# The Application and Selection of Lightning Arresters

By Larry Pryor, P.E., GE, Sr. Specification Engineer

## Abstract

Each piece of electrical equipment in an electrical system needs to be protected from voltage surges. To prevent damage to electrical equipment, surge protection considerations are paramount to a well-designed electrical system. Modern metal oxide arresters provide exceptional overvoltage protection of equipment connected to the power system. The proper selection and application of the arrester, however, involves decisions in several areas, which will be discussed in the paper.

## Introduction

The original lightning arrester was nothing more than a spark air gap with one side connected to a line conductor and the other side connected to earth ground. When the line-to-ground voltage reached the spark-over level, the voltage surge would be discharged to earth ground.

The modern metal oxide arrester provides both excellent protective characteristics and temporary overvoltage capability. The metal oxide disks maintain a stable characteristic and sufficient non-linearity and do not require series gaps.

Due to the broad nature of this subject, this paper will concentrate on the application of the gapless metal oxide arrester to circuits and systems rated 1000 V and greater.

## Nature of the Problem

The states around the Gulf of Mexico have the highest annual average number of lightning storms in the United States. This is called the isokeraunic level for an area. On average, between 40 and 80 thunderstorms hit the areas along the Gulf Coast each year, while California and some states along the Canadian border have an average of less than 5 per year. So, it is easy to understand that surge protection of electrical equipment is a very important part of the electrical system design.

Lightning strikes are not the only sources of voltage surges in the electrical system. The following are a few of the more frequently encountered causes of transient voltage surges:

1. Surge voltages associated with switching capacitors
2. Surge voltages due to a failure in equipment insulation resulting in a short circuit on the distribution system
3. Surge voltages associated with the discharge of lightning arresters at other locations within the facility

When capacitors are switched in and out of the circuit, it is possible to get a restrike when interrupting the capacitor circuit current. A steep-front voltage excursion may be created from each restrike. These voltage excursions may be high enough to damage rotating machines applied at the same voltage. A surge capacitor applied at the motor terminals can change the steepness of the wave front enough to protect the motor.

A short circuit can cause a voltage surge in excess of 3 times the normal line to neutral crest value. The magnitude and steepness of the wave front is not as severe as that of a lightning strike, but can cause damage or weaken motor windings that do not have the higher Basic Impulse Insulation Level (BIL) ratings of other equipment.

When lightning discharges through an arrester, surge currents are discharged into the grounding terminal. It is very important that substations and overhead lines be protected with well-grounded shield wires. It is also equally important that the ground system between pieces of equipment be bonded together with interconnected ground wires dedicated to the grounding system.

When a surge is released on a line by direct strokes or induced strokes, the stroke travels in both directions from the point where the stroke originated. Wave velocity is an inverse function of the surge impedance. Waves travel on an overhead line at approximately 1000 ft. per microsecond, in cables about 300 – 600 ft. per microsecond and in a buried conductor about 300 ft. per microsecond. The velocity internal to a rotating machine may be only 25 ft. per microsecond.

The current resulting from a traveling wave is equal to the voltage divided by the impedance (E/Z). Wave current is approximately two to four amps per kilovolt of surge voltage. Lightning waves on overhead lines gradually attenuate with travel.

When the wave runs into a change in impedance (transformer, another line, etc.), the wave continues in the same direction at a different magnitude. It will also reflect back in the direction from which it came.

