MO Surge Arresters
Stresses and Test Procedures

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Introduction

The Cigre TB 60 was published in 1991 describing effects on gapless metal oxide surge arresters (MO arresters) from various electrical stresses encountered in 3-phase AC systems. Since then, continued improvements in equipment technologies coupled with de-regulated power industry's interest in maximizing utilization of existing infrastructure has revolutionized MO arrester applications and their expected performances in a more stressful environment.

Today's proven confidence in the reliability and capability of modern MO arresters offers new possibilities of overvoltage protection and improved management of power system disturbances.

The WG A3.17 of SC A3 took over the task to evaluate the stresses on MO arresters and review the existing test procedures. Further on, the actual state of MO arrester design was investigated, as well as various applications in different types of electrical networks.

Emphasis was given to the MO resistors as the active part of the MO arresters. A research project was started to experimentally investigate the energy handling capability of the MO resistors. The resulting TB covers and describes the actual MO resistor and arrester technology and the results of the first part of the research project on the energy handling capability of MO resistors.

Electrical stresses on MO arresters can be divided in stresses at power frequency, which can have long time durations, and transient stresses of short time duration resulting from switching and lightning.

IEC 60071-4 gives some recommendations for the evaluation of overvoltages, adapted to the use of numerical programs.

Temporary Overvoltages

A temporary overvoltage (TOV) is an oscillatory phase-to-ground or phase-to-phase condition that is of relatively long duration and is undamped or only weakly damped.

The following causes of TOV are typically considered:

- Earth fault temporary overvoltages occur in a large part dependent on the effectiveness of system earthing. Guidance for the determination of TOV amplitudes is given in IEC 60099-5 and IEC 60071-2.
- Disconnection of a load will cause the voltage to rise at the source side of the operating circuit breaker. The amplitude of the overvoltage depends on the disconnected load and the short-circuit strength of the feeding substation. The amplitude of load rejection overvoltages is usually not constant during their duration. Accurate calculations have to consider many parameters.
- Voltage rise along long unloaded lines (Ferranti effect)
- Harmonic overvoltages, originating from e.g. DC converters or saturated transformers.
- Resonances, in particular Ferro resonances.
- Overvoltages due to flashover between two systems of different system voltages installed on the same tower.

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Slow-front overvoltages

Slow-front overvoltages, in most cases generated by switching or faults, are associated with load switching or fault clearing. Different switching cases have to be considered: line re-energization, switching of capacitive loads and inductive loads.

Fast-front overvoltages

Fast-front overvoltages are in many cases caused by thunderstorms and occur all over the world. The heaviest thunderstorms with the most intensive lightning will normally be experienced in the equator region. Other sources are, for instance, current chopping of breakers or back flashovers.

In low voltage (LV) power systems up to 1 kV and medium voltage (MV) power systems (1 kV < Us ≤ 52 kV) distribution lines are generally of lower height and less exposed to direct flashes than transmission lines. Most of the occurring overvoltages are due to induced voltages originating from lightning to surrounding structures.

High voltage (HV) systems in the range of 52 kV $< U_s \leq$ 245 kV can be found in transmission and sub-transmission rural areas. Direct strokes, back flashovers and induced overvoltages will statistically result in a higher stress for the installed arresters than in other voltage systems.

Transmission lines in extra high voltage (EHV) with 245 kV < Us ≤ 800 kV and ultra high voltage (UHV) systems above 800 kV have steel towers with shield wires and are in spite of their height above ground well protected against direct lightning strokes to the phase wires. Most of the lightning will hit the towers or the shield wires, and only shielding failures and back flashovers will cause a critical surge in the phase wire.

Countries such as Norway or Japan experience rather often thunderstorms during winter. Typical weather conditions to create the winter thunderstorms are strong winds from the west, which transport warm air from the ocean to the mountains of the mainland. The typical positive lightning flashes of winter thunderstorms transfer higher charge than negative lightning flashes, which are typical for summer thunderstorms. In 90% of all cases, in general, lightning flashes are negative flashes from cloud to earth.

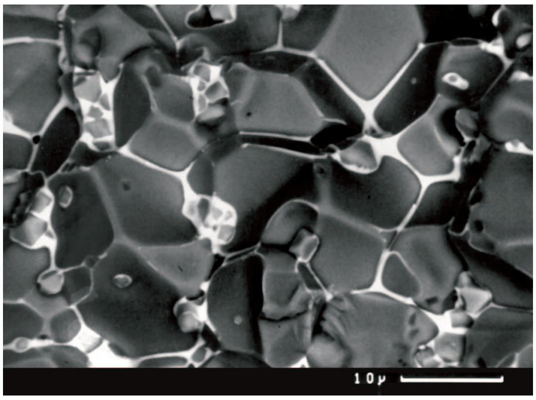


Fig. 1 Microstructure of an MO resistor (dark: doped ZnO grains, white: Bi2O3-phase at triple points, grey: spinel secondary phase).

