Surge Arresters

Application and Selection

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Adria Jones

Functions of Surge Arresters

- Mounted in parallel to the transformer/equipment
- Handle over voltage surge, clamp it down
- Absorb energy from the surge
- Discharge the surge current to the ground
- Protect the transformer / equipment
- Dissipate the energy and remain thermally stable
- Provide reliable & predictable service, safe performance

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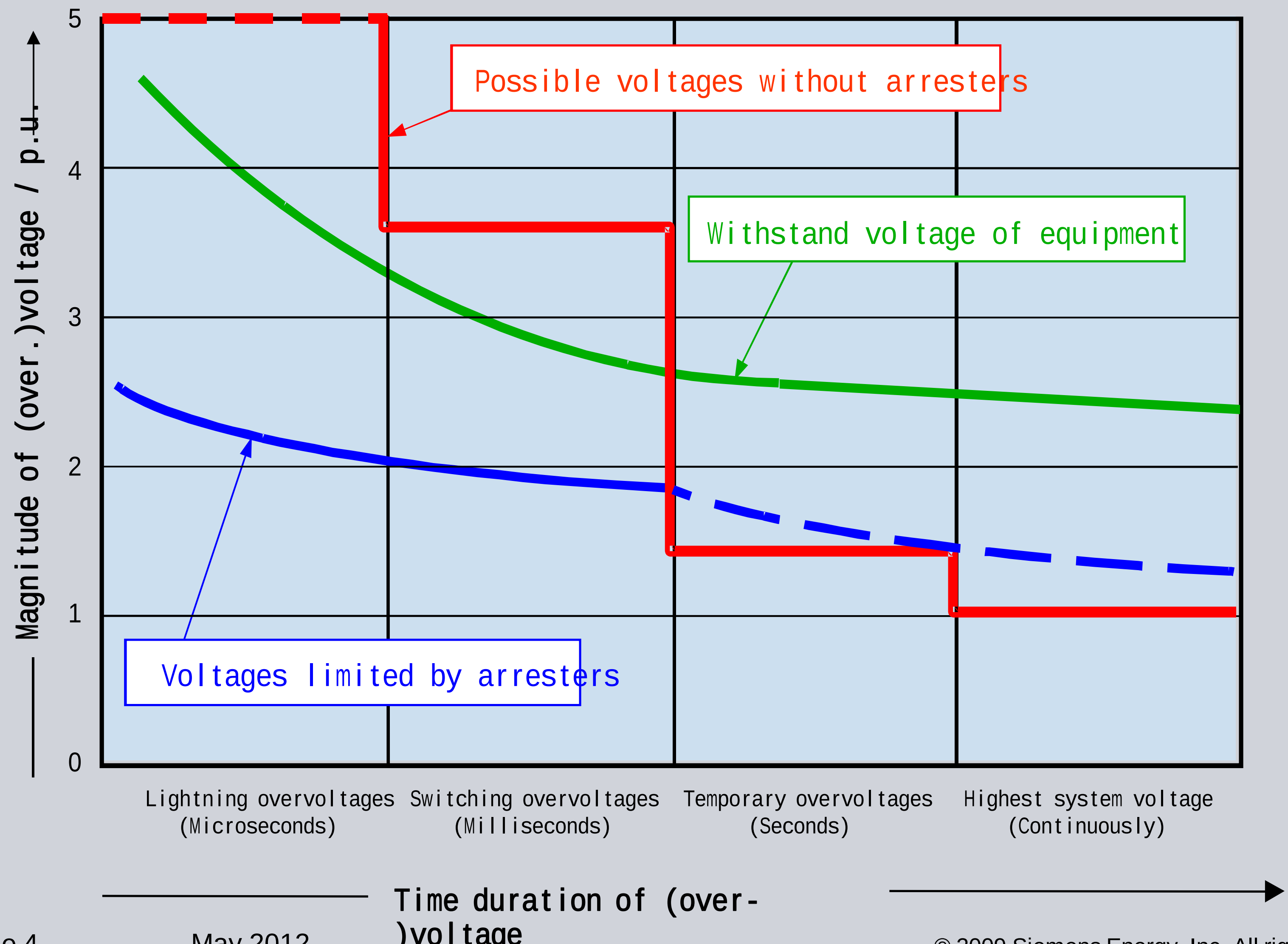
Sources of Surges

- ❑ Lightning
- ❑ Switching
- ❑ System generated TOV

Fundamentals of Insulation Coordination



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Design Transformations

- SiC + Porcelain (thru 1978)
- MOV + Porcelain (1978 thru 1986)
- MOV + Polymer (1986 thru now)

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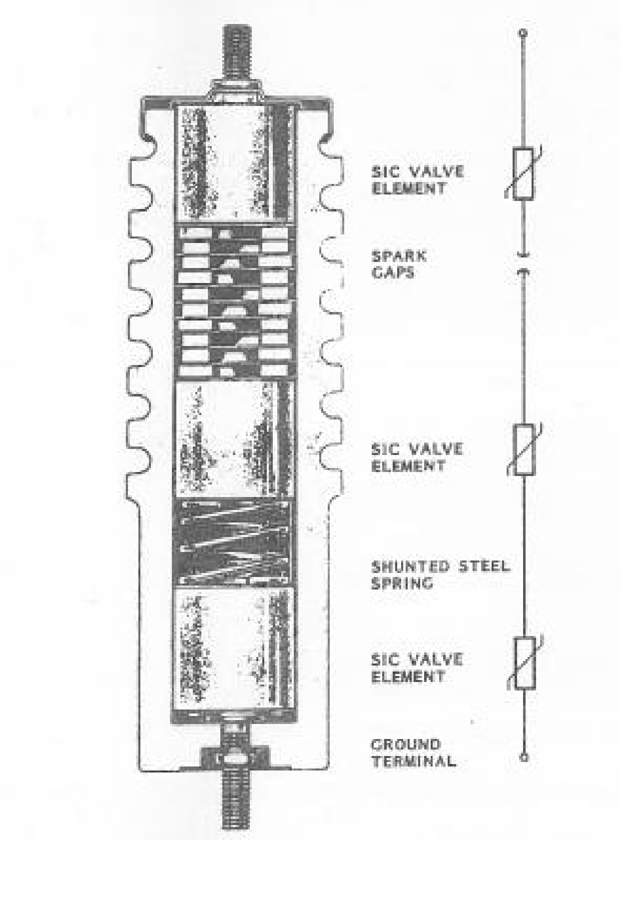
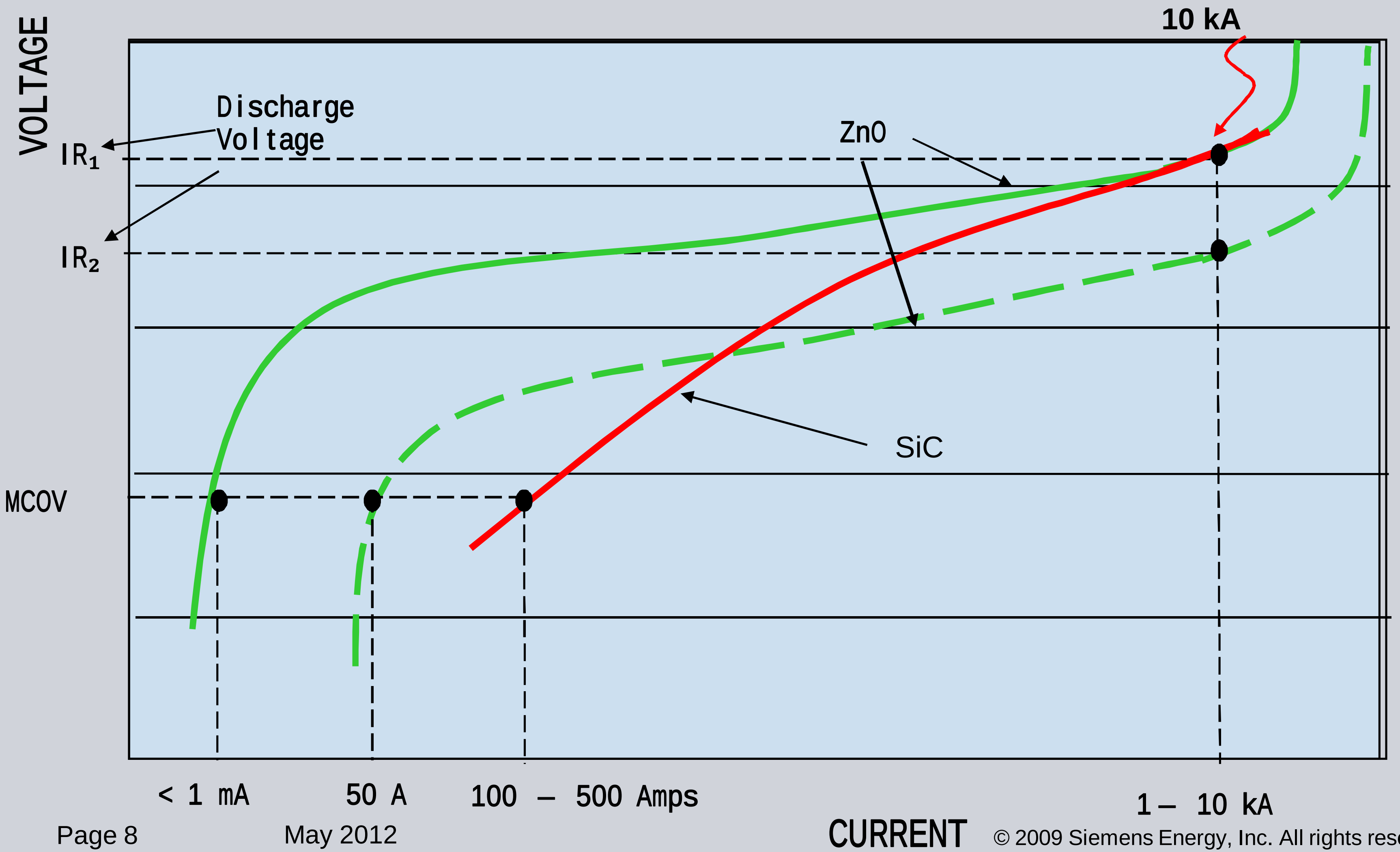
Internal Elements and Housing

