

# TECHNICAL REPORT

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**Components for low-voltage surge protection -  
Part 333: Characteristic equations and life evaluation for metal oxide varistors  
(MOV)**

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**Components for low-voltage surge protection -  
Part 333: Characteristic equations and life evaluation  
for metal oxide varistors (MOV)**

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IEC TR 61643-333 has been prepared by subcommittee 37B: Components for low-voltage surge protection, of IEC technical committee 37: Surge arresters. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
37B/269/DTR	37B/272/RVDTR

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

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at [www.iec.ch/members\\_experts/refdocs](http://www.iec.ch/members_experts/refdocs). The main document types developed by IEC are described in greater detail at [www.iec.ch/publications](http://www.iec.ch/publications).

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## INTRODUCTION

Since the invention of metal oxide varistors (MOV) which are also known as zinc oxide non-linear resistors, in 1968, MOV has become the key surge protection component with the widest use, largest production and mature technology. In addition, driven by the market demand and the efforts of researchers, production engineers and field application engineers, people have further deepened their understanding of it.

Although impulse life characteristic curve and life data under continuous working voltage stress have been given in current MOV product manuals and related technical data, they are only empirical and rough estimate. The life value of MOV (average value, median value and minimum value) is essentially a statistic, which needs to be dealt with by the theory of mathematical statistics.

Additionally, there is an increasing user's demands in recent years for the MOVs having estimated lifetime duration. The estimated value is evaluated and tested under continuous working voltage stress and impulse current stress. Although MOV manufacturers provide the service life characteristic curves under impulse current stresses, such curves are empirical. This is the reason why a theoretical approach is provided in this technical report.

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## 1 Scope

This part of IEC 61643, which is a Technical Report, presents the  $U-I/R-I$  characteristic equations and the life evaluation method for MOVs, which are used for applications up to 1 000 V AC or 1 500 V DC in power line, or telecommunication, or signalling circuits. They are designed to protect apparatus or personnel, or both, from high transient voltages.

This document specifically addresses the zinc-oxide type of MOVs.

## 2 Normative references

There are no normative references in this document.

## 3 Terms and definitions

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

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

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

**3.1 population**  
totality of items under consideration

[SOURCE: ISO 3534-1, 1.1]

**3.2 sampling unit**  
one of the individual parts into which a population is divided

[SOURCE: ISO 3534-1, 1.2]

**3.3 sample**  
subset of a population made up of one or more sampling units

[SOURCE: ISO 3534-1, 1.3]

**3.4 sampling size  $n$**   
number of sampling units in a sample

[SOURCE: ISO 3534-4, 3.1.9]

**3.5 observed value**  
obtained value of a property associated with one member of a sample (3.3)

[SOURCE: ISO 3534-1, 1.4]

**3.6****peak shift**

interval time between voltage peak and current peak

**3.7****voltage non-linearity index  $\alpha$** 

ratio of  $(\log I_1 - \log I_2) / (\log V_1 - \log V_2)$ , for a specified current range  $(I_1, I_2)$  with corresponding voltage range  $(V_1, V_2)$ .

Note 1 to entry: If  $I_2/I_1 = 10$ , the index denoted by " $\alpha$ ", if  $I_2/I_1 = 2$ , the index denoted by " $\alpha_2$ ".

**3.8** **$B_x$ -Life**

time (or any other usage measure) by which  $x$  percent of the population can be expected to fail

Note 1 to entry:  $x = 10$  is commonly used.

Note 2 to entry:  $B_x$ -Life means mission life, i.e., the life time of reliability RL being  $(1-x)$  %.

Note 3 to entry: For Weibull distribution, the reliability RL is expressed as

$$RL(B_x) = \exp\left[-\left(\frac{B_x}{\eta}\right)^\beta\right] = 1 - \frac{x}{100}$$

**3.9****expressions of MOV lifetime****3.9.1****average life** **$L_{ave}$** 

length of time a device or other product is expected to last in operation

**3.9.2****median life** **$L_{med}$** 

length of time at which 50 % of the items fail, the  $B_{50}$  life is the median time to failure

**3.9.3****minimum life** **$L_{min}$** 

length of time (or any other usage measure) by which zero percent of the population can be expected to fail

Note 1 to entry: This can also be referred as guarantee life.

**4 Characteristics of MOV****4.1 General**

Under electrical stress, the current  $I$  flowing through MOV and the voltage  $V$  between two terminals of MOV will present different characteristics from that of linear resistance. These characteristics are linked by the equation  $R = V/I$ .

## 4.2 Important properties associated with MOV $R$ - $I$ - $V$ characteristics

### 4.2.1 General

The MOV can be considered as a combination of three components in parallel, which are capacitance  $C$ , non-linear resistance  $R_V$ , and insulation resistance  $R_{ins}$ . see Figure 1. The resistive current through  $R_V$  is  $I_R$  and the capacitive current through capacitance  $C$  is  $I_C$ .

