PROTECTION ENGINEERS GROUP

Electrical Protection for Communications Networks

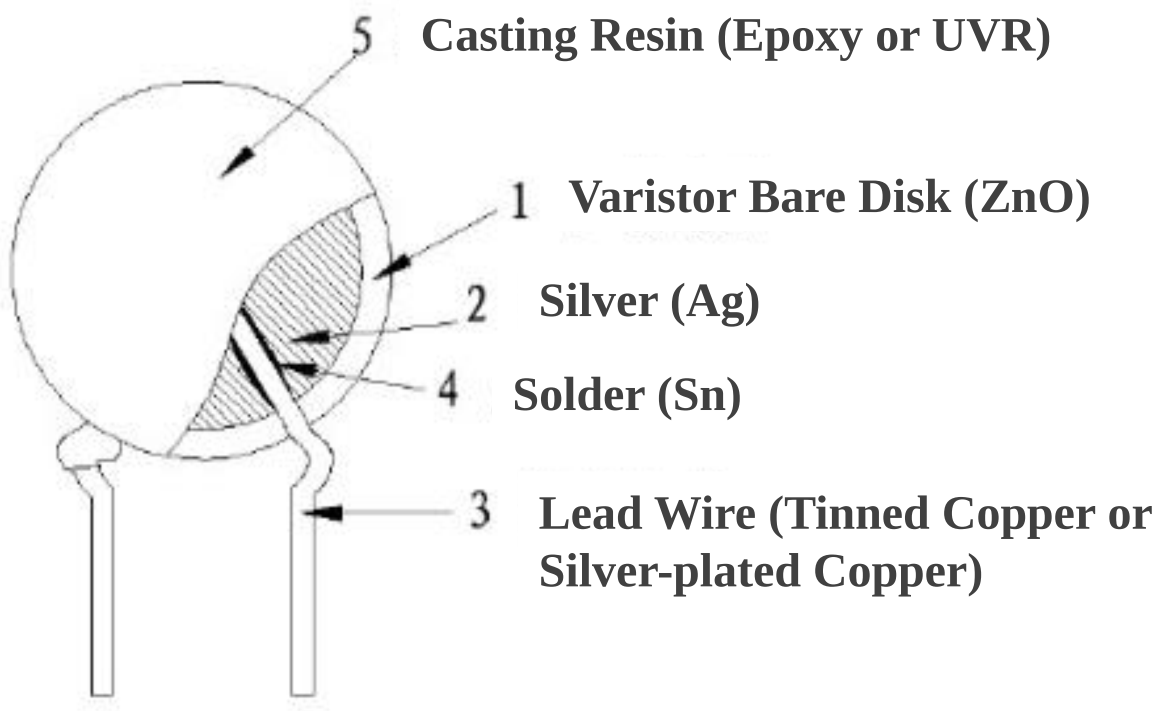
MOV Enhancements in the 21st Century

By Jim Pelegris

Webinar Series February 10, **17** and 24, 2021

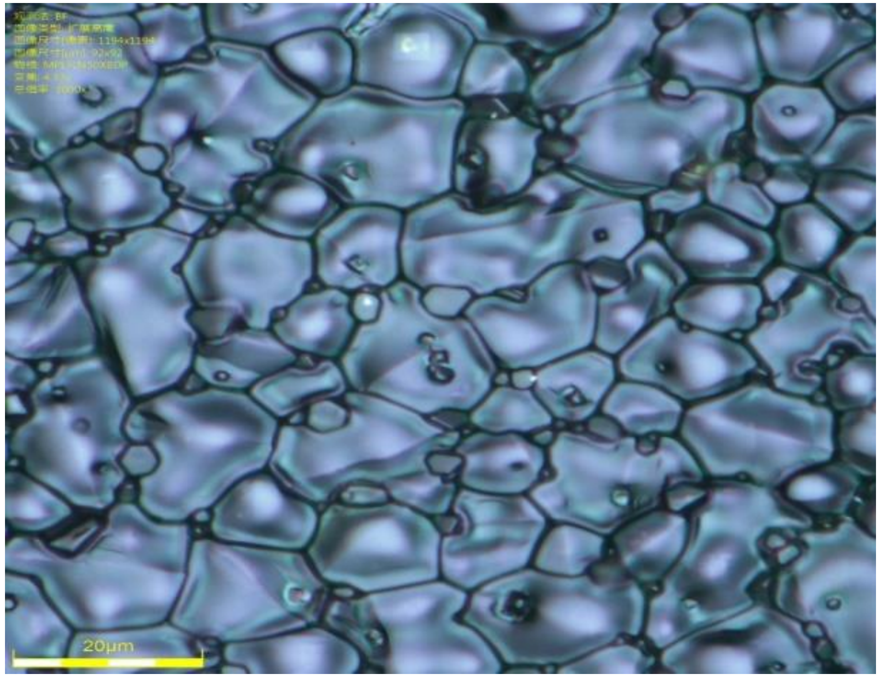
What is MOV

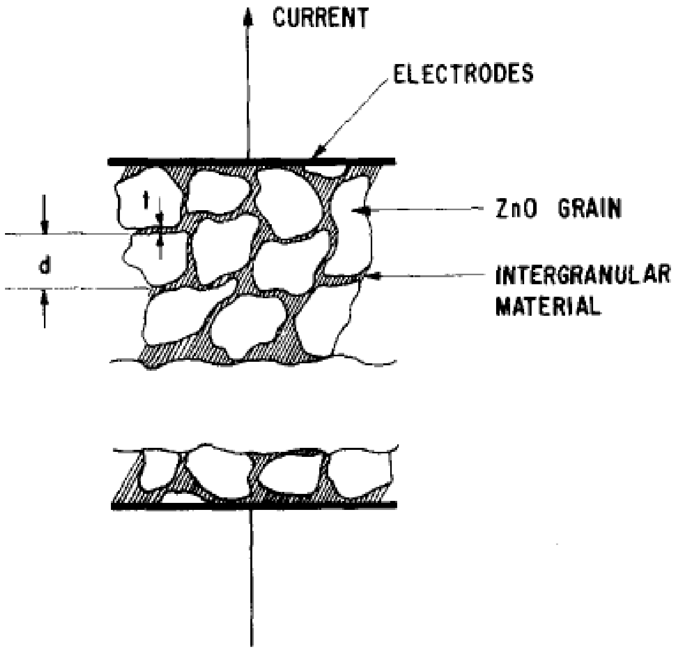
◆**Metal Oxide Varistor (MOV):** Is a (nonlinear) resistor *whose resistance value varies with voltage* over a range of current and voltage. (*VDR: Voltage Dependent Varistor*)

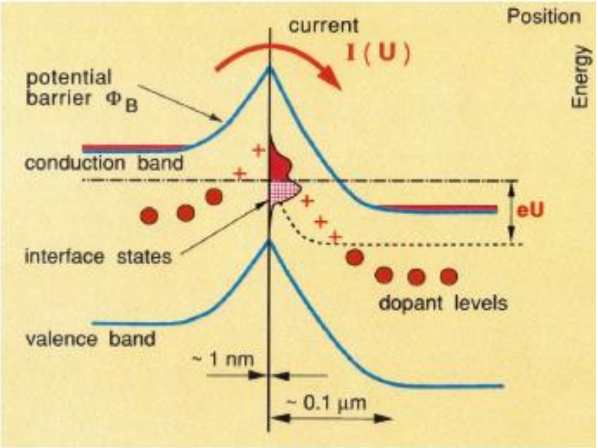


Typical Structure of MOV

What is MOV cont.







***Microstructure* of MOV**

What is MOV cont.

- MOV, Material composition

  1) ZnO (90%wt)

  2) doping elements Bi, Sb, Co, Mn etc. (10%wt)

Change the conductivity of ZnO grains and properties of grain boundaries.

- Note: 1) Pure ZnO: Linear V-I characteristic

  2) MOV: Nonlinear V-I characteristic

ZnO=Zinc Oxide ***Bi*** = Bismuth ***Sb***= Antimony ***Co***= Carbon Monoxide ***Mn***= Manganese

What MOV does

- MOVs are utilized in Electrical/Electronic designs as Surge Protection Components to protect equipment, systems, and networks from extreme conditions caused by internal and external threats*

- Internal and External Threats* lightning, induced lightning, AC power cross, AC power industrial induction, AC power transients, harmonics, solar flare/storms etc.

History of MOV

The development of the Varistor, as a new type of rectifier made from a copper oxide layer (Cu20), originated by L.O. Grondahl and P.H. Geiger in 1927.

