

# TECHNICAL REPORT

---

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

## CONTENTS

FOREWORD .....	3
INTRODUCTION .....	5
1 Scope .....	6
2 Normative references .....	6
3 Terms and definitions .....	6
4 Characteristics of MOV .....	7
4.1 General .....	7
4.2 Important properties associated with MOV $R-I-V$ characteristics .....	8
4.2.1 General .....	8
4.2.2 MOV clamping voltage waveforms at 8/20 current .....	10
5 MOV $R-I$ and $V-I$ characteristic equations .....	10
5.1 Early characteristic curves and equations .....	10
5.2 Types of $R-I$ and $V-I$ characteristic equations .....	13
5.3 Measuring circuit, testing procedures and method of $R-I$ and $V-I$ characteristic equations for upturn region with 8/20 impulse current .....	14
6 Degradation of MOV .....	16
6.1 General .....	16
6.2 Performance parameter degradations .....	17
6.3 Physical destruction .....	17
7 Life evaluation method of MOV .....	17
7.1 Overview of Weibull distribution .....	17
7.1.1 Weibull cumulative distribution function (CDF) .....	17
7.1.2 Evaluation method of $\beta$ and $\eta$ .....	18
7.1.3 Evaluation method of $t_0$ .....	18
7.2 Life evaluation of MOV under continuous working voltage stress .....	18
7.2.1 General .....	18
7.2.2 Evaluation procedure of $\beta$ and $\eta$ .....	19
7.2.3 Evaluation procedure of the parameter $t_0$ .....	20
7.3 Life evaluation procedure of MOV under impulse current stress .....	23
7.3.1 General .....	23
7.3.2 Life characteristics equations of MOV under impulse current stress .....	23
7.3.3 Evaluation method of the parameters $I_p$ , $\tau$ , and $n$ .....	24
7.3.4 Evaluation example .....	25
Annex A (informative) Characteristics of various surge voltages and currents .....	31
A.1 The sources of surge voltages and surge currents .....	31
A.2 Lightning surges .....	31
A.2.1 Lightning flash and stroke .....	31
A.2.2 Lightning parameters .....	32
A.2.3 Coupling mechanisms .....	34
A.3 System switching surge .....	35
A.4 Interactions between different systems, such as the power system and a communication system during surge events occurring in one system .....	35
A.5 Electrostatic discharge .....	35
A.6 System voltage fluctuation .....	36
A.7 Mis-operation overvoltage .....	36
Annex B (informative) Mathematical methods in statistics for life valuation .....	37

B.1	Best linear unbiased estimate (BLUE) .....	37
B.2	Maximum likelihood estimation (MLE) .....	38
B.3	Median rank regression estimation (MRRE) .....	39
Bibliography .....		40
Figure 1	– MOV equivalent circuit model .....	8
Figure 2	– Current waveforms of MOV under power frequency voltage .....	8
Figure 3	– $R$ - $V$ - $I$ waveforms during half cycle of 50 Hz (Sample 34 × 34 mm, $V_V = 560$ V) .....	9
Figure 4	– Current waveforms (yellow) and voltage waveforms (blue) of an MOV subjected to 8/20 .....	10
Figure 5	– Early characteristic curves .....	11
Figure 6	– A practical example of $\alpha$ value varying with test current .....	11
Figure 7	– Maximum leakage current ( $A$ ) and maximum clamping voltage ( $B$ ) .....	12
Figure 8	– Regression equation curves .....	16
Figure 9	– The fitting curve from the experiment results .....	20
Figure 10	– Evaluation curve of $t_0$ .....	21
Figure 11	– Fitting line of CDF versus $\ln(t-110)$ curve .....	22
Figure 12	– Fitting line of CDF versus $\ln(t-120)$ curve .....	22
Figure 13	– Fitting line of CDF versus $\ln(t-130)$ curve .....	23
Figure 14	– Impulse life curve when $n$ is constant .....	23
Figure 15	– Impulse life curve when $\tau$ is constant .....	24
Figure 16	– Three approximate impulse life characteristics curves .....	30
Figure 17	– Impulse life characteristics curve (when $I_p = 400$ A) .....	30
Figure A.1	– An example of the waveform of lightning discharge .....	31
Table 1	– Measured values and their calculated values .....	14
Table 2	– Three different calculation methods of regression equation .....	15
Table 3	– Deviation of $V_{cal}$ % with respect to the Measured value $V_i$ .....	16
Table 4	– Calculation Procedure of Weibull Function Parameters .....	19
Table 5	– Evaluation Table of $t_0$ .....	21
Table 6	– Test data of Sample 1 .....	25
Table 7	– Test data of Sample 2 .....	26
Table 8	– Test data of Sample 3 .....	26
Table 9	– Test data of Sample 4 .....	27
Table 10	– Test data of Sample 5 .....	27
Table 11	– Test data of Sample 6 .....	28
Table 12	– Median life of six samples .....	29
Table A.1	– Lightning current parameters from negative flashes (Berger et al., 1975) .....	32
Table A.2	– Maximum values of lightning parameters according to LPL .....	33
Table A.3	– Minimum values of lightning parameters and related rolling sphere radius corresponding to LPL .....	33

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

## FOREWORD

- 1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
- 2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
- 3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
- 4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
- 5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
- 6) All users should ensure that they have the latest edition of this publication.
- 7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
- 8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
- 9) IEC draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). IEC takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, IEC had not received notice of (a) patent(s), which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at <https://patents.iec.ch>. IEC shall not be held responsible for identifying any or all such patent rights.

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).

A list of all parts in the IEC 61643 series, published under the general title *Components for low-voltage surge protection*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under [webstore.iec.ch](http://webstore.iec.ch) in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

## 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.

## **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.

## Bibliography

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

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

IEC 61643-12:2020, *low-voltage surge protective devices - Part 12: Surge protective devices connected to low-voltage power distribution systems - Selection and application principles*

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

IEC 61643-332:2024, *Components for low-voltage surge protection - Part 332: Selection and application principles for metal oxide varistors (MOV)*

IEC 61649:2008, *Weibull analysis*

ISO 3534-1, 2006, *Vocabulary and symbols - Part 1: General statistical terms and terms used in probability*

ISO 3534-4, 2014, *Statistics - Vocabulary and symbols*

ITU-T K.77, 2019-07, *Characteristics of metal oxide varistors for the protection of telecommunication installations*

ITU-T K.128, 2018-01, *Surge protective component application guide - metal oxide varistor (MOV) components*

MIL Std. 690 D, *Failure rate sampling plans and procedures*

Berger, K., 1975, *Parameters of lightning flashes*. *Electra*, 80, 223-237

---