Development of high energy absorption capability ZnO MOV arrester blocks

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Introduction

- India is going through an ambitious programme to increase its electrical generation capacity by an additional 100 GW as well as to upgrade the network service quality to satisfy the ever increasing demand of electrical energy.

- One major project from Power Grid is the implementation for the first time in India of a 1200 kV UHV AC and ± 800 kV HVDC transmission technology.

- LAMCO Industries Private Ltd. took up the challenge to develop indigenous surge arrester know-how and manufacturing capability to satisfy above demands.

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- **LAMCO interpretation of PGCIL main requirements:**
  - Energy handling capability: Specified 170 J/cc
    - Block energy 54 kJ
    - Arrester rated 850 kV 61 MJ
  - MOV block low clamping voltage:
    RDV (pulse $^{8}/_{20}$ μs) to nominal voltage: V_{20kA} / $V_{DC1mA:}$
    - Required: **≤ 1.50 clamp ratio**
  - Higher specific voltage: 210 → 240 $^{V}/_{mm}$
  - Low leakage (resistive) current at COV: < 800 μA
  - T.O.V. Protection arrester rated 850 KV: 1.0 sec → 1.4 pu
    10.0 sec → 1.15 pu

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LAMCO R&D objective: **better MOV blocks, i. e.**

1 - Increased protection margin

2 - Higher survival probability when subjected to high energy over-voltages

3 - Long term reliability

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1 – Increased protection margin:

i.e.: to reduce the clamp ratio

Increase ZnO intrinsic conductivity at high currents by addition of donor dopants:

Al^{3+} , Sb^{5+} , F^{+} , . . .

Caution:

Too little dopant: high clamp at high currents
Too much dopant: high power losses at low currents

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MOV blocks survival threads:

- Electrical impulses
  - Duty cycle (Square waves): High energy, long duration
  - Lightning impulses: High power, short duration
- Long life reliability under power load
- Moisture intrusion (Critical issue for arrester manufacturer)

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The aim of this presentation is to show:

- How to increase the survival probability of ZnO MOV arrester blocks when subjected to high energy (duty cycle) pulses and high power (lightning) atmospheric discharges.

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- Electrical impulse failure modes:
  - **Crack mode failure due to fast generation of thermally induced mechanical stresses.**
  - **Puncture mode failure due to current concentration at a non-uniform spot with lower threshold voltage.**

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- **MOV block failures under electrical impulses are due to brittle fracture.**

- **A brittle fracture in a MOV block initiates at a very precise weak spot (crack initiator):**

    - **Micro flaws**
    - **Voids**
    - **Inhomogeneities**

Development challenge: ***How can these weak spots be eliminated or minimized?***

The answer: ***Proper ceramic processing.***

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ZnO MOV manufacturing process flow summary:

Process steps	Critical requirements
• Raw materials	
• - Metal oxides	*- Water quality (purity)*
• - Organic additives	*- Trace contaminants*
• Powder (Spray dried)	*- "Most critical step"*
• Compaction	*- Pressure profile*
• Firing	*- Temperature profile and atmosphere*
• Surfacing, glazing and metallizing	*- Proper handling*
• Block mechanical control	*- Micro cracks detection (Ultrasonics)*
• Electrical testing	*- Weed out "weak" blocks*

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MOV Raw materials

- **Metal oxides:**

  ZnO, Bi_2O_3, Co_3O_4,
  Sb_2O_3, MnO, NiO, …

- **Organic additives**

  Deflocculant, Binder,
  Antifoaming agent,
  Plasticizer, …

Critical spec. parameters

- Part. Size Distr.; Spec. Surf. Area, etc.
- Trace contaminants (Clamp**)**

- Low ash content
- “Easy” burn off
- No gelling

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Varistor powder formulation (Oxides and organics)

- **Electrical requirements:**
  - Better peak pulse stability (No degradation)
  - Low current power losses (Long life)
  - **Improved energy handling capability (Survival)**
  - Reduced residual voltage by enhanced doping (Protection)
- **Better control of ceramic crystalline microstructure:**
  - Enhanced grain uniformity to reduce residual voltage and leakage at low voltages
- **Physical and mechanical aspects of the ceramic body:**
  - **Higher mechanical strength for better energy handling capability**

