The Application and Selection of Surge Arresters

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AGENDA

- General Introduction
- Insulation Co-ordination
- Over-voltages
- Application
- Limitations
- Selection/Configuration of Surge Arrester

INTRODUCTION

- To achieve insulation coordination.
- Limit voltage rise in the power system.
- To avert any stress in the insulation of any of the equipment.
- To provide a low impedance path to the ground for the current resulting from an overvoltage.

IRONICAL

•Surge arresters have often been classified as non-critical, as compared to other equipments in network.

• They are often overlooked even though they have severe consequences when they fail.

• The proper selection and location of Surge Arrester is vital to ensure power quality issues and prevent system losses.

Insulation Coordination

Coordination between:

- Characteristics of line insulation

  - Critical Flashover voltage is decided from point of view of acceptably low outage rate

- Transformer Insulation level against transients

  - Decided based on surge arrester characteristics and suitable factor of safety

- Max voltage across surge arrester under any condition

Line-Insulation

V_{CFO} of line insulation > 1.3 $V_{a\text{-}max}$

$V_{CFO} \rightarrow$ should be high enough to keep line voltage to acceptable levels. Otherwise

- too many outages
- electrical & mechanical stresses on power transformer due to faults.

If V_{CFO} too high – outages reduce but higher voltages appear across arresters causing higher arrester currents and higher residual voltage

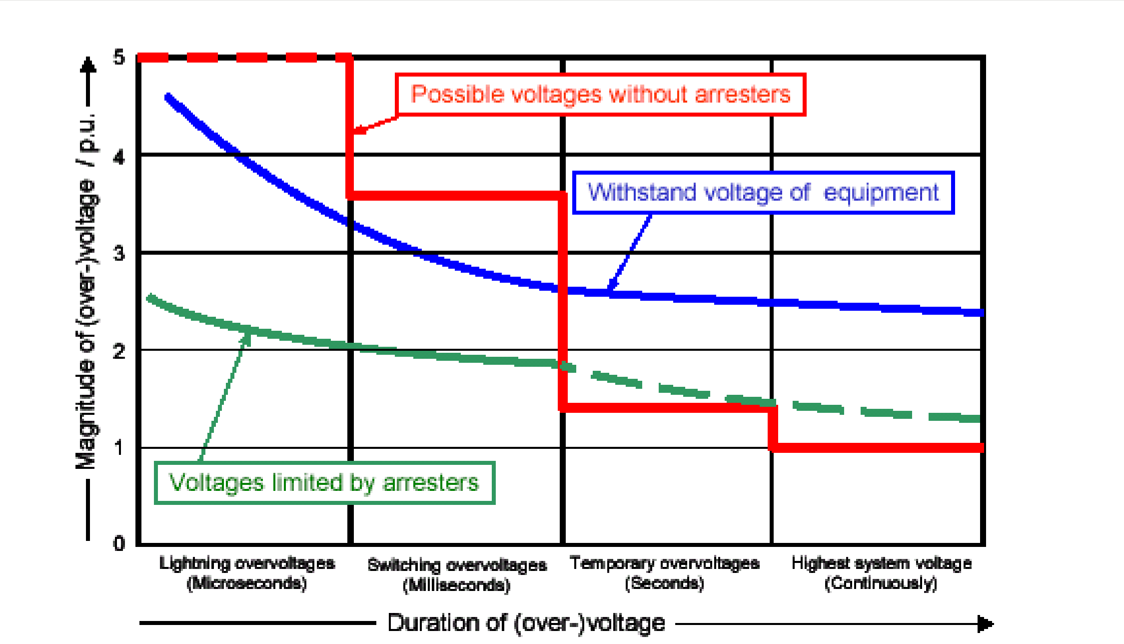
Factor of safety

- To decide Insulation level against transients.
- To consider reduction in voltage withstand-level of transformer insulation level due to-ageing ≈ 15% minimum
- To consider additional voltage due to voltage-drop in leads ≈ 15%

Maximum voltage across SA

- Residual voltage at rated current
- Steep fronted current – residual voltage

Surge arresters constitute an indispensable aid to insulation coordination in electrical power supply systems.



