Lightning Induced Faults on Power Lines

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Introduction

In many power systems across the country, lightning is a leading cause of interruptions and momentary events. Power system structures (poles/towers) are often the tallest structures around and as such they make a good conduit for lightning strikes. This paper will serve as a primer to define lightning interactions with the power system, lightning and fault measurement techniques, and mitigating technologies that help make the power system more robust to lightning-induced faults.

Lightning

Lightning is an electrostatic discharge between two clouds or the cloud and ground. Cloud to ground discharges will be the primary focus of this paper since they are the ones that usually cause problems for the power system. There are a variety of hypothesis on how the charges form. However, when the charges become strong enough they initiate a discharge. The discharge occurs in multiple stages.

During the discharge process invisible positively and negatively charged leaders form. The ionized particles that make up these channels ultimately meet in a process called attachment. After the attachment completes, a return stroke may be formed. Each discharge event may consist of several strokes. Most lightning location systems group multiple strokes into a single flash. An example of a single flash with multiple strokes is shown in Figure 1, below.

Figure 1 - Flash with 3 strokes

Lightning flashes radiate both electric and magnetic fields. Naturally, the lightning location systems utilize wideband sensors to detect lightning. The sensor systems then use direction finding techniques to locate the position of the discharge. At present there are 3 networks that cover all of the United States: the National Lightning Detection Network (NLDN), the United States Precision Lightning Network and the Weatherbug Total Lightning Network.

All three networks report similar types of lightning parameters. Namely, they report location, magnitude, and classification (cloud-cloud vs. cloud-ground). The location accuracy for each of the networks varies, but they all claim to be within 500 meters or better for most of the US. The magnitude reported by each network is estimated and reported in terms of peak current.

Some of the networks have the ability to report additional parameters. These may be of use to the power system community in determining failure causes. However, they are not typically reported at this time. These parameters include rise time, charge transfer and continuing current. These additional parameters would be useful in identifying damage related to overvoltage as well as heat-related damage.

Power System Interactions

Lightning can strike a number of locations along the power delivery system. This can be seen in Figure 2, below. For the purposes of this paper, only lightning that strikes the utility part of the power system will be considered.

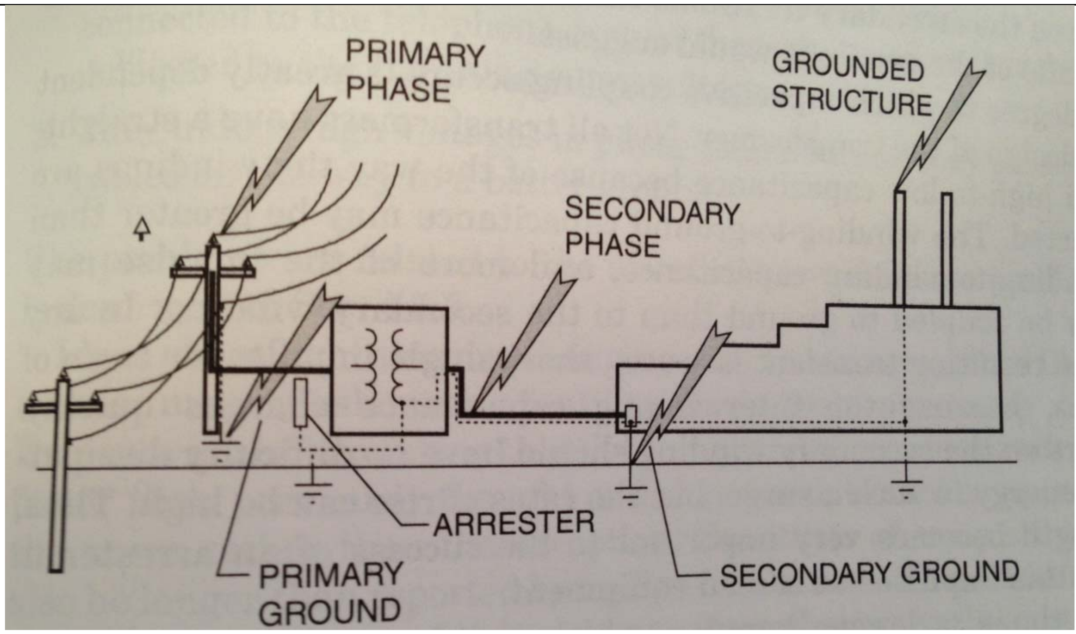

Figure 2 - Lightning Interactions

There are several ways that lightning can cause problems on the power system. The first way is for lightning to strike a tower or shield wire on a tower. If the magnitude of the strike is sufficient, back flash or flashover may occur. As the current of the lightning strike rises, so does the voltage. Eventually, the voltage between the phase conductors and ground is sufficient to create an electric arc.

At times, lightning can attach directly to a phase conductor. If the line has a shield wire, then this is referred to as shield wire failure. If the line does not have a shield wire, then it is simply referred to as direct attachment. The lightning event may transfer enough energy to the phase conductors to cause damage to lines, insulators and other equipment.

When lightning causes a fault on the power system, the transient that occurs is too fast to measure directly with an oscillograph or relay.   The sampling rate simply is not sufficient to record the lightning transient. However, sags resulting from lightning events are readily measureable with oscillographs or relays. See Figure 3 below for an example waveform recorded by a Digital Fault Recorder.