- MOV Vs SiC
- Porc Vs SR
- SR Vs EPDM

Silicone Carbide Gapped Arrester



- ❑SiC blocks in Porcelain housing with gap structure
- ❑Design prior to mid 70s
- ❑Had serious problems of
  - -Moisture Ingress
  - -Unstable Protective Levels
  - -Violent Failures



10 kA
VOLTAGE
Discharge
Voltage
IR_1
IR_2
ZnO
SiC
MCOV
< 1 mA
50 A
100 – 500 Amps
1 – 10 kA
CURRENT

Silicone Housed Surge Arresters
- Effect of Hydrophobicity

Different Polymers: Silicone vs. EPDM

Silicone (+++)

Highly Hydrophobic (water-repellent)

- **UV-resistant**
  → the best pollution & long-term stability

- **Non-hydrophobic**
- **Low UV Rating**
  → poor pollution and long-term stability

EPDM (- - -)

Refer to Dow Corning R & D Paper

Silicone rubber for electrical insulators

Jim Goudie
Dow Corning Corporation
USA

Most electric power transmission is done via overhead lines, with insulators providing mechanical support and electrical protection. The two predominant designs are suspension- and post-type, both characterized by angled 'sheds' that direct water off the device and maximize the leakage distance between line and tower. (Leakage distance is the shortest path along the surface of the insulator from conductor to ground.)

Ceramic and glass have long been the materials of choice for high-voltage insulators and lightning arresters, offering good resistance to electrical stress and outdoor exposure without significant deterioration. The pros and cons of these materials are well known, and their use is addressed in acknowledged international standards.

The market for composite insulators is growing steadily, both in long-rod line applications and hollow core station insulators. Composite designs typically use engineered polymers which offer higher mechanical strength, greater design flexibility, reduced weight, and lower breakage rates than ceramic components. The emerging shift to composites adds new importance to the debate over which polymeric material should be used for the housing. Insulator field experience and extensive, multi-stress lab testing of different elastomer formulations have shown silicone's unique surface behavior to be an advantage in these applications

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- ❑Test data Compare SR against EPDM and PORCELAIN
- ❑Recommends SR as the best insulation for Power Systems Applications
- ❑Most utilities prefer SR for housings and insulators

Types of Surge Arresters

- Station Class
- Intermediate Class
- Distribution Class (HD, ND, RP)
- Transmission Line Arresters (TLA)

IEEE

C62.11™

IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV)

IEEE Power Engineering Society

Sponsored by the
Surge Protective Devices Committee

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

22 March 2006

IEEE Std C62.11™-2005
(Revision of
IEEE Std C62.11-1999)

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IEEE

C62.22™

IEEE Guide for the Application of Metal-Oxide Surge Arresters for Alternating-Current Systems

IEEE Power & Energy Society

Sponsored by the
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IEEE
3 Park Avenue
New York, NY 10016-5997, USA

3 July 2009

IEEE Std C62.22™-2009
(Revision of
IEEE Std C62.22-1997)

Surge Arresters Classification
Performance Requirements
(Table B.1 of Annex B from IEEE Std C62.11)

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Table B.1—Surge arrester classification prescribed test requirements

Class	Rated voltage (kV)		Lightning impulse classifying current (kA)	Switching surge classifying current (A)	Minimum high-current short-duration withstand (kA)	Minimum low-current long-duration withstand (A, µs)	Minimum line discharge capability	High-current pressure relief (kA)[a]	Low current pressure relief (A)[a]
	Duty cycle	MCOV							
Station	3–48	2.55–39	10	500	65	—	Table 11	40-65	400–800
	54–312	42–245	10	500-1000	65	—	Table 11	40-65	400–800
	396–564	318–448	15	2000	65	—	Table 11	40-65	400–800
	576–612	462–485	20	2000	65	—	Table 11	40-65	400–800
Intermediate	3–144	2.55–115	5	500	65	—	Table 11	16.1	400–800
Distribution, heavy duty[b]	3–36	2.55–29	10	—	100	250, 2000	—	—	—
Distribution, normal duty[b]	3–36	2.55–29	5	—	65	75, 2000	—	—	—
Distribution, light duty[b]	3–36	2.55–29	5	—	40	75, 2000	—	—	—

[a] Test values for arresters with porcelain tops have not been standardized.
[b] Riser pole, liquid-immersed, and deadfront are arrester types, not classifications.

