Lightning Arresters
A Guide to Selection and Application

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Surge protection has been a primary concern when connecting devices and equipment to low-, medium-, or high-voltage electrical systems. As the use of products and equipment with components and insulation systems vulnerable to voltage surges and spikes continues to increase, the requirement for surge arresters to protect against the effects due to lightning strikes, switching phenomenon, etc., continues to increase as well. From personal computers to HV transmission and distribution systems, everything is susceptible to these surges and their destructive effects. This subject is very broad with numerous conditions to address, such that it is possible to treat only the basic aspects of selection and application in a single article. Therefore, this article will concentrate on circuits/systems 1000V and greater and is intended to provide the reader with some general guidelines for the appropriate selection and application of lightning/surge arresters.

Definition

Per the NEC 2005, a surge arrester is defined as: "*A protective device for limiting surge voltages by discharging or bypassing surge current, and it also prevents the flow of follow current while remaining capable of repeating these functions*".

Types/Classifications

Originally, there were three types of surge arresters. They are:

1. Expulsion type
2. Nonlinear resistor type with gaps (currently silicone-carbide gap type)
3. Gapless metal-oxide type.

There are four (4) classifications of surge arresters. They are:

1. Station class
2. Intermediate class
3. Distribution class (heavy, normal, and light duty)
4. Secondary class (for voltages 999V or less)

Of the three types noted above, the expulsion types are no longer being used. The nonlinear resistor type with gaps was utilized through the middle of the 1970s and is currently being phased out. The conventional gap type with silicone-carbide blocks/discs are still being used and the gapless metal-oxide type are the most widely used today. We are not addressing the secondary class in this article.

With respect to the four classes of surge arresters we are addressing as part of this article, the station class surge arrester is the best because of its cost and overall protective quality and durability. It has the lowest (best) available protection level and energy discharging capability with successively higher (poorer) protection levels for the other classifications. As noted above, the distribution class has several duty ratings, which are dependent upon the test severity. Heavy-duty arresters are more durable and have lower protective characteristics. The housing/enclosure construction of surge arresters can be of either polymer or porcelain.

Our focus will be on the gapless metal-oxide surge arrester (MOSA), since it provides the best performance and reliability. Please note that both the gap and gapless type arresters do the same job and the selection and application process of both types are similar. However, the need to select higher voltage levels for the silicone-carbide gap type and the possibility of contamination of the gap means the protection and reliability is slightly less. When gapped type arresters fail, the reader should consider or recommend replacing them with the metal-oxide gapless type.

Standards/Codes

Surge arresters are designed and tested per ANSI/IEEE C62.1, *Standard for Gapped Silicone-Carbide Surge Arresters for AC Power Circuits*, for the gapped type and ANSI/IEEE C62.11, *Standard for Metal-Oxide Surge Arresters for Alternating Current Systems*, for the gapless type. Article 280 of the NFPA70/National Electrical Code governs surge arrester's general requirements, installation requirements and connection requirements. In addition, surge arresters are listed by UL under the category of, Surge Arresters (OWHX), and other NRTLs (Nationally Recognized Testing Laboratories) using the applicable sections of the ANSI/IEEE standards noted above.

Selection and Application

The primary objective in arrester application is to select the lowest rated surge arrester that will provide adequate protection of the equipment insulation and be rated such that it will have a satisfactory service life when connected to the power system. An arrester of the minimum practical rating is preferred because it provides the highest margin of protection for the equipment insulation system. There is a fine line between protection and service life of a surge arrester. Higher arrester ratings will increase the capability of the arrester to survive on a specific power system but reduce the margin of protection provided for the insulation level of the equipment it is protecting. Therefore, the reader should consider both issues of arrester survival and equipment protection when selecting surge arresters.

The best location for installation of a surge arrester is as close as possible to the equipment it is protecting, preferably at the terminals where the service is connected to the equipment. This is based on the mathematics of wave theory addressing incident and reflected waves at a junction (or protected equipment terminal). Lead length for the connection of the surge arrester to the equipment terminals and to ground should be minimized and installed as straight, minimizing bends in the leads, as possible. This will ensure that the surge energies are shunted to ground by the most direct path. Increases in the lead length will reduce the protection capabilities of the surge arrester, due to the additional increase of impedance in the lead.

There are some basic considerations when selecting the appropriate surge arrester for a particular application:

- Continuous system voltage
- Temporary overvoltages
- Switching surges (more often considered for transmission voltages of 345KV and higher, capacitor banks, and cable applications)
- Lightning surges
- *System configuration (grounded or ungrounded/effectively ungrounded)

Table 1 below lists arrester ratings that would normally be applied on systems of various line-to-line voltages. The rating of the arrester is defined as the RMS voltage at which the arrester passes the duty cycle test as defined by the referenced standard.