In the 1930s, multiple-varistor assemblies of less than one inch diameter found application in replacing bulky electron tube circuits as modulators and demodulators in carrier current systems for telephone transmission.

In 1952 Western Electric utilized Type 3B Varistor in the telephone plant to protect circuits from voltage spikes and as click suppression on receiver (*ear-piece*) elements to protect users' ears from popping noises when switching circuits.

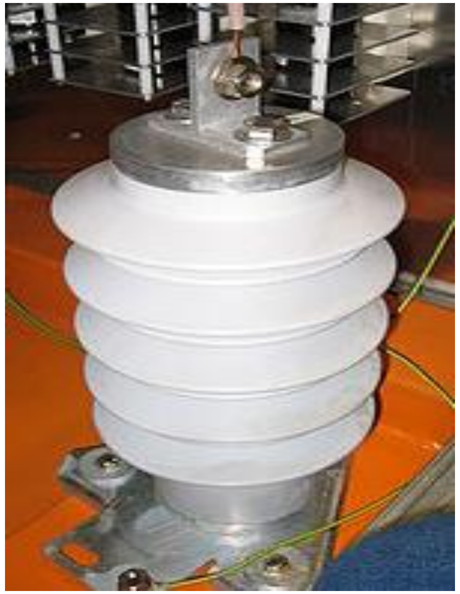
In 1958 Western Electric manufactured the Type 44A and mounted it on a U1 telephone receiver element for click suppression.

The History of MOV cont.

In the early 1970s, researchers recognized the semiconducting electronic properties of zinc oxide (ZnO) as being useful as a new varistor type in ceramic sintering process, which exhibited a voltage-current function like that of a pair of back-to-back voltage limiting diodes. And this technology became the preferred method for protecting circuits from power surges and other destructive electric energy disturbances.

Today MOV's are available in several shapes - sizes and packaging to satisfy the ever-changing requirements in the Electrical Protection.

Focusing on precision design and optimization coupled with state-of-the-art manufacturing processes will ensure that MOV will keep improving its performance and continue to be the KEY protection device.



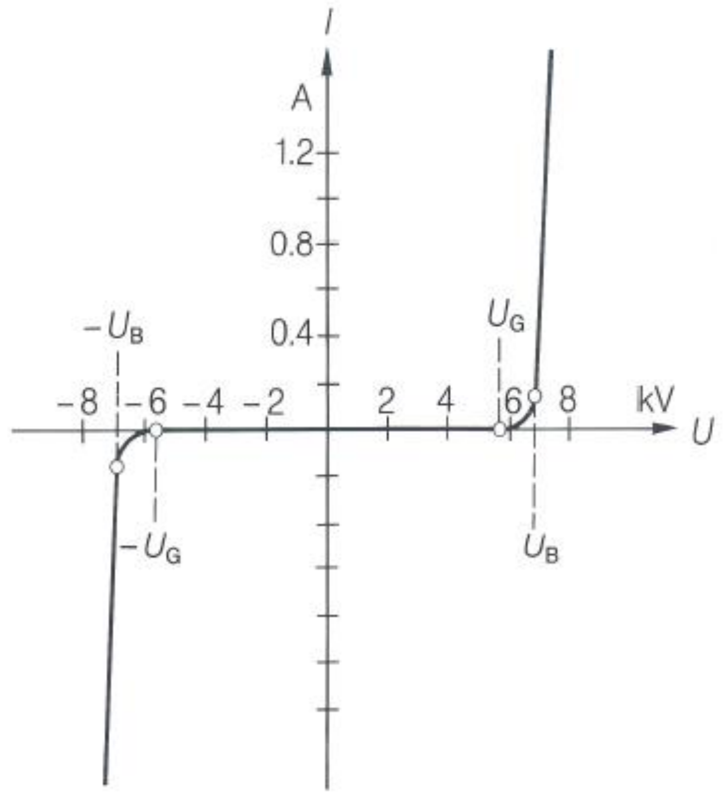
How MOV is made

- The Metal-Oxide Varistor is made of a ceramic based on *ZnO*, a wide band gap semiconducting material. Its special electrical properties are the direct result of its microstructure. (*90%wt*)

- By adding a few percent of selected doping elements such as *Bi, Sb, Co, Mn etc. to ZnO* and using a suitable sintering process, it is possible to influence both the conductivity of the ZnO grains and the properties of the high-resistance grain boundaries. (*10%wt*)