HVDC networks

Since the late 1970s overvoltage protection of HVDC converter stations has been based exclusively on MO arresters. This is due to their superior protection characteristics and their reliable performance even when connected in parallel.

The continuous operating voltage stress for HVDC MO arresters differs from that of a normal a.c. arrester in that it consists of not only the fundamental frequency voltage but also of components of direct voltage, fundamental frequency and harmonic voltages, and high frequency transients.

These waveforms require other dimensioning rules for the continuous operating voltage and some specific tests of the MO arresters, e.g. the accelerated ageing procedure, as described in the emerging IEC 60099-9. Furthermore, polarity reversals might be an issue.

Ambient stresses

Ambient stresses can be very different in the different regions of the world. Very cold climates with ice and snow loads have to be considered as well as climates of high temperature and high humidity. Mechanical stresses like seismic loads strongly affect the structure and materials used for the design of the MO arresters. Vibrations as well as static and other dynamic loads have to be considered and appropriate test procedures have been developed accordingly.

Observations of biological growth on the surface of polymer insulation have been made in various places. Three types of organic growth have been identified: Algae, Fungi and Lichen. Despite all the reports of biological growth on the insulation in some areas of the world there are up to now no known failures of MO arresters caused by it. Animal impact may be an issue in some countries of the world, e.g. Australia, where cockatoos would nibble on some sorts of polymeric material.

MO Resistors

Steady progress has been made over the last decades in MO resistor technology, their application in overvoltage surge protection devices and the understanding of the basic mechanisms of non-linear conduction, energy handling capability etc. A lot of new insights have been gained, new physical phenomena have been •••

observed, improved and more consistent models have been developed and much progress has been made in simulations related to materials and components.

Fig. 1 shows the typical microstructure of an MO resistor after fracturing preferentially along the grain boundaries.

The non-linear conduction mechanism of the material as shown in Fig. 2 can be traced back to individual grain boundaries in the ceramics, which show a typical value for the switching- or breakdown voltage UB of approximately 3,2 V - 3,4 V each. Combining many grain boundaries in series and in parallel within an MO element allows to scale the voltage and current characteristic of an MO resistor. For a sufficiently large number of grain boundaries, the field strength E and current density J then describes the material characteristic more generally. In the log-log representation of the characteristic in Fig.2 there are three distinguished regions, i.e. the pre-breakdown region A, the breakdown region B, and the upturn region C.

Design of MO arresters

Different basic design principles are used for high voltage arresters and medium voltage arresters. In the high voltage field mechanical requirements are much higher than in normal distribution applications. This is why for high voltage MO arresters still porcelain housings are used besides the growing number of hollow core insulators with outer polymer insulation (so called tube designs) and the designs with the polymeric material (mostly silicone rubber) directly molded to the active parts. For distribution arresters in medium voltage systems almost exclusively the direct molded design is used. Fig. 3 and Fig. 4, respectively, show example designs of high voltage and medium voltage MO arresters.

Energy handling capability of MO resistors

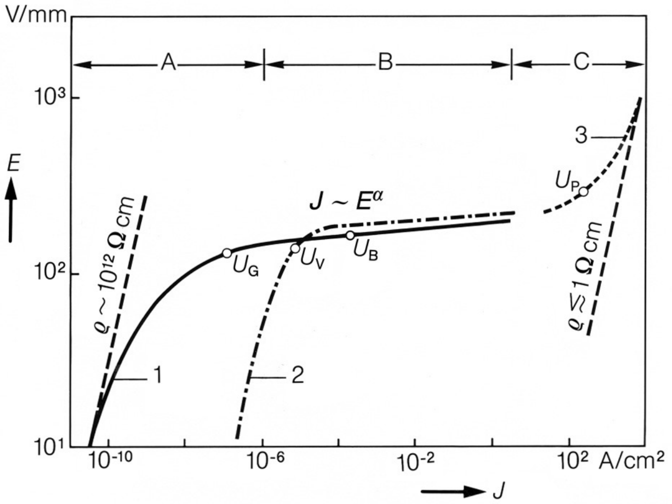
The energy handling capability of MO arresters has many different aspects, which are only partly or not at all reflected in the actual standards. At least, although this list may be not complete, they have to be divided into:

- "thermal" energy handling capability
- "impulse" energy handling capability

For the "impulse" energy handling capability single impulse stress, multiple impulse stress (without sufficient cooling between the impulses), and repeated impulse stress (with sufficient cooling between the stresses) have to be considered.