Key Features for Arrester Selection

- Protection (IR, TOV, Energy)
- Durability (MOV blocks, Construction, Mechanical strength, Creepage distance, PD level)
- Safety (Non-fragmenting design, Moisture proof)

Current Designs

- Gapless MOV
- Poly Wrapped with Grease or Dry interface
- Poly Cage – Directly molded
- Poly Tube – Directly molded
- Metal Enclosed (GIS)

Porcelain Housed Surge Arresters for High Voltage

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O-ring seal

Sulphur cement bonding
(non-porous)

Housing filled with nitrogen
to avoid oxygen
(causing moisture)

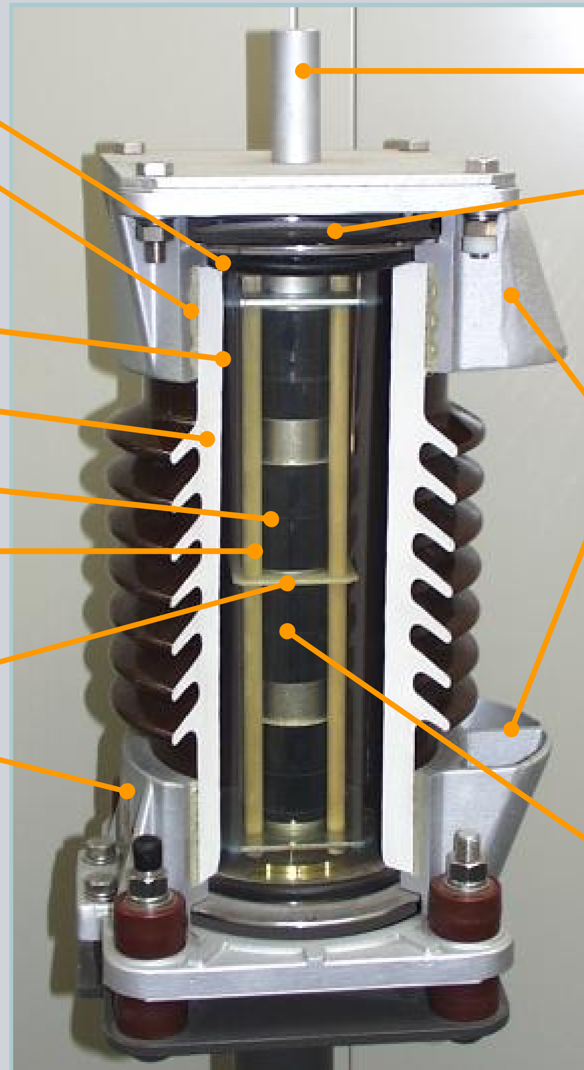
Porcelain housing

MO column

Support for MO column
Material: FRP rods

Fixing plate (FRP)

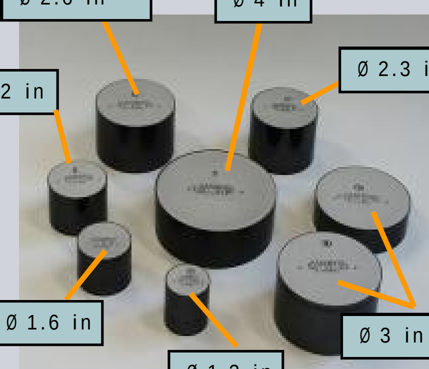
Aluminium flange



Bolt terminal
(flat terminal available)

Pressure relief diaphragm
Material: Stainless steel

Pressure relief vent
Material: Aluminium



Silicone Housed Surge Arresters for High Voltage
High Strength Cage Design, Directly Molded

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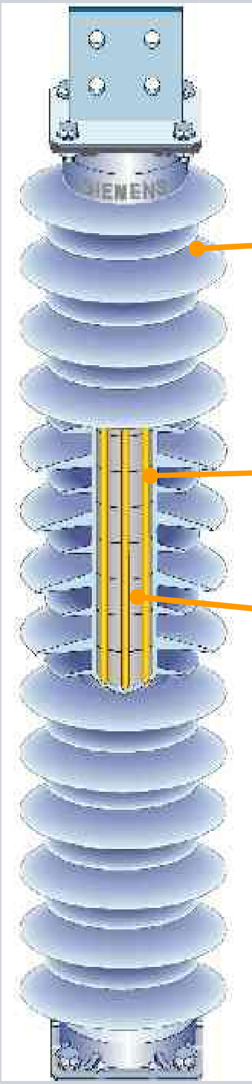

Silicone rubber housing
Material: LSR
directly molded onto the active part

Cage of 8 FRP rods
as reinforcement structure

Column of MO resistors
totally surrounded by silicone rubber (SR)

Polymer Housed Surge Arresters for High Voltage - Wrapped Design with Grease Interface

- EPDM housing in multiple units
- Not directly moulded
- No mechanical member inside
- Deflects under load -- potential for moisture ingress

Ploymer Housed Surge Arresters for High Voltage Cantilever Strength Compared

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Cantilever Strength (inch -lbs)

	MFR - 1	MFR - 2	MFR - 3
	Directly Molded **SR**	**Wrapped (*)** **EPDM**	**Directly Molded** **SR**
WORKING	**24,782**	**10,000 – 3,000**	**22,125 – 7,000**
ULTIMATE	**35,400**	**20,000 – 5,000**	**35,400 – 11,500**

(*) JOINTS BETWEEN THE RUBBERS – POOR MECHANICALS -- HIGH DEFLECTION

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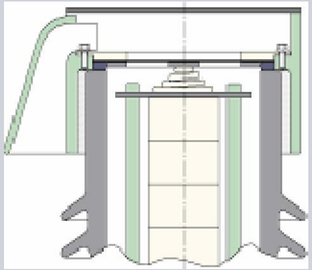
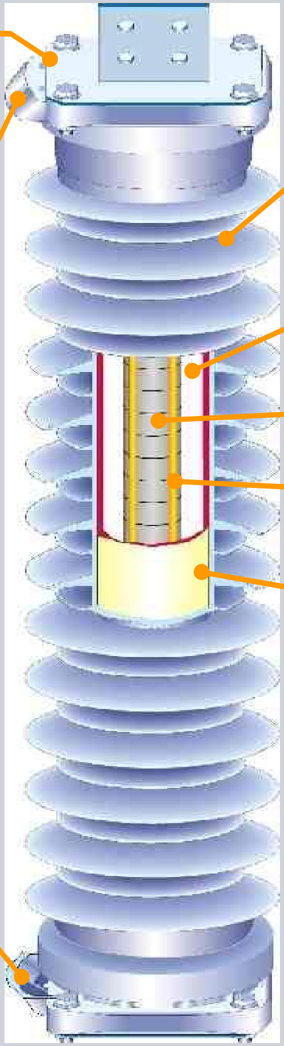
Silicone Housed Surge Arresters for High Voltage
Extra High Strength Tube Design

Pressure relief diaphragm
Material: Stainless steel



Pressure relief vent
Material: Aluminium



Silicone rubber sheds
Material: SR
directly molded onto
FRP tube

Housing filled with nitrogen
to avoid oxygen

MO column

Support for MO column
Material: FRP rods

FRP tube for extra – high mechanical strength

Silicone Housed Surge Arresters for High Voltage
Comparison of Cantilever Strength Compared

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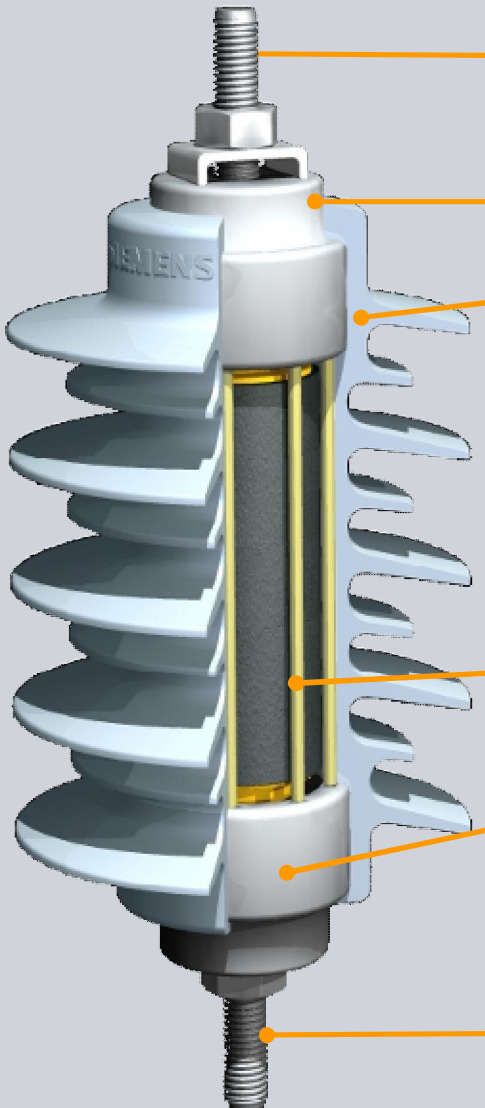
Cantilever Strength (inch - lbs)