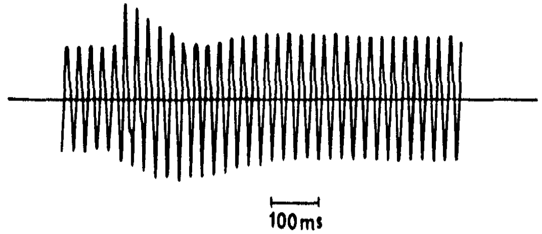
OVER VOLTAGES IN POWER SYSTEM

The overvoltages that can affect the power system can be classified into:

- Power Systems Over voltages
  - Temporary Over-voltages
  - Switching Over-voltages
  - Over-voltages due to lightning.

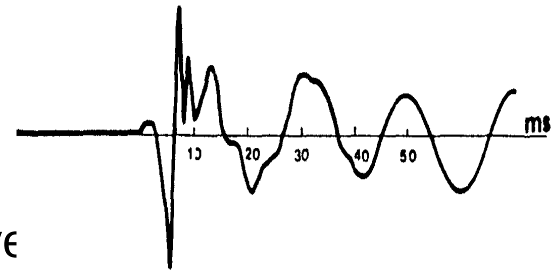
Temporary Overvoltages :Essentially of normal power frequency.

- Due to faults (SLG) $\underset{\sim}{\sim}$ 1.2 pu in effectively grounded systems.
- Duration – one to a few cycles.
- Decide Surge arrester voltage rating.



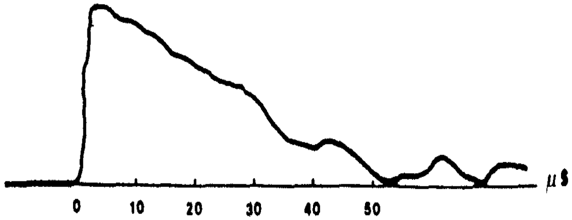
Swtiching Overvoltages

- Due to switching operations in a system.
- It is damped, asymmetric sinusoids.
- The magnitude, frequency & damping vary depending on system conditions at instant of switching.
- Can cause flashover of line insulation at relatively low voltages – hence an outage.
- Switching surges involve enormous energies which have to be discharged essentially by the Surge Arresters



Lightning Overvoltages

- Lightning overvoltages are shorter than the others and very strongly damped.
- They are mainly due to lightning strokes on overhead lines or vicinity
- Highest in magnitude of all overvoltages in Power Systems - can go upto several Mega volts.



CONSIDERATIONS

Three significant reasons can cause the voltage at *the terminals of the equipment to be protected* to take on a considerably higher value:

a) **Traveling wave processes**

b) **Inductive voltage drops**

c) **Discharge currents higher than the arrester nominal discharge current**

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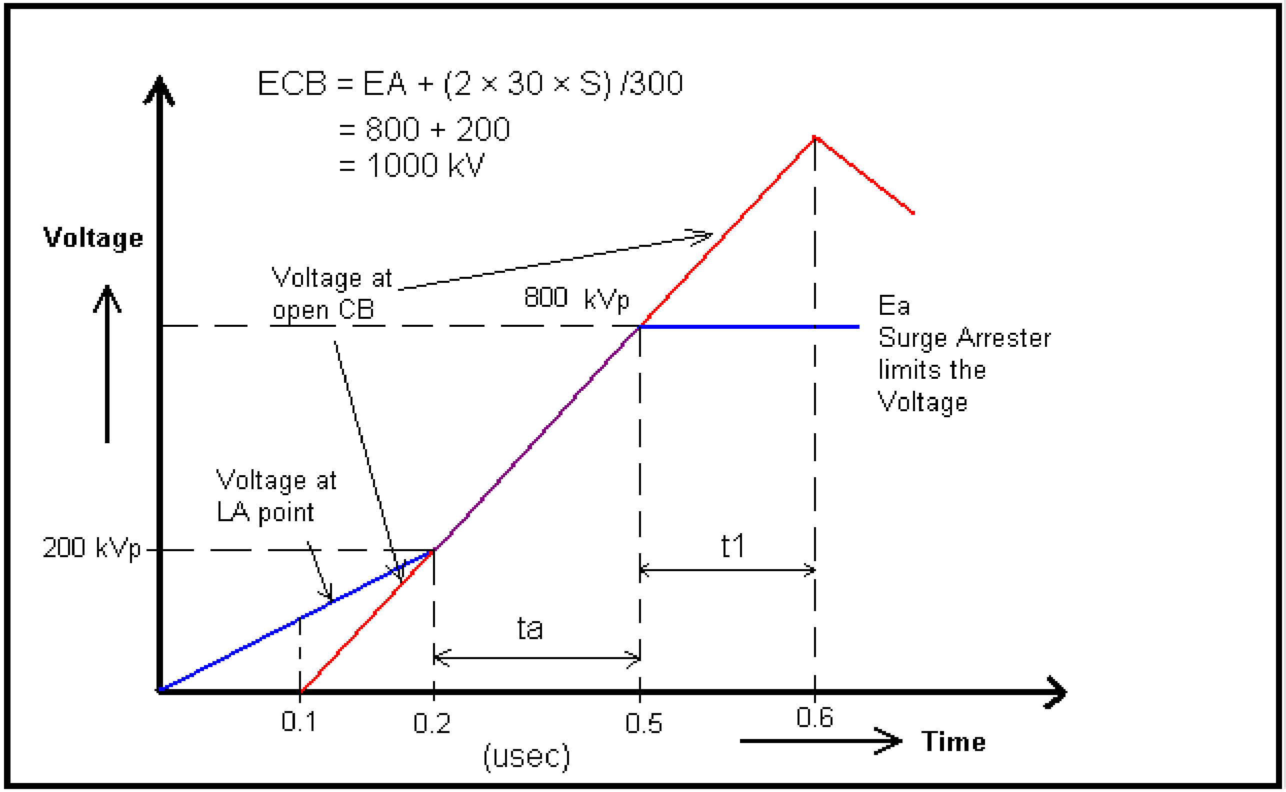
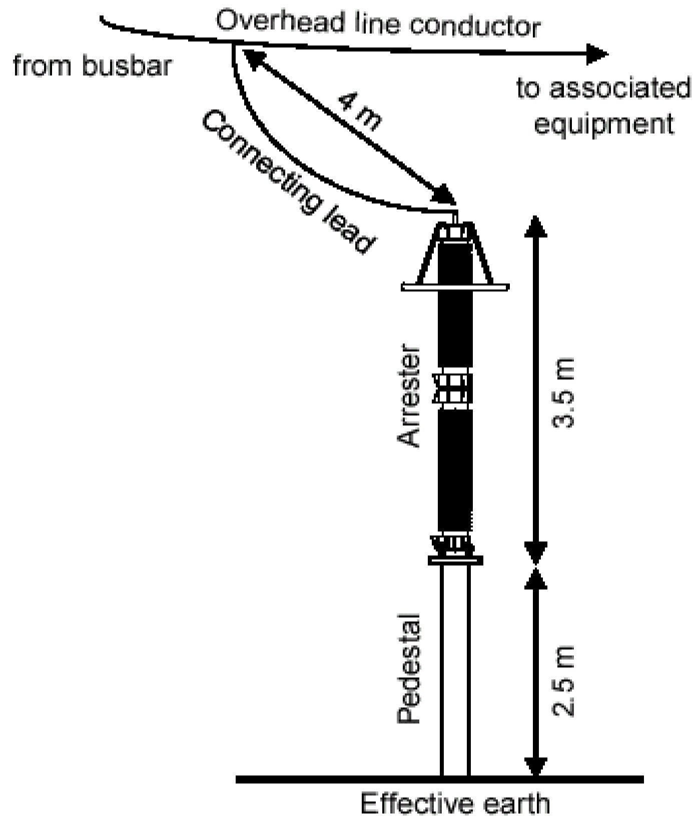
Travelling wave



Inductive voltage drops

- The current path from the termination of the arrester to the overhead line conductor, down to the effective earth, is approx. fifteen meters long.
- Due to inductance of conductor, there is some inductive voltage drop.
- This **voltage drops can superimpose the arrester residual voltage**.



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Discharge currents higher than the nominal discharge current

- The protective level of the arrester is defined as its residual voltage at the nominal discharge current.
- Higher discharge currents may also occur.
- The arrester can withstand this undamaged, but it results in a **higher residual voltage across its terminals depending on the shape of the U-I-characteristic**.

Substation Equipments Insulation level in POWERGRID

	765kV	400kV	220kV	132kV
Power Freq withstand for 1 min	830kV	630kV	460kV	275kV
Lightning Impulse	2100kVp	1550kVp	1050kVp	650kVp
Switching Impulse	1550kVp	1050kVp	-	-

Surge Arrester Ratings in POWERGRID

	765kV	400kV	220kV	132kV
Rated Voltage-10 second rating	624kV	336kV	216kV	120kV
COV	490kV	267kV	168kV	102kV
SIPL-1/2kA	1180/ 1220kVp	670kVp (at 2kA)	500kVp (at 1 kA)	280kVp
LIPL-10/20kA	1480kVp	800/ 850kVp	600kVp	330kVp
kJ/kV	13kJ/kV	12kJ/kV	5kJ/kV	5kJ/kV

LIMITATIONS OF SELECTION

- Higher COV will increase the stability of arrester but will reduce the protective margin
- They are not expected to limit temporary

overvoltages. They must be designed to withstand the voltage without sustaining damage.