Thermal energy handling capability, on the other hand, can only be considered for complete arresters, as it is mainly affected by the heat dissipation capability of the overall arrester design, besides the electrical MO block properties.

For a deeper understanding of the energy handling capability of MO resistors and the influencing parameters, the working group A3.17 initiated a research project to evaluate the energy handling capability under different impulse stresses such as rectangular impulse currents, sine half waves, alternating currents and double exponential high-current impulses. More than 3000 specimens of commercially available MO resistors from seven well established American, European and •••



A Pre-breakdown region
1 DC voltage characteristic
E Field strength
U_B Breakdown (or switching) voltage
U_p Residual voltage at I_n

B Breakdown region
2 AC voltage characteristic
J Current density
ρ Resistivity

C Upturn region
3 Residual voltage characteristic
U_G Continuous operating voltage (DC)
U_v Continuous operating voltage (50 Hz)
∝Non-linearity exponent ∝(U)

Fig.2 Log-log plot of the normalized E-J characteristic of a typical MO resistor. Explanation is given in the text.

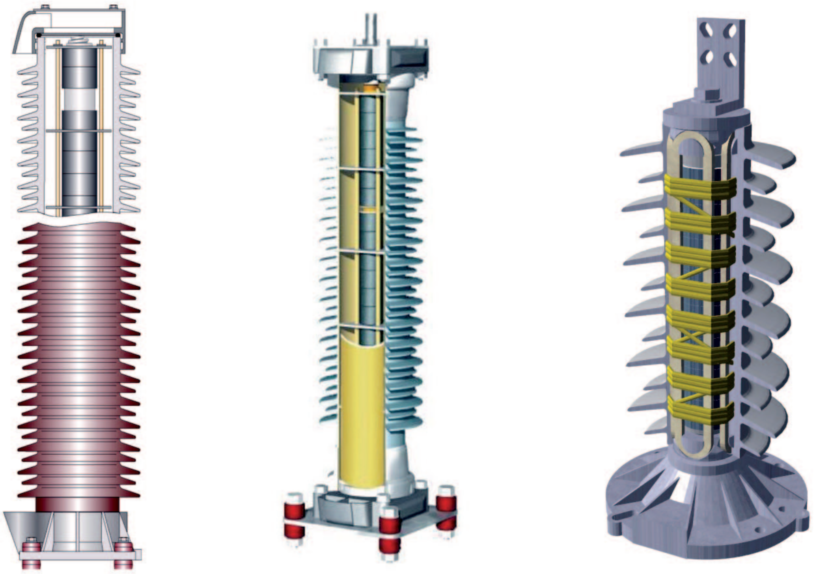


Fig. 3 Design examples of MO arresters for high voltage systems (left: arrester with porcelain housing, middle: tube design with composite hollow core insulator, right: cage design completely molded in silicone rubber).

Japanese manufacturers were tested. Two basically different sizes of MO resistors were considered, one for applications in high voltage arresters (“Size 1”: ≈ 40...45 mm in height, ≈ 60 mm diameter) and one for applications in medium voltage arresters (“Size 2”: ≈ 30...40 mm in height, ≈ 40 mm diameter).

For the tests with impulse stresses, an extended failure criterion, beyond simple visible damages, was introduced for the first time to differentiate the various failure modes and to quantify changes in the electric material characteristics. The a.c. tests were performed up to mechanical failure.

As an example Fig. 5 shows the mean failure energy versus the amplitude of current density found for the tested MO resistors of “Size 1”. The results are compared with findings published by Ringler et al. in 1977 (where partly different failure criteria where applied).

In Fig. 6 the change of a characteristic a.c. voltage U_{ch} (approximately corresponding to the arrester’s reference voltage) specified in the low current region is shown vs. the energy injection by a 4/10 μs impulse current. These tests were performed on MO resistors of “Size 2”.

For the statistical evaluation of failures, it has turned out that the a.c. test (compared to impulse stress tests) gives more reliable information on very low failure probabilities, which are difficult to assess with limited testing efforts. An example of a statistical evaluation for a.c. tests is given in Fig. 7.