- ***ZnO***=Zinc Oxide ***Bi*** = Bismuth ***Sb***= Antimony ***Co***= Carbon Monoxide ***Mn***= Manganese

Electrical Characteristics and Performance



Linear representation of the characteristic of a metal-oxide resistor for the high-voltage sector

U_G : Continuous operating voltage (DC)

U_B : Breakdown (or switching) voltage

U_V : Continuous operating voltage (AC, 50/60 Hz)

- The sharp transition from the insulating to the conducting state, which takes place at the breakdown voltage U_B, is the **outstanding feature** of this strongly **non-linear and voltage-dependent resistor**. The **switching** is both extremely fast (in the range of pico- to nano-seconds) and also fully **reversible**, i.e. the resistor reverts to blocking the current flow as soon as the applied voltage U falls below U_B.

Electrical Characteristics and Performance cont.

◆ *Nonlinear V-I characteristics:*

1) **Pre-switch region**: normal use, MOV subjected to a voltage below their characteristic switch voltage and pass only a leakage current

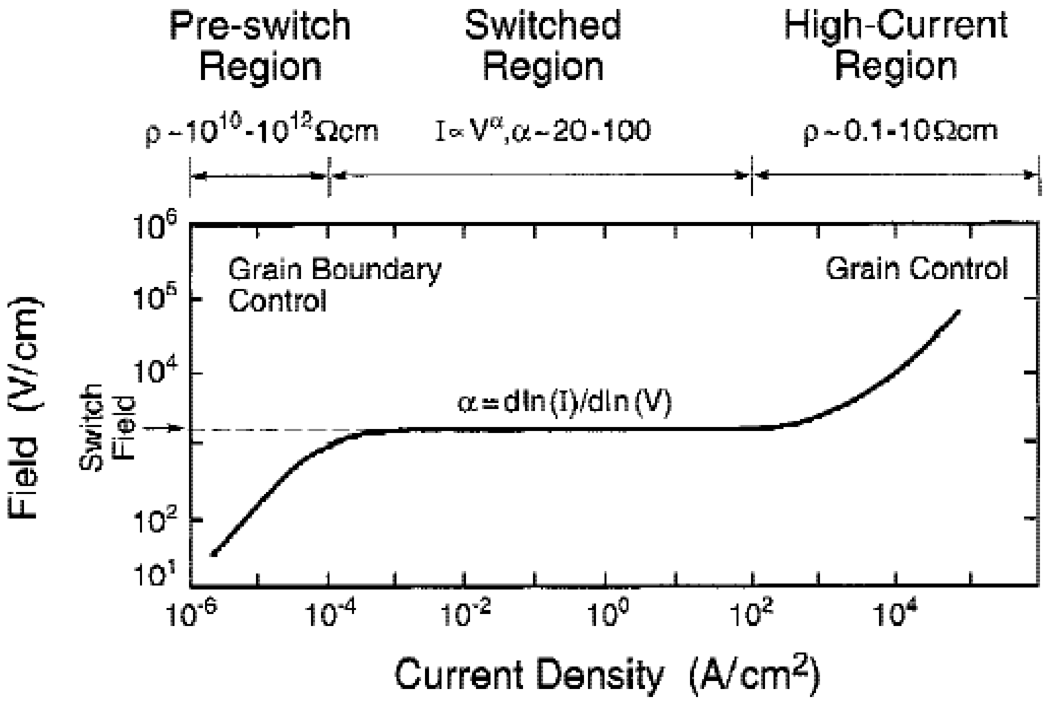
--- Ohmic/temperature dependent

2) **Switched region**: Voltage exceed the switch voltage, eg. Transient overvoltage or Surge, MOV becomes highly conducting and draws the current through it.

---highly nonlinear/reversible

3) **High current region**: MOV can degrade under electrical loading.

---Ohmic



V - I Characteristic Curve

Electrical Characteristics and Performance cont.

