CHAPTER 1

Overview of High Voltage Protection for Telecommunications

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LEARNING OBJECTIVES

- Discuss the purpose of high voltage (HV) isolation protection equipment
- Describe ground potential rise (GPR) and how it can damage telecommunications equipment and expose people to unsafe working conditions
- Describe what is meant by zone of influence (ZOI) and the 300-V point
- Explain the problems encountered if HV isolation equipment is not used
- Explain where to install HV isolation equipment
- Describe the two main types of HV isolation equipment (copper vs. fiber) and the corresponding IEEE recommended practices for proper design and installation
- Explain how copper versus fiber HV isolation equipment works

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BASIC PURPOSE AND APPLICATIONS

Copper wire-line telecommunication facilities (as opposed to fiber optics, radio, microwave, satellite, and power line carrier systems) that are used in electric supply locations (ESLs) often require special high voltage (HV) protection equipment to provide safety to personnel, to prevent damage to equipment, and to assure the reliable operation of the telecommunications circuits themselves. There are various means of properly protecting telecommunications facilities equipment and personnel. The goal of high voltage protection for telecommunications (HVPT) is to provide the design engineer with safe, reliable, and cost-effective installations when exposed to unexpected HV events such as power faults and lightning strikes. Power faults are HV flashovers of insulation, the breakdown of equipment used in HV systems, or when something happens to HV equipment causing it to discharge large amounts of electrical energy into its surroundings. When personnel are working in HV environments such as electric power substations, power plants, cell sites on power towers, and other potentially dangerous locations where an HV event is possible, properly protecting critical telecommunications facilities is essential. Copper telecommunications cables can transfer dangerous potentials from remote locations due to their insulated jackets and remote connections. All dielectric optical fiber systems, on the other hand, offer electrical isolation due to the nonconductive properties of glass. This chapter summarizes the potential problems with telecommunications circuits in HV environments, the industry solutions, and the recommended methods to work in these environments safely.

The first point to make in explaining the potential problem associated with these facilities is to clarify the difference between HV "isolation" of telecommunications circuits and HV "protectors" used on telecommunications circuits. The terms are almost synonymous when it comes to protecting telecommunications circuits from HV conditions. Both terms apply to HV exposure conditions where circuits need to protect themselves from damage. However, the term HV "protectors" refers to circuit protection equipment that is used to limit the voltage across telecommunications circuit conductors by shunting the energy to the earth grounding electrodes (i.e., circuit protectors such as gas tubes and carbon blocks as discussed in more detail later in this book). The term HV isolation is used to describe circuit protection from HV damage by isolating the copper conductors from the damaging HV potentials. Shunt "protectors" are usually applicable to HVs 1000 V or less, and HV "isolation" devices are applicable to exposure HVs above 1000 V. Hence, both HV protectors and HV isolation equipment may be required at HV environments such as power substations, personal communications system (PCS) cell sites located on electric power towers, stand-alone mountaintop telecommunications antenna towers, and 911 emergency call centers. One of the main purposes of this book is to explain when and where to use shunt protectors and/or HV isolation equipment.

THE HV PROTECTION CHALLENGE

Electrical disturbances that cause damage to telecommunications equipment and possible injuries to personnel are commonly lumped into two categories, "power faults" and "lightning strikes." Power faults typically occur when HV power lines come in contact with earth-grounded equipment and/or substation HV power equipment failures. Power faults and lightning strikes cause high currents to flow through metallic paths to earth-grounded objects. The portion of faulted current that flows through the earth itself, returning to voltage sources, can have harmful effects on telecommunications cables and equipment. For example, Figure 1.1 shows a basic cable and equipment scenario *not* under a fault condition. The telephone company termination side (referred to as "central office" or "CO" side) is on the left, and the power company equipment side (referred to as "substation") is located

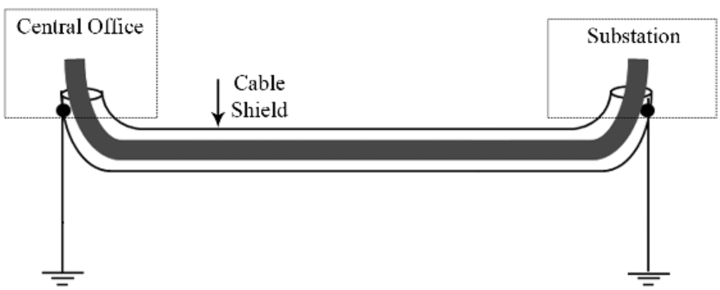

Figure 1.1 Basic cable configuration.

on the right. Notice that the cable shield is grounded on both ends (grounded is the term used to describe how the connection is made between the metal cable shield and the metal conductors buried in the earth). For the sake of illustration, intermediate grounds of the cable shield are not shown. In this case, the earth serves as a natural conductive body that can potentially conduct electrical current should a voltage appear between the grounded objects. In the normal state, the earth has zero potential between these two grounded objects, and no current is flowing through the cable shield.

