



Property Risk Consulting Guidelines

SURGE PROTECTION

INTRODUCTION

PRC.5.7.1.3 describes electrical surges as part of a broad, power quality problem. This guide identifies specific loss control methods including protective devices and general electrical preventive maintenance to prevent or limit electrical surge damage to equipment. Although lightning surges are discussed, the primary discussion of lightning protection is PRC.5.2.1.

An electrical surge is a transient wave of voltage or current in a circuit. The major causes of surges are:

- Lightning strikes;
- Switching (On/Off and Off/On) including line and power factor capacitor switching;
- Equipment load changes.

Whether those events occur on or off the insured's premises, they can cause surges which lead to power or data problems on the premises. Because faults cause surges by mechanisms similar to switching and to load changing, they are not discussed separately; in general, more damage is caused by the fault than by the resulting induced voltage surge.

Surges usually manifest themselves as overvoltages or overcurrents. Most last less than a millisecond (ms). Overvoltage can directly cause electrical breakdown. Overcurrent can trip relays and cause overheating. Generally, the larger the surge amplitude, the greater the likelihood damage will result.

Typically, a surge has an impulse or oscillatory waveform. An impulsive wave is unipolar, exponentially rising to its peak, then exponentially decaying to a steady-state value. An oscillatory or "ring wave" has a fast rise to the first peak, and a fast decay during which the wave fluctuates through one or more cycles. Figure 1 shows both waveforms.

When a voltage surge is induced on a power line carrying a normal, sinusoidal voltage, the result is a distorted waveform with a value equal to the mathematical sum of the two waveforms. Similarly, normal current waveforms and current surges are additive. A spike is usually a high amplitude, short duration wave. Figure 2 shows a sinusoidal power wave with a spike.

A voltage surge in a closed circuit causes both current and power surges as predicated by Ohm's Law. Similarly, a current surge causes voltage and power surges. Therefore, a surge usually results in a short-term increase in voltage, current and power. Unless electrical breakdown results, a waveform returns to its normal steady-state condition after a surge passes.

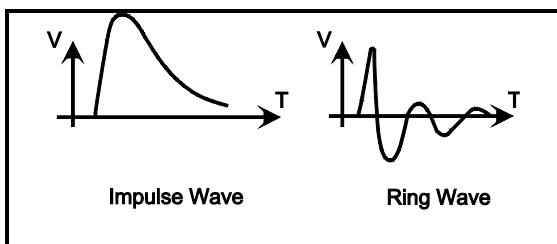


Figure 1. Surges - Voltage (V) Versus Time (T).

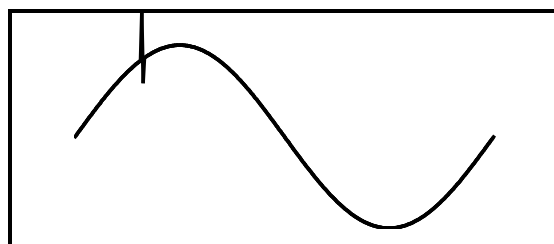


Figure 2. Waveform With Transient Spike.

Additional guidance on surge protection is in *National Electrical Code® (NEC)*, *NFPA 780*, *NFPA Fire Protection Handbook*, *IEEE Standard 142* and *IEEE Standard 1100*.

POSITION

As part of a comprehensive electrical preventive maintenance (PM) program, periodically evaluate the adequacy of surge protection for all electrical equipment. Review power quality, power outages and equipment operating history. Document this evaluation and resolve all unsatisfactory conditions. Schedule these evaluations yearly for designated equipment and every 2 yrs for all other equipment. Equipment which should be scheduled yearly includes the following:

- All power distribution equipment, including transformers, fuses, circuit breakers and cables.
- Rotating machinery meeting any one or more of the following criteria:
 - The machine is important or critical. A machine's importance is related to production dependency and is evaluated by comparing the productive output dependent on each machine. A machine is critical if deprival of its service can lead to unsafe conditions or catastrophic loss, as described in AXA XL Risk Consulting's *OVERVIEW*.
 - The power rating of the machine is above 500 hp (373 kW).
 - The utilization voltage of the machine is 2300 volts ac or higher.
- Solid-state equipment that can cause high property damage or injury upon failure.