A: Pre-breakdown region

B: Breakdown region

C: Upturn region

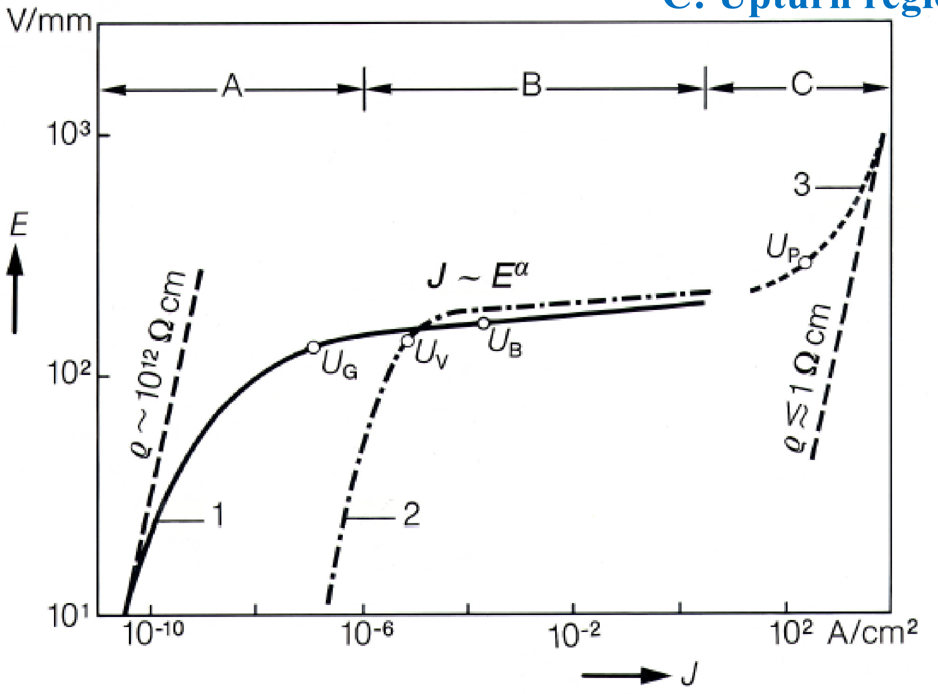


Fig.3 Log-log plot of the normalized J(E) - characteristics of a typical ZnO varistor

U_G Continuous operating voltage (DC)
U_B Breakdown (or switching) voltage
U_V Continuous operating voltage (AC, 50/60 Hz)
U_P Residual voltage , 8/20 μs

Curve 1: DC voltage characteristic E Field strength
Curve 2: AC voltage characteristic (50/60 Hz)
Curve 3: Residual voltage characteristic corresponding to a current wave with a rise time of 8 μs and a time to half value of 20 μs

- During normal system operation, in which no overvoltages occur, the voltage applied to the arrester is the continuous operating value (U_V or COV for AC or U_G for DC), which lies in the upper part of the pre-breakdown region.

Electrical Characteristics and Performance cont.

PROTECTION ENGINEERS GROUP

- (1) **Varistor Voltage**
  - Voltage at specified DC current (also named as DC reference current), used as a reference point in the component characteristic.
  - Unless otherwise specified, the DC reference current is **DC 1 mA**. (IEC 61051-1)
  - ➢ Physical meaning: cut-off point of clamping conduction zone. When the external voltage is less than the nominal varistor voltage, the MOV is in the cut-off zone with high resistivity. When the external voltage is higher than the nominal varistor voltage, the varistor is in the conduction clamp state.

Electrical Characteristics and Performance cont.

PEG PROTECTION ENGINEERS GROUP

- (2) **Maximum Continuous Operating Voltage**
  - **Maximum Continuous AC voltage**

  Maximum AC RMS voltage of a substantially sinusoidal waveform (less than 5 % of THD "Total Harmonic Distortion") which can be applied to the component under continuous operating conditions at 25 ^{o}C.

  - **maximum continuous DC voltage**

  maximum DC voltage (with less than 5 % ripple) that can be applied to the component under continuous operating conditions at an ambient temperature of 25 ^{o}C.

The operating voltage of MOV shall not exceed this value to ensure that MOV is in a high resistance state without Surge influence.

Electrical Characteristics and Performance cont.

- (3) **Leakage Current (standby current)**

Current passing through the MOV at the maximum DC voltage and at a temperature of 25 ^{o}C or at any other specified temperature.

The leakage current determines the power consumption of the Varistor, and the power consumption can be predicted when the stable operating voltage is applied.

Electrical Characteristics and Performance cont.

- (4) **Maximum Peak Current**

➢ maximum current per pulse that can be passed (Conducted) by a varistor at an ambient temperature of 25 ^{o}C, for a given number of pulses.

