

Low-Side Surges

Some utility and customer problems with lightning impulses are closely related. One of the most significant ones is called the "low-side surge" problem by many utility engineers. The name was coined by distribution transformer designers because it appears from the transformer's perspective that a current surge is suddenly injected into the low-voltage side terminals. Utilities do not apply secondary arresters at low voltage levels as a general rule. From the customer's point of view it appears to be an impulse coming from the utility and is likely to be termed a "secondary surge".

Both problems are actually different side effects of the same surge phenomenon: The lightning current from either the utility side or the customer side along the service cable neutral. Figure 1 shows one possible scenario. Lightning strikes the primary line and the current is discharged through the primary arrester to the pole ground lead. This lead is also connected to the X2 bushing of the transformer at the top of the pole. Thus, some of the current will flow toward the load ground. The amount of current into the load ground is primarily dependent on the size of the pole ground resistance relative to the load ground. Inductive elements may play a significant role in the current division for the front of the surge, but the ground resistances basically dictate the division of the bulk of the stroke current.

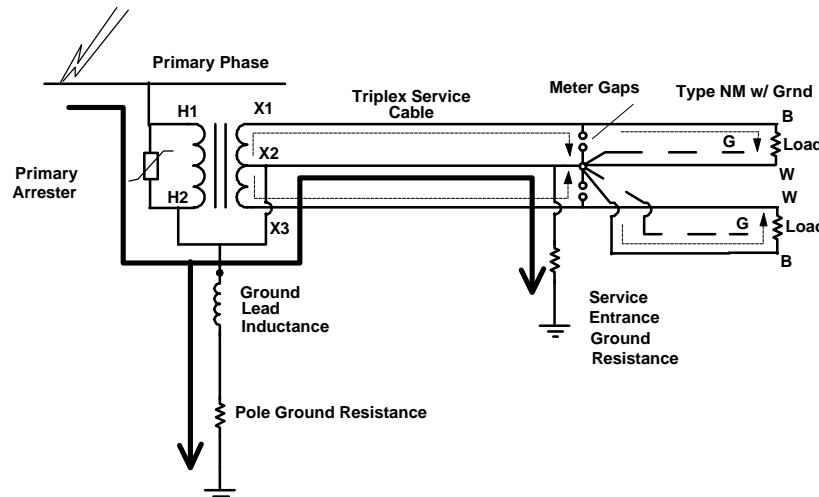


Figure 1 - Primary Arrester Discharge Current Divides Between Pole and Load Ground

The current that flows through the secondary cables causes a voltage drop in the neutral conductor that is only partially compensated by mutual inductive effects with the phase conductors. Thus, there is a net voltage forcing current through the transformer secondary windings and into the load as shown by the dashed lines in the figure. If there is a complete path, substantial surge current will flow. As it flows through the transformer secondary, a surge voltage is induced in the primary, sometimes causing a layer-to-layer failure near the grounded end. If there is not a complete path, the voltage will build up across the load and may flash over somewhere on the secondary. It is common for the meter gaps to flash over, but not always before there is damage on the secondary because the meter gaps are usually 6-8 kV, or higher. The amount of voltage induced in the cable is dependent on the rate-of-rise of the current, which is dependent on other circuit parameters as well as the lightning stroke.

The chief power quality problems this causes are:

1. The impulse entering the load can cause failure or misoperation of load equipment.
2. The utility transformer will fail causing an extended power outage.

3. The failing transformer may subject the load to sustained steady state overvoltages because part of the primary winding is shorted, decreasing the transformer ratio. Failure usually occurs in seconds, but has been known to take hours.

The key to this problem is the amount of surge current traveling through the secondary service cable. Keep in mind that the same effect occurs regardless of the direction of the current. All that is required is for the current to get into the ground circuits and for a substantial portion to flow through the cable on its way to another ground. Thus, lightning strikes to either the utility system or the end user facilities can produce the same symptoms. Transformer protection is more of an issue in residential services, but the secondary transients will appear in industrial systems as well.

Protecting the Transformer

There are two common ways for the utility to protect the transformer:

1. Use transformers with interlaced secondary windings,
2. Apply surge arresters at the X terminals.

Of course, the former is a design characteristic of the transformer and cannot be changed once the transformer has been made. If the transformer is a non-interlaced design, the only option is to apply arresters to the low voltage side.