	MFR - 1	MFR - 2	MFR - 3
	Tube Design **SR**	**Hollow Core** **SR**	**Tube Design** **SR**
WORKING	**446,000**	**35,000**	**168,000**
ULTIMATE	**637,000**	**70, 800**	**240,000**

Typical porcelain arresters:
Ultimate 150,000 in-lbf
Working 60,000 in-lbf

Directly Molded SR Housed Surge Arresters for Distribution Systems
(Completely sealed, one piece construction)



stainless steel stud

Aluminium end fitting

Silicone Rubber sheds
directly molded on active part

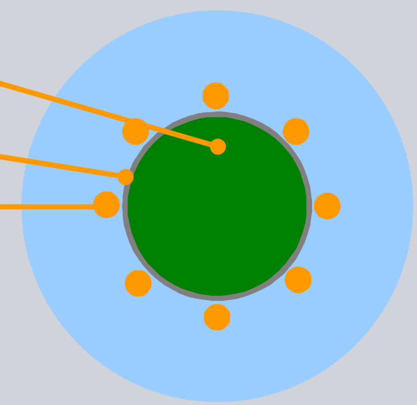
Metal oxide varistor (MOV)

Glass coating on MOV block

Cage of FRP Rods
surrounding MOV column

Aluminium end fitting

stainless steel stud



Horizontal cross sectional view of surge arrester

“Gapped” SR housed Surge Arrester for Distribution Systems

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Wrapped Design, EPDM Housed
Surge Arrester for Distribution Systems

Fibre-glass wrapped around MOV resistor column

Pre-manufactured EPDM-housing pushed over the wrapped core impregnated with grease

Cover plate with grease

Screw used for "sealing" with Top Cap plate

Arrester Terms and Definitions

- ❑ MOV
- ❑ MCOV
- ❑ Duty Cycle voltage
- ❑ Discharge Voltage
- ❑ BIL
- ❑ Protective Margin
- ❑ TOV

- ❑ Short circuit / Pressure relief rating
- ❑ Creepage distance
- ❑ Cantilever Strength
- ❑ Grading Ring
- ❑ Corona Ring

Arresters Ratings
Duty Cycle and MCOV
(Table 1. of IEEE Std C62.11)

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IEEE Std C62.11-2005
IEEE Standard for Metal-Oxide Surge Arresters for AC Power Circuits (>1 kV)

Table 1—Arrester ratings[a]

Duty-cycle voltage (kV rms)	MCOV (kV rms)	Duty-cycle voltage (kV rms)	MCOV (kV rms)
3	2.55	144	115
6	5.1	168	131
9	7.65	172	140
10	8.4	180	144
12	10.2	192	152
15	12.7	228	180
18	15.3	240	190
21	17	258	209
24	19.5	264	212
27	22	276	220
30	24.4	288	230
36	29	294	235
39	31.5	312	245
45	36.5	396	318
48	39	420	335
54	42	444	353
60	48	468	372
72	57	492	392
90	70	540	428
96	76	564	448
108	84	576	462
120	98	588	470
132	106	612	485

[a]For ratings not shown, consult with manufacturer.

Surge Arrester's Application Data

Refer to Manufacturers' Catalog

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Electrical Characteristics													Mechanical Characteristics				
Duty cycle voltage	MCOV	TOV Capability[1]	Protective level Maximum discharge voltage									Arrester order number	Creepage distance	Flashover distance	LIWV[3]	Height „H"	Weight
			FOW[2]	for 8/20 µs						for 45/90 µs							
[kV]	[kV]	for 0.1 s [kV]	[kV cr]	1.5 kA [kV cr]	3 kA [kV cr]	5 kA [kV cr]	10 kA [kV cr]	20 kA [kV cr]	40 kA [kV cr]	250 A [kV cr]	500 A [kV cr]		[inch]	[inch]	[kV]	[inch]	[lbs]
9	7.65	11.9	24.2	19.0	19.8	20.7	22.0	24.5	27.8	17.2	17.6	3EL2 009-2PC31-4NH5	59.1	16.0	235	19.0	35
10	8.4	13.1	26.4	20.7	21.6	22.6	24.0	26.7	30.3	18.8	19.2	3EL2 010-2PC31-4NH5	59.1	16.0	235	19.0	36
12	10.2	15.9	31.9	25.0	26.1	27.3	29.0	32.2	36.6	22.7	23.2	3EL2 012-2PC31-4NH5	59.1	16.0	235	19.0	36
15	12.7	19.8	39.6	31.0	32.4	33.9	36.0	40.0	45.4	28.1	28.8	3EL2 015-2PC31-4NH5	59.1	16.0	235	19.0	36
18	15.3	23.9	47.3	37.0	38.7	40.5	43.0	47.8	54.2	33.6	34.4	3EL2 018-2PC31-4NH5	59.1	16.0	235	19.0	37
21	17.0	26.5	55.0	43.0	45.0	47.0	50.0	55.5	63.0	39.0	40.0	3EL2 021-2PC31-4NH5	59.1	16.0	235	19.0	37
24	19.5	30.4	63.8	49.9	52.2	54.6	58.0	64.4	73.1	45.3	46.4	3EL2 024-2PC31-4NH5	59.1	16.0	235	19.0	37
27	22	34.3	71.5	55.9	58.5	61.1	65.0	72.2	81.9	50.7	52.0	3EL2 027-2PC31-4NH5	59.1	16.0	235	19.0	38
30	24.4	38.1	79.2	62.0	64.8	67.7	72.0	80.0	90.8	56.2	57.6	3EL2 030-2PC31-4NH5	59.1	16.0	235	19.0	38
36	29.0	45.2	94.6	74.0	77.4	80.9	86.0	95.5	108	67.1	68.8	3EL2 036-2PF31-4NH5	94.4	24.8	365	27.8	47
39	31.5	49.1	103	80.9	84.6	88.4	94.0	104	119	73.4	75.2	3EL2 039-2PF31-4NH5	94.4	24.8	365	27.8	48
45	36.5	56.9	119	92.9	97.2	102	108	120	136	84.3	86.4	3EL2 045-2PF31-4NH5	94.4	24.8	365	27.8	48
48	39	60.8	127	99	104	108	115	128	145	89.7	92.0	3EL2 048-2PF31-4NH5	94.4	24.8	365	27.8	49
54	42	65.5	143	112	117	122	130	144	164	101	104	3EL2 054-2PF31-4NH5	94.4	24.8	365	27.8	50
60	48	74.9	158	124	130	135	144	160	182	112	115	3EL2 060-2PF31-4NH5	94.4	24.8	365	27.8	51
72	57	88.9	190	149	156	163	173	192	218	135	138	3EL2 072-2PJ31-4NH5	151	38.8	571	41.9	65
90	70	109	238	186	194	203	216	240	272	169	173	3EL2 090-2PJ31-4NH5	151	38.8	571	41.9	68
96	76	119	253	198	207	216	230	255	290	179	184	3EL2 096-2PJ31-4NH5	151	38.8	571	41.9	69
108	84	131	285	223	233	244	259	288	326	202	207	3EL2 108-2PM31-4NH5	179	45.9	676	48.9	77
111	88	137	293	229	239	250	266	295	335	208	213	3EL2 111-2PM31-4NH5	179	45.9	676	48.9	77
120	98	153	317	248	259	271	288	320	363	225	230	3EL2 120-2PM31-4NH5	179	45.9	676	48.9	79
132	106	165	349	273	285	298	317	352	400	247	254	3EL2 132-2PQ32-4NH5	245	54.7	900	69.4	99
144	115	179	381	298	311	325	346	384	436	270	277	3EL2 144-2PQ32-4NH5	245	63.6	900	69.4	108
168	131	204	443	347	363	379	403	447	508	314	322	3EL2 168-2PJ32-4NH5	301	77.6	900	83.5	132
172	140	218	454	355	372	388	413	459	520	322	330	3EL2 172-2PJ32-4NH5	301	77.6	900	83.5	133
180	144	225	475	372	389	406	432	480	544	337	346	3EL2 180-2PJ32-4NH5	301	77.6	900	83.5	134
192	152	237	507	397	415	433	461	512	581	360	369	3EL2 192-2PJ32-4NH5	301	77.6	900	83.5	137
228	180	281	602	471	492	514	547	607	689	427	438	3EL2 228-2PW32-4NH5	329	84.6	1000	90.5	149
240	190	296	634	495	518	542	576	639	726	449	461	3EL2 240-2PW32-4NH5	357	91.7	1000	97.5	155
258	209	326	652	516	534	558	593	652	712	469	480	3EL2 258-3PW42-4NH5	329	84.6	1000	96.7	153
264	212	331	668	528	546	571	607	668	728	480	492	3EL2 264-3PW42-4NH5	329	84.6	1000	96.7	155
276	220	343	699	553	572	597	635	699	762	502	514	3EL2 276-3PW42-4NH5	329	84.6	1000	96.7	156
288	230	359	728	576	596	622	662	728	794	523	536	3EL2 288-3PM42-4NH5	357	91.7	1100	104	165
294	235	367	744	588	608	636	676	744	811	534	548	3EL2 294-3PM42-4NH5	357	91.7	1100	104	166