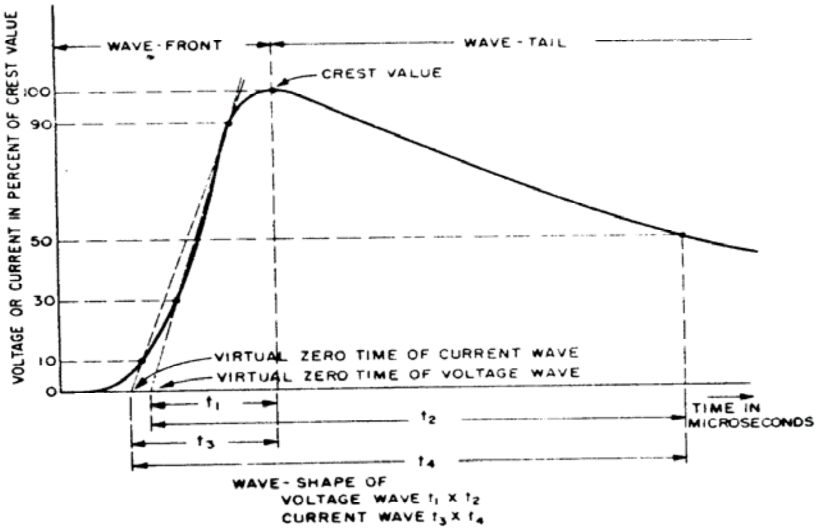
When a wave E1 traveling on surge impedance Z1 encounters another surge impedance Z2, the voltage on the new wave Z2 becomes:

$$E2 = E1\left(\frac{2 * Z2}{E1 + E2}\right)$$

Note: as the new surge impedance Z2 approaches infinity, representative of an open line, $E2 = 2E1$.

The reflected wave will actually double in magnitude in its return in the opposite direction. Unless the wave is discharged to ground (lightning arrester connected to ground), the reflected wave can severely damage electrical equipment.

Surges produced by lightning have high magnitudes, but their durations are very short. See figure below:

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The lightning discharge may reach its crest value in approximately 1 to 20 microseconds and produce conduction flashover voltages of 5 to 20 times normal in 1 microsecond or less.

The wave shape is customarily expressed by two intervals associated with the wave geometry. The first time interval is between a virtual zero and crest; the second time interval is between the virtual zero and the half crest value on the wave tail. The wave is defined if the crest value is added to the two time-interval designations. For example, a 20000 amp 10 x 20 microsecond current wave rises to a crest of 20000 amperes in 10 microseconds after virtual zero and decays to 10000 amperes in 20 microseconds after virtual zero.

## Protective Margin

Most electrical equipment is rated for traveling wave voltage surge capability by the Impulse Test. The Impulse Test is most common and consists of applying a full-wave voltage surge of a specified crest value to the insulation of the equipment involved. The crest value of the wave is called the Basic Impulse Insulation Level (BIL) of the equipment. Each type of electrical equipment has a standard BIL rating. Lightning arresters are coordinated with standard electrical equipment insulation levels so that they will protect the insulation against lightning over voltages. This coordination is obtained by having an arrester that will discharge at a lower voltage level than the voltage required to break down the electrical equipment insulation. Equipment has certain applicable impulse levels or BIL as defined in industry standards.

It is important to recognize that rotating machines do not have BIL ratings.

However, it is generally accepted that a rotating machine can withstand a voltage wave at the motor terminals, which rises to a maximum level at a rate not exceeding 1.25 time the crest value of the one-minute hi-pot test voltage in 10 microseconds. Steepness of the wave front should also be considered when applying surge protection to rotating machines. A fast rising voltage at the motor terminals lifts the potential of the terminal turn, but the turns deeper in the windings are delayed in their response to the arriving voltage wave due to the large capacitance coupling between conductors and the grounded core iron. The result is a high voltage gradient across the end-turns of the terminal coil, resulting in severe voltage stress on the turn-to-turn insulation.

Surge arresters are applied to limit the magnitude of impulse waves. Surge capacitors reduce the steepness of the wave fronts so that the equipment being protected is not subjected to as severe a voltage wave. Surge capacitors should be considered only for rotating machine protection and must be applied at the motor terminals.

For insulation coordination, protective ratios are calculated at three separate points within the volt-time regions. These are: the switching surge withstand, the full wave withstand and the chopped wave withstand. The following protective ratios must be met or exceeded if satisfactory insulation coordination is to be achieved, according to the minimum recommendations given in ANSI C62.22.