Some of the most important conclusions from the research program, as discussed in more detail in the TB, are:

- Energy handling capability has generally been improved over the last decade by the established manufacturers.
- Energy handling capability increases with current density.
- Statistical evaluation is easier to perform for a.c. tests and leads to more reliable predictions than for impulse testing.
- Due to different dominating failure mechanisms, the energy handling capability is somewhat lower for “Size 2” resistors.
- For the lightning current impulse (≈ 90/200 μs), recently introduced in the arrester standard IEC 60099-4, the energy handling capability may be affected by the coating of the MO resistor. ●●●

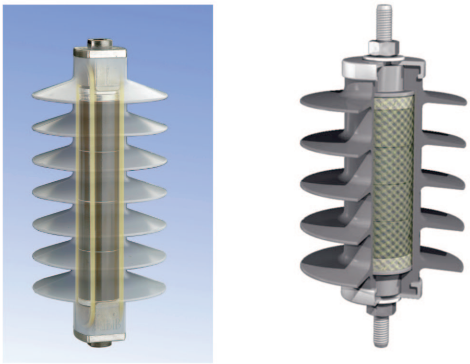


Fig. 4 Examples of a directly molded cage design MO arrester (left) and a wrapped design (right) for medium voltage systems

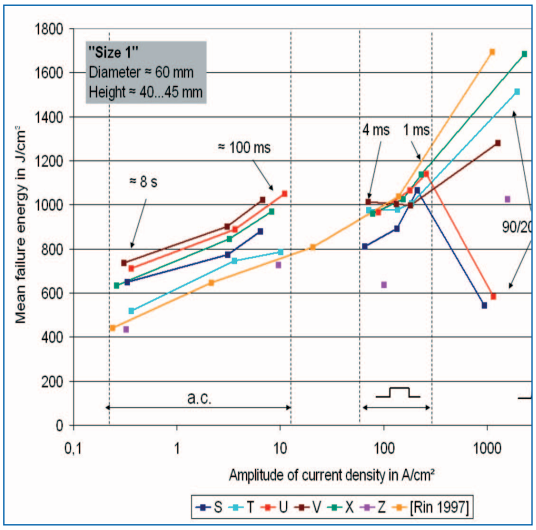


Fig. 5 Mean failure energy vs. amplitude of current density for MO resistors for high voltage application. The letters S to Z indicate the different makes compared to results by Ringler et al. published in 1997

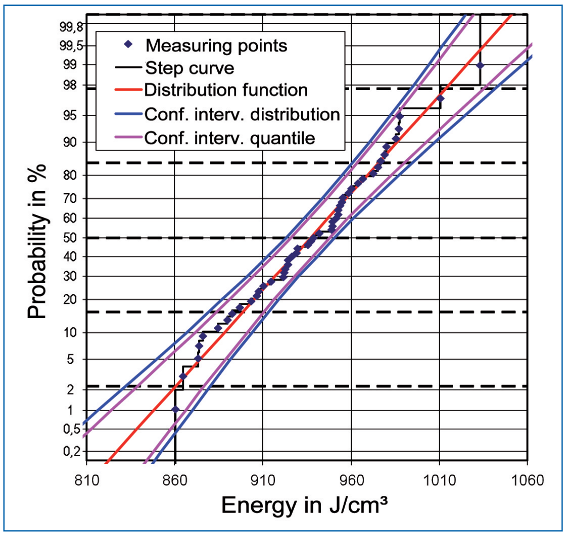


Fig. 7 Example of the statistical evaluation (Normal Distribution) for an alternating current test with 95% confidence interval

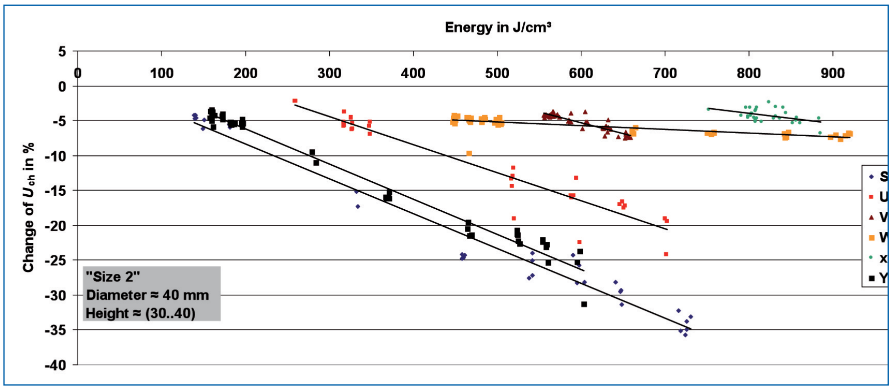


Fig. 6 Change of the characteristic voltage vs. energy injection by 4/10 µs impulse currents for blocks of "Size 2". The letters S to Y indicate the different makes

Outlook

The follow up working group of A3.17 (A3.25: Metal oxide varistors and surge arresters for emerging system conditions) is working on:

- Further aspects of the energy handling capability such as durability (repeated impulses) or combined stresses
- UHV arresters
- Consequences of increasing the field strength of MO resistors

Long term ageing of MO resistors

- Consequences of the axial temperature distribution in an MO arrester

The outcome of WG A3.25 will be given in an additional TB. ■