Install surge protection where any surge protection evaluation concludes such action is needed. Give priority to protecting equipment having had previous surge exposures.

Replace surge protection if a surge protection evaluation concludes such action is needed.

Inspect, test and maintain each surge protection device as recommended by its manufacturer. Replace surge protection devices as appropriate based on test results and manufacturer's recommendations.

For important transformers meeting the criteria in PRC.5.9.0.1, provide a surge arrester at each primary and secondary line-connection if any segment of either line runs outdoors or is exposed to lightning surges. Protection at the primary or secondary connection(s) alone cannot adequately protect a transformer. A surge through either winding, or set of windings, will pass to the other based on the turns ratio of the transformer.

Arrange surge protection components installed to protect transformers as follows:

- For multi-phase transformers, use identical arresters on each phase of the primary.
- For multi-phase transformers, use identical arresters on each phase of the secondary.
- Locate an arrester as close as possible to the winding it protects.
- Arrange each lead wire to be in a straight line path and as short as possible. The lead wire is the conductor between the phase wire (power line) and the high voltage tap of an arrester. Avoid sharp bends in the lead wire. If a bend or curve is necessary, establish the turn with no less than an 8 in. (203 mm) radius.

- Arrange each arrester ground wire so its path to ground is as short and straight as practical. If a bend or curve is necessary, arrange it to have no less than an 8 in. (203 mm) radius. Interconnection with the transformer's other arrester grounds and tank ground is permissible. In lieu of using arrester ground wires, arresters may be bolted to the grounded transformer tank or frame if the tank or frame has sufficient current carrying capacity (size) and is itself connected to ground through a low impedance ground connection.
- Connect surge arresters in a manner that minimizes mechanical stress and provides adequate support during adverse weather conditions.

If surge protection is required for a motor, arrange components as follows:

- Electrically, locate surge arresters and surge capacitors as close to motor terminals as practical. In no case should the conductor path between the protective device and the motor terminal be greater than 3 circuit ft (0.9 m).
- Connect power supply circuits directly to surge protective devices, and connect motors only to protected sources.

As described in Article 280 of the NEC, use only listed surge arresters for premises wiring involving power systems rated less than 1000 V.

Use valve-type arresters having adequate discharge capacity to protect bus and switchgear. Use arresters that will maintain anticipated lightning surge voltage levels below the insulation levels of protected equipment.

DISCUSSION

Generally, electrical insulation is designed to withstand low and moderate voltage surges. Many electrical systems experience frequent, slow-rising, low energy surges that pose little or no threat. Approximately 100 small surges were recorded in 1 hr while monitoring a representative industrial system.

But the longer a surge lasts, the higher its amplitude or the faster its voltage rises, the more likely the insulation will fail. Electrical breakdown can result in major electrical damage and can start a chain of events that leads to catastrophic loss.

Besides causing insulation damage, surges can damage electronic data. Surges can also cause false operation or misoperation of production, control and safety equipment.

When lightning strikes near an electrical circuit, the "lightning bolt" or discharge usually induces a very high-amplitude, short-duration impulse wave in the system. Even cloud-to-cloud discharges **that do not strike earth** cause surges in earth-based electrical systems.

Often, equipment and systems are specially designed to withstand "typical" lightning and switching surges. Equipment manufacturers evaluate the ability of equipment to withstand simulated lightning and switching surges by prototype and production model testing.

One test procedure uses an impulse wave with a rise time of 1.2 microseconds (μs) and a duration of 50 μs . This is called a 1.2 \times 50 (or 1.2/50) impulse wave. Another test uses an 8 \times 20 (or 8/20) impulse wave. Sometimes, a 0.5 μs /100 kHz ring wave is used; this ring wave has a rise time of 0.5 μs and an oscillatory frequency of 100 kHz. Equipment can be designed to handle one, two or all three test waveforms.

Generally, surge-tested equipment withstands lightning and switching surges better than equipment not so designed and tested. But surges are unpredictable. A surge that is more severe than the test surge can cause insulation to fail. Additionally, even protective equipment deteriorates over time.

Some equipment can be highly susceptible to surges. Even slow-rising, low energy surges can damage unprotected solid-state equipment.