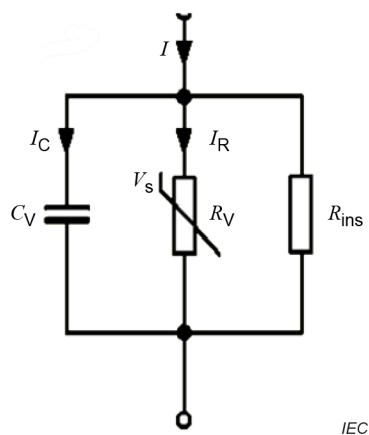


Figure 1 – MOV equivalent circuit model

The equivalent circuit model of the MOV shown in Figure 1 can explain waveforms illustrated in Figure 2. It shows the variations of the current waveforms of an MOV with the variation of the applied voltages, when it is powered by 50 Hz voltage source.

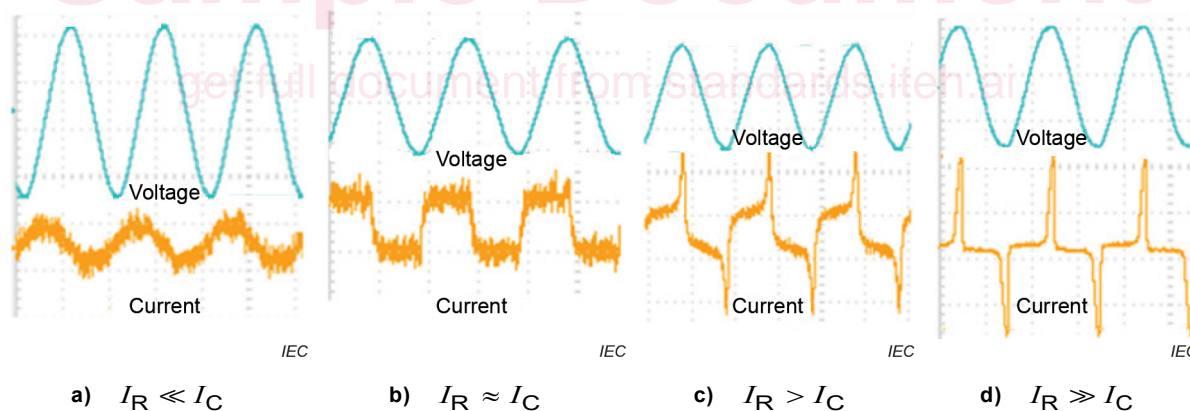


Figure 2 – Current waveforms of MOV under power frequency voltage

Figure 2a) shows that when the peak value of the 50 Hz voltage source  $V_S$  is lower than the varistor voltage  $V_V$ , the nonlinear resistance  $R_V$  is extremely large. Therefore the resistive current component  $I_R$  is much lower than the capacitive current component  $I_C$ .

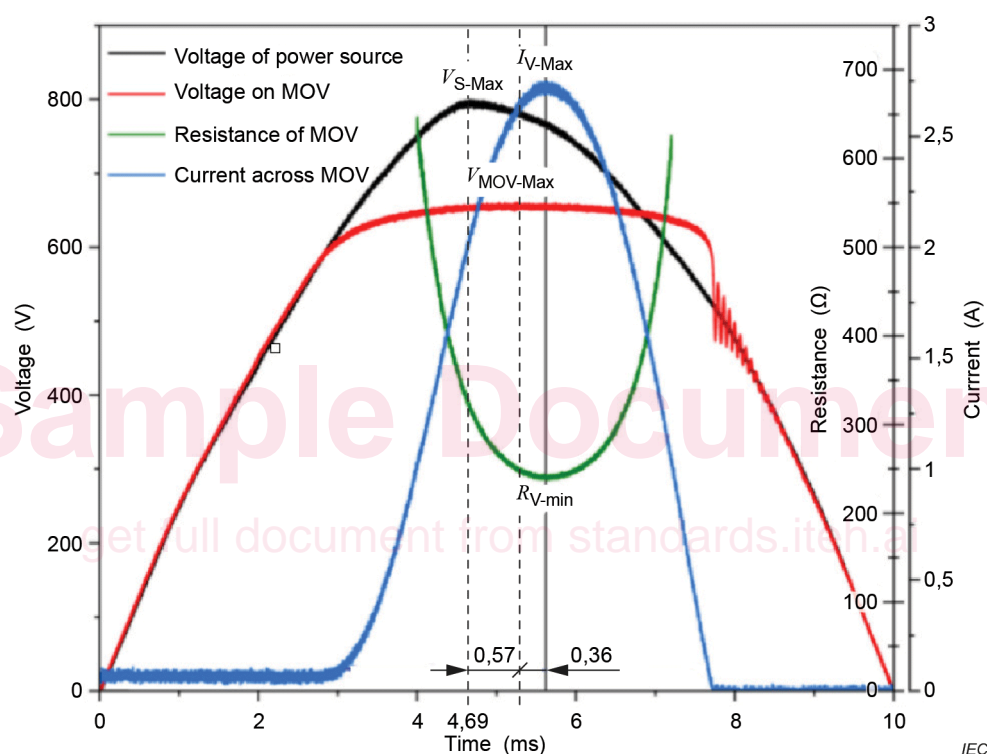
Figure 2b) shows that when the peak value of the 50 Hz voltage source  $V_S$  exceeds the varistor voltage  $V_V$ , the nonlinear resistance  $R_V$  is comparable to the capacitive reactance  $C_V$ .

