TECHNOLOGICAL DEVELOPMENTS IN SURGE ARRESTERS

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INTRODUCTION:

1. The first generation silicon carbide spark gap arresters were superseded by second generation Zinc Oxide varistors and gapless Arresters.

2. The present changeover is from porcelain Arresters to third generation polymer arresters and in near future for high performance Zinc Oxide varistors for AIS application.

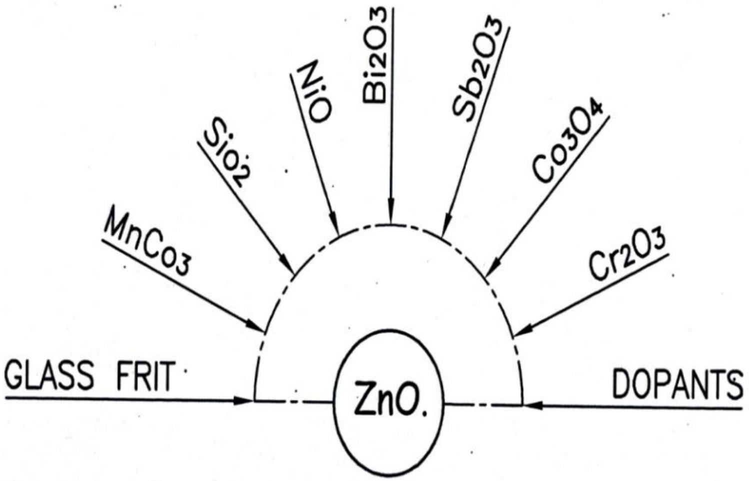
IEC 60099-4 Edition.3-VARISTOR REQUIREMENTS:

- Repetitive charge transfer rating Q_{rs}.
- Thermal energy W_{th} withstand capabilities.
- Long term stability of the Zinc Oxide blocks.
- Temporary over voltage withstand capabilities.

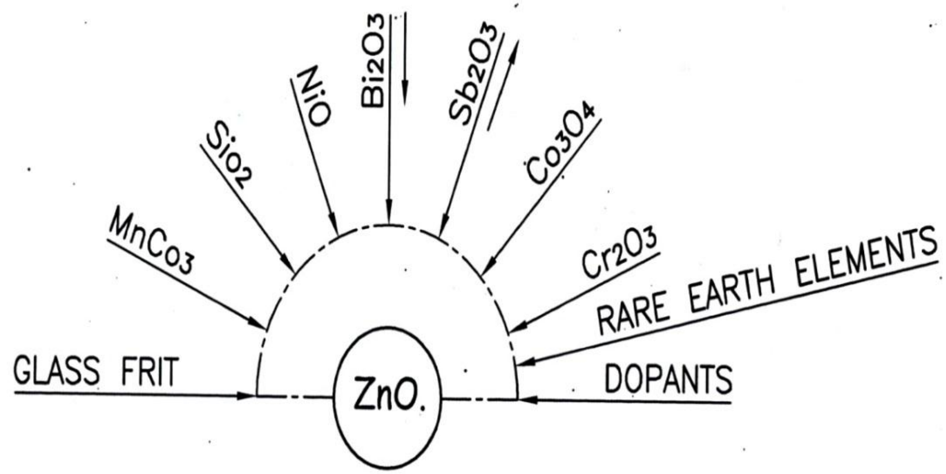
GENERATION OF ELECTRICAL CHARACTERISTICS

- Varistor Electrical characteristics depend on its V-I characteristics.
- V-I characteristics depends on micro structure.
- Micro structure depends on formulation and process.
- Formulation is preparation of pressable powder with desired additives (metallic oxides) and process chemicals.
- Process is compaction for a desired green density and creating micro structure through thermal treatment .

ZnO VARISTOR FORMULATION



NORMAL GRADIANT -200V/mm



HIGH GRADIANT -400V/mm

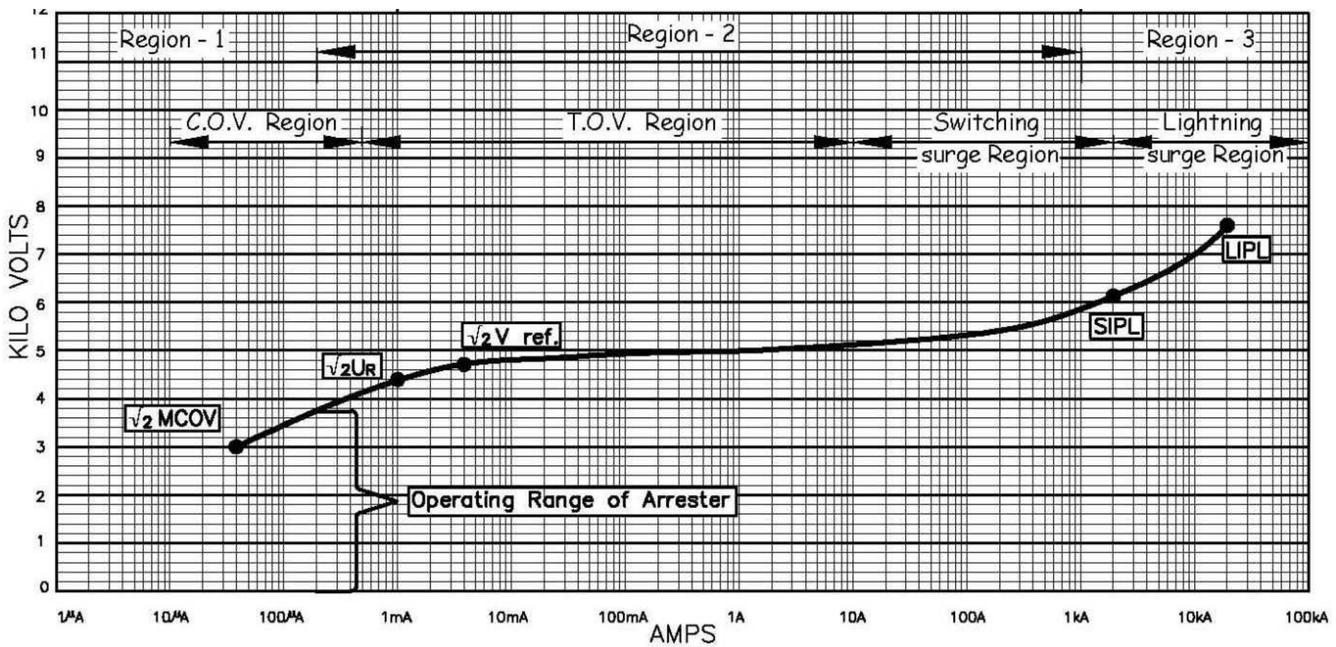
HIGH GRADIANT FORMULATION

- Increase in gain growth inhibitor additives
- Reduce the additives which promote grain growth
- Add Rare earth elements
- Use finer particles of ZnO
- Adjust sintering temperatures.

DEVELOPMENTS IN TECHNOLOGY OF ZNO VARISTOR

VI CHARACTERISTICS

$\alpha \leq 5$ **$I = kV^{\alpha}$ $\alpha \geq 30$** **$\alpha \leq 5$**



Normal Functioning :

- The heart of the Arrester is Zinc Oxide Varistor .
- The performance of Zinc Oxide varistor is dependent on its V- I characteristics which shows the resistance change as a function of voltage.
- For MCOV the arrester acts like near insulator for its life time.
- For over voltages the arrester acts like a conductor to limit the over voltage to around 60% of BIL of equipment to be protected .
- After the surge discharge traces back to insulating characteristics for operating voltage.