Fuses and circuit breakers cannot provide surge protection. They cannot react with sufficient speed even if surge current and surge voltage have very high amplitudes. Most surges pass through these overcurrent devices before they can react.

Voltage Surges

Any increase in current passing through a conductor simultaneously increases the electric field around that conductor. Any decrease in current decreases this electric field. As the intensity of any electric field changes, the change induces a voltage surge in any conductor or circuit located within.

Switching operations and electrical load changes are examples of electrical activities that cause magnetic fields to change. Lightning is another.

In the case of an indirect lightning strike, the electric field changes as lightning follows its path to ground. A surge develops on any circuit, power or distribution line within this electric field. These lightning-induced voltage surges are much less severe than current surges from direct lightning strikes.

Opening or closing a switch starts or stops a current flow. This stopping and starting of current causes the field around this circuit to change. All conductors in the changing field, including those in the switched circuit, experience a voltage surge. In general, these surges are not as severe as induced voltage lightning surges. Rise times are slower and amplitudes are lower.

As electrical loads change, power and current requirements change. As the drive circuit current changes, its electric field changes. Voltage is induced in all conductors in or passing through the field. These surges are not usually as severe as switching surges.

Lightning and high-current switching operations can cause damage to electrical systems and equipment located far away. Utility power lines can carry surges for miles. However, most surge damage is caused by indirect lightning strikes or switching operations on or near protected properties. All surges weaken or diminish as they travel long distances in a power system; some dissipate entirely.

Surge Arresters, Surge Capacitors, Surge Suppressors And Surge Protectors

Specially designed surge protective devices can prevent or minimize property and production losses caused by surges. Surge protective devices include surge arresters, surge capacitors and surge suppressors. They constrain surges to safe levels. They divert, slow and dissipate surges. They absorb much of a surge's energy.

Surge protective devices range in size from a fraction of an inch to over 15 ft (4.5 m) long. They can weigh a few ounces to over 4000 lbs (1.8 Mg). Figure 3 shows examples of surge protective devices.

A surge arrester is a protective device for limiting surge voltages as it discharges or diverts surge currents through itself to ground. The surge arrester provides a current path to shunt some or all of the surge current. Electrically, it is connected in parallel with equipment requiring surge protection. Generally, the higher the rating of the arrester over that of the equipment, the less the level of protection.

An ordinary wall-mounted electrical receptacle can serve a surge dissipation function. In the U.S., electrical systems in buildings constructed in accordance with the NEC seldom experience electrical surges above 6 kV. The reason is U.S.-designed electrical outlets flash over when the voltage between lines exceeds 6 kV. These receptacles provide inherent protection against surges in buildings. Surge arresters limit surge voltages to lesser amounts, commonly, to a few hundred volts.

The term surge arrester is commonly shortened to arrester. A less-used term, lightning arrester, refers to any surge arrester installed to protect against lightning surges. However, the term has no special design or construction significance. Its use can be misleading and generally is avoided. As a general term, although not technically correct, "arresters" sometimes refers to surge suppressors and surge protectors.

