Activities in Cigré in the Field of Surge Arresters

- an overview -

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A3.17

Evaluation of stresses of Surge Arresters and appropriate test procedures

First meeting: October 2003 in Darmstadt / Germany
Last meeting: August 2008 in Paris / France
(in total 11 meetings)
20 members (15/5) representing 13 countries

A3.25

MO varistors and surge arresters for emerging system conditions

First meeting: August 2009 in Stellenbosch / South Africa
Next meeting: March 2013 in Beatenberg / Switzerland
22 members (18/4) representing 10 countries
Technical Brochure
(to be published in 2012/2013)

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1. Stresses on Surge Arresters

- Stresses from three phase systems
- Stresses from HVDC networks
- Stresses in traction systems
- Stresses from lightning
- Stresses from ambiance
Stresses from the power system network

- temporary overvoltages with power frequency (TOV)
  => mainly a problem in medium voltage systems
- voltage increase due to load rejection
- switching overvoltages

Voltage stresses generated in the system can be calculated if the system parameters and characteristics of the circuit breakers etc. are known (mostly worst case scenarios).
Example: TOV in a MV system with isolated star point

Symmetric load

Earth fault in phase L3
HVDC networks

The voltage waveforms in HVDC networks require other dimensioning rules for the continuous voltage and some specific tests on the MO arresters (e.g. the accelerated ageing procedure).
Lightning stresses

- lightning categories
- summer and winter lightning

Lightning overvoltages and the energy content of a surge depend on the lightning current only and are pure statistically.

But only a fraction of the lightning current will stress the MO arrester, depending on the system voltage and line configuration.
Lightning categories (acc. Berger)

Negative downwards

Positive downwards

Positive upwards

Negative upwards
Annual number of days with thunderstorms

Source: Martyn D., Climates of the World, Elsevier, Amsterdam, 1992
Probability of lightning currents

Statistical evaluation of lightning measurements all over the world. Described is the probability of occurrence above the lightning currents' peak value.
**Winter lightning**

Japan as well as Norway and some other countries experience rather often thunderstorms during winter. Typical weather conditions to create the winter thunderstorms are strong winds from the west which bring rather warm air from the ocean to the mountains of the main land.

Example of a positive lightning current in a winter lightning at Fukui in Japan in February 1983. Winter lightning flashes have typically one discharge only, but with a very high charge lowered to earth.
In low voltage (LV) and medium voltage (MV) power systems (0,23 kV ≤ U_s ≤ 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 coming from lightning to or in surrounding structures.

High voltage (HV) systems in the range of 52 kV < U_s ≤ 245 kV consist both of distribution and transmission lines which pass through rural areas. Direct strokes, back flashovers and induced voltages 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 < U_s ≤ 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. Only shielding failures and back flashovers will cause a critical surge in the phase wire.
Stresses from ambiance

Ambient stresses can be very different in the different regions of the world.

Very cold climates with ice and snow load have to be considered as well as climates with high temperature and high relative humidity.

Mechanical stresses like seismic loads influence strongly the structure and materials used for the design of the MO arresters. Vibrations as well as static 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 worldwide. 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 no known failures of MO arresters caused by it.
Seismic records in the past 75 years from 1921 to 1995 in Japan

Seismic test of GIS arrester, horizontal installation
The world’s climatic zones. The most humid climates in equatorial and tropical climate zones are indicated by colors.

Source: Martyn D., Climates of the World, Elsevier, Amsterdam, 1992
Internal leakage currents of MO arresters (for MV system with $U_c = 24$ kV) according to their internal structure during a “humidity chamber test” at 18 kV DC.

**Group I**  housing molded directly onto the arrester body, no end caps
**Group II**  housing manufactured separately and pressed onto the arrester body, end caps
**Group III**  as group II, but a considerable gas volume in the arrester due to the design
Change of leakage current due to diffusion and recovery

![Graph showing change of leakage current over time for Type X and Type Y](image-url)

Testing time (days)

Leakage current (nA)

- Type X
- Type Y
Possible risks due to pollution

Risk of "internal" partial discharges, degradation of the MO resistors and deterioration of the supporting structure

Risk of partial heating of the active parts (see Annex F of IEC 60099-4)

Risk of external flashover (see IEC 60507)

Possible voltage distributions of an arrester unit under polluted condition
Ambient stress: biological growth (examples)
Ambient stresses: animal attack
2. Surge Arresters