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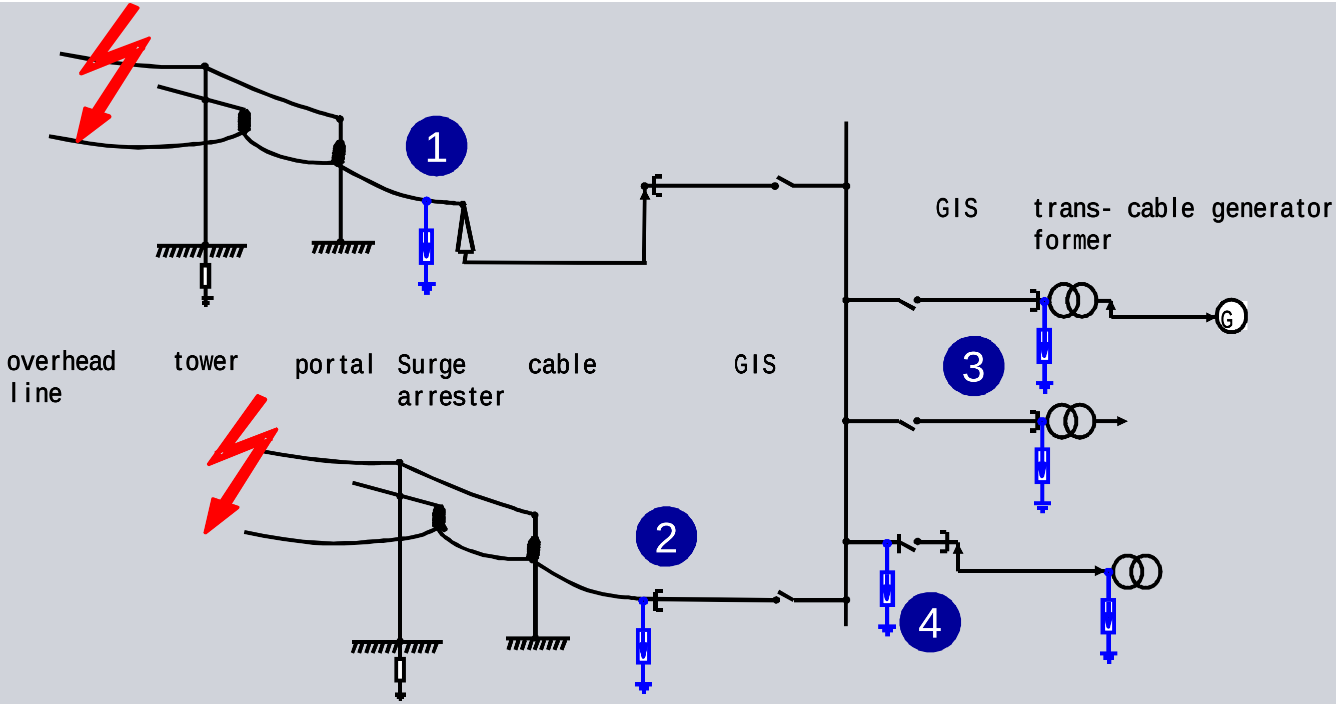
Recommeded Installation Points



- generally at transitions overhead line - cable
- generally at the entrance of overhead lines into a station
- usually in the HV-bushing area of transformers
- additionally at breakers

Service Conditions
Arresters Applications
Per IEEE Std. C62.11

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Usual Service Conditions :

- Temperature : (-) 40 to (+) 40 degrees C ambient air ; arresters max. 60 C
- Altitude 1800 meters (6000 ft.)
- 48 – 62 Hz
- Upright mounting

Unusual Service Conditions :

- Higher temperatures
- Higher altitude
- Highly contaminated environments
- High mechanical , wind, and seismic loads
- Underhung, horizontal mounting

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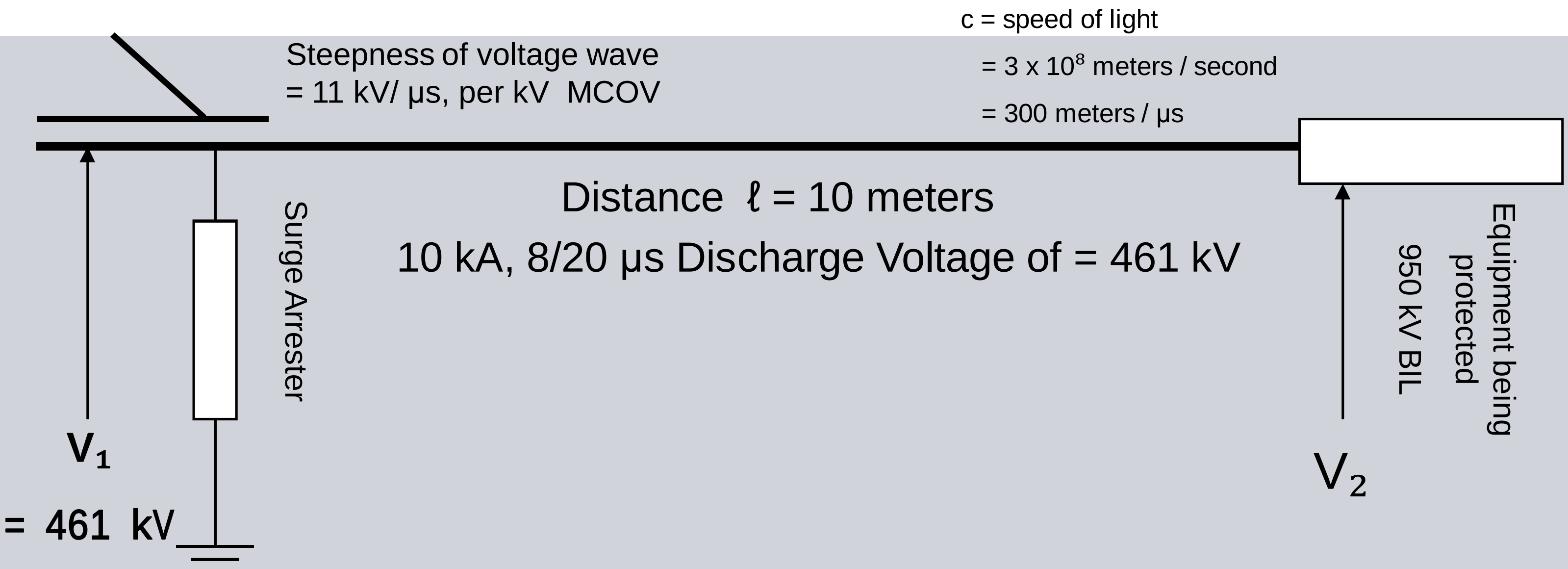
Arrester Selection
System Parameters Required