- Location of Surge Arrester decides its protective zone.
- Energy handling capability of arrester without causing thermal runaway.
- Mechanical strength of unit.
- Pollution
- Ageing effect of resistor
- Cost

SELECTION OF SURGE ARRESTER

- The proper selection and application of surge arresters in a system involve decisions in four areas:

1. Selecting the arrester voltage rating (TOV).
2. Selecting the class of arrester (Energy).
3. Protective margin of arrester (Residual voltage).
4. Determine where the arrester should be physically located (Protective distance).

Continuous Operating Voltage *Uc*

- Continuous phase-to-earth voltage of the system.
- With allowance to take into account possible harmonics in the system voltage.

- In 400kV system (400/1.732= 231kV), considering high voltage condition and over voltage/ over flux relay provided, system voltages are generally limited to 110% i.e. upto 253 kV.
- 5-6% margin is kept for other factors.
- Hence COV rating upto 270kV should be adequate.

At present, 260kV (1.125p.u.) has been specified as continuous voltage rating for 400kV arrestor and 490kV (1.11p.u.) for 800kV arrestor.

Temporary overvoltage and Rated Voltage *Ur*

•If the temporary overvoltage which occurs in a system for a period of 1sec is known, then this voltage according to U-t characteristic curve corresponds to 1.15 times the arrester rated voltage.

•If no information is available then as per IEC-60071(2) and also as per IEEE-C62., temporary overvoltages may reach values of up to 1.4 p.u. for Earth faults and Load rejection conditions for a time period from a few tenths of a second to up to several seconds.

•**The rated voltage for 400kV arrestor is calculated to be 336kV (1.45p.u.) and for 800kV arrestor it is taken as 624kV (1.41p.u.)**

LINE DISCHARGE CLASS

- Energy stored in a line of capacitance C_L at a switching surge voltage of V_{SS} is:

$$W_S = \frac{1}{2} C_L V_{SS}^2$$

where, C_L increases with line length and voltage increases with system voltage.

- Hence for system up to 132kV Lightning surges are more important, however for 220kV and above switching surges play a vital role in selection of Surge arresters.

- The energy handling capability of an arrester is specified by Line discharge class of arrester.
- However, higher line discharge class is recommended for arrestors with lower residual voltage levels to account for larger protective margins.
- **The discharge class for 400kV arrester is class-4 and for 800kV arrester is class 5.**

PROTECTIVE DISTANCE

- A detailed system study is required to determine how far a surge arrester can be located away from the equipment and still provide adequate protection.
- In the absence of system studies, approximate calculations for evaluation of the increase in surge voltage due to separation is evaluated by the method

U = Ua + (2 x S x L)/v where

Ua = Arrester residual voltage

S = Steepness of incoming surge

L= Distance between arrester and protected object

v = Velocity of incoming surge

U = Voltage at protected object

L = a+b where a= separation distance and b=b1+b2 = lead length

- For 400kV system considering wave of 2000kV per microsec, the protective distance calculated according to above formula is

  L = (1425/1.15-800)*300/2*2000

  L=32.9m

1200kV AC TRANSMISSION LINE TECHNICAL ARAMETERS

Sr.No.	Parameters	Value
1	Nominal Voltage	1150 kV
2	Highest voltage	1200 kV
3	Resistance	4.338×10^{-7} p.u./km
4	Reactance	1.772×10^{-5} p.u./km
5	Susceptance	6.447×10^{-2} p.u./km
6	Surge Impedance Loading (SIL)	6030 MW
7	Surge Impedance	239 Ohm

Switching Over Voltage

Source Strength	Switching Over Voltage (p.u)			
MVA	W/O PIR	300Ω	600Ω	700Ω
10,000	2.27	1.51	1.71	1.78
15,000	2.17	1.36	1.55	1.58
20,000	2.07	1.35	1.50	1.52

Temporary Over-voltages

Source Strength	**Temporary Over Voltage(p.u)**	
MVA	Without Line Reactor	With Line Reactor
10,000	1.58	1.33
15,000	1.48	1.31
20,000	1.45	1.30