IMPROVEMENTS DESIRED TO SATISFY LATEST IEC 60099-4 ED.3

- Reference voltage predominance for T.O.V withstand capability and thermal stability.
- Small change in leakage over a large temperature increase for thermal withstand.

PRIMARY CHARACTERISTICS FOR TOV WITHSTAND CAPABILITY AND THERMAL STABILITY OF AN ARRESTER ARE

1. Ratio of Vref to MCOV
2. Long term stability of the MOV which is dependent on formulation, forming process and the thermal treatment.
3. Energy capabilities are based on Mechanical integrity and thermal stability of MO blocks.
4. MOV discs that demonstrate a small change in leakage over a large temperature increase are preferred.

T.O.V. WITHSTAND CAPABILITY

1. Temporary over voltage starts above Ur and during conduction in this region the varistors get rapidly heated since there is considerable energy dissipation
2. The IEC criteria of test evaluation includes change in Vref (reference voltage before and after testing for Qrs) to be within ±5% (IEC 60099-4 new edition)
3. The reference voltage is normally 30% above MCOV
4. This difference in voltage strongly affects an arrester TOV withstand capability.
5. Choosing a higher MCOV arrester for a lower operating voltage increases the difference between Vref and MCOV thus increasing the TOV capability.

DEVELOPMENTS IN ARRESTER TECHNOLOGY

- Traditionally the housing of the arrester has been made of porcelain
- Arrester failure is due to moisture entry or radial discharges due to pollution and non uniform voltage distribution in EHV and UHV arrester, thermal run away or T.O.V withstand capability Inadequate.
- Porcelain shatters due to heavy thermal shock during short circuit damaging the nearby costly equipment and injuring the personnel .

- It was a long desire for the manufacturers and application engineers to have replacement material for porcelain to make with increased pollution performance , non shattering behavior and for reduced number of units in a column for better voltage distribution.
- At first the polymer arresters were made in wrap design for medium voltage in fully moulded construction and with various configurations .
- Next development was the assembly of ZnO elements in a prefabricated FRP tube with slots or holes with an inner diameter just larger than the ZnO elements. The active Zinc Oxide blocks are enclosed by **hard FRP Tube.**

- The gap between the ZnO elements and the tube is filled with solid or semi solid material and the ends are sealed .
- As there is no chemical bonding of the housing to end fittings there exists a sealing deficiency and weak areas created for exit of short circuit gases reduces the mechanical strength and can not classify as a fool proof short circuit performance.
- **Next the technological development has given birth to fool proof cage design of fully moulded construction** for HV,EHV Arresters (66kV to 400kV) regarded as no failure arresters.
- In the case of EHV and UHV Arresters tube design is being adopted for building taller arresters to decrease the number of units per column to increase the mechanical integrity and to improve the voltage distribution.
- The IEC 60099-4 of 2014 and 60099-5 of 2013 explain exhaustively the configuration and testing of wrap, cage and Tube designs.

CAGE DESIGN -OPEN CAGE CONSTRUCTION

1. Zinc Oxide blocks of each unit of Arrester are assembled in a cage of 8 Boron free ECR grade FRP Rods to form open cage design
2. End terminals are assembled under axial pre compression of 100kN to add to the cantilever strength of FRP rods.
3. The pre compressed unit stack is crimped on the end terminals, at high crimping force to hold the cage for a tensile force of 20T.
4. Silicone rubber directly surrounds the Zinc Oxide blocks. There is no gas volume included.
5. In case of arrester failure an internal arc will be established.
6. Due to the open cage design the arc will burn and tear open the silicone polymer permitting the Arc and the resulting gases to escape and so no necessity of separate pressure relief device.

CAGE

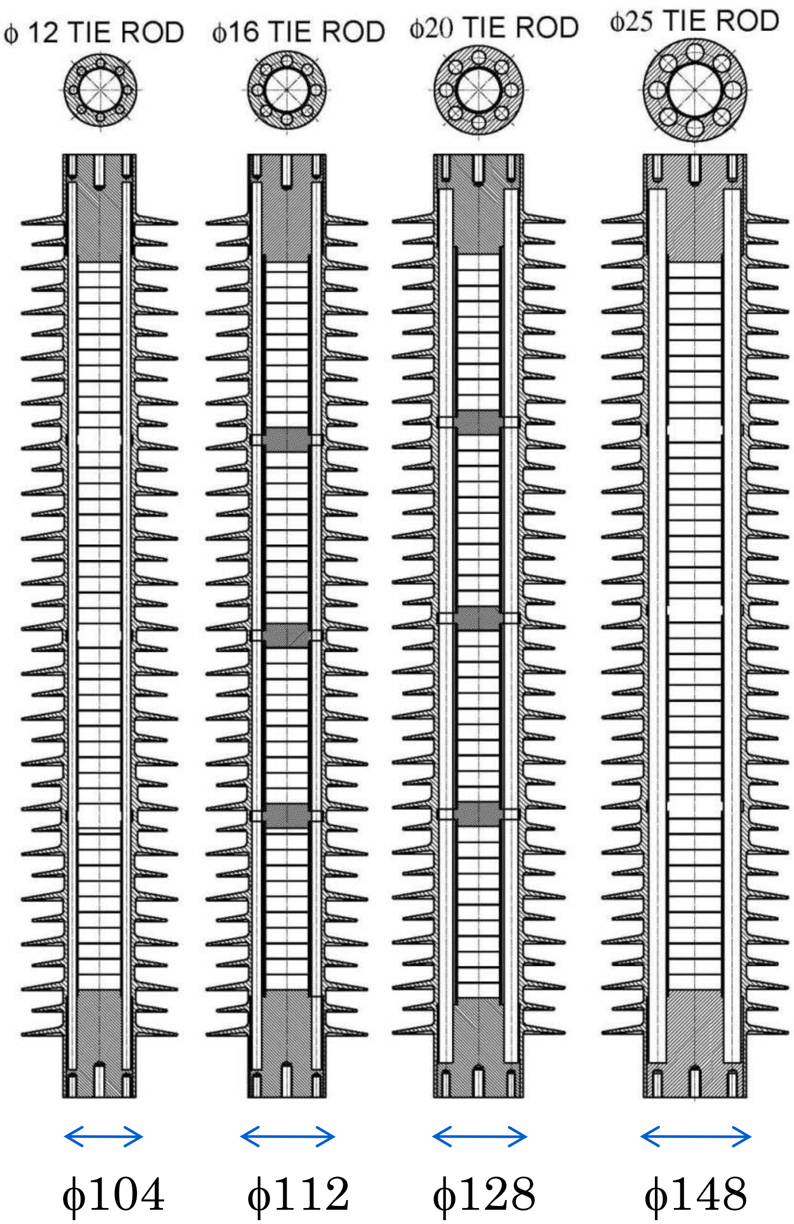
CAGE DESIGN - OPEN CAGE CONSTRUCTION

1. The module is sealed throughout the length from top terminal to bottom terminal and from outside till the surface of the blocks, making a fully moulded voidless construction with no internal gas space.
2. MO elements are in direct contact with silicone polymer. Heat produced by MO elements is more easily dissipated through the housing into environment, thus increasing the thermal stability.
3. MO elements are used as mechanical support by clamping the ZnO blocks at pre-stress of 100 kN to add to the cantilever strength given by FRP rods.

