caused by MOV capacitance C_Z

It can be seen from Figure II.6 that when an impulse is applied to the MOV, it first charges C_Z, then the voltage on the C_Z increases to the varistor voltage U_N; at this point the resistance R_Z is ∞, with no current passing through the R_Z. After the voltage on the C_Z exceeds U_N; at this point, R_Z decreases following equation 3-3, and the current passing through it increases rapidly. The charging current to C_Z results in a jump on the leading edge of the current waveform, as is shown by Figure II.7. It is proved by experiment that a current density of greater than 0.3 A/cm^2 is needed for a proper 8/20 waveform delivered by an ordinary impulse generator loaded by commercially available MOVs; therefore, a 8/20 current peak as low as 1 mA is not practical for the V-I characteristic, but that is demonstrated by the current data sheets from most manufacturers.

In this Recommendation, the clamping voltage refers only to the rear peak voltage U_R of the MOV; therefore, the current range of V-I characteristic in Figure II.5 is 300 A~40 kA (40 kA is the I_{max} of the sample), because the sample has front peak voltage U_F only when I_P is less than 300 A. The reasons why only U_R is considered here are as follows:

1) The significant current lies in the range (0.1~1.0) I_{max} for the most applications of overvoltage protection and, in this range, U_R is always greater than U_F.

2) The U_F is hard to measure accurately because it has "historic effect", the measured value of U_F depends on the previous electric stresses to which the sample had been subjected. In addition, the U_F is frequently affected by interference, while U_R can be measured more accurately. Therefore, the current range for the V-I characteristic is specified from $J_P = 32$ A/cm^2 to I_{max} (approximately corresponding to J_P = 3200 A/cm^2) in this Recommendation.

Based on the equivalent circuit (Figure II.6), the clamping voltage of the MOV depends on the equivalent non-linear resistance R_Z and equivalent linear resistance R_V, the V-I characteristic has two distinctive regions, as is shown by Figure II.5, the region b-c and the region c-d. The region b-c corresponds to the current density about 32~320 A/cm^2 where R_Z is much greater than R_V, and R_V can be ignored. Because R_Z decreases with the increasing current following equation 3-3, this results in a slow increase of the clamping voltage with the increasing current in the b-c region. The V-I characteristic in this region is expressed by equation II-1.

$$\lg U_{cla} = \lg A_1 + \beta \lg I_P \tag{II-1}$$

It is realized by comparing equation II-1 and Figure II.5 that the β signifies the slope of the V-I characteristic in b-c region:

$$\beta = \tan \theta \tag{II-2}$$

and A_1 signifies a virtual clamping voltage at $I_P = 1$ A. It is the intersection of extended line b-c with the axis of ordinates (point "a" in Figure II.5).

In the region c-d of the V-I characteristic, I_P becomes so large and R_Z becomes so small that the voltage drop of ΔV (see Figure II.5) caused by the effective linear resistance R_V is of such significance that the V-I curve turns upward quickly. The value of R_V can be determined by equation II-3.

$$R_V = \Delta V / I_P = \frac{U_{cla} - A_1 \cdot I_P{}^{\beta}}{I_P} \tag{II-3}$$

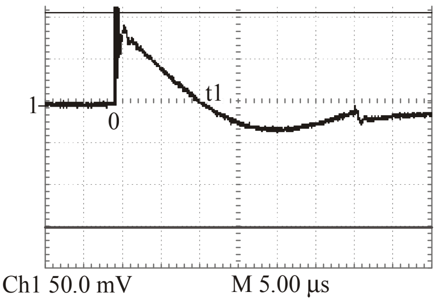
In summary, the V-I equation 3-5 of the MOV can be determined by making three tests on the sample at test currents I_{P1}, I_{P2} (in the region b-c) and I_{P3} (in the region c-d), respectively, measuring each clamping voltage at each test current, and calculating the three constants A_1, β and R_V; see clause 9.1 for a detailed description of the method.

Additionally, it is noted that the value of A_1 depends on the varistor voltage U_N in direct proportion for one production lot of the MOV as shown by Figure II.5. Sample 2 has a higher U_N than that of sample 1, the value A_1 of sample 2 is higher than that of sample 1 as well, but the ratio of $a_1 = A_1 / U_N$ is the same for the two samples hence if A_1 is replaced by $a_1 U_N$, the V-I equation 3-6 is obtained. By using this equation, the V-I characteristic of any given U_N can be found more easily.