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Varistor powder organic additive requirements:

- **Binder plasticity**
- **Powder compactability**
- **Solid body lubricity**
- **Mechanical strength of green discs**
- **Avoid creation of mechanical defect generators**

ZnO MOV ceramic powder: Single spray dry

- **Powder requirements:**
  - *Fully homogenized powder.*
  - *No segregation.*
  - *Well controlled Part. Size Distr.*
  - *Good flowability (short flow time)*
  - *High flow and tap density*
  - *Spherical solid particles (No "doughnuts", no "egg-shells)*
  - *Solid lubrication present*
  - *No foreign contamination (Particles, fibres, aggregates, etc.)*

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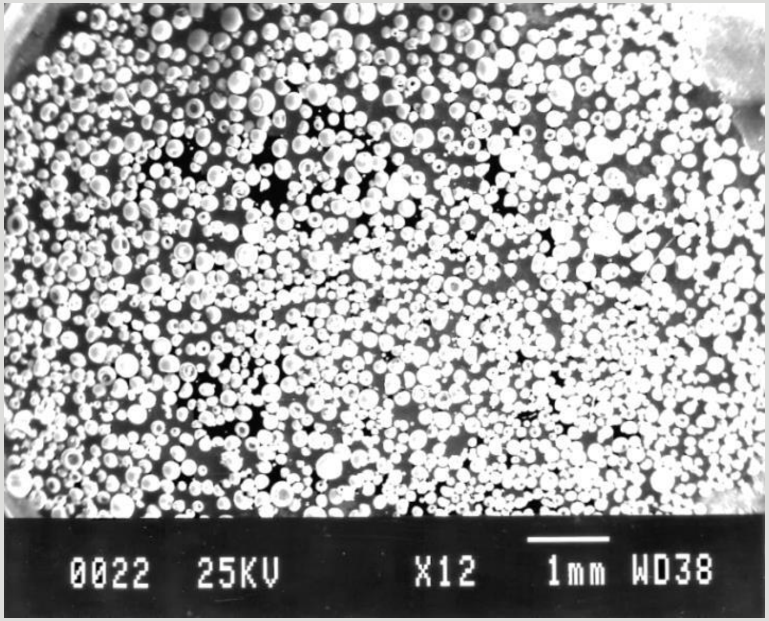
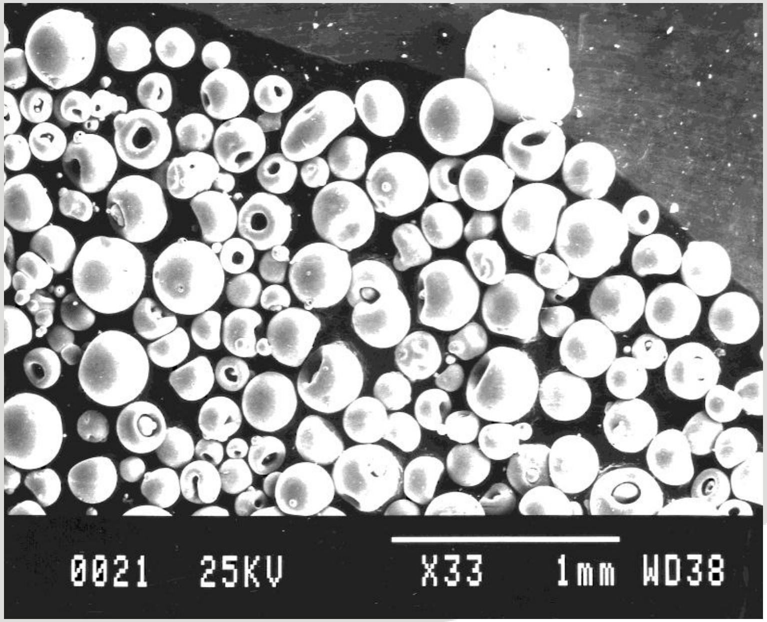
ZnO MOV ceramic powder: SEM pictures

- Spray dried agglomerates:



Close-up:



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Parameters affecting block compaction:

Powder character.:
Particle shape, size and distrib.; Spec. Surf. Area; flow time; hardness.