120kV ARRESTER CAGE DESIGN

MECHANICAL STRENGTH -CAGE DESIGN

1. By increasing the diameter of Tie rods in cage construction, the cantilever strength can be increased.
2. Because of the cost involved for the mould to suit different trunk dia meters the shift is towards the Tube design for EHV and UHV Arresters for mechanical considerations.
3. When the mechanical force Vs deflection is specified and tested satisfactorily, shift over to cage design for 400KV EHV Arresters will be a best proposition to be considered seriously .



ADVANTAGES OF CAGE DESIGN:

- Fully moulded construction of all internal and external components and so no way for moisture ingress.
- No partial discharges as the construction is voidless.
- Non-explosive failure mode as silicone rubber provides low pressure escape of the arc during a short circuit.
- Excellent resistance to ageing under climatic and electrical stress.
- Excellent track and erosion resistance.
- High resistance to Ozone and Corona

ADVANTAGES OF CAGE DESIGN:

- Insensitive to UV Radiation
- Self extinguishing flame retardancy.
- Excellent dielectric strength.
- Good pollution performance due to hydrophobic nature with excellent dielectric strength.
- Exceptional tolerance to seismic disturbance.
- Low weight and resistant to transport damages and careless handling.

SHORT CIRCUIT TEST ON 120KV CAGE ARRESTER - 63KA

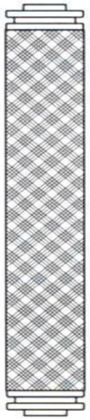
Photograph No. 202: Condition of the sample after test

BEFORE TEST

AFTER TEST

WRAP DESIGN ARRESTERS

- Metal Oxide varistor blocks are wrapped helically with boron free ECR grade banding ribbon
- The crosswise helical winding is such, as to create rhombic “windows”
- The MOV stack is moulded with silicone polymer to cover total length including the end terminals.



STACK

ARRESTER

SHORT CIRCUIT TEST ON 30kV ARRESTERS (WRAP DESIGN)

Test Report CESI B3000134

Approved Page 10

Photo No.1

Before the tests

Photo No.2

After the test No.2

BEFORE TEST

AFTER TEST

TUBE DESIGN FOR 400kV AND 800kV

1. For EHV (400kV) Arresters of 4 M and UHV arrester of 8M Tube design is adopted. Immediate requirement is for 3 units of 208kV for 624kV for mechanical considerations with arrester height of 6.624M .

2. Primarily the number of units per column of arrester are to be reduced for proper distribution of voltage across units and to reduce deflection for a particular load.

3. With the reduction of units per arrester column along with proper design of grading ring near uniform voltage distribution can be achieved.

Section of 624kV Arrester (TUBE DESIGN)

MAIN FEATURES OF TUBE DESIGN:

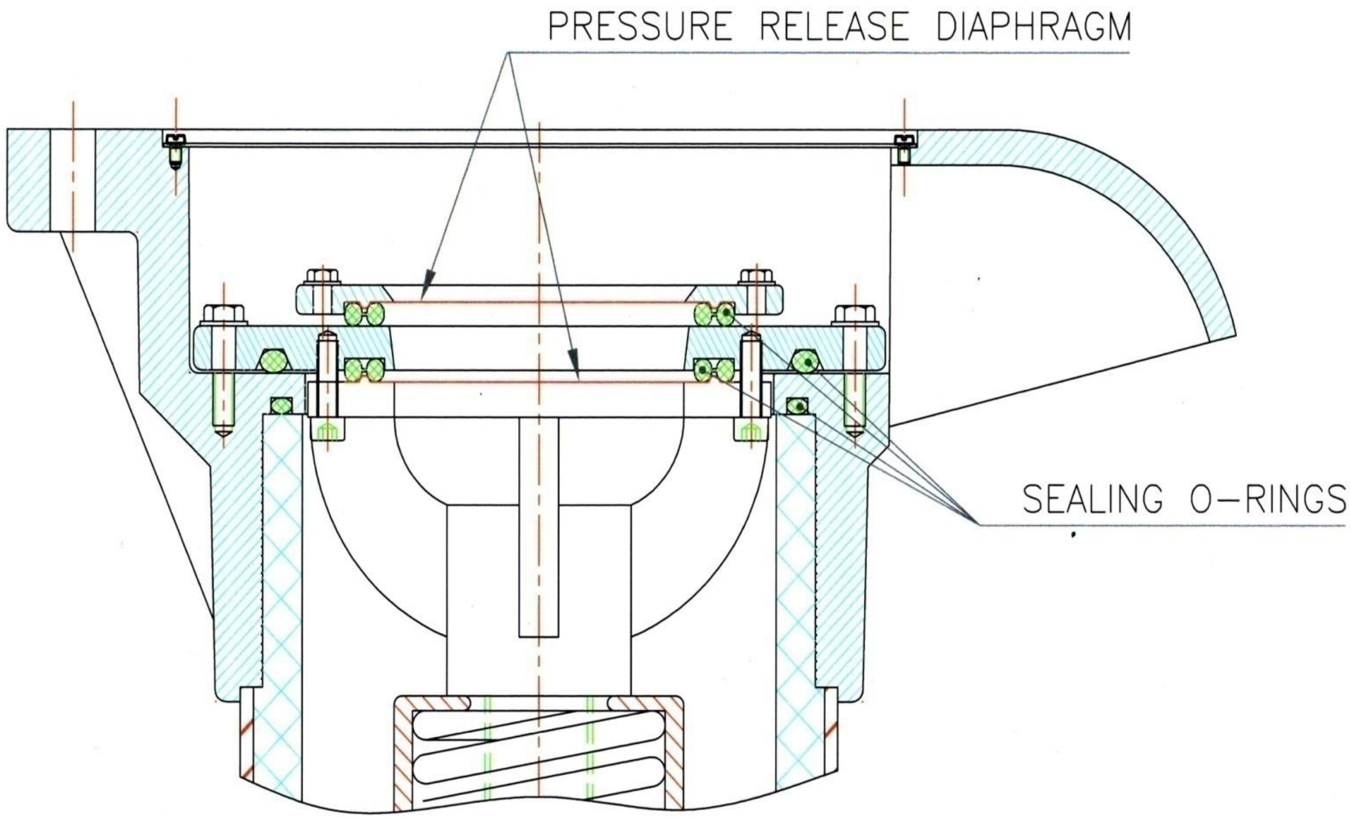
- Safest short circuit performance with no failure and no ejection of internal components.
- Available in two units in series (each of 168kV for 336kV rating) for 420kV system.4 units x 156kV or 3 units x208kV in series for 624kV rating for 800kV system .4 units of each of 212.5kV for 850kV rating. 4 Nos. of 850kV units in parallel for 1200kV system.
- Longest arresters with highest rated voltage can be made to reduce number of units per column of arrester for uniform distribution of voltage.

- Mechanical strength can be improved with increase of wall thickness of composite hollow core insulator used in the tube design.
- Internal radial discharges can be avoided by increasing gap between disc and tube.
- Excellent track and erosion resistance with high resistance to Ozone and Corona and insensitive to UV Radiation with self extinguishing flame retardancy.