Note that arresters at the load service entrance will not protect the transformer. In fact, they will virtually guarantee that there will be a surge current path and thereby cause additional stress on the transformer. While interlaced transformers have a lower failure rate in lightning-prone areas than non-interlaced, recent evidence suggests that low-voltage arresters have better success in preventing failures. The primary arrester is mounted directly on the tank with very short lead lengths. With the evidence mounting that lightning surges have steeper fronts than previously believed, this is an ever increasing requirement for good protection practice. It requires a special fuse in the cutout to prevent fuse damage on lightning current discharge. The transformer protection is completed by a robust secondary arrester (either externally mounted or internally mounted). An arrester rating of 40 kA discharge current is recommended. The voltage discharge is not extremely critical in this application, but is typically 3 to 5 kV. Transformer secondaries are generally assumed to have a BIL of 20 to 30 kV. Gap-type arresters also work in this application, but cause voltage sags, which the MOV-type arrester avoid.

Impact on Load Circuits

Figure 2 shows a waveform of the open-circuit voltage measured at an electrical outlet location in a laboratory mock-up of a residential service. For a relatively small stroke to the primary line (2.6 kA), the voltages at the outlet reached nearly 15 kV. In fact, higher current strokes caused random flashovers of the test circuit, which made measurements difficult. This reported experience is indicative of the capacity of these surges to cause overvoltage problems.

The waveform is a very high frequency ringing wave riding on the main part of the low-side surge. The ringing is very sensitive to the cable lengths. A small amount of resistive load such as a light bulb would contribute greatly to the damping. The ringing wave differs depending on where the surge was applied while the base low-side surge wave remains about the same; it is more dependent on the waveform of the current through the service cable.

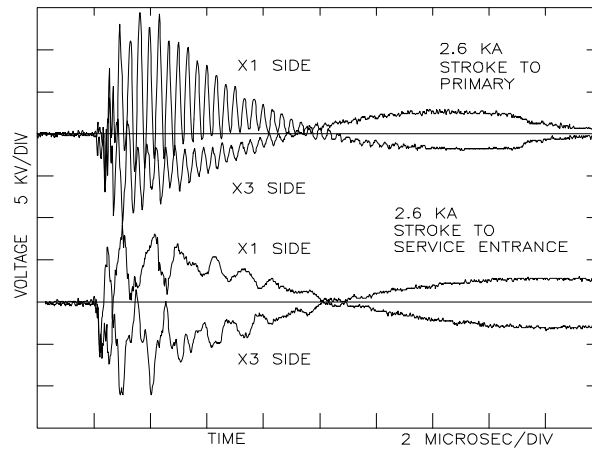


Figure 2 - Voltage appearing at outlet due to low-side surge phenomena.

One interesting aspect of this wave is that the ringing is so fast that it gets by the spark gaps in the meter base even though the voltage is 2 times the nominal sparkover value. In the tests, the outlets and lamp sockets could also withstand this kind of wave for about 1 μ sec before they flashed over. Thus, it is possible to have some high overvoltages propagating throughout the system. The waveform in this figure represents the available open-circuit voltage. In actual practice, a flashover would have occurred somewhere in the circuit after a brief time.

MOV arresters are not entirely effective against a ringing wave of this high frequency because of lead length inductance. However, they are very effective for the lower-frequency portion of this transient, which contains the greater energy. Arresters should be applied both in the service entrance and at the outlets serving sensitive loads. Without the service entrance arresters to take most of the energy, arresters at the outlets are subject to failure. This is particularly true of single MOVs connected line-to-neutral. With the service entrance arresters, failure of outlet protectors and individual appliance protectors should be very rare unless lightning strikes the building structure closer to that location than the service entrance. Service entrance arresters cannot be relied upon to protect the entire facility. They serve a useful purpose in shunting the bulk of the surge energy, but cannot suppress the voltage sufficiently for remote loads. Likewise, the transformer arrester cannot be considered to take the place of the service entrance arrester although it may be only 15 meters away. This arrester is actually in *series* with the load for the low-side current surge. The basic guideline for arrester protection should always be followed: Place an arrester directly across the insulation structure that is to be protected. This becomes crucial for difficult-to-protect loads such as submersible pumps in deep water wells. The best protection is afforded by an arrester built directly into the motor rather than on the surface in the controller.

Some cases may not have as much to do with the surge voltage appearing at the outlet as with the differential voltage between two ground references. Such is the case for many TV receiver failures. Correct *bonding* of protective grounds is required as well as arrester protection.

The protective level of service entrance arresters for lightning impulses is typically about 2 kV. The lightning impulse current-carrying capability should be similar to the transformer secondary arrester, or approximately 40 kA. One must keep in mind that for low frequency overvoltages, the arrester with the lowest discharge voltage is apt to take the brunt of the duty. MOV-type arresters will clamp the overvoltages without causing additional power quality problems such as interruptions and sags.