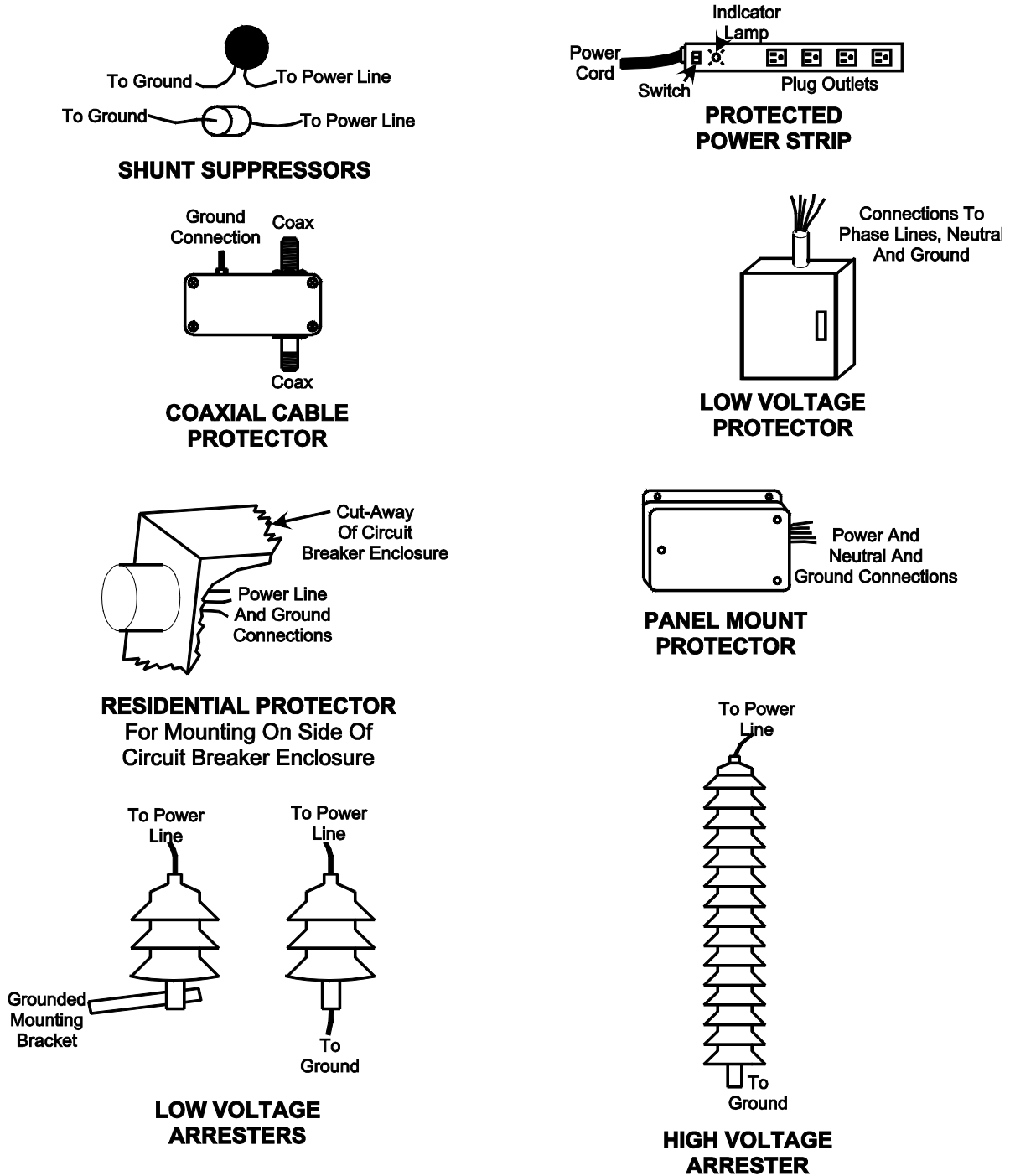


Figure 3. Examples Of Surge Protection Devices.

Arresters are used at transformer terminals, at motor terminals and with other machinery. An arrester is commonly installed on each phase of a power circuit. It is usually connected between each phase and ground.

Normally, voltage surges induced by lightning can be safely dissipated by protective devices; current surges from direct lightning strikes cannot. For this reason, lightning protection requires both shielding electrical systems from direct strikes and dissipating surges by use of arresters.

When lightning strikes a static wire above a utility power line, voltage is induced into the power line. Arresters control these surges and limit flashovers. Arresters not only protect the power lines and equipment from lightning damage, they also improve utility service reliability.

A surge capacitor is any capacitor placed in an electric circuit to slow surge voltage changes. By spreading a surge voltage increase over a longer time span, less electrical stress occurs to equipment encountering that surge.

A surge suppressor is typically a semiconductor-type surge protective device. Surge suppressors may be mounted on circuit boards to protect electronic components.

Typically, a surge protector is a gas-tube surge protective device or an assembly composed of one or more gas-tube devices, usually mounted in a metal enclosure. These are used for low voltage applications (up to 1000 V rms or 1200 V dc).

The purpose and features of arresters and protectors used in communications circuits as described by Article 800 of the NEC are beyond the scope of this guide.

Generally, the smaller, suppressor-type devices cannot protect high energy equipment. Major electric systems and major power equipment typically require the larger, power system surge arresters.