MOISTURE INGRESS IN DESIGN ‘A’ ARRESTERS (TUBE DESIGN)

1. In Tube design arrester either of porcelain or polymer the gas space around the column of MOV block is filled with dry air or nitrogen. Even a tiny leak can result in “seal pumping “ due to pressure differentials.
2. During the day the arrester gets heated and so the internal pressure of the arrester increases relative to ambient and gas leakage occurs to outside.
3. When the arrester cools at night, this process reverses with internal pressure dropping below ambient and external air with all moisture content gets drawn into the arrester.
4. Such a cycle can repeat itself over many days, months, or even years before the moisture inside builds to a point where there is a problem with reduced insulation resistance.

DOUBLE SEALING SYSTEM



- Two stage sealing and double pressure release diaphragm to avoid or minimize the chances of seal pumping

COMPOSITE HOLLOW CORE INSULATOR

1. The FRP tube is the structural part in a hollow composite insulator.

2. The tube material consists of Boron free ECR grade fiberglass rowing embedded in epoxy to give good electrical insulation and mechanical properties.

3. The volume fraction of fibre with fibre architecture influences the properties of the FRP tube.

4. The wall thickness of the FRP tube is based upon axial stress and cantilever strain.

HOLLOW CORE INSULATOR

FRP TUBE

Hollow core Insulator after Moulding

Hollow core Insulator With end flanges

The Tube is duly Moulded with Silicone Rubber and glued with end flanges

TUBE DESIGN FOR 400kV AND 800kV

FRP Tube

Hollow core Insulator after Moulding

Internal Assembly

Arrester Assembly

CONSTRUCTION OF TUBE DESIGN
(4 UNITS OF 156KV OR 3 UNITS OF 208 KV FOR 624KV)

1. Blocks of a stack consisting of around 12 Zinc Oxide blocks covered with a silicone Sleeve -protects the blocks from the effect of radial discharge.
2. The stacks of ZnO blocks are fixed with strong FRP rod with spacers of Silicone Rubber between the unit stacks.
3. The Arrester stack is heated at 60°C in a Hot chamber.
4. The hollow core insulators are also heated in a Hot chamber at 60° C
5. The arresters stack is placed inside hollow core insulators and closed with Flanges with pressure relief venting arrangement.

INTERNAL ASSEMBLY OF TUBE DESIGN ARRESTERS

Stack of Class-V ZnO Blocks

Q_{rs}:5.2C (Ed 3)

Internal Assembly

Section of 624kV Arrester (TUBE DESIGN)

SHORT CIRCUIT TEST ON ARRESTERS OF TUBE DESIGN UPTO 65KA

SHORT CIRCUIT TEST ON 156kV ARRESTER AT 65kA

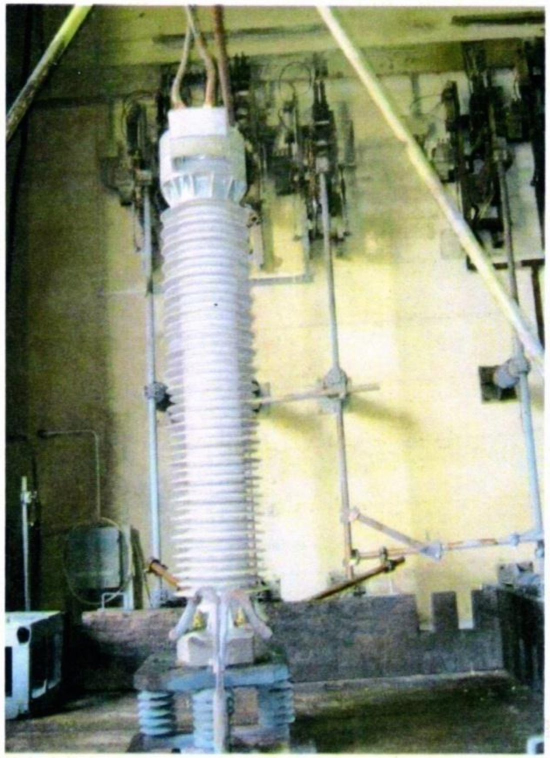


Photo No.2
New

BEFORE TEST

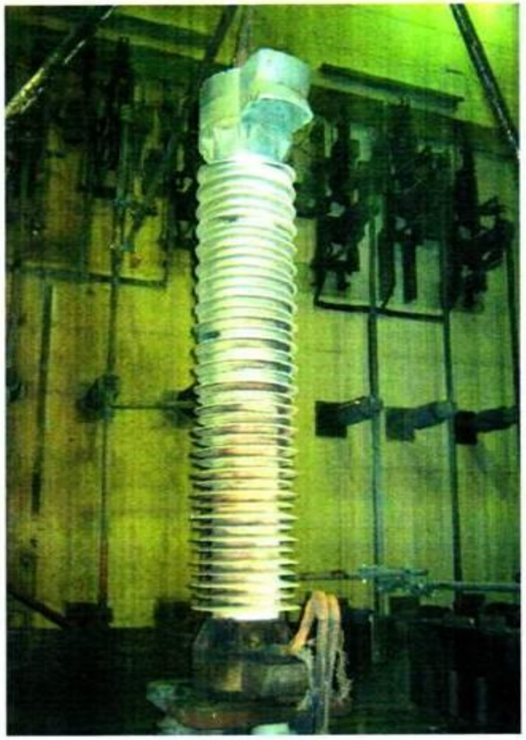


Photo No.9
After the test No.4

AFTER TEST

CONSIDERATIONS FOR SELECTION OF AN ARRESTER

PORCELAIN ARRESTERS Vs POLYMER ARRESTERS

1. The claimed pressure relief capability of porcelain housed arrester is only for the first venting.
2. When porcelain arrester vents, the housing becomes weak.
3. Porcelain arrester may explode violently, expelling porcelain and internal components damaging the equipment and injuring personnel in the substation.

4. The venting of a shorted arrester results in a circuit breaker operation followed by automatic reclose at least once into a fault.

5. This could cause the porcelain arresters definitely to explode

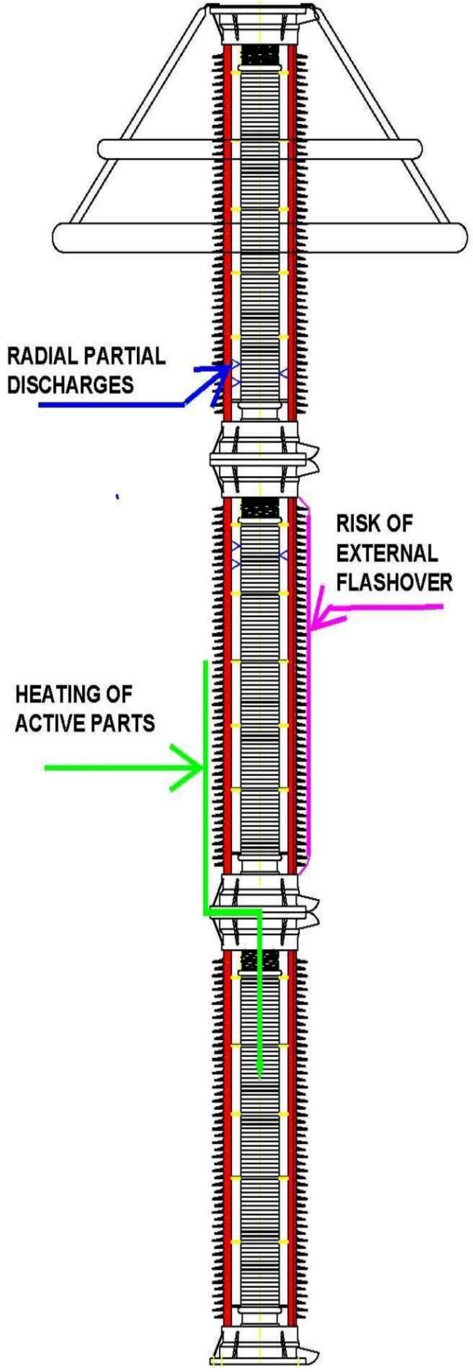
6. The failed polymer housed surge arrester can be reclosed number of times without violent shattering.