Body geometry:
Height; density, (Aspect ratio).

Compact properties:
Specified density; minimized density gradient; green strength; (min. defects).

Organic system:
Binder type and qty.; plasticizer; deflocculant; lubricant.

Compaction technique:
Die filling, pressing profile (ramps and dwells) ; maximum force; ejection procedure.

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Block compaction

Requirements:

- Optimize compaction pressure profile.
- Reduce spring-back effect
- Minimized pressure gradients in blocks.

Methods:

- **Floating die**
- **Fixed die and opposing rams (Preferred)**
  - *Better control of body neutral plane*
  - *Improved mechanical consistency of the green body (critical for HE MOV blocks)*

Other consideration:

- Tooling material and design

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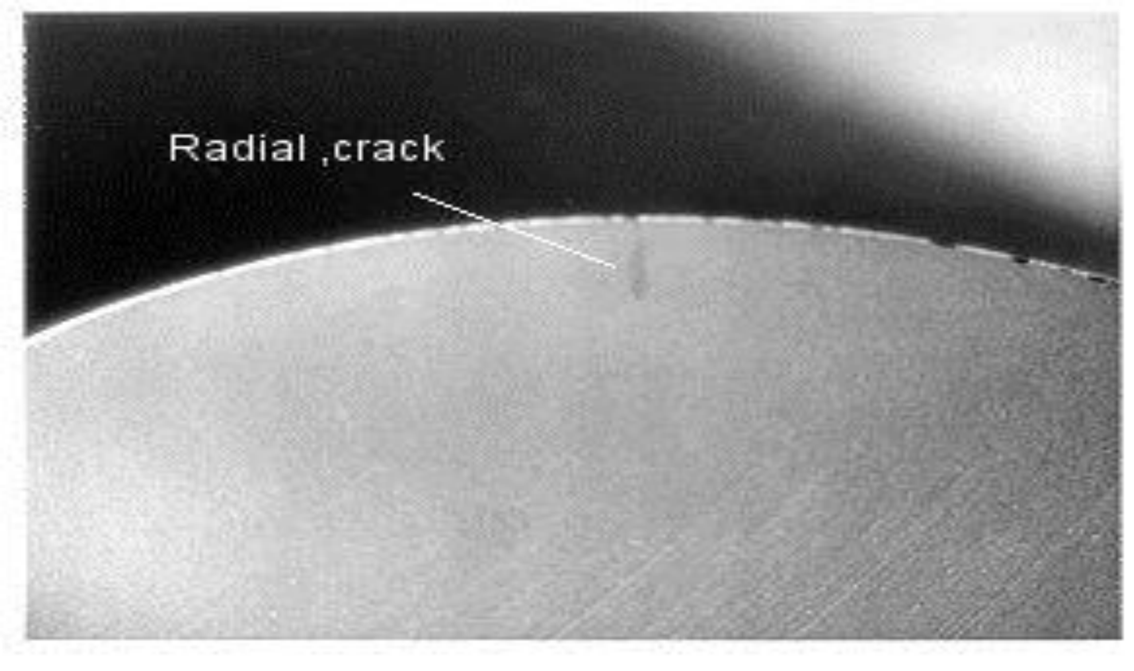
MOV block compaction defect:

Radial crack visualized on a sintered block.