Table 1 Typical Arrester Ratings for System Voltages

	Arrester Rating (kV)			Arrester Rating (kV)	
Nominal Sytem L-L Voltage (kV)	Grounded Neutral Circuits	High Impedance Grounded, Ungrounded, or Temporarily Ungrounded	Nominal System L-L Voltage (kV)	Grounded Neutral Circuits	High Impedance Grounded, Ungrounded, or Temporarily Ungrounded
2.4	2.7	3.0	69	54	--
				60	--
4.16	3.0	--		--	66
	4.5	4.5		--	72
		5.1	115	90	--
4.8	4.5	--		96	--
	5.1	5.1		108	108
	--	6.0		--	120
			138	108	--
6.9	6.0	--		120	--
	--	7.5		--	132
	--	8.5		--	144
12.47	9.0	--	161	120	--
	10	--		132	--
	--	12		144	144
	--	15		--	168
13.2,13.8	10	--	230	172	--
	12	--		180	--
	--	15		192	--
	--	18		--	228
23, 24.94	18	--		--	240
	21	--	345	258	--
	24	24		264	--
	--	27		276	--
34.5	27	--		288	288
	30	--		294	294
	--	36		300	300
	--	39		312	312
46	39	--	400	300	--
	--	48		312	--
				336	--
				360	--

Note: The arrester TOV capability must exceed the magnitude and duration of the expected temporary overvoltages considering the response time of the primary and back-up system protection.

Continuous System Voltage

When arresters are connected to an electrical system, they are continually exposed to the system operating voltage. For each arrester rating, there is a recommended limit to the magnitude of voltage that may be applied continuously. This is termed the Maximum Continuous Operating Voltage (MCOV) of the arrester. The arrester rating must be selected such that the maximum continuous power system voltage applied to the arrester is less than, or equal to, the arrester's MCOV rating. Consideration should be given to both the circuit configuration (wye or delta) and arrester connection (Line-to-Ground or Line-to-Line). In most cases the arresters are connected line-to-ground. If arresters are connected line-to-line, then phase-to-phase voltage must be considered. In addition, in determining the arrester rating, attention should be given to the grounding configuration of the system, either solidly grounded or effectively ungrounded (impedance/resistance grounded, ungrounded, or temporarily ungrounded). This is a key factor in the selection and application of an arrester. If the system grounding configuration is unknown, the reader should assume the system is ungrounded. This will result in choosing an arrester with a higher continuous system voltage and/or MCOV rating. Also, attention should be given to special arrester applications such as that on the delta tertiary winding of a transformer where one corner of the delta is permanently grounded. In this instance, the normal voltage continuously applied to the arrester will be the full phase-to-phase voltage, even though the arresters are connected line to ground.

An example of some of the MCOV ratings for GE TRANQUELL® polymer arresters is noted in Table 2 below.

Table 2a Polymer Station Arrester Characteristics

				8/20 µs Maximum Discharge Voltage - kVcrest					
Rated Voltage kVrms	MCOV kVrms	0.5 µsec 10 kA Max IR-kVcrest	Switching Surge Maximum IR-kVcrest[1]	1.5 kA	3 kA	5 kA	10 kA	20 kA	40 kA
3	2.55	8.4	6.0	6.4	6.7	7.1	7.6	8.4	9.6
6	5.10	16.7	11.9	12.8	13.5	14.1	15.2	16.8	19.1
9	7.65	25.0	17.8	19.2	20.2	21.1	22.7	25.1	28.3
10	8.40	27.8	19.8	21.4	22.5	23.5	25.3	28.0	31.8
12	10.2	33.3	23.7	25.6	26.9	28.1	30.3	33.5	38.1
15	12.7	41.7	29.7	32.0	33.7	35.2	37.9	42.0	47.6
18	15.3	50.1	35.6	38.4	40.4	42.3	45.5	50.0	57.2
21	17.0	56.3	40.1	43.2	45.5	47.6	51.2	56.7	64.4
24	19.5	63.9	45.5	49.1	51.6	54.0	58.1	64.3	73.0
27	22.0	72.9	51.9	56.0	58.9	61.6	66.3	73.4	83.3
30	24.4	80.4	57.2	61.7	64.9	67.9	73.1	80.9	91.9
36	29.0	95.9	68.3	73.6	77.4	81.0	87.2	96.5	109.6
39	31.5	104.2	74.2	80.0	84.1	88.0	94.7	104.8	119.0
45	36.5	120.9	86.1	92.8	97.6	102.1	109.9	121.7	138.1
48	39.0	128.7	91.6	98.8	103.9	108.7	117.0	129.5	147.1
54	42.0	144.4	102.8	110.9	116.6	122.0	131.3	145.3	165.0
60	48.0	163.5	116.4	125.5	132.0	138.0	148.6	164.5	186.8
66	53.0	179.9	128.0	138.1	145.2	151.8	163.5	181.0	205.5
72	57.0	191.8	136.6	147.3	154.9	162.0	174.4	193.1	219.2
90	70.0	241.8	172.1	185.6	195.2	204.2	219.8	243.3	276.3
96	76.0	257.4	183.2	197.6	207.8	217.4	234.0	259.0	294.1
108	84.0	288.9	205.6	221.8	233.2	244.0	262.6	290.7	330.1
120	98.0	326.9	241.3	251.0	263.9	276.1	297.2	329.0	373.6
132	106.0	362.7	267.7	278.5	292.8	306.3	329.7	365.0	414.4
144	115.0	386.1	285.0	296.5	311.7	326.1	351.0	388.6	441.2