- Function and relevant parameters
- MO-Varistors: state of the art and actual trends
- Design of surge arresters
- Special designs of surge arresters
- \( \text{SF}_6 \) gas insulated MO surge arresters
- Integrated arrester systems
Function and design of MO arresters

MO arresters have basically two parts:
- the active part => stack of MO resistors
  => electrical characteristic
- the housing, providing insulation and mechanical support
Main criteria for selecting MO surge arresters:

Protection level $U_{pl}$ and maximum continuous operating voltage $U_c$

Energy capability $W$ and highest temporary overvoltage $U_{TOV}$

Economic and safety margin aspects
Log-log plot of the normalized E-J characteristic of a typical MO resistor

A Pre-breakdown region                B Breakdown region                  C Upturn region
1 DC voltage characteristic           2 AC voltage characteristic        3 Residual voltage characteristic
E Field strength                        J Current density
U\(_G\) Continuous operating voltage (DC)           \(U_B\) Breakdown (or switching) voltage
\(U_v\) Continuous operating voltage (50 Hz)             \(U_p\) Residual voltage at \(I_n\)
\(\rho\) Resistivity                             \(\alpha\) Non-linearity exponent \(\alpha(U)\)
Electron microscope image of the MO structure

Schematic view of the structure
A: ZnO-crystal
B: triple point, phase Bi$_2$O$_3$
C: mono atomic layer of O- and Bi-atoms
D: electrical active grain boundary (voltage controlled “switch”)

Fracture surface, 2000 times enlarged
Band diagram scheme of the hole induced breakdown mechanism

Breakdown: Rapid collapse of potential barrier through accumulation of hole charge for $U_B \approx 3.2\, V$
Long term performance of MO resistors

Power loss ratio vs. time for stable and unstable MO resistors during accelerated ageing tests at 115 °C and slightly elevated AC operating voltage.

left: AC stress only

right: influence of the surrounding medium
MO Surge Arrester Design – Polymer Housed

Due to their simple internal structure, MO arresters were amongst the first apparatuses in electrical power systems equipped with polymer housings:

- **Mid 1980s** – first polymer housed *distribution* arresters
- **End 1980s** – first polymer housed *high-voltage* arresters

In the meantime, three basic design principles have emerged:

- "*tube*" design
- "*wrapped*" design
- "*cage*" design
History of surge arresters for medium voltage systems

Gapped designs

MO surge arresters without gaps


Example ABB
MO Surge Arrester Design – Porcelain Housed

- Pressure relief vent
- Compression spring
- Pressure relief diaphragm
- O-ring
- Sulfur cement bonding
- MO column
- Supporting rod (FRP)
- Fixing plate (FRP)
- Porcelain housing
- Aluminum flange
- Insulating base

Example: Siemens
Polymer Housed – "Tube" Design

Examples: Siemens
Polymer Housed – "Cage" Design

Example: ABB

Loops (+ bondage)

Example: ABB

Rods

Example: Siemens
Progress in arrester design

HV arresters station class for $U_s = 145\, \text{kV}$

Left: SiC arrester with gaps and porcelain housing (about 40 years ago)

Right: completely molded MO arrester without gaps

Both arresters have the same ratings.
HV substation 245 kV

HV: $U_c = 174$ kV
MV: $U_c = 44$ kV
Tertiary winding:
$U_c = 18$ kV

Example ABB, Switzerland
High-voltage arrester integrated in a 420-kV center break disconnecter (Siemens/RWE)
Polymer housed arresters serving as post insulators: EnBW/Germany (left), Powerlink /Australia (right)
3. Energy handling capability of MO surge arresters

- The different aspects of “energy handling capability”

- State of the knowledge about energy handling of MO arresters

- Energy handling capability in international arrester standards
"Thermal" vs. "Impulse" Energy

If the arrester is permanently connected to power frequency voltage no use can be made from single impulse energies that are higher than the thermal energy limit (else: thermal runaway!)