➢ Waveform: 8/20 μs (defined by ANSI/IEEE C62.41)

Electrical Characteristics and Performance cont.

- (5) **Clamping Voltage**

Limiting voltage under standard atmospheric conditions, when passing (Conducting) an 8/20 us current pulse

Used to characterize the voltage protection level of a Varistor.

Electrical Characteristics and Performance cont.

- (6) **Category Temperature Range**

Range of ambient temperatures defined by the temperature limits of its appropriate climatic category for which the varistor is designed to operate continuously.

- **upper category temperature**: 85℃/105℃/125℃
- **lower category temperature**: -5℃/-40℃

- (7) **Rated Energy**

- Maximum pulse energy that the varistor can withstand one time when it is exposed to 10/1 000 current pulse or 2 ms rectangular wave pulse, at an ambient temperature of 25 °C
- $E = \int V(t) \cdot I(t)dt = K \cdot V \cdot I \cdot \tau$
- K: waveform factor
- V: clamping voltage at peak current
- I: peak current
- τ : pulse duration

Simplified calculation：
2ms: $E=2 \times 10^{-3}$ V·I
10/1000: $E=1.4 \times 10^{-3}$ V·I

Electrical Characteristics and Performance cont.

- **Key Features**

➢ **Low clamping voltage**

  - As seen from the breakdown area of V-I curve (Fig.3), when the current changes from mA to kA, the voltage growth is small.