7. Porcelain surface has hydrophilic properties

8. The silicon polymer has hydrophobic property.

PERFORMANCE UNDER POLLUTION CONDITIONS

1. Problems due to pollution was the reason to change over to Polymer housed Arresters.
2. The figure illustrates three possible mechanisms which can effect a multi unit MO HV Arrester operating in polluted environment.
3. The surface current along one unit of high external conductivity commuting to the MO column of next unit heating the MO resistors of this unit.



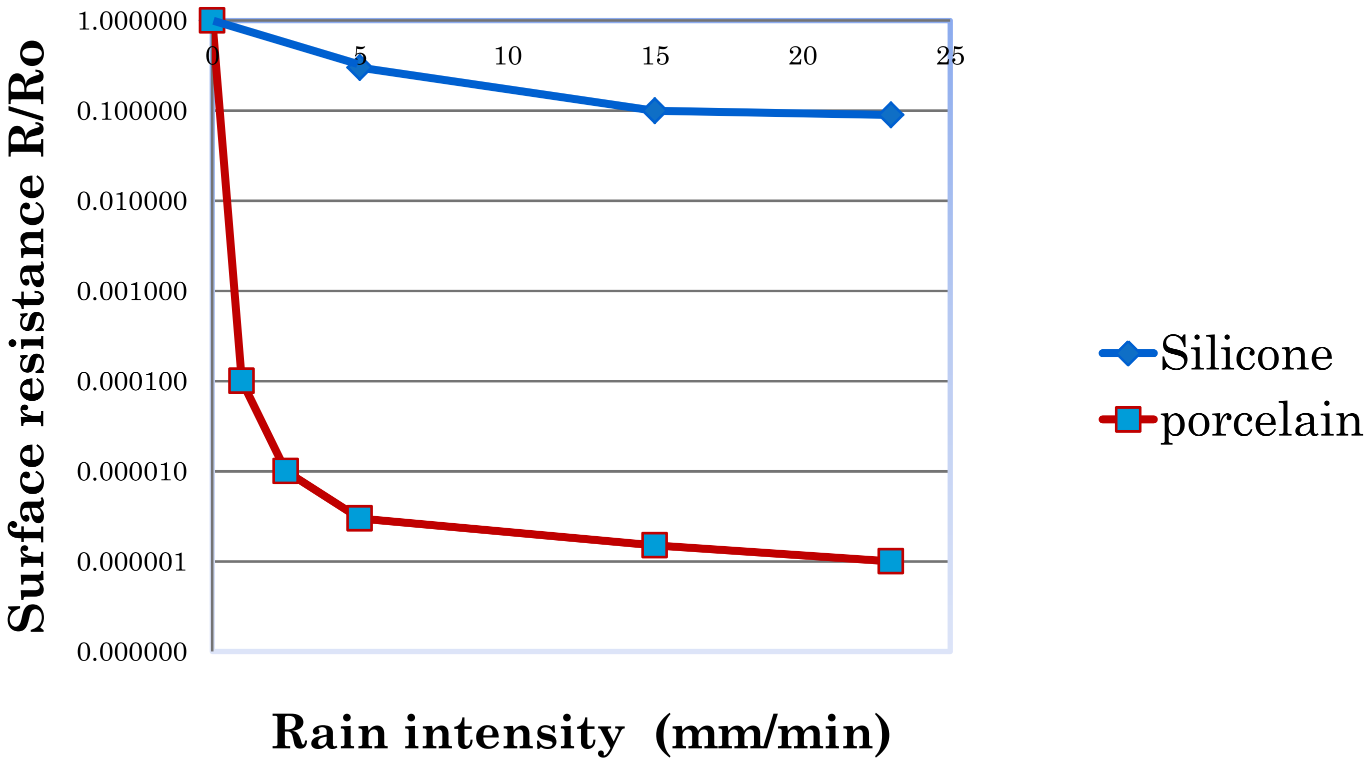
PERFORMANCE UNDER POLLUTION CONDITIONS

4. Internal partial discharges are initiated by radial electric field stress due to different voltage distributions along the internal MO column and the outer surface of the housing.
5. In Type A design the radial voltage stress appears across the gap between MO resistors and the housing due to geometry and the dielectric constants of different materials.
6. To reduce the effect of radial discharges it is necessary to have sufficiently large gap between MO column to housing. The salt fog tests have shown that a minimum gap of 30mm to 40mm is necessary depending on the rating to effectively avoid any internal partial discharges.
7. The hydrophobic surface of Polymeric housing reduces considerably the problem of pollution.

TO MITIGATE EFFECTS OF POLLUTION:

1. Lower leakage current on the insulator surface by hydrophobic nature of the housing.
2. Increase the radial gap between ZnO block and the inside surface of the housing in the tube design.
3. Lower power loss at MCOV
4. High energy capability of Blocks
5. Higher thermal stability- Improved heat conduction of Blocks

SURFACE RESISTANCE –PORCELAIN & POLYMER



Creepage level of 31mm/kV is not required in the case of polymer surge Arresters

Limitations in series parallel connection of EHV Arresters:

1. By connecting in series the desired rated voltage is achieved.
2. Connecting in parallel results in necessary energy absorption capability and to certain extent mechanical stability.
3. The ZnO blocks are to be adjusted carefully for current distribution at switching surge levels for energy sharing.
4. Any deviation in current distribution above 15% leads to electrical and thermal over loading of the arrester with lowest residual voltage.

ARRESTERS WITH SERIES UNITS AND IN PARALLEL COLUMNS

1. For applications requiring arresters with parallel columns and several units connected in series, the general rule is that the units should not be connected at unit levels except at the top and bottom.
2. If the units are connected in parallel at levels in between, the ZnO blocks in one unit could conduct the external leakage current from all of the parallel connected arresters.