Station arresters, distribution arresters

But there are (more and more!) other applications, e.g. Externally Gapped Line Arresters

Here, only impulse energy limits are of interest.
Energy Handling Capability

Thermal:

Loss of thermal stability
Outlook

WG A3.17 will publish the outcome of the WG in a TB
MO Surge Arresters
Part 1
– Stresses and Test Procedures –

Follow Up working group A3.25 (Metal oxide varistors and surge arresters for emerging system conditions) is working on

- Further aspects of energy handling capability such as durability or combined stresses
- UHV arresters
- Consequences of increasing field strength of MO resistors
- Consequences of axial temperature distribution in an MO arrester
- The outcome of WG A3.25 will be published in an additional Technical Brochure (Part 2)
Publications of the working group A3.17
(or in the name of the working group)

*Integrated Surge Arrester Systems*
Cigré colloquium, Tokyo /Japan, September 2005, paper No. 201

*A critical review of the actual standard IEC 60099-4: Metal Oxide surge arresters without gaps for a.c. systems*
Cigré colloquium, Rio de Janeiro, 2007, PS3-06

*Energy handling capability of High Voltage Metal-Oxide Surge Arresters: A Critical Review of International Arrester Standards*
Cigré colloquium, Rio de Janeiro, 2007, PS3-08

*MO-surge arresters for voltage systems above 550 kV*
- Experience and challenges for the future -
B. Richter (A3.17), M. de Nigris (A3.21), V. Hinrichsen (IEC TC 37 MT4)
IEC/CIGRÉ UHV Symposium Beijing 2007, paper 2-5-1
Publications of the working group
(or in the name of the working group)

*Energy handling capability of High Voltage Metal-Oxide Surge Arresters, Part 2: results of a research project*
Cigré 2008, Paris

*Long Term Performance of Polymer housed MO Surge Arresters*
B. Richter et.al., Cigré 2004, Paris
Tutorials given in the name of the working group A3.17

**Concapan XXIV/IEEE**
Costa Rica, 10. November 2004

**Brazilian Cigré NC**
(contributions of several working group members)
Rio de Janeiro, 6./7. April 2005

**SC A3/B3 meeting**
Tokyo, Japan, September 2005

**SC A3/B3 meeting**

**CIRED**
Prague, 8.-11. June 2009

**SC A3 meeting (outcome of A3.17)**
Vienna 2011
Structure of A3.25 (intended TB to be published in 2013)

EXECUTIVE SUMMARY
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Introduction

1 History of Surge Arresters

2 Energy handling capability of MO surge arresters

3 Ageing of MO varistors

4 High Field MO varistors

5 Simulation
5.1 Simulation of MO varistors
5.2 Simulation of MO arresters
5.3 Electro-thermal and temperature distribution
Structure of A3.25 (intended TB to be published in 2013)

6 Indirect means for determining insulation withstand

7 MO surge arresters for UHV systems

8 EGLAs and NGLAs

9 Mitigation

10 Monitoring

Conclusion
References
Annexes
MO arresters for UHV systems

Examples Siemens

Example ABB
GIS arresters for 550 kV systems with MO resistors with «normal» field strength (left) and high field MO resistors of 400 V/mm (middle) and 600 V/mm (right), courtesy Toshiba.
Possible executions of line arresters (description in principle)

MO arrester in parallel to an insulator in an overhead line. These so-called NGLAs (Non Gapped Line Arresters) can be installed with or without disconnectors.

MO arrester with an external spark gap in series parallel to an overhead line (EGLA = Externally Gapped Line Arrester)
Technical Brochures from various working groups dealing with surge arresters

**TB 60**
METAL OXIDE ARRESTERS IN AC SYSTEMS
1991

**TB 287**
PROTECTION OF MV AND LV NETWORKS AGAINST LIGHTNING
PART 1: COMMON TOPICS
2006

**TB 441**
Protection of Medium Voltage and Low Voltage Networks against Lightning
Part 2: Lightning protection of Medium Voltage Networks
2010

**TB XX**
Protection of Medium Voltage and Low Voltage Networks against Lightning
Part 3: Lightning Protection of Low-Voltage Networks
To be published 2012/2013
Technical Brochures from various working groups dealing with surge arresters

TB 440
Use of Surge Arresters for Lightning Protection of Transmission Lines
2010

TB 362
TECHNICAL REQUIREMENTS FOR SUBSTATION EQUIPMENT EXCEEDING 800 KV
2008

TB 456
Background of Technical Specifications for Substation Equipment exceeding 800 kV AC
2011

TB 455
Aspects for the Application of Composite Insulators to High Voltage (≥72 kV) Apparatus
2011
Thank you for your attention!
And

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