How Surge Protective Devices Work

Typically, the operative component of a surge protective device is an air gap, several air gaps, a solid dielectric such as a metal oxide, a gas dielectric or some combination of such components.

A “valve-type arrester” is a surge arrester whose operative component is a highly nonlinear resistor. Zinc oxide, gapless, valve-type arresters are relatively new to the market. Silicon carbide, gapped, valve-type arresters have been in use for years.

If the operative component is an arcing chamber in which an arc-extinguishing material limits the voltage, the arrester is an “expulsion-type arrester.”

Generally, surge protective devices operate in either of two modes; they “clamp” voltage to a specified level, or they provide a direct short to ground for as long as the excessive voltage lasts. Clamping devices shunt excess voltage. Metal oxide varistors (MOVs) are clamping devices.

“Crowbar” devices ground all voltage. Gas tube, carbon block and spark gap devices are crowbar devices. Their operating design is not based on providing non-linear resistance, but rather on providing a direct short around the protected device, so the surge bypasses it.

Generally, surge protective devices are reusable. They return to a normal protective mode following each operation.

Readiness And Life

Some power strip protective devices are installed with a pilot lamp to indicate readiness. Others use lamps to indicate that a surge-protection operation has taken place. In some cases, lamps identify when arresters go bad and should be replaced. These contrasting lamping purposes demonstrate the importance of understanding the design and function of these devices.

Some arresters are built with pressure relief openings in their end caps. The openings vent gases that develop as a surge is shunted. These units cannot be reused. A quick check tells when they have failed and must be replaced.

Surge counters are sometimes used with large arresters. Counters provide a history of the number of strikes or protection events, and can provide the means for scheduling maintenance or arrester replacement.

Some protective devices have a life expectancy of 5 yrs. Some have a life expectancy of 100 yrs. Some degrade and should be replaced after being struck once by a surge.

Generally, MOVs last 12 to 18 months; electrical stress and normal aging cause them to lose 10% of their protective abilities during that time. Surge device manufacturers can provide specific information

regarding arrester use and life expectancy. Customers should also seek the advice of manufacturers regarding testing and replacing these units.

Because these devices protect transformers, machinery, cables, switchgear, power equipment and circuit board components, they extend the life of that equipment by controlling electrical stress reaching insulation. These devices slow equipment deterioration and the aging process. One electric utility company reported a decreased underground 35 kV cable failure rate once they installed metal oxide arresters.

Transmission And Distribution (T&D) Arresters

Power arresters used with utility T&D are classified by design, construction and prescribed tests. The four main classifications are:

- Station arresters. Station arresters are the most costly of the four types. They are rated from 3 kV to 684 kV. They provide the best protection levels and can discharge the most energy.
- Intermediate arresters. Intermediate arresters can be rated 3 kV to 120 kV. They, too, can be costly.
- Distribution arresters. Distribution arresters can be rated from 1 kV to 30 kV. Distribution arresters are sometimes placed into one of two subclassifications: heavy duty and normal duty distribution arresters.
- Secondary arresters. Secondary arresters are the least expensive and the most common. They are rated at either 175 V or 650 V. They satisfy a minimal level of manufacturing tests as identified in IEEE C62.1 and ANSI/IEEE C62.11.

A 15 kV arrester could be a distribution, intermediate or station class arrester. The rating does not establish its classification. Product specifications must be reviewed for such information.