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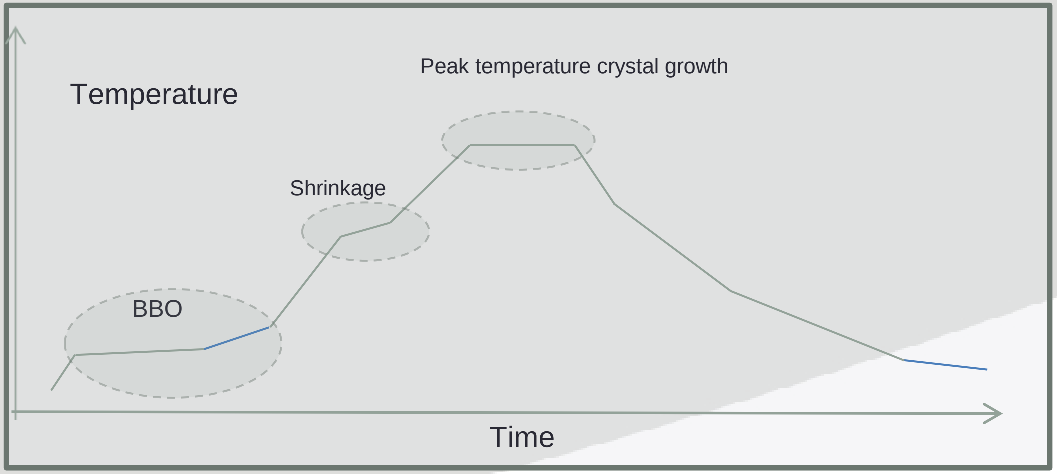
ZnO MOV firing profile:

The temperature profile and the firing atmosphere must be controlled. With proper control, watt loss at low voltage and residual voltage at high current will improve:

- **Binder Burn Off (BBO):**
  to be tailored for binder system and disc type
- **Uniform densification:**
  (Porosity elimination, LPS Bi_2O_3 compounds)
- **High Temp. dwell:**
  Homogeneous crystal growth (narrow and uniform)



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ZnO MOV firing:

- **BBO is a critical step:** ***Most mechanical defects are generated at this stage: <u>Voids, cracks, microfisures</u>***
- **Uniform densification:** ***Avoid thermal gradients; atmosphere control***
- **HT sintering:** ***Optimize t and T to promote homogeneous crystal growth.***

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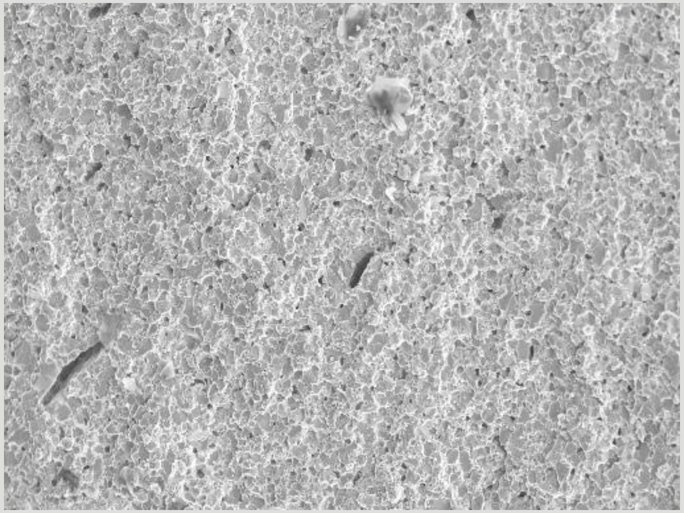
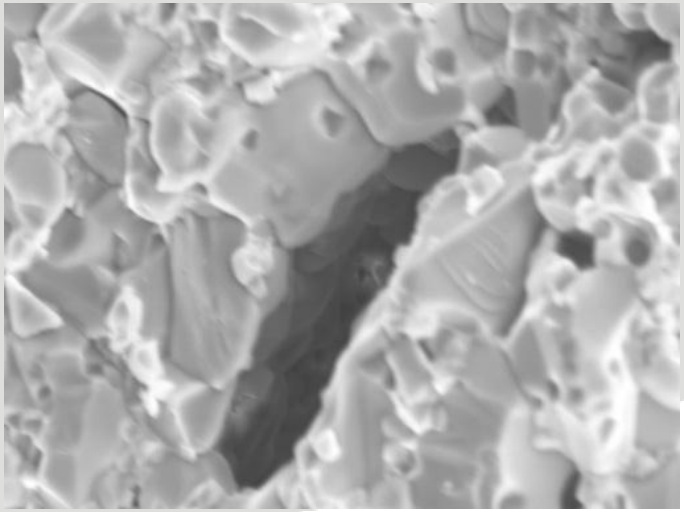
ZnO MOV firing bulk defects:

Micro-fissures / voids **Close - up**





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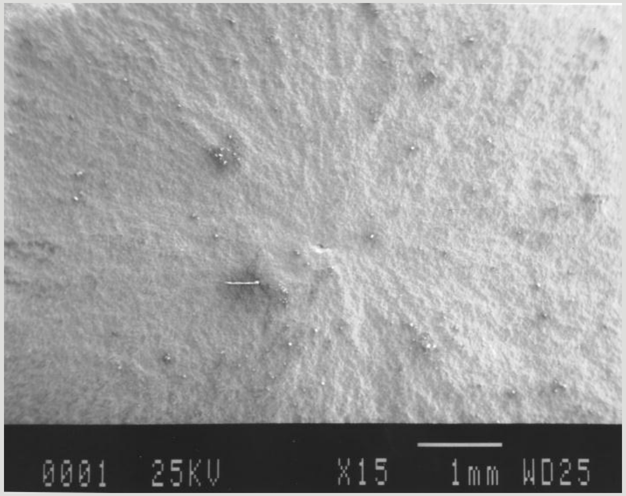
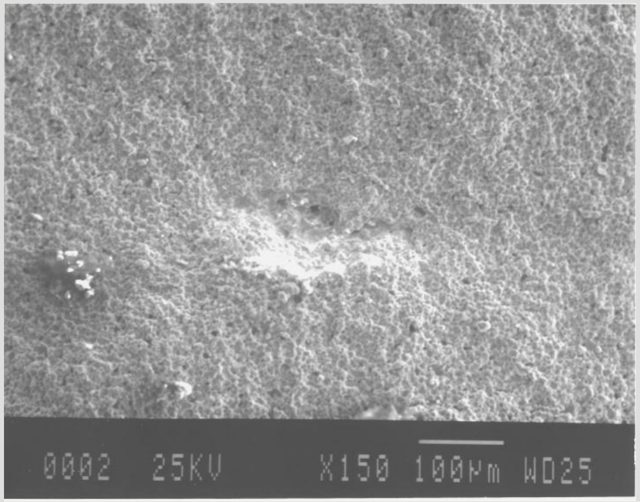
ZnO MOV firing bulk defects:

Micro-fissures / voids
Failure at 100 kA / $^{4}/_{10}$ µs: fracture surface



Close – up
Fracture origin



Sb rich agglomerate determined by EDX analysis

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Flat surface grinding:

- Lapping
- Grinding (Preferred)
- Intense US washing, rinsing and degreasing.

Flat surface specs:

- *No scratches*
- *No edge chips*
- *Surface suitable for molten metal adhesion.*
- *Parallel surfaces.*

Testing of "black" MOV block before metallizing and passivation:

- *Visual inspection*
- *Ultrasonic testing (Internal cracks, other defects)*

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Metallisation process:

- Flame spray
- Arc spray (Preferred)
- Masking procedure (Critical for edge definition)
- Accurately defined margin geometry for every block

Passivation coating:

- Air spray of a glass powder suspension.
- Lead glass (Environm. Issue)
- Leadless glass (Cost issue)
- *Glass coating thickness can be an issue for HASD test (Distr., class 1 and 2).*

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Final electrical testing:

The only possible outcome is to weed out weak blocks that are non performing under energy impulses.

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Conclusions and recommendations:

- More homogeneous blocks will show better survival performance under temporary over-voltages.
- MOV blocks with higher mechanical strength will have a higher probability of survival under energy impulses.
- Stronger MOV material will make it possible some reduction of the block size. Smaller blocks with similar energy characteristics can make it possible to reduce the size of the arresters. However, block over heating must be considered when reducing MOV block size.
- A block size reduction can have an impact on costs for the block and arrester manufacturers as well as for the arrester user since a smaller and lighter arrester will be cheaper to install and to replace.

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Namaskar

and Thank you
for your attention!

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