Note 1: Based on 500A surge of 45µs time to crest through 84 kV MCOV, and 1kA surge of 45µs time to crest for MCOV ≤ 98kV.
Note 2: For more detailed information on Polymer Station Arresters, refer to page 17.

Temporary Overvoltages (TOV)

Temporary overvoltages (TOV) can be caused by a number of system events, such as switching surges, line-to-ground faults, load rejection and ferroresonance. The system configuration and operating practices should be evaluated to identify the most probable forms and causes of temporary overvoltages. If detailed transient system studies or calculations are not available, it is acceptable, as a minimum, to consider the overvoltages due to single line-to-ground faults. The configuration and details of the system grounding will determine the overvoltages associated with single line-to-ground faults. The arrester application standard, ANSI 62.22, can give the reader guidance in determining the magnitude of overvoltages associated with single line-to-ground faults. The primary effect of TOV on metal-oxide arresters is the increased current and power dissipation, and a rising arrester temperature. These conditions affect the protection and survivability characteristics of the arrester. The arrester's TOV capability must meet or exceed the expected temporary overvoltages of the system.

Table 3 below defines the TOV capability of all of GE's arrester designs in per unit of the MCOV. The table includes the duration and magnitude of temporary overvoltages that may be applied to the arrester before the arrester voltage must be reduced to the arrester's continuous operating voltage capability. These temporary overvoltage capabilities have been defined independent of system impedance and are valid for the voltages applied at the arrester location.

Table 3 - TOV Chart

		Polymer (per unit of MCOV)				Porcelain (per unit of MCOV)
Duration (seconds)	Prior Duty[1]	Normal Heavy Duty Distribution	Riser Pole	Intermediate	Station	EHV Station (396 - 612kV)
0.02	No	1.75	1.58	1.58	1.61	1.56
0.1	No	1.64	1.52	1.52	1.55	1.52
1	No	1.57	1.43	1.43	1.47	1.45
10	No	1.49	1.37	1.37	1.39	1.38
100	No	1.43	1.32	1.32	1.34	1.32
1000	No	1.35	1.29	1.29	1.30	1.25
10000	No	--	1.27	1.27	1.28	1.18
0.02	Yes	1.73	1.56	1.56	1.56	1.49
0.01	Yes	1.62	1.49	1.49	1.50	1.45
1	Yes	1.55	1.41	1.41	1.42	1.38
10	Yes	1.47	1.35	1.35	1.36	1.32
100	Yes	1.40	1.31	1.31	1.32	1.26
1000	Yes	1.33	1.28	1.28	1.28	1.19
10000	Yes	--	--	--	1.27	1.13

[1]Prior duty energy levels as defined in Table 4

Switching Surges

The arrester's ability to dissipate switching surges can be quantified to a large degree in terms of energy. The unit used in quantifying the energy capability of metal-oxide arresters is kilojoules/kilovolt (kj/kv).

The maximum amount of energy that may be dissipated in GE TRANQUELL® arresters is noted in Table 4 below. These capabilities are defined assuming multiple discharges distributed over a one-minute period. In applications where the discharges are distributed over a longer period of time, the GE TRANQUELL® arresters will have considerably more capability. As noted previously, arresters applied correctly can repeat these capabilities; therefore, after a one-minute rest period the above discharges may be repeated. The one-minute rest period allows the disk(s) temperature distribution to reach equilibrium and become uniform. These energy ratings assume that the switching surges occur in a system having surge impedances of several hundred ohms, which would be typical for overhead transmission lines. In low impedance circuits having cables or shunt capacitors as elements, the energy capability metal-oxide arresters may be reduced because currents can exceed the values noted in Table 4 below.