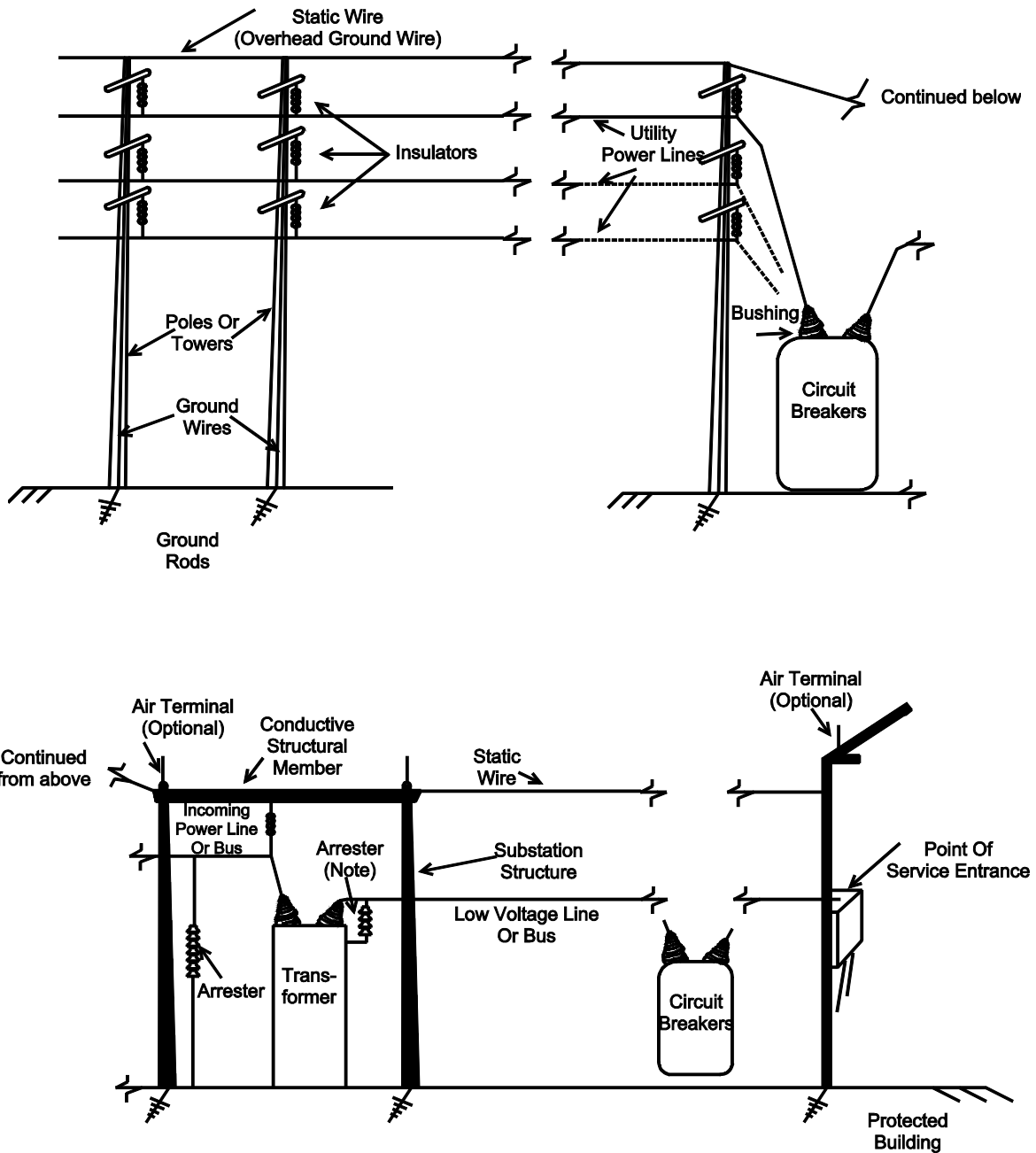
Figure 4 shows how arresters might be arranged in a substation to protect a transformer in a distribution system. Further, the figure shows shielding using static wires and conductive structural members. A shield is installed to prevent direct lightning strikes to the system, thus minimizing surge potentials. The figure shows the overlap of lightning protection and surge protection.

Selecting Devices

Selecting the proper surge protection depends on the construction of equipment needing protection, the location of this equipment in the electrical system, the environment and electrical considerations.

Electrical considerations include system coordination requirements and a device's "maximum continuous operating voltage" (MCOV). In a large electrical system, a series of surge protective devices might each clamp voltages to lower levels than the previous device. These devices are essentially electrically coordinated to the insulation withstand capabilities of the system. Generally, operating an arrester at a voltage exceeding its MCOV causes current leakage, unit overheating and decreased service life. Also, because an air dielectric is affected by altitude, arresters are derated if installed at or above 3300 ft (1000 m).

Outdoors or indoors, arresters are placed close to the equipment they protect. Arresters are often located at line connections or nearby in metal-clad switchgear panels. One reason becomes evident when considering the sudden change in the flow of current occurring in an arrester discharge line when it discharges a surge. This discharge will create its own surge. By placing the arrester close to the protected equipment, and making the ground connection as short as possible, the effects of this additional surge are minimized.