- ❑ Equipment being protected and its BIL
- ❑ Nominal System Voltage - U_n
- ❑ Maximum System Voltage - $U_m = U_n \times 1.05$
- ❑ Maximum L – G voltage, i.e. MCOV
- ❑ Grounding Condition (grounded system ?)
- ❑ Expected fault current level
- ❑ Expected TOV
- ❑ Expected switching surge energy
- ❑ Pollution level and creepage distance
- ❑ Excessive mechanical loadings (wind, ice, seismic)
- ❑ Application altitude
- ❑ Temperature range
- ❑ Mounting – Underhung, horizontal?
- ❑ Cap bank ?

Effects of Separation Distance

230 kV System - 950 kV BIL Station
192 kV Rated Arresters / 152 kV MCOV



V_2 = Voltage stress at the equipment 10 meters away from the arrester

$$= V_1 + \frac{2 \times S \times \ell}{C}$$

$$= 461 + \frac{2 \times (11 \times 152)\ \text{kV} / \mu s \times 10\ \text{meters}}{300\ \text{meters} / \mu s}$$

$$= 461 + 112$$

$$= 573\ \text{kV}$$

Protective Margin

$$PM\% = \frac{950 - 573}{573} \times 100$$

$$= \frac{377}{573} \times 100$$

$$= 66\%$$

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Effects of Lead Length

230 kV System - 950 kV BIL
192 kV Rated Arresters / 152 kV MCOV

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Steepness of voltage wave (S) = 11 kV/ µs, per kV MCOV

Z = Surge Impedance = 350 Ω

25 ft. long lead

L = Inductance of the lead

$$= 25\,ft \times 0.4\mu H / ft$$

$$= 10\mu H$$

$$\frac{di}{dt} = \frac{2 \times S}{Z} = \frac{2 \times (11kV/\mu s \times 152)}{350\Omega}$$

$$= \frac{2 \times 1672}{350} = 9.55kA/\mu s$$

Voltage drop due to 25 ft. lead length

$$= L \times \frac{di}{dt}$$

$$= 10 \times 9.55$$

$$= 95.5\,kV$$

Arresters Clearances

Arrester Clearance Calculation

1. Recommended Clearance Table 5 in Application Guide C62.22
2. Quick rough calculation for minimum clearance:
   Use (20 kA, 8/20 Discharge Voltage – IR), air insulation strength of 500 kV/meter, factor for safety of 1.30 to account for variation in atmospheric conditions and discharge current higher than normal

Minimum Clearance

$$= \begin{bmatrix} 20\ kA \\ 8/20 \\ IR \end{bmatrix} \times 1.30$$

Divided by Insulation strength of air

$$= \frac{512 \times 1.30}{500}$$

$$= 1.33\ M$$

$$= 52 \text{ inches}$$

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Altitude Correction for Clearance

- IEEE / ANSI standard considers 1800 meters as normal application altitude.
- Insulation strength of air diminishes with higher altitude.
- Allow 1% additional clearance for every 100 meters beyond 1800 meters.

Example: 10,000 ft. altitude
$\approx$3,000 meters

Therefore, $\frac{3000-1800}{100}=12$% additional clearance

BIL of Arresters Housing

1. Surge Arresters are voltage sensitive devices
2. Clamp the over voltage down below the BIL of the equipment
3. BIL of the Arresters' housing is irrelevant
4. Check insulator withstand capability of the housing (Use paragraph 8.1.2.4 of C62.11 and manufacturer's data sheet).

****Lightning Impulse withstand value must be > 20 kA 8/20 IR x 1.42****

$$= 512 \times 1.42 \qquad \begin{bmatrix} \text{Actual} \\ 850\ \text{kV} \end{bmatrix}$$
$$= 727kV$$

**** Wet power-frequency withstand value > switching impulse discharge voltage x 0.82

$$= 378 \times 0.82 \qquad \begin{bmatrix} \text{Actual} \\ 400\ \text{kV} \end{bmatrix}$$
$$= 310kV$$

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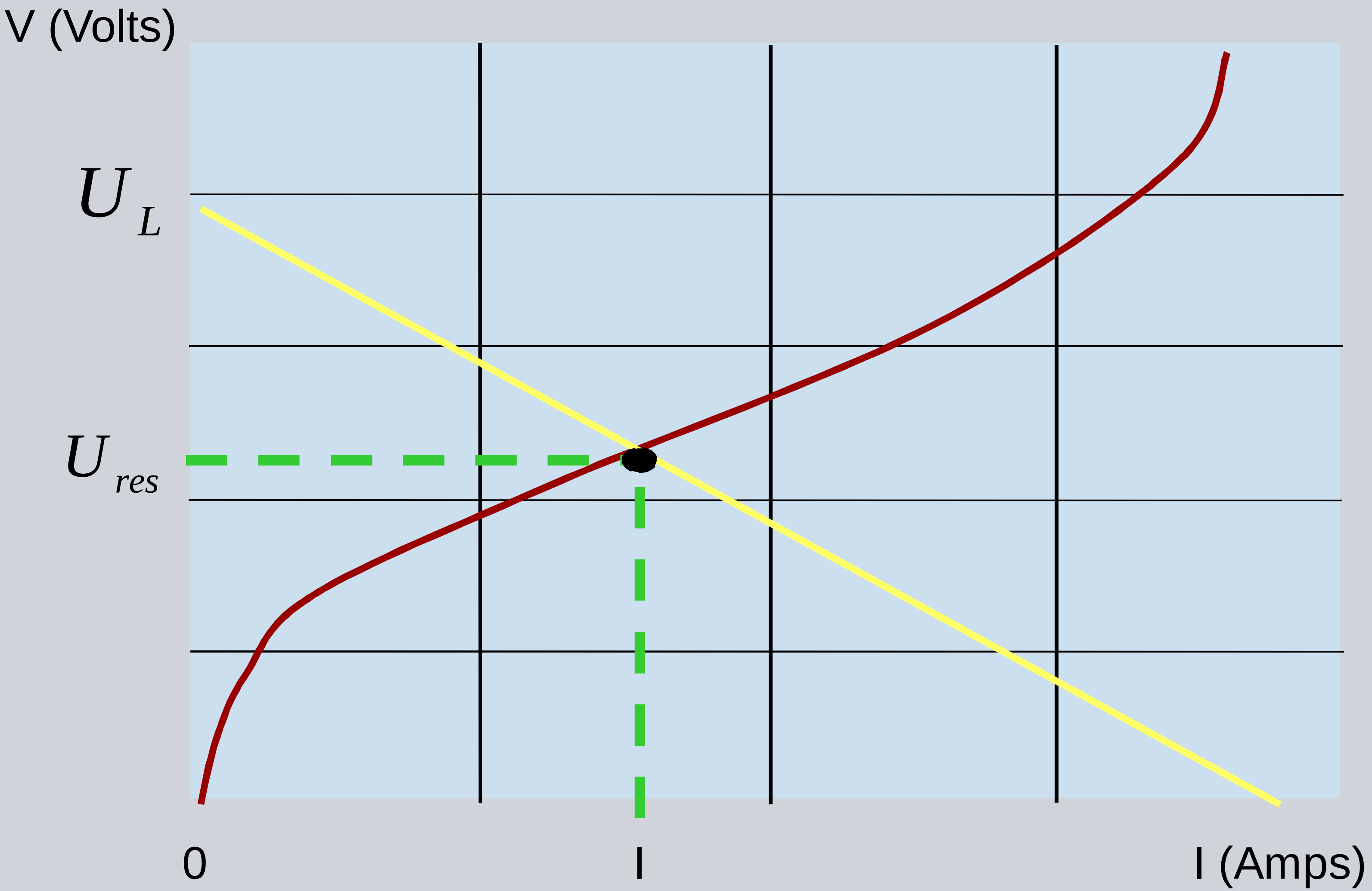
Energy from Switching Surge (Refer Annex G of IEEE Application Guide C62.22)