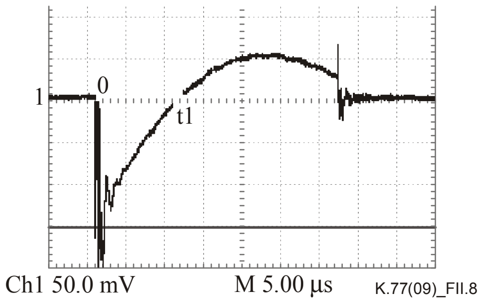
II.4 Methods for avoiding interference during clamping voltage measurement

High impulse current may induce appreciable interference voltage in the clamping voltage measuring circuit, hence causing significant measurement errors. Therefore, a check to see if such interference exists will be necessary before a clamping voltage measurement is made. A method for checking is recommended below.

The lead which normally joins the voltage divider to the live end of the test object should be disconnected from this point and connected instead to the earthed end of the test object, but maintaining approximately the same loop. The voltage measured under this condition, when the generator is discharging, should be negligible in comparison with the clamping voltage of the MOV. The measured interference voltage usually has two kinds of shape as shown in Figure II.8.



a) Interference voltage – in phase



b) Interference voltage – out of phase

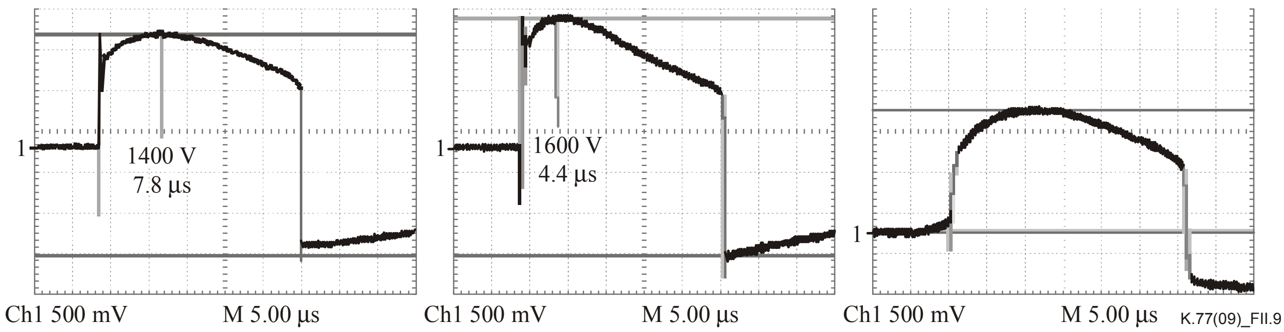
Figure II.8 – Measured interference voltage

The interference voltage *u* is expressed by equation II-4:

$$u = -M(di/dt) \qquad \text{(II-4)}$$

Where *M* is the mutual conductance between the discharge current and the clamping voltage measuring circuit, and di/dt is the discharge current rate. Figure II.8 shows that the interference voltage may be in phase with the normal clamping voltage of the MOV, or out of phase if the direction of the discharge current reversed, and at the instant t_1, $di/dt = 0$, hence the interference voltage at this time is also zero.

Superposing the interference voltage onto the normal clamping voltage of the MOV will change the shape of measured clamping voltage waveforms; Figure II.9 depicts these situations. Figure II.9a and Figure II.9b are two voltage waveforms measured on the same MOV sample (34 × 34 mm, 639 V) and at the same applied impulse current of 8/20-12.1 kA delivered by the same generator, but Figure II.9a was so measured that the voltage divider was positioned far away from the conductors carrying the discharge current while, for Figure II.9b, the voltage divider was very close to the discharge current, so the former waveform was un-interfered with the peak of 1400 V at 7.8 μs, and the latter waveform was interfered with the peak of 1600 V at 4.4 μs. That means that the interference voltage is in phase with the normal clamping voltage that results in an error of +14.3% in voltage peak and the peak time being shifted forward by 3.4 μs. Figure II.9c shows the measured waveform that is interfered with by an out-of-phase interference voltage. It should be noted that this graph was obtained from another sample on another generator.



a) Normal waveform b) Interfered waveform (in phase) c) Interfered waveform (out of phase)

Figure II.9 – Measured clamping voltage waveforms

If serious interference is found, correction measures to the clamping voltage measuring circuit have to be taken. Usually, the interference can be removed by changing the position and orientation of the clamping voltage test probe (voltage divider), reducing the loop of the voltage measuring circuit as far as possible, and using a double screened voltage divider.

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

[b-IEC 61249-2-7] IEC 61249-2-7 (2002), *Materials for printed boards and other interconnecting structures – Part 2-7: Reinforced base materials clad and unclad – Epoxide woven E-glass laminated sheet of defined flammability (vertical burn test), copper clad*.

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