These protective ratios assume negligible arrester lead length and distance between the arrester and the transformer.

$$\frac{\text{Switching Surge Withstand}}{\text{Switching Surge Protective Level}} >= 1.15$$

$$\frac{\text{Full Wave Withstand (BIL)}}{\text{Impulse Protective Level}} >= 1.20$$

$$\frac{\text{Chopped Wave Withstand}}{\text{Front-of-Wave Protective Level}} >= 1.25$$

The protective ratios typically exceed the minimum protective ratios recommended by ANSI by a considerable amount in actual power system applications.

Overwhelming evidence points to the fact that surge voltage is a significant contributor to cable failure. When transformers are subjected to surge voltages, if the insulation strength of the transformer is sufficient to withstand the surge, there is typically no damage to the transformer. However, cable has memory. Each impulse on a cable contributes to the deterioration of cable insulation strength, such that the cable may ultimately fail by overvoltage levels below the BIL.

The important thing to note is that each apparatus has a design rating. Many lightning and switching surges are of a magnitude much higher than the design rating. It is of vital importance, therefore, to properly select, locate, and apply surge arresters in order to avoid damaging equipment. Properly applied surge protection can reduce the magnitude of the traveling wave to a level within the rating of the equipment.

# Arrester Selection

The objective of arrester application is to select the lowest rated surge arrester which will provide adequate overall protection of the equipment insulation and have a satisfactory service life when connected to the power system. The arrester with the minimum rating is preferred because it provides the greatest margin of protection for the insulation. A higher rated arrester increases the ability of the arrester to survive on the power system, but reduces the protective margin it provides for a specific insulation level. Both arrester survival and equipment protection must be considered in arrester selection.

The proper selection and application of lightning arresters in a system involve decisions in three areas:

1. Selecting the arrester voltage rating. This decision is based on whether or not the system is grounded and the method of system grounding.
2. Selecting the class of arrester. In general there are three classes of arresters. In order of protection, capability and cost, the classes are:
   - Station class
   - Intermediate class
   - Distribution class

   The station class arrester has the best protection capability and is the most expensive.
3. Determine where the arrester should be physically located.

**Arrester Voltage Rating**

The lower the arrester voltage rating, the lower the discharge voltage, and the better the protection of the insulation system. The lower rated arresters are also more economical. The challenge of selecting and arrester voltage rating is primarily one of determining the maximum sustained line-to-ground voltage that can occur at a given system location and then choosing the closest rating that is not exceeded by it. This maximum sustained voltage to ground is usually considered to be the maximum voltage on the unfaulted phases during a single line-to-ground fault. Hence, the appropriate arrester ratings are dependent upon the manner of system grounding.

Table 1 lists arrester ratings, for one manufacturer, 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 reference standard. Metal oxide arresters are designed and tested in accordance with ANSI/IEEE C62.11.

For surge arrester applications the “solidly grounded” classification is usually found in Electric Utility distribution systems where the system is usually only grounded at the point of supply. These systems can exhibit a wide range of grounding coefficients depending upon the system or location in the system. Accordingly, these systems may require a study to ensure the most economical, secure, arrester rating selection. If this information is not known or available, the ungrounded classification should be used.

The “ungrounded” classification includes resistance grounded systems, ungrounded systems and temporarily ungrounded systems. Both high resistance and low resistance systems are considered ungrounded for the selection of the proper surge arrester since during a line-to-ground fault the unfaulted phases and their arresters experience essentially line-to-line voltage. The same is true for the infrequently used ungrounded system. This simply means that the maximum continuous operating voltage, as discussed below, must be at least 100 % of the maximum operating voltage of the system.