During a power fault or lightning strike situation, the earth's electrical potential (voltage) rises and causes anything metal that is buried in the earth at or near that location to also rise in potential. When the earth's potential rises, referred to as "ground potential rise" (GPR), the voltage of these grounded cable shields also rises and can be significantly different. These GPR voltages can differ on the order of tens of thousands of volts at the location where the fault occurs. Due to the earth's electrical resistance to current flow, the earth's potential decays outward from the GPR event location where the energy is dissipated by the soil. Therefore, the potential at the CO's ground can be much lower than that at the substation ground (where the power fault occurs), causing an HV potential between the two grounded objects. The "remote" location (CO) becomes the reference point in a GPR situation. The degree at which the earth's ground potential rises, with respect to the remote location, follows an exponential curve as shown in Figure 1.2. Thus the earth's potential drops exponentially as the distance from the faulted location increases.

Figure 1.2 shows how the earth's potential rises nonlinearly with respect to remote ground during a power fault occurrence in a

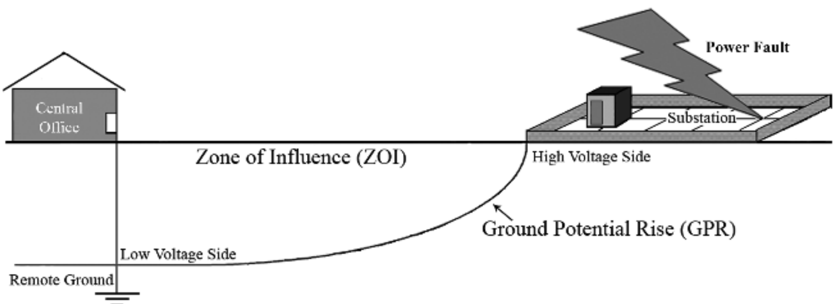

Figure 1.2 Substation ground potential rise.

substation. The same is true with all ESLs. The HV GPR occurs at the substation in this case, and the low voltage (LV) side of the GPR is located at the "remote ground" location (the CO side in this case). Since the fault is located at the substation, the CO side is also referred to as the remote ground location. In other words, when a copper telecommunications cable is connected between the CO and a substation and both ends of the cable are grounded, the CO side is referred to as remote ground location, and the station side of the cable is referred to as the ESL.

> *The paramount issue is when the ESL (substation) side of the telecommunications cable shield (or sheath) is connected to the substation's ground conductors (i.e., ground grid) when a power fault occurs and GPR is created, the telecommunications equipment is likely to be damaged due to the large potential difference across the cable shield, and personnel injures are possible when equipment fails catastrophically. Further, personal injury can also occur if the person comes in contact with both potentials at the same time*. (These situations are discussed in more detail throughout this book.)

The distance between the HV fault location (substation) and the remote LV area is called the "zone of influence" (ZOI). Note that the LV location of the ZOI does not have to be the CO location. The ZOI is usually measured or calculated as the distance from the HV side (substation) to a point in the ZOI that measures or is calculated to be 300 V. This is referred to as the "300-V point." Thus, the 300-V point is the location where the HV GPR decays exponentially to the 300-V level regardless of the magnitude of the GPR at the substation. For example, the substation GPR could be 30,000 V or 5000 V, and the ZOI is the distance to the 300-V point. The length or area of the ZOI depends on GPR magnitude and the soil type (details of GPR and ZOI are discussed later in this book).

Note that the "300-V point" is recommended in the United States, and other countries may use other values in a similar manner.

Combining the conditions of cable grounding at both ends, as in Figure 1.1, with the effects of earth's GPR shown in Figure 1.2 when a power fault or lightning strike occurs, as in Figure 1.2, results in the possible cable damage and personal injury scenario shown in Figure 1.3. GPR is directly imposed on the copper cable and the copper cable

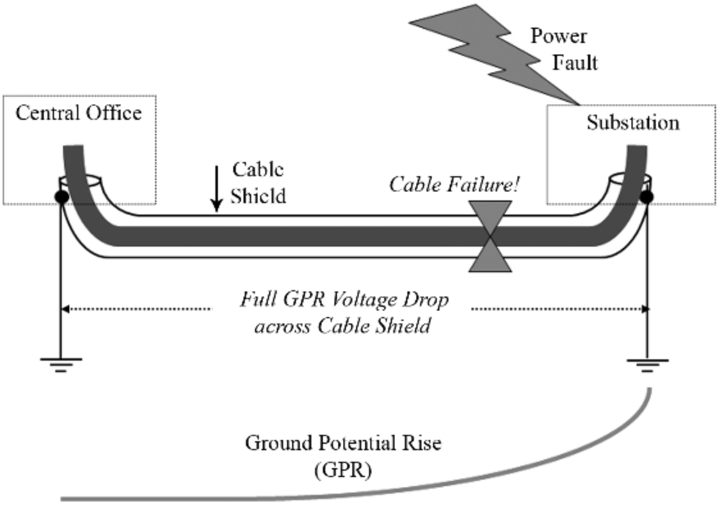

Figure 1.3 Unprotected cable in failure mode both ends grounded.

is not designed to withstand that much voltage. Although the copper shield of the telecommunications cable is typically jacketed with insulation, the conductive shield will most likely fail the cable and create safety concerns.