➢ **High surge capacity**

  - Surge current density up to 7000 A/cm^2

➢ **Quick response**

  - <20 ns

➢ **No residual current**

Electrical Testing

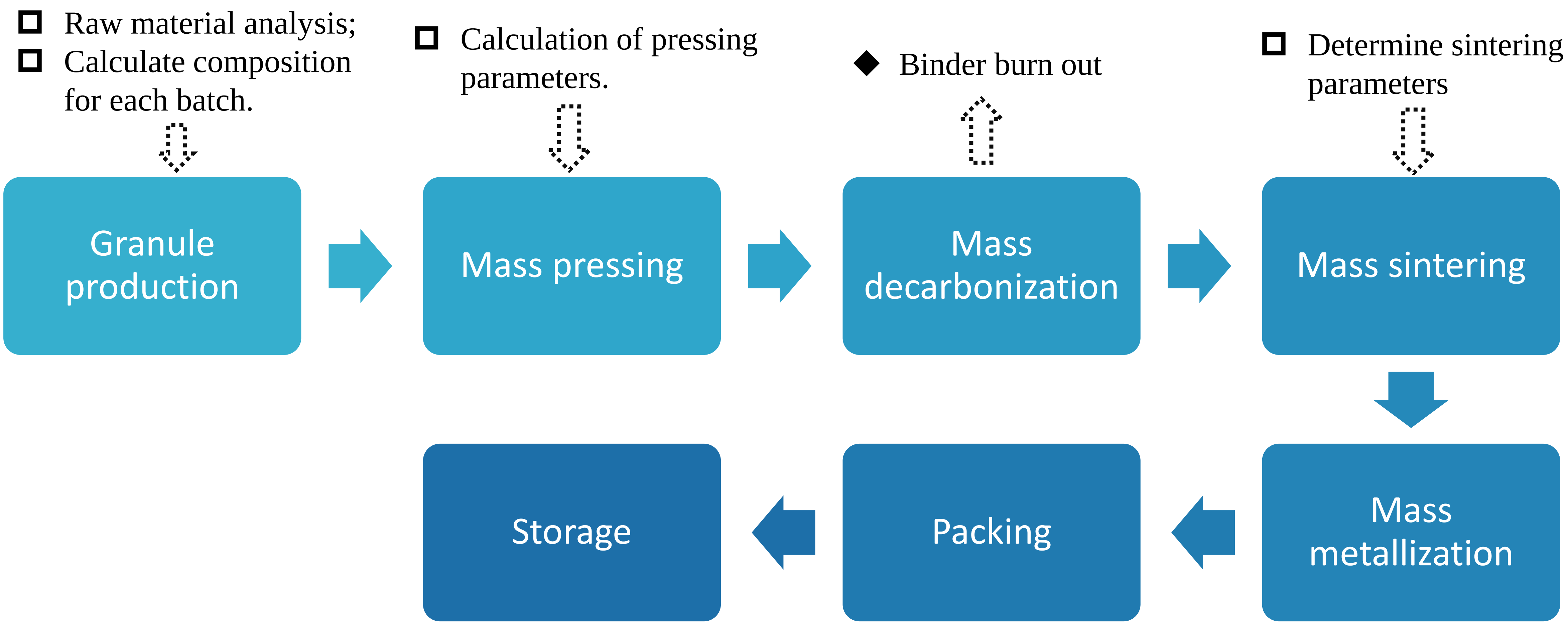
PEG PROTECTION ENGINEERS GROUP

- Before leaving the production line each MOV has to pass a series of tests to verify its electrical properties, with additional sampling of the resistors for ageing tests. These tests vary from one manufacturer to another, depending upon their product quality and company standards.
- They typically include *discharge voltage U_P, AC or DC reference voltage, power loss at continuous operating voltage, long duration and/or high amplitude current impulses (LCLD, HCSD) and ageing.*
- Some of them are performed on every MOV disk while others are by nature almost destructive and therefore sample tests.
- Some of these values are typically marked on the disk along with production information such as the lot or batch number. These almost always include the discharge voltage. Often the information is coded and not disclosed to third parties.

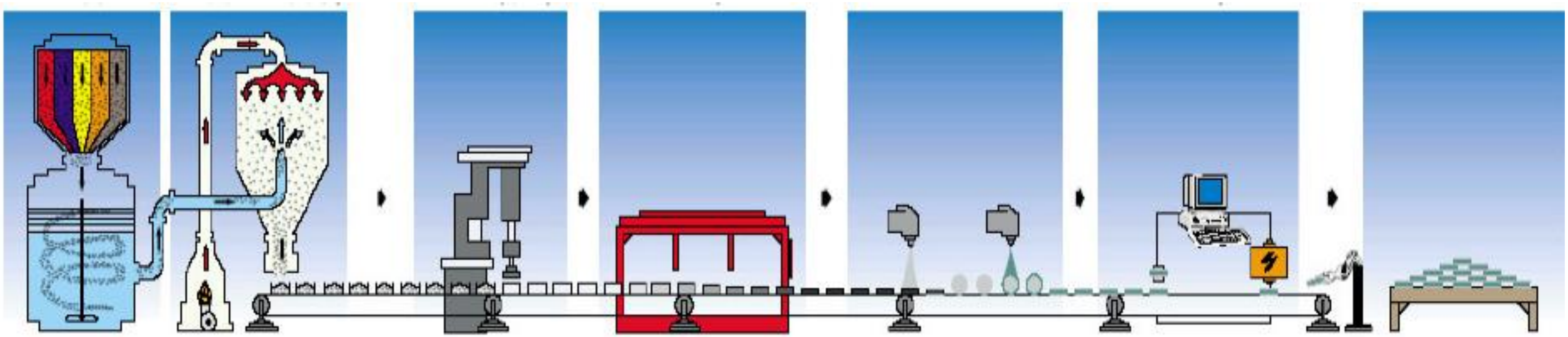
Failure Modes

- **Thermal Runaway,** is a very critical failure mode for the device and the equipment that it protects and that's why you see unique Integration with Thermal Protection methods to solve this issue.
- **Puncture** from current concentrations followed by local thermal runaway and melting
- **Cracking** due to localized heating (with or without puncturing)
- C**racking** due to thermo-elastic stresses during high current impulses (even for a perfectly homogeneous block)
- **Flashover** from high dielectric stresses at the rim or surface of the blocks.

Manufacturing Process



Manufacturing Process cont.



Production of homogeneous slurry by wet-mixing of oxide powders	Drying and granulation in a spray-drier	Compacting the granulate to form resistor blocks	Sintering to obtain dense ceramic bodies	Addition of electrical contacts and a protective coating	Electrical testing	MOV resistors ready for assembly

Applications

MOV Protection components are utilized across all industries where equipment are connected to AC/DC or powered by it.

You will find MOVs in Fire Protection, Telecommunication, Industrial, Medical and Automotive applications to name few.

MOV Selection and Considerations

1) AC/DC mains voltage fluctuation, the highest transient voltage and duration time.
2) Impulse voltage/current peak, source impedance and frequency
3) Voltage withstand level of protected equipment and systems
4) Certification Standards and Safety Requirements (UL/CSA/IEC)
5) Special environmental requirements

PEG PROTECTION ENGINEERS GROUP

Thank you for Attending

Q & A