850kV 55MJ SA with 4 parallel columns (4 no. of 212.5kV connected in series for each column)

ENERGY CALCULATION AS PER IEC 60099-5

Thumb rule for Energy dissipated through the system during switching operations as per IEC 60099-5

$$W = U_{ps} \times \frac{U_{rp} - U_{ps}}{Z_s} \times 2 \times \frac{L}{C}$$

Where

W is the energy

L is the line length

C is the speed of light

Z_s is the line surge Impedance

U_{ps} is the arrester RDV at switching Impulse current

U_{rp} is the maximum switching over voltage

Calculation for 800kV System of 600kM length

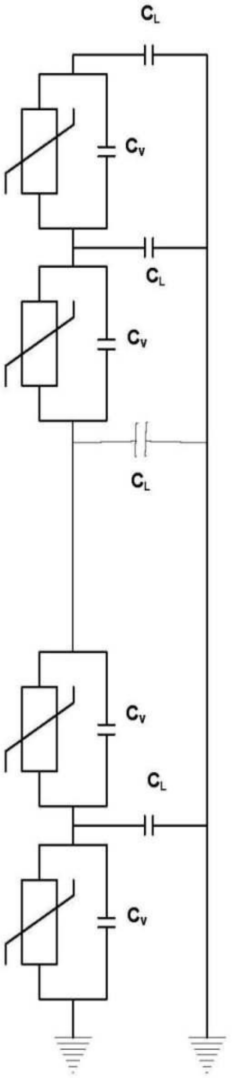
- U_{rp} = 1550 kVp U_{ps} = 1100 kVp Z_s = 0.5 Ur (as per IEC 60099-4)
- C= 299732.458 km /s. L=600kM

$$W = U_{ps} \times \frac{U_{rp} - U_{ps}}{Z_s} \times 2 \times \frac{L}{C}$$

$$W = 1100k * \frac{1550k - 1100\,k}{0.5*624} * 2 * \frac{600k}{299732.458\ km} = \frac{1100k*450k*2*600}{312*299732.458}$$

=6.3MJ

INFLUENCE OF LEAKAGE CAPACITANCE ON EHV AND UHV ARRESTERS:

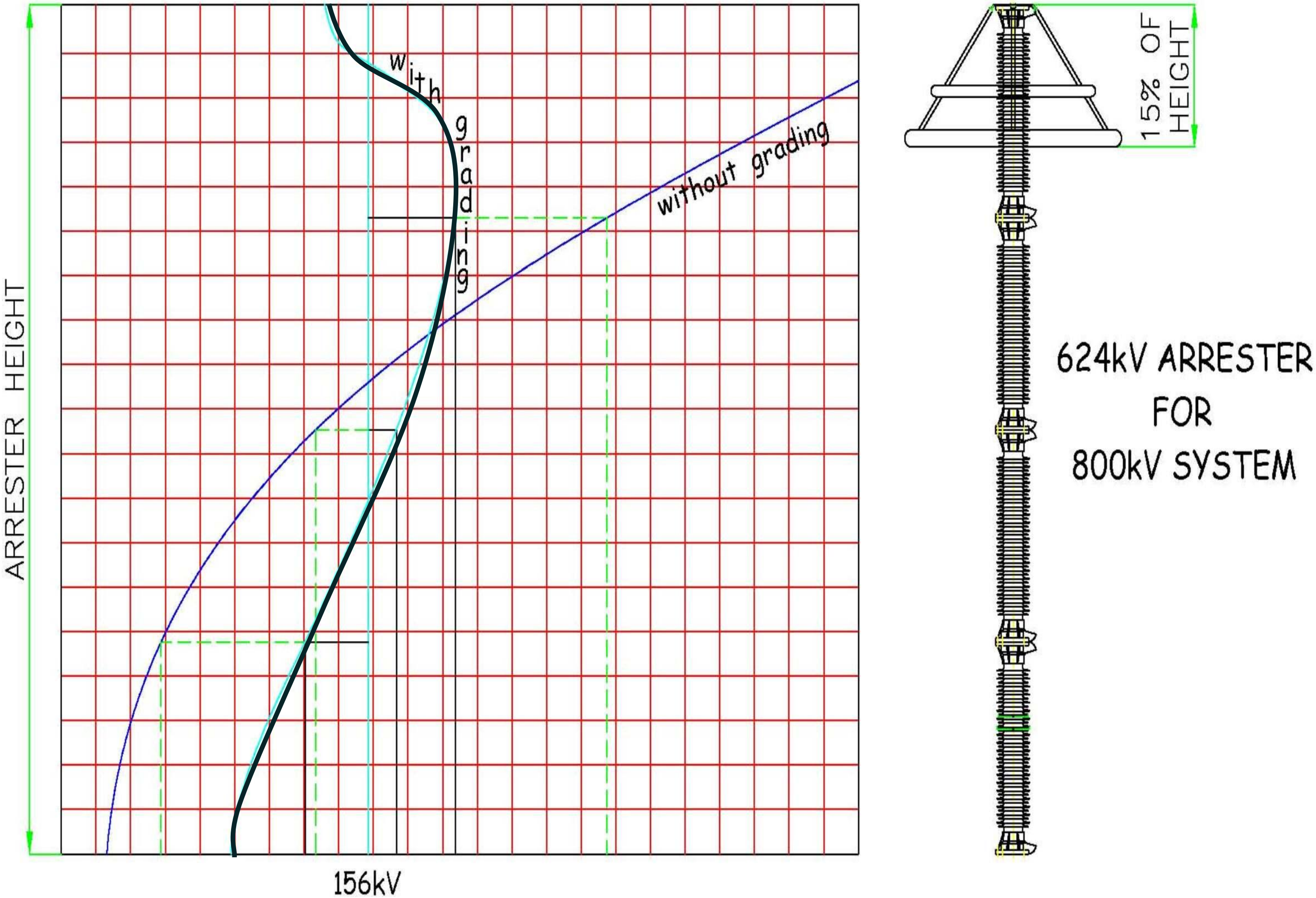


Series connected capacitance of MO resistors -624kV 20kA class-V rating:

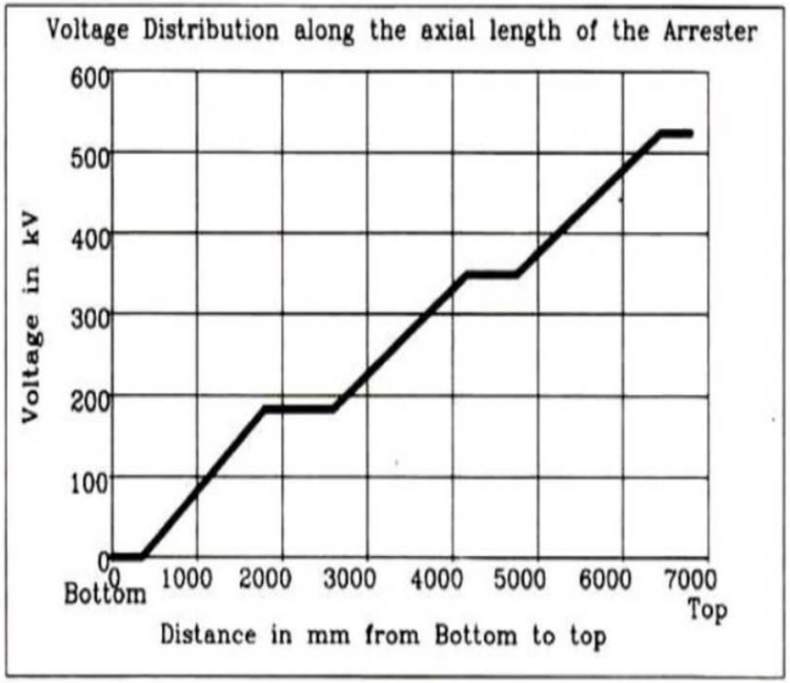
- Height of the Arrester =8 m
- Self capacitance of 624kV 20kA class-V Arrester (800kV system) =30 pF
- Leakage capacitance CL≈ 15 pF/m
- Leakage capacitance for complete Arrester= 15*8=120 pF

1. Earth capacitance is much higher compared to Arrester capacitance.
2. Voltage distribution to be improved either by suitable grading ring configuration or grading capacitors.