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Switching Surge Energy Calculation

Energy Discharged into the arrester

= Voltage x Current x (Duration of Switching Surge) Time

$$= U_{res} \times \frac{U_L - U_{res}}{Z} \times \frac{2 \times L}{C} \text{ watt - sec. (or Joules)}$$

$$= 0.021 \times MCOV \times \frac{L}{Z} \text{ kJ/kV of MCOV}$$

U_{L-G} = Max rms L - G voltage i.e. MCOV

U_L = Line charging voltage $\approx \left(U_{L-G} \times \sqrt{2})\right) \times 2.6 \approx \left(MCOV \times \sqrt{2}\right) \times 2.6$

U_{res} = Switching Surge Discharge Voltage $= \left(\text{MCOV} \times \sqrt{2}\right) \times 1.64$

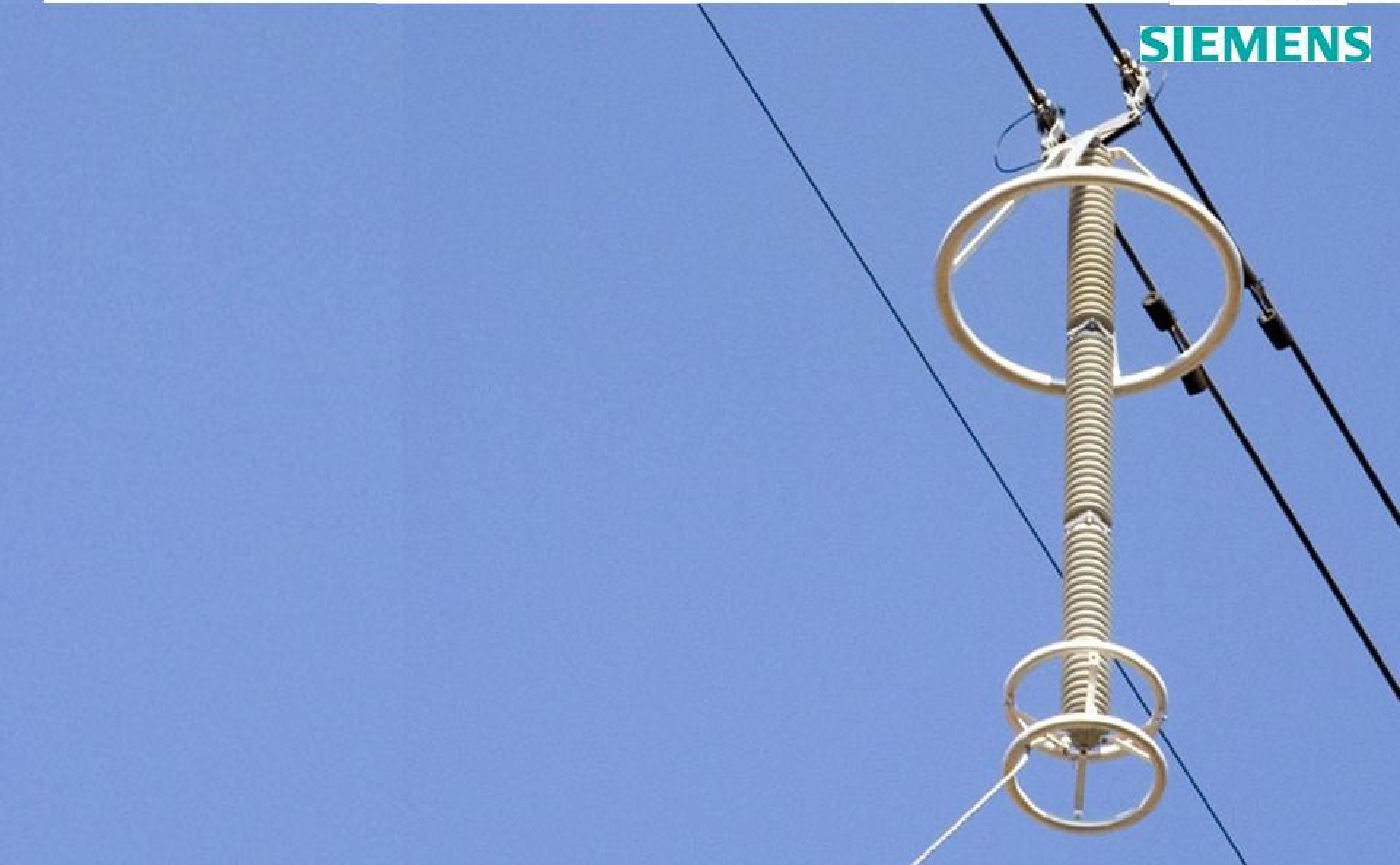
I = Switching Surge Current

L = Length of line in km.

Z = Surge Impedance of the line ≈ 350 - 400 Ω

C = Speed of light = 300,000 km / sec.

Transmission Line Arresters for Increased System Reliability



Solution for unshielded or poorly shielded Transmission Lines

SIEMENS

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TLA Application – Cross Arm Mounted

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TLA Application – Suspended from phase conductor

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Routine Factory Tests
Per IEEE Std. C62.11

- ❑ **Discharge Voltage Test**

On MOV blocks, arrester sections, or complete arresters

- ❑ **Partial Discharge (PD) Test**

Very important test,   Less than 2 pC preferred

- ❑ **Sealing Test**

Vacuum decay test method preferred

- ❑ **Watt Loss Test @ MCOV x 1.20 to 1.25**

{ Diagrams or pictures of test set ups, raw test data , and oscillograms can substitute for pre-shipment inspections and acceptance tests . }

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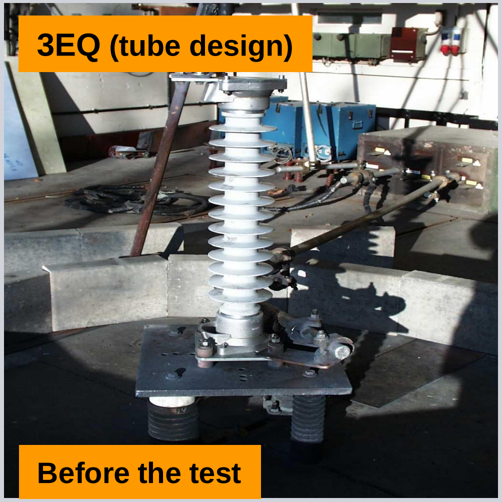
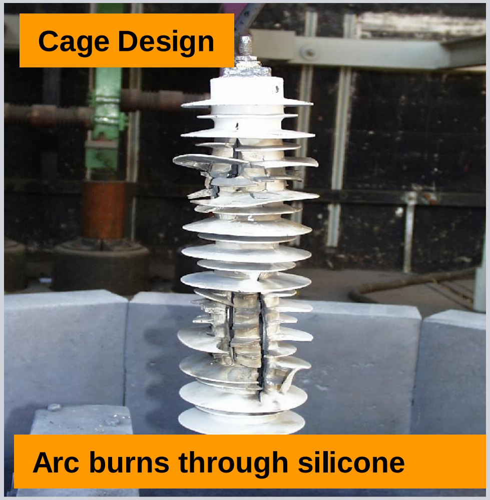
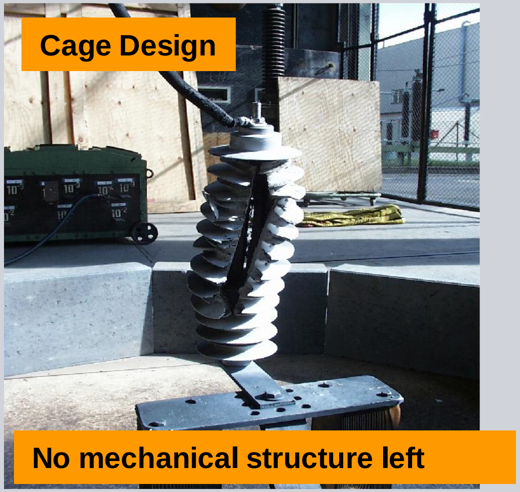
Pressure Relief Testing - - Failure Mode
Avoid Potentials of Violent Failures with Porcelain Housing