**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 | -- |

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**Continuous System Voltage**

When arresters are connected to the power system they continually monitor the system operating voltage. For each arrester rating, there is a limit to the magnitude of voltage that may be continuously applied to the arrester. This is referred to as the Maximum Continuous Operating Voltage (MCOV). The MCOV values for each arrester rating are shown, for one manufacturer, in Table 2a below. These values meet or exceed those values contained in the referenced standard. Note that the MCOV is less that the arrester voltage rating. The arrester selected must have a MCOV rating greater than or equal to the maximum continuous system voltage. Attention must be given to the circuit configuration (single phase, wye, or delta) as well as the arrester connection (line-to-ground or line-to-line). Most arresters are connected line-to-ground, in which case, the grounding methods discussed above must be considered. If the arrester is connected line-to-line, then the phase-to-phase voltage must be considered. There are also special applications that require additional consideration such as the use of a delta tertiary winding of a transformer where one corner of the delta is permanently grounded. In this case the normal voltage applied to the arrester will be full phase-to-phase voltage even though the arresters are connected line-to-ground.

**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.

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## Temporary Overvoltages

Temporary overvoltages (TOV) may be caused by a number of events such as line-to-ground faults, circuit back feeding, load rejection, and ferro-resonance. The system configuration and operating practices will identify the most probable forms of temporary overvoltage that may occur at the arrester location. The temporary overvoltage capability must meet or exceed the expected temporary overvoltages.

Table 3 identifies the temporary overvoltage capability of one manufacture's arresters in per unit of MCOV. It also defines the time duration that the overvoltages may be applied before the arrester voltage must be reduced to the arrester's continuous operating voltage capability. These capabilities are independent of system impedance and are, therefore, valid for voltages applied at the arrester location. If detailed transient system studies or calculations are not available, the overvoltages due to a single line-to-ground fault should be considered as a minimum. The arrester application standard ANSI C62.22 gives some guidance in determining the magnitude of single line-to-ground fault overvoltages. The effects of TOV on metal oxide arresters are increased current and power dissipation and a rising arrester temperature.

**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

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**Switching Surges**

The energy capability of an arrester determines the ability of the arrester to dissipated switching surges.
The units used in defining the energy capability of metal oxide arresters are kilojoules per kilovolt.

The maximum amount of energy that can be dissipated in one manufacture's arresters is given in Table 4. These capabilities are based on the assumption that multiple discharges are distributed over a one-minute period. Arresters have more capability if the discharges take place over a longer period of time. After a one-minute rest period, the discharges, as defined, may be repeated. These energy ratings assume that switching surges occur in a system having surge impedances of several hundred ohms, which is typical for overhead transmission circuits. In circuits having low surge impedance involving cables or shunt capacitors, the energy capability of metal oxide arresters may be reduced because currents can exceed the values stated.

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 |

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**Arrester Failure and Pressure Relief**

Metal oxide disks may crack or puncture if the capability of the arrester is exceeded reducing the arrester internal electrical resistance. This will limit the arrester's ability to survive future system conditions but does not jeopardize the insulation protection provided by the arrester.

Should a complete failure of the arrester occur, a line-to-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.

Once an arrester has safely vented, it no longer possesses its pressure relief/fault current capability and should be immediately replaced. For a given application, the arrester selected should have a pressure relief/fault current capability greater than the maximum short-circuit current available at the intended arrester location taking in allowances for future growth. Table 5 shows relief/fault current capability for one manufacture's 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 |

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**Arrester Class**

The class of lightning arrester to be applied depends upon the importance and value of the protected equipment, its impulse insulation level and the expected discharge currents the arrester must withstand.

**Station class** arresters are designed for protection of equipment that may be exposed to significant energy due to line switching surges and at locations where significant fault current is available. They have superior electrical performance because their energy absorption capabilities are greater, the discharge voltages (protective levels) are lower and the pressure relief is greater. The value of the protected equipment and the importance of uninterrupted service generally warrant the use of station class arresters throughout their voltage range. Industry standards dictate the use of both station class and intermediate class arresters for equipment protection in the 5-to 20-mVA size ranges. Above 20 mVA, station class arresters are predominately used.