AXIAL VOLTAGE DISTRIBUTION WITH AND WITHOUT GRADING RING :



GRADING RING OPTIMIZATION FOR 624KV SURGE ARRESTER



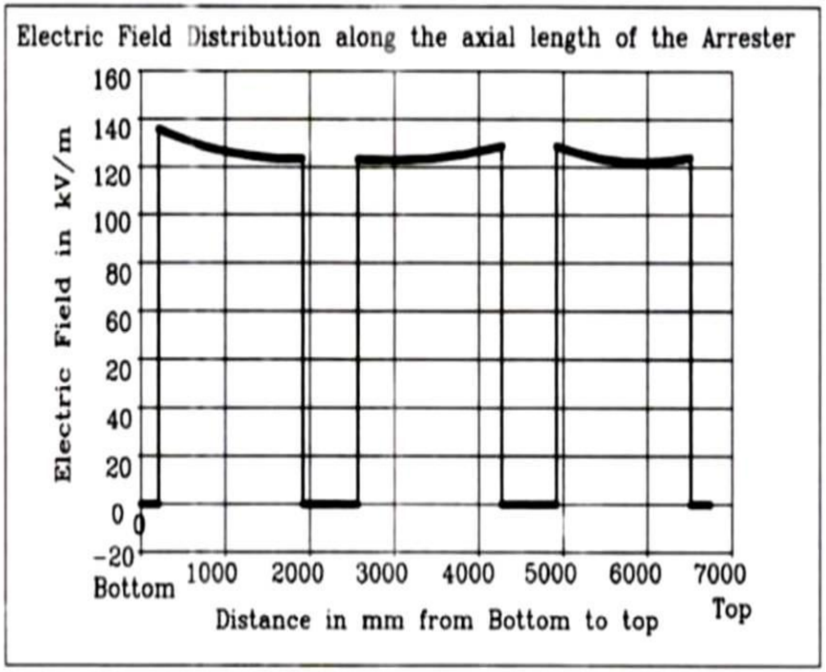


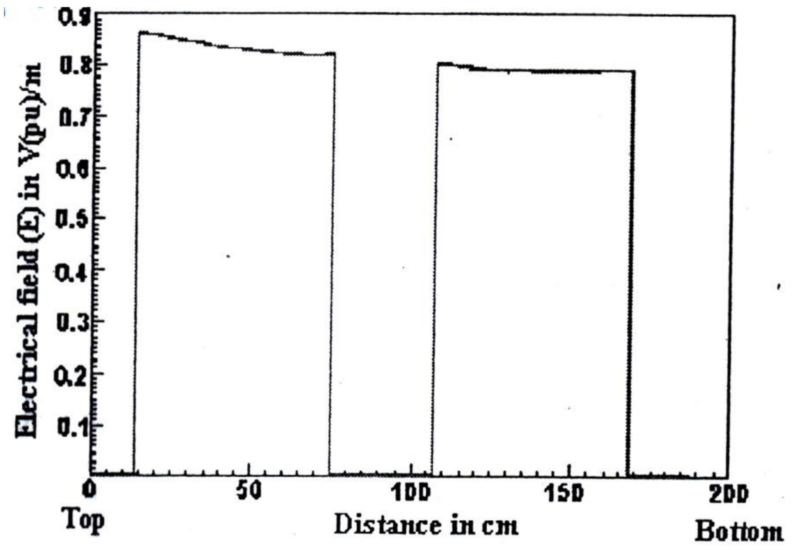
Fig.a Computed voltage distribution along the axial length of the 624kV SA

Fig.b Computed Electric Field Distribution along the axial length of the 624kV SA

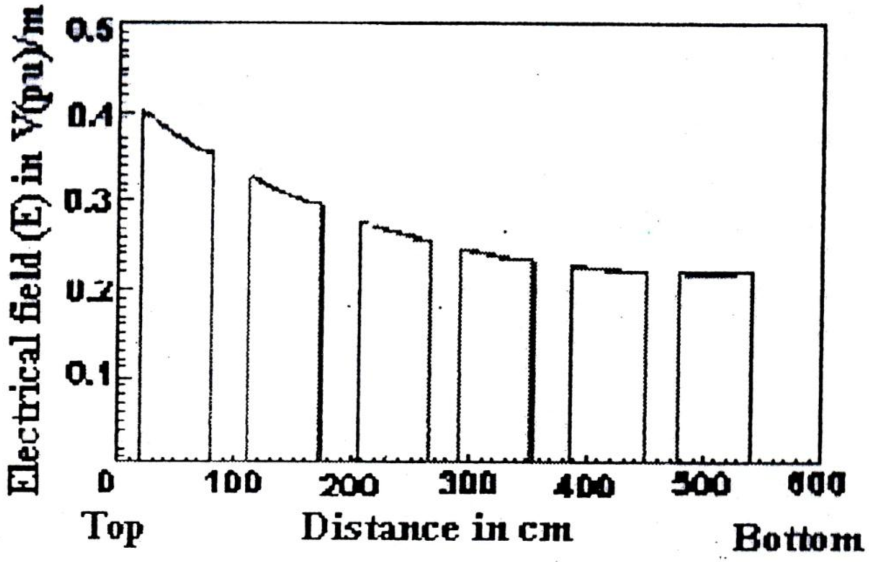
Voltage distribution along the length of the ZnO column of the arrester with optimized grading ring

Section -1 : 177.8kV Section -2: 174.97kV Section-3: 177.2kV

NON UNIFORMITY IN VOLATGE DISTRIBUTION



Electrical field along the 132kV arrester in two units



Electrical field along the 396kV arrester in 6 units

Effect of stray capacitance on Surge Arrester performance presented in the world congress on Engineering and computer science **WCECS 2009 in SANFRANSCISCO, USA.**

Force Vs deflection for 624kV surge Arresters- tube design

Number of units 4

Applied cantilever load in kg force	Distance from a fixed reference in mm	Cumulative deflection in mm
0 (Start)	500	0
50	590	90
100	680	180
150	777	277
0 (End)	505	**5 (residual deflection)**

- Height of each unit=1910 mm
- Total height =7624mm
- OD of FRP Tube =210mm

Number of units 3 -Cantilever load upto 250kgf

Applied cantilever load in kg force	Distance from a fixed reference in mm	Cumulative deflection in mm
0 (Start)	710	0
100	788	78
150	830	120
200	873	163
250	**920**	**210**
0 (End)	720	**10 (residual deflection)**