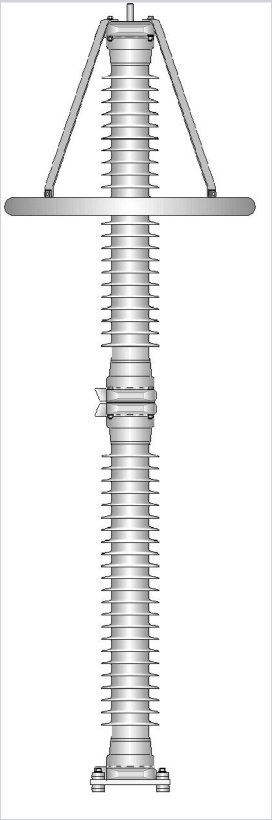






Minimize number of segments per arrester

Preferred



Example left side (Preferred):
2 segments for up to 550 kV system voltage

Example right side (avoid them):
4 units per stack for the same voltage level or arrester with additional insulators for stabilization or multiple segment arrester built up with MV arresters

Minimizing the number of segments per arrester means:

- more stability
  = higher cantilever strength
- less segments to mount
  = less installation time / costs
- better voltage distribution

Poor Design

Multiple-segment arresters are generally not recommended as their electrical and mechanical performance is poor!

Silicone Housed Surge Arresters for High Voltage
IEEE 693 of 2005 - Seismic Performance Level
Shake Table Test

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Monitoring Devices

Arrester monitor with remote indication

3EX5 060/062

Control Spark Gap

3EX6 040

Surge Counter

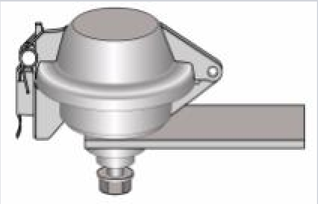
3EX5 030

Surge Counter with leakage current meter

3EX5 050

Arrester Condition Indicator

3EX5 070

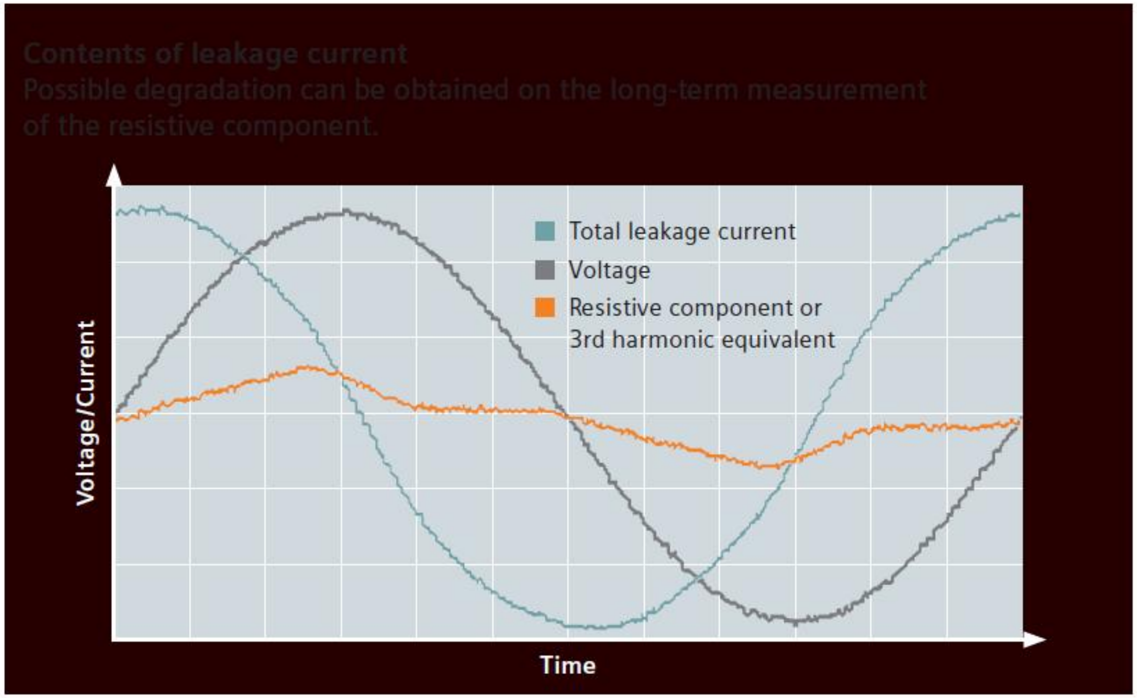


May 2012

3EX5 070 – Arrester Condition Indicator

Display of surge counts
The number of all registered surges higher than a certain level are displayed alternating to the leakage current.

Display of leakage current



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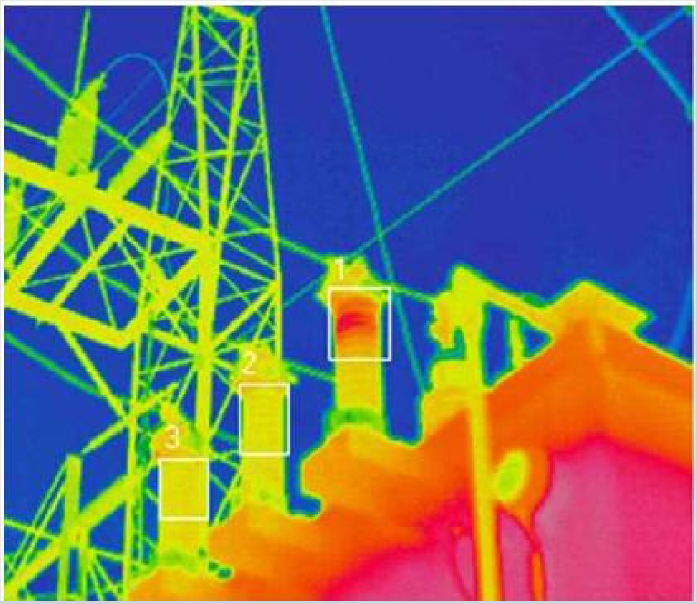
Field Testing Arresters



- Understanding remaining life of a critical component – IMPORTANT
- Common Methods for Sensing Gapless MOV Arresters

  1. Infrared Thermography
  2. Leakage Current – resistive component
  3. Watt Loss

- Surge Counters with Leakage Current Meter

  -not very effective

Surge Arresters are the Best Insurance for Your Assests

Surge arrester protects your costly equipment (like transformers, breakers) from damage due to switching or lightning over voltages.

Source: APS

DO NOT ECONOMIZE ON SURGE ARRSTERS !

For additional information call me:

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http://www.energy.siemens.com/fi/en/power-transmission/high-voltage-products/surge-arresters-limiters/

Thank you for your time!