**Intermediate class** arresters are designed to provide economic and reliable protection of medium voltage class power equipment. Intermediate arresters are an excellent choice for the protection of dry-type transformers, for use in switching and sectionalizing equipment and for the protection of URD cables. Traditional applications include equipment protection in the range of 1 to 20 mVA for substations and rotating machines.

**Distribution class** arresters are frequently used for smaller liquid-filled and dry-type transformers 1000 kVA and less. These arresters can also be used, if available in the proper voltage rating, for application at the terminals of rotating machines below 1000 kVA. The distribution arrester is often used out on exposed lines that are directly connected to rotating machines.

All of the system parameters need to be considered while choosing an arrester classification. If the actual arrester energy duties are not known and a transient study cannot be performed, then it is suggested that Station class arresters be applied. This is a conservative approach that reduces the chances of misapplication.

**Location of Arresters**

The ideal location for lightning arresters, from the standpoint of protection, is directly at the terminals of the equipment to be protected. At this location, with the arrester grounded directly at the tank, frame or other metallic structure which supports the insulated parts, the surge voltage applied to the insulation will be limited to the discharge voltage of the arrester. Practical system circumstance and sound economics often dictate that arresters be mounted remotely from the equipment to be protected. Often, one set of arresters can be applied to protect more than one piece of equipment. Low BIL apparatus (certain dry-type transformers and rotating machines) will often require surge protective devices be connected directly at the terminals of the equipment being protected.

In many switchgear installations, the only exposure to lightning will be through a transformer located on its up stream side. When the transformer has adequate lightning protection on its primary, experience has shown that the surge transferred through the transformer is usually not of a magnitude that would be harmful to the switchgear. Hence, it is generally not necessary to provide arresters in the switchgear.

When arresters are located away from the terminals of the protected equipment, the voltage wave will reflect positively on the equipment terminals and the voltage magnitude at the terminal point will always be higher than the discharge voltage of the arrester. This, as discussed earlier, is due to the fact that the protected equipment usually has a higher surge impedance than the line or cable serving it. If the circuit is open at the protected equipment (infinite surge impedance), the voltage will be double the arrester discharge voltage.

The actual surge voltage appearing at the protected equipment depends, in part, on the incoming wave magnitude at the instant of arrester discharge. If a positive reflected surge from the protected equipment arrives back at the arrester before arrester discharge, it will add to the incoming wave to produce discharge at a lower incoming wave magnitude. The reflected wave, in this case, results in improved protection. The closer the arrester is to the protected equipment, the greater the effect of the reflected surge on arrester discharge and the better the protection.

## Conclusion

All electrical equipment in an electrical system needs to be protected from voltage surges. The rating of the arrester, the class of arrester and the location of the arrester all play a part in the surge protection. Modern metal oxide arresters provide markedly superior protective characteristics and energy absorption capability, compared to previous generation arresters.

The application and selection of metal oxide arresters requires a thorough review of the power system, including voltage, system stresses, switching surges, grounding method and MCOV.

## References:


1. ANSI/IEEE C62.11 Standard for Metal-Oxide Surge Arresters for Alternating Current Systems.

2. ANSI/IEEE C62.22 Guide for Application of Metal-Oxide Surge Arresters for AC Systems.

3. George W. Walsh, “A Review of Lightning Protection and Grounding Practice”, IEEE Transactions on Industry Applications, Vol.IA-9, No. 2, March/April 1973 (reprint/Ref GE Publication GER-2951)

4. TRANQUELL Surge Arresters, Product Selection & Application Guide – GE Publication no. FETA – 100A

5. Bob M. Turner, GE, Power Systems Information Letter No. 3, May 1986

6. Bob M. Turner, GE, Power Systems Information Letter No. 4, August 1986