The resistive current component  $I_R$  flowing through the MOV is also comparable to the capacitive current component  $I_C$ . The current waveform begins to be distorted due to the MOV nonlinearity.

Figure 2c) shows that when the peak value of the 50 Hz voltage source further increases, the nonlinear resistance  $R_V$  becomes smaller than the capacitive reactance  $C_V$ . Therefore the resistive current component  $I_R$  flowing through MOV is also larger than the capacitive current component  $I_C$ . The current waveform distorts more due to the MOV increasing nonlinearity.

Figure 2d) shows that when the peak value of the 50 Hz voltage source  $V_S$  is much higher than the varistor voltage  $V_V$ , the nonlinear resistance  $R_V$  is much smaller than the capacitive reactance  $C_V$ . The resistive current component  $I_R$  flowing through MOV is also much larger than the capacitive component  $I_C$ . The current waveform distorts greatly due to the MOV nonlinearity.

Figure 3 illustrates the waveforms of power source voltage, MOV voltage, MOV current and MOV equivalent resistance  $R$  during half of a period.



**Figure 3 –  $R$ - $V$ - $I$  waveforms during half cycle of 50 Hz (Sample  $34 \times 34$  mm,  $V_V = 560$  V)**

There are two voltages in Figure 3. One is the voltage of power source ( $V_S$ ) and the other is the voltage on MOV ( $V_{MOV}$ ). If the power source impedance is  $Z_S$ , then,  $V_{MOV} = V_S - I_S \times Z_S$ . Figure 3 clearly shows the following properties of MOV:

The point of the peak power source voltage ( $V_{S-Max}$ ), is located at 4,69 ms. The point of the peak MOV voltage ( $V_{MOV-Max}$ ) is about 0,57 ms behind the point of ( $V_{S-Max}$ ). The point of the peak current ( $I_{V-Max}$ ) is about 0,36ms behind the peak point of MOV voltage ( $V_{MOV-Max}$ ), while the point of resistance valley ( $R_{V-min}$ ) is located at the same point as the point of the peak current ( $I_{V-Max}$ ).

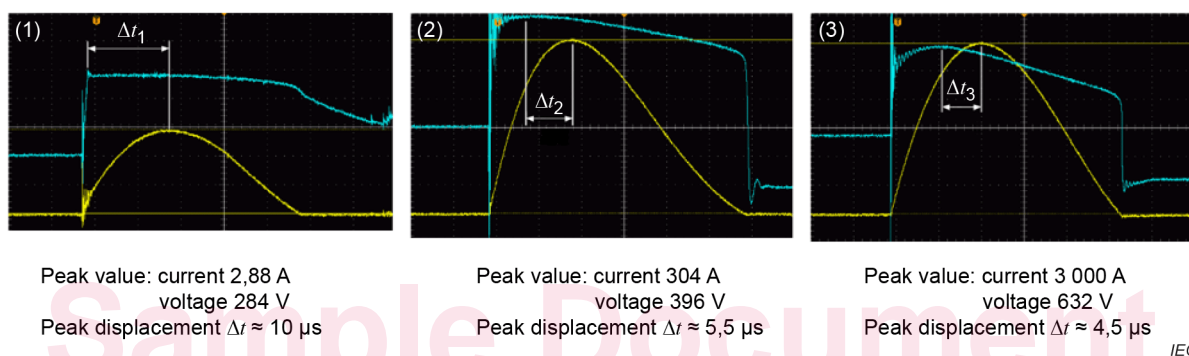
A characteristic of the current waveforms in Figure 3 indicates the time effect of the MOV.

#### 4.2.2 MOV clamping voltage waveforms at 8/20 current

8/20 impulse current with three different peak values were applied to an MOV sample ( $\varnothing 14$  mm,  $V_V = 220$  V), the waveforms of clamping voltage and impulse current were recorded by an oscilloscope, see Figure 4, which shows following properties:

When the peak current of 8/20 is quite small, for example 2,88 A, the clamping voltage starts a peak (front peak), and then drops continuously, so that the peak displacement  $\Delta t$  has the maximum value 10  $\mu$ s. The peak displacement  $\Delta t$  refers to the time interval between the clamping voltage peak and impulse current peak, so that the  $\Delta t$  value decrease with increasing current peak. The oscillation at the beginning of the residual voltage waveform is disregarded.

During the time interval  $\Delta t$ , the voltage value decreases ( $dv/dt$  is negative) and the current value increases ( $di/dt$  is positive), so that the incremental resistance of the MOV is negative. It is noted that in the case of power frequency test, during the  $\Delta t$ ,  $di/dt$  is negative,  $dv/dt$  is positive, they are just opposite.



**Figure 4 – Current waveforms (yellow) and voltage waveforms (blue) of an MOV subjected to 8/20**

## 5 MOV $R$ - $I$ and $V$ - $I$ characteristic equations

### 5.1 Early characteristic curves and equations

Figure 5 is a widely used curve. It approximates the expression of MOV  $V$ - $I$  characteristic.