Table 4 - Energy Capability				
Arrester Rated Voltage (kVrms)	Housing Type	Arrester Type	Max. Current for Energy Rating (Amps)	kJ/kV of MCOV
3 - 36kV	Polymer	Normal Duty Distribution	300	1.4
3 - 36kV	Polymer	Heavy Duty Distribution	450	2.2
3 - 36kV	Polymer	Riser Pole	650	3.4
3 - 144kV	Polymer	Intermediate	650	3.4
3 - 144kV	Polymer	Station	1000	4.9
3 - 48kV	Porcelain	Station	1000	4.9
54 - 360kV	Porcelain	Station	1500	8.9
396 - 612kV	Porcelain	Station	2400	17.0

***System Configuration**

Knowing the system configuration, wye/delta, grounded or ungrounded, is a key factor in selecting an arrester rating. As noted in Table 1, the arrester nominal ratings for various utilization system voltages (line-to-line) are based on the system's grounding configuration. If the system is solidly grounded, then a lower-rated arrester can be chosen. If the system is ungrounded, impedance grounded or temporarily ungrounded, then a higher arrester rating must be chosen to compensate for the potential of a higher continuous voltage, or MCOV, being impressed on the arrester for an extended period of time. Other than a solidly grounded system, any other system configuration is considered to be effectively ungrounded and a higher arrester rating should be chosen. Knowing the system configuration and choosing the correct arrester rating is critical in averting an application where the arrester can potentially have a failure and cause violent end of life. If the system configuration is unknown, then the reader should assume the system is ungrounded.

Arrester Failure & Pressure Relief

If the capability of an arrester is exceeded, the metal-oxide disk(s) may crack or puncture. Such damage will reduce the arrester internal electrical resistance. This condition will limit the arrester's ability to survive future system conditions; it does not jeopardize the insulation protection provided by the arrester.

In the unlikely case of complete failure of an arrester, a line-ground arc will develop and pressure will build up inside the housing. This pressure will be safely vented to the outside and an external arc will be established provided the fault current is within the pressure relief fault current capability of the arrester. This low-voltage arc maintains equipment protection. Once an arrester has safely vented, it no longer possesses its pressure relief/fault current capability and should be replaced immediately. For a given application, the arrester selected should have a pressure/fault current capability greater than maximum short-circuit current available at the intended arrester location. This rating of arrester capability should include appropriate allowances for future growth in the system.

Table 5 below provides a listing of pressure relief/fault current capabilities for various GE TRANQUELL® arresters.

Table 5- Pressure Relief / Fault Current			
Arrester Rated Voltage (kVrms)	Housing Type	Arrester Type	Fault Current Capability (A sym.)
3 - 36kV	Polymer	Normal Duty Distribution	10,000
3 - 36kV	Polymer	Heavy Duty Distribution	20,000
3 - 36kV	Polymer	Riser Pole	20,000
3.0 - 144kV	Polymer	Intermediate	20,000
3.0 - 144kV	Polymer	Station	80,000
3.0 - 27kV	Porcelain	Station - Porcelain Top	10,000
3.0 - 48kV	Porcelain	Station - Metal Top	65,000
54 - 360kV	Porcelain	Station	93,000
396 - 612kV	Porcelain	Station	65,000

Arrester Selection and Application Summary

The arrester selection and application process should include a review of all system stresses, service conditions expected, and system-grounding configuration (grounded or effectively ungrounded) at the arrester installation location. System stresses shall include continuous operating voltage, temporary overvoltages, and switching surges. If arresters of different ratings are required to meet these individual criteria, then the highest resulting arrester rating should be chosen.

References

[1] *NFPA 70/National Electrical Code 2005*

[2] ANSI/IEEE C62.1, Standard for Gapped Silicone-Carbide Surge Arresters for AC Power Circuits

[3] ANSI/IEEE C62.11, *Standard for Metal-Oxide Surge Arresters for Alternating Current Systems*

[4] UL – General Information for Electrical Equipment Directories and/or Electrical Equipment Construction Directory

[5] TRANQUELL® Surge Arresters, Product Selection & Application Guide – GE Publication No. FETA-100A

[6] George W. Walsh, "A Review of Lightning Protection and Grounding Practice", IEEE Transactions on Industry Applications, Vol. IA-9, No. 3, March/April 1973 (reprint/Ref GE Publication GER-2951)