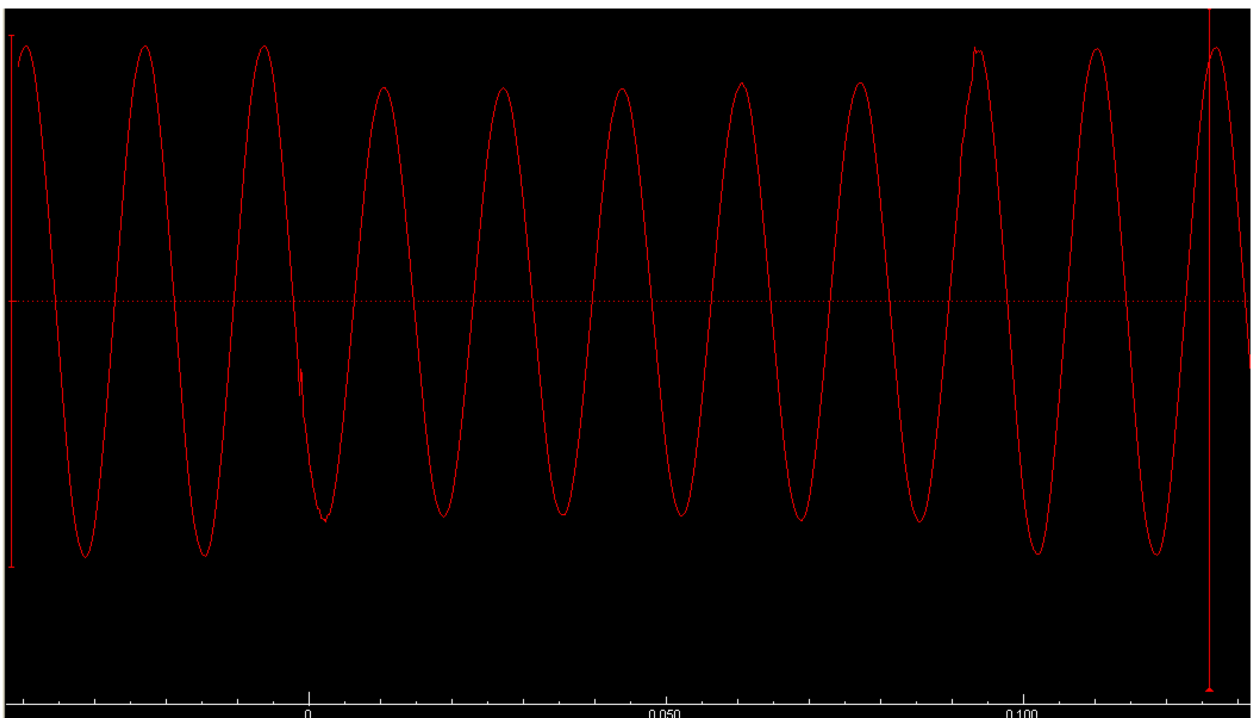

Figure 3 - DFR Event

When travelling down the power system, lightning also exhibits some other interesting characteristics. For example, the traveling voltage wave that results from a lightning interaction doubles in magnitude at open points along the conducted path. An example of an open point is an open breaker. Conversely, the lightning impulse is damped out after a few spans. This can be seen in Figure 4 below.

Figure 4 - Impulse Dampening

Mitigating Technologies

Fortunately, a variety of technologies and techniques exist to make the power system more robust to lightning events. Grounding, shield wires, insulation coordination and lightning arresters represent the most comment ways to improve lightning performance. The measurement of the efficacy of these various approaches is typically measured as a function of the number of lightning challenges the equipment receives over some period of time.

Most lines are designed with direct strikes in mind. The most common way to protect lines is to use a shield wire. This wire is usually at the top of the structures that hold the phase conductors. The shield wire is bonded to ground and when struck hopefully routes most of the energy from the strike to ground. The phase conductors must be mounted under the shield wire within a certain angle of protection. Figure 5 shows a single circuit tower with a shield wire at the top.

Figure 5 - Single Circuit Tower

Shield wires must be connected to Earth. However, the soil resistivity varies with soil composition, moisture, etc. So, the tower must have a good footing resistance in order for this approach to be effective.

Additional insulation of phase conductors can also improve the lightning performance of a line. The insulation placed on a tower rarely has to do with the voltage class of the line, but instead is based on the lightning or switching transient performance of the line. The amount of insulation placed on the line is done by computing the probability of a certain magnitude stroke over a distance of the line based on the typical number of storm days per year.

Yet another approach to insuring the lines are not disrupted is by placing lightning arresters on the line. There are a variety of technologies that perform this function. Essentially, they all work by diverting any excess current to ground. When there is a nominal amount of current, they effectively are not in the circuit. A surge arrester is shown in Figure 6 below.

Figure 6 - Surge Arrester

Conclusions

Lightning is a complicated event. However, there are ways to measure and identify the location of lightning strikes. Lightning impacts a variety of equipment on the system. However, there are techniques that exist to make the system more tolerant to lightning events.

References

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