NOTE: The low voltage arrester may use a ground conductor or may be bolted to tank.

Figure 4. Example Of Electric Distribution Lightning And Surge Protection.

To protect low-voltage solid-state equipment against surges, special arresters might be needed. Low energy surges that get by the main surge arresters, and surges caused by branch switching and load changing, can damage sensitive equipment. Special arresters might be installed in electronic equipment by manufacturers. These surge arresters can be components on circuit boards. Alternately, users can employ protective power control systems such as power strips or power control centers having built-in surge suppression.

Equipment manufacturers and electric system designers must work together to evaluate surge protection requirements. The need for protection depends on the design and the location of the utilization equipment and reliability requirements. Sometimes, a surge arrester is installed at the electrical service entrance to protect all equipment in a system. Other times, additional devices are needed throughout the system. Or, equipment comes with built-in surge suppression. A user might not have knowledge of the existence of or need for specific surge protection devices until the issue is researched with equipment manufacturers and electric system designers.

Listed Equipment

Underwriters Laboratories Inc. (UL) lists surge protection devices in their *Electrical Construction Materials Directory*. Their three categories are Surge Arresters, Surge Arresters Classified For Use In Specified Equipment, and Transient Voltage Surge Suppressors (TVSS). UL category designations are OWHX, OWIW and XUHT, respectively.

Listed surge arresters are designed to protect secondary distribution wiring systems and equipment as described in Articles 280 and 285 of the NEC. Surge arresters classified for use in specified equipment are plug-in devices for panelboards.

TVSS are intended to be installed indoors on the load side of main service disconnects, and are for use only on 50 or 60 Hz systems rated 600 V or less. Periodically during manufacturing, samples of these devices are tested to UL1449. By this standard, a 1.2×50 6 kV impulse voltage is impressed across the arrester. The voltage to which the device clamps (an average of repeated tests) is the suppressed voltage rating (SVR), which is stamped on all devices manufactured to UL 1449 specifications.

However, some TVSS are additionally tested to the IEEE C62.41 recommended tests to demonstrate performance in suppressing ring waveforms. Devices passing these tests are so marked. Additional tests are performed on some TVSS to indicate electrical noise suppression capabilities.

Large arresters like those used by utilities in their T&D systems are often not listed. This equipment is expensive to manufacture, is produced in low volumes, and would require costly test equipment for the listing process. Some equipment is unique for a specific utility customer. For these reasons, UL listing may not be practical.

Special Considerations

A transformer BIL (Basic Impulse Insulation Level) defines the amplitude of the lightning impulse wave that insulation in the transformer is designed to withstand. The BIL is listed on the transformer nameplate. A surge arrester is selected to limit the amplitude of the incoming voltage surge to the “insulation withstand” level with a “margin” of safety.

Motor and generator windings have relatively low withstand strength. Both the amplitude and the slope of the wave can cause winding damage. Protective surge capacitors are usually placed in parallel with surge arresters to protect major rotating equipment. The capacitor limits the winding-to-winding voltage as the wavefront progresses. A capacitor has the effect of lengthening the time it takes for voltage to rise, reducing the slope of the wavefront. The arrester-capacitor combination is installed as close to the machinery as possible, often in a terminal box on or next to the equipment.

Arresters can cause what appears to be overcurrents in motor circuits. Because arresters are installed in parallel with protected motors, surge discharge currents pass through arresters and bypass motor windings. However, upstream protective relays cannot determine if the winding currents are normal or if they are causing overheating. The relays can sense only the total current in the protective circuit, and cannot sense the current split between the motor winding and the arrester. Therefore, relays used in motor-arrester protection schemes are typically time-delay units.

Maintenance

Keeping arresters clean, maintaining grounds, and keeping connections tight are important basic precautions for surge protection. Maintenance should be performed only by trained and competent maintenance personnel who have the appropriate test and safety equipment.

Because of the variety and complexities of surge controlling devices, this Property Risk Consulting Guideline cannot give specific testing or maintenance recommendations. In general, insulation resistance, overvoltage, power factor and leakage current tests are among the tests that can be used in arrester preventive maintenance programs. Manufacturers recommendations should be followed.