The essence of this book is to explain how this undesirable situation can be prevented and how to design reliable telecommunications circuits in the event of a high GPR condition. Locations where these HV events can occur are referred to as HV environments.

Aside from wireless and other telecommunications systems that provide GPR isolation by nature, there are two IEEE recommended practices of protecting telecommunications cables from the adverse effects of GPR. The two IEEE standards are

1. IEEE Std. 487-2007™; "IEEE Recommended Practice for the Protection of Wire-Line Communications Facilities Serving Electric Power Stations." This standard applies to copper cables traversing the ZOI as shown in Figure 1.4.
2. IEEE Std. 1590-2006; "IEEE Recommended Practice for the Electrical Protection of Optical Fiber Communication Facilities Service, or connected to, Electrical Supply Locations." This standard applies to all dielectric optical fiber cables traversing the ZOI as shown in Figure 1.5.

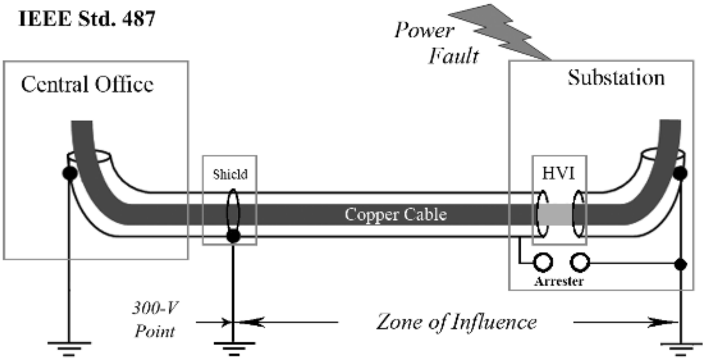

Figure 1.4 Isolated copper cable in failure mode.

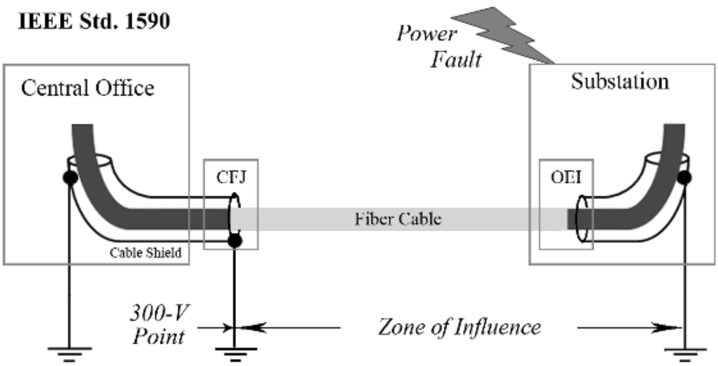

Figure 1.5 Isolated optical fiber cable in failure mode.

HV ISOLATION STANDARDS

There are two standard practices to protect telecommunications circuits in HV environments: those associated with copper cables crossing the ZOI and those associated with optical fiber cables crossing the ZOI. There are acceptable variations of the recommended practices, usually resulting in additional protection; however, minimum conditions must be met to assure equipment protection, personnel safety, and reliable circuit operations.

Copper Cables Crossing the ZOI (IEEE Std. 487-2007)

The most significant point to recognize when using copper telecommunications cables across the ZOI is that the cable shield is *not* grounded at both ends. The cable shield is grounded only at the remote ground location (300-V point, CO side) and isolated from all grounded conductors at the ESL and everywhere in the middle (see Fig. 1.4). Note that the cable shield is not connected directly to the substation ground grid.

The high voltage interface (HVI) is the telecommunications equipment that provides isolation from the voltage across the cable when the GPR occurs. Lightning arresters can be part of the HVI equipment. The lightning arrester protects the HVI when the GPR exceeds the insulation strength of the HVI by limiting the voltage across the HVI to the clamping voltage of the lightning arrested. When the GPR exceeds the breakdown voltage level of the arrester, the arrester conducts and limits or clamps the voltage across the HVI. The arrester is connected to the copper telecommunications cable between the cable shield and the station ground grid.

Lightning arresters are often installed at the substation end. The arrester connects the copper cable's shield to the substation ground grid. The purposes of the lightning arrester are to limit the voltage potential across the HVI and to utilize the remote ground to help dissipate some lightning energy during extreme lightning strike conditions. During extreme lightning strike conditions, the lightning arrester conducts (fires