



# Electric Distribution Overvoltage Protection

An Online Continuing Education Course for Engineers

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## Table of Contents

<b><u>Section</u></b>	<b><u>Page</u></b>
Introduction .....	3
I. Lightning .....	4
Lightning flash mechanism .....	4
Electrical characteristics of lightning .....	9
Ground flash density .....	10
II. Surge Arrestors .....	12
Arrestor design .....	12
Arrestor operation .....	14
Arrestor types .....	16
III. Equipment Protection .....	17
IV. Overhead Line Protection .....	23
Shielding .....	23
Arrestor application to overhead lines .....	26
Structure design .....	29
V. Underground Line Protection .....	34
VI. Grounding .....	36
VII. Ferroresonant overvoltages .....	39
Conclusion .....	42

## Introduction

Overvoltage situations occur everyday on electric distribution power systems. The overvoltages may be the result of external conditions such as lightning or from internal conditions such as from switching surges and ferroresonance. These overvoltages may breakdown equipment insulation causing equipment damage and possibly failure and often result in disruption in service to customers.

The most common cause of distribution overvoltages is lightning strikes from electrical storms in the atmosphere each year. In the United States alone there are over 30 million cloud to ground lightning strikes, so the potential for damage to an electric distribution system is significant. Lightning may cause an insulation breakdown in a single transformer, which results in only few homes losing power, or the lightning strike may flashover an insulator on a three-phase line interrupting power to thousands of homes. Usually the damage from a single lightning strike to an electric distribution system is not a sufficient economic loss, but when the total number of strikes is considered, the annual economic impact is in the millions of dollars, not to mention the interruption in electrical service that occurs.

In comparison to lightning, switching surges and ferroresonance have only a minor economic or service impact on an electric distribution system. Transient switching surges are not much of an issue with distribution systems and will not be discussed here, but, we will briefly look at how ferroresonance may cause an overvoltage condition.

To analyze overvoltages, we must first understand something about how lightning occurs and how it impacts the electric system. The first section of this course describes how lightning occurs, the characteristics of lightning, and how to calculate ground flash densities. Next, we will look at the design and operation of surge arresters. Subsequent sections include information about electrical line design methodologies to minimize the impacts of lightning, equipment protection strategies, and the impacts of grounding on lightning protection.

But first, let's look at how lightning is created and how it impacts an electric system.

# **I. Lightning**

From mythology we learned that lightning was used as a weapon by the Greek god, Zeus who hurled it at his adversaries. From the Vikings we learned that lightning was produced by Thor as his hammer struck an anvil while riding his chariot across the clouds. Today we know much more about how lightning originates, but we are still in awe at its power. And we should be, because each year lightning is responsible for numerous deaths in the U.S. and millions of dollars in property damage to utility equipment and consumer electronics.

Since 1989 a lightning detection network has been in place over the continental 48 states. During this time, an average of 20,000,000 cloud-to-ground flashes has been detected every year. In addition, about half of all flashes have more than one ground strike point, so at least 30 million points on the ground are struck on average each year in the US. There are roughly 5 to 10 times as many cloud to cloud flashes as there are cloud to ground flashes.

Damage from lightning occurs as a result of both direct and indirect strikes. Lightning may directly contact a power line causing damage or it may contact a nearby tree or other object where the current flows through the ground and into the power line circuit. Quite often underground power equipment is damaged when lightning strikes an overhead line and the lightning strike current travels along the power line damaging insulation in the underground cable or underground equipment.

## **Lightning Flash Mechanism**

Lightning originates in cumulonimbus clouds, which are the cloud formations that generate thunderstorms. These thunderstorm clouds are formed wherever there is enough upward motion, vertical instability, and sufficient moisture to produce a cloud that reaches up to levels somewhat colder than freezing. Thunderstorms are divided into two types: convective and frontal system storms. Convective thunderstorms are usually short-lived, lasting for 30 minutes to a few hours. Frontal storms can cover hundreds of miles as they travel across the country.

The formation of a thunderstorm requires three basic ingredients, moisture, cooling, and lifting action. The basic fuel is moisture, or water vapor, in the atmosphere. The air above the water vapor must cool off rapidly with height. There must be something in the atmosphere to push the moist air from near the ground up to where the air around it is cold. This may be a cold front or the boundary between where the cold air from one thunderstorm meets the air outside of the storm (called an outflow boundary) and anything else that forces the air at the ground together. When this happens the moist air is pushed up. As the moist air rises it cools off and some of the water vapor condenses into liquid water cloud drops. This warms up the rest of the air mass so that it doesn't cool off as fast as it would if the air was dry. When the air mass gets into the colder atmosphere, it will be warmer and less dense than the air around it. Since it is less dense, it will start to rise faster without being pushed. Then more water vapor turns into liquid in

the air mass and the air mass warms up more and rises even faster until all of water vapor is gone and the air mass eventually reaches a point in the atmosphere where it isn't warmer than the environment.

Strong updrafts and down drafts occur with regularity, even within small thunderstorms. The updrafts transport water droplets up into the cloud, while ice particles descend from the frozen upper regions of the cloud. As they do, they bump and collide with each other. Through this process, electrons shear off of the ascending water droplets and collect on the descending ice particles. This generates an electric charge within the cloud, with the top having a positive charge and the bottom having a negative charge. An electric field is also generated between the top and bottom of the cloud. The electric field is also generated between the top of the cloud and the surface of the earth. The electric field is most intense near the surface of the earth.

In a thunderstorm, the electric field between its top and bottom is the greater than the electric field between the top of the atmosphere and the surface of the earth. The electric field is most intense near the surface of the earth.

Lightning is a discharge of electric charges, which can occur between clouds (IC), between a cloud and the ground (CG), or between the ground and the ground (GG).

Cloud-to-ground lightning is the most common type of lightning. Although it is the most common, it is also the most dangerous. However, it is not the most frequent type of lightning. Some of the most frequent lightning strikes are intra-cloud lightning, which occurs within the cloud.

*Intra-cloud lightning* occurs between opposite charges within the cloud. Usually the process takes place within the cloud, but sometimes the flash may exit the boundary of the cloud and a bright channel, similar to a cloud-to-ground flash, can be visible for many miles.

The ratio of cloud-to-ground and intra-cloud lightning can vary significantly from storm to storm. Storms with the greatest vertical development may produce intra-cloud lightning almost exclusively. Some suggest that the variations are latitude-dependent,