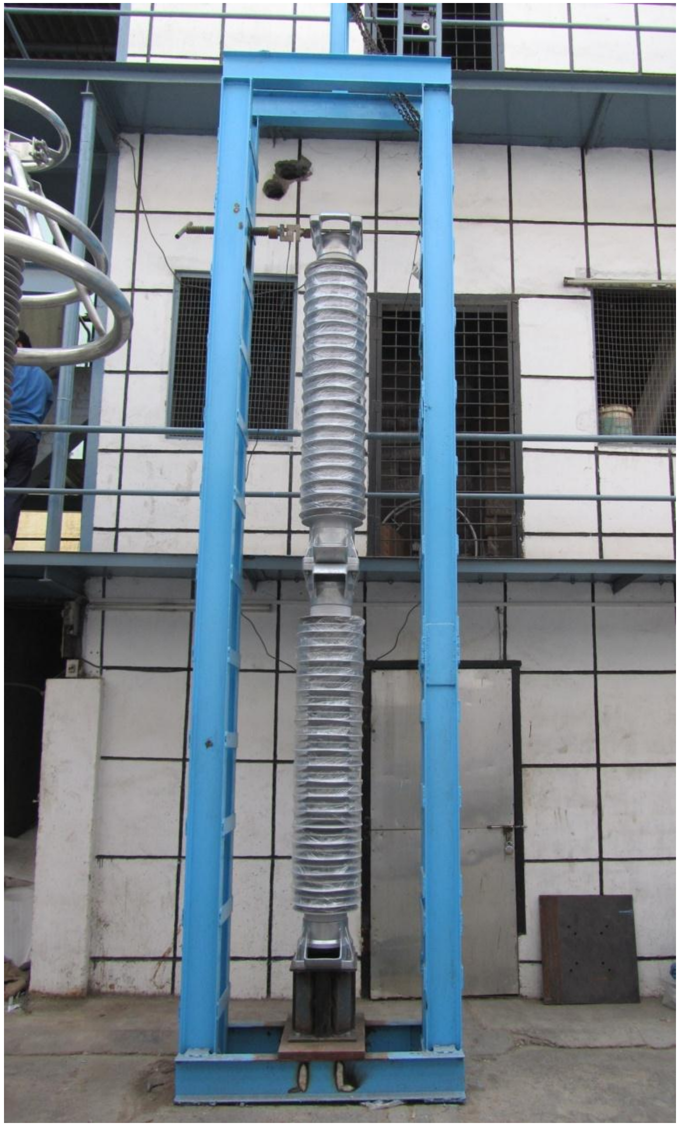
- Height of each unit=2262 mm
- Total height =6786mm

Force Vs deflection for 624kV Surge Arrester (Improved Tube construction)
3 units for cantilever load upto 500 kgf

Applied cantilever load in kg force	Distance from a fixed reference in mm	Cumulative deflection in mm
0 (Start)	507	0
100	533	26
200	561	54
300	590	83
400	617	110
500	**649**	**142**
0 (End)	508	**1 (residual deflection)**

Height of Tube construction for 624kV =6 M
Height of hollow core insulator with venting system =6.6 M
Outer diameter of FRP tube =300mm
Thickness of the TUBE =25 mm

FORCE VS DEFLECTION FOR 336KV SURGE ARRESTERS



Applied cantilever load in kg force	Distance from a fixed reference in mm	Cumulative deflection in mm
0 kN (start)	2490	Nil
0.5 kN	2470	20
1 kN	2452	38
1.5 kN	2432	58
2 kN	2413	77
2.5 kN	2392	98
0 kN (load released)	2490	Nil

Test result

a. No visible mechanical damage
b. No permanent deflection (Elastic stage)
c. <u>Uniform</u> positive force deflection proves the adequacy of the housing for usage.

CONSIDERATIONS FOR SELECTION

- Number of units per Arrester column
- In case of Tube design proper gap between disc and FRP Tube to be maintained to avoid effect of radial discharges.
- MCOV to ref. voltage ratio for T.O.V withstand capability.
- Encapsulation of blocks (EHV & UHV applications) in silicone Rubber to withstand the radial discharges under heavy pollution conditions.
- Larger units with reduced no. of units per column to be considered.

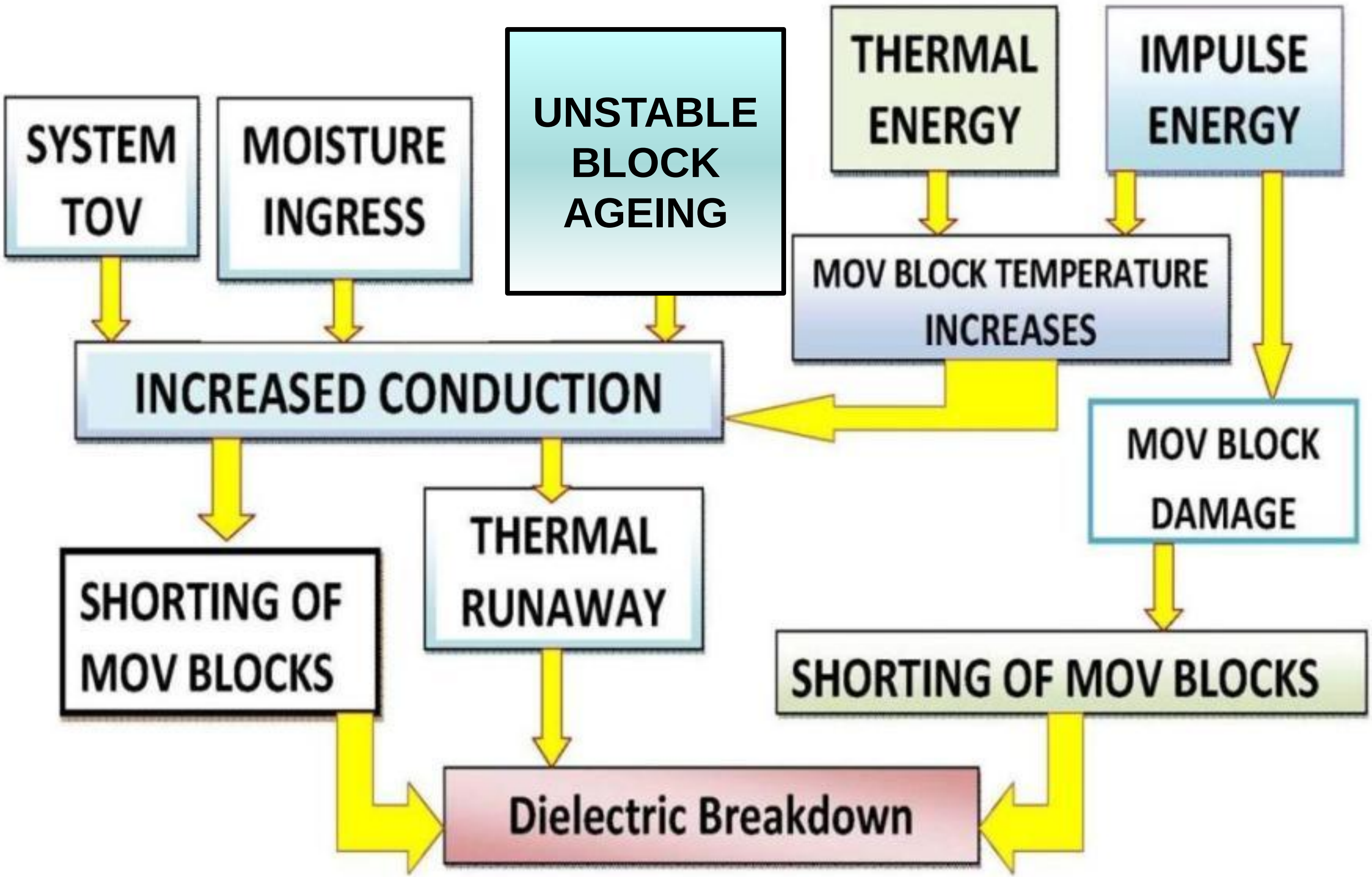
  120kV – Single unit

  216kV- Single unit or two units

  336kV – two units

  624kV- Three units
- For the same system voltage the rating of the arrester and energy level to be freezed for all the utilities in India.

ARRESTER FAILURE MODES



CONCLUSION:

As long as proper selection of voltage rating, charge transfer rating and thermal energy withstand capabilities are considered along with the earthing practice the failure of Arresters does not arise and the application engineer has free hand in selection of the duty of the Arresters as per IEC 60099-4 Ed.03.

THANK "U"