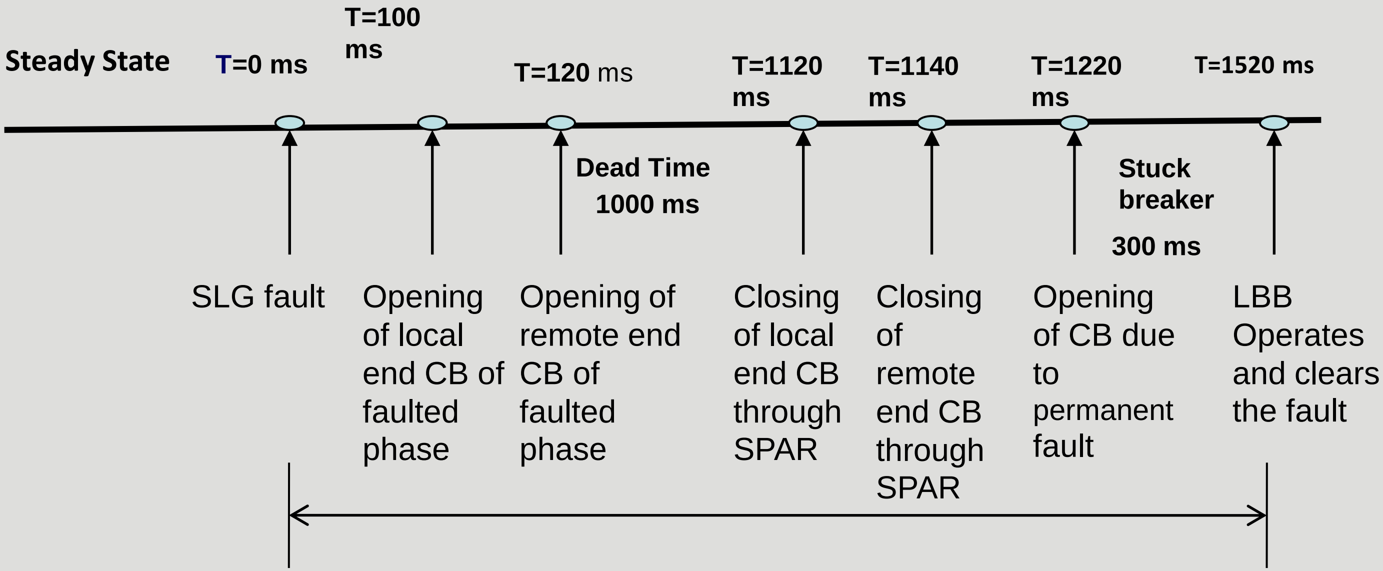
Characteristics of the 850kV Surge Arrester

Sr.No.	Surge Arrester Current (kA)	Residual Voltage (kVp)
1	0.5	1380
2	1.0	1440
3	2.0	1500
4	10.0	1600
5	20.0	1700

The salient features of Surge Arrester (SA) are as under:

- Rated Voltage as 850kVrms of SA shall take care power frequency voltage upto 1.15 p.u. for 10 seconds and 1.4 p.u. for about 1second.
- Switching Impulse Protective level at 2.0kA is 1500kV and hence about 20% protective margin are available for 1200kV. Equipments with 1800kV Switching Impulse withstand voltage.
- Lightning Impulse Protective Level at 20.0 kA is 1700kV and hence margins for bay equipments with BIL- 2400kV and for transformers with BIL-2250kV.
- Lightning Arresters to be installed at line entry, transformers, reactors and at the bus.

Surge Arrester Energy



Surge Arrester Energy accumulation

Calculated Energy Requirements = 35 MJ for TOV + 2 shots of 5 MJ each of class-5 discharges + margins

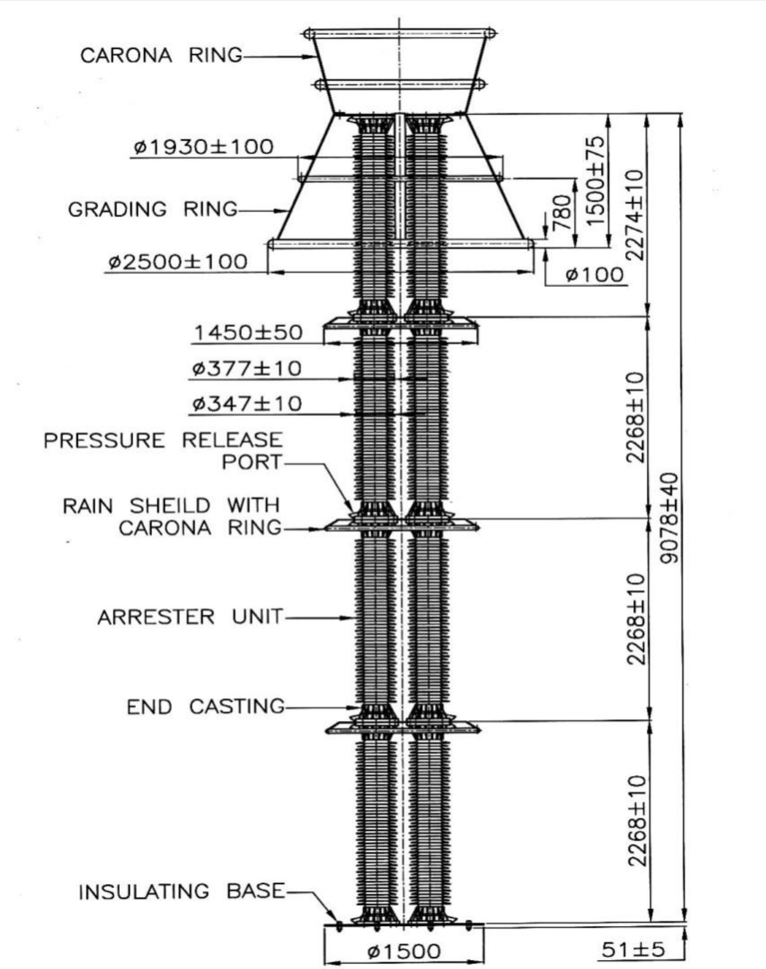
= 55MJ

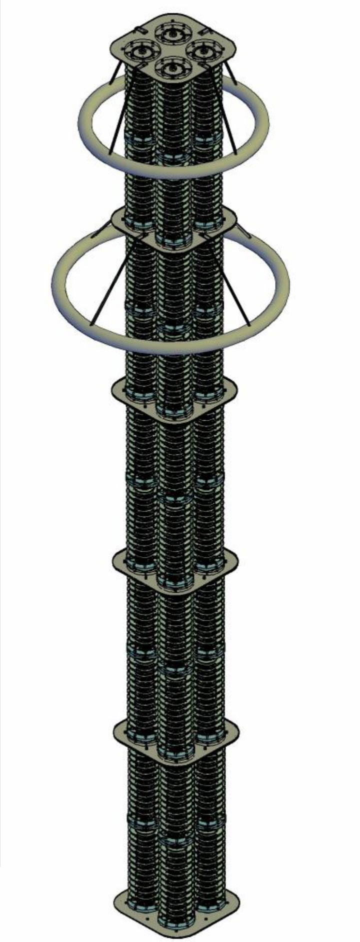
SURGE ARRESTER PARAMETER

SA Class	5
Rated Voltage	850 kVrms
Continuous Operating Voltage(COV)	723 kVrms
Nominal discharge current	20 kA
Lightning Impulse residual voltage	1700 kVp at 20 kA
Switching Impulse residual voltage	1500 kVp at 2 kA
Lightning Impulse Protective level	41% for Equipment, 32% for Transformer
Switching Impulse Protective level	20%
Energy level	55 MJ

Sl.No	Parameters	Tested Data	
1	Number of arrester in Parallel	4 Parallel columns	
2	Zinc Oxide Element	Outer Diameter : 136 mm & Thickness 21mm Inner Diameter : 52mm	
3	Rating of Zinc Oxide Element	3.15kV RMS	
4	No. of Zinc Oxide Blocks in One Column	$\frac{850}{3.15}$	= 270 Blocks
5	Residual Voltage (Protection Level) LIPL with 4 Parallel Columns at NDC of 20kA (20kA ÷ 4 = 5kA per column)	$\frac{1700}{270}$	= 6.3kV at 5kA.
6	Residual Voltage (Protection Level) SIPL with 4 Parallel Columns at NDC of 2kA (2kA ÷ 4 = 0.5kA per column)	$\frac{1500}{270}$	= 5.56kV at 0. 5kA.
7	Energy Handling capability for 4 Parallel Column	Total Energy handling of the arrester : V X I X T XNo.of DiscsXNo.of ColumnsX2(single application) 5.56 X 1000 V X 2500A X 2000 X 10-6sec X 270 X 4 X 2 = 60MJ	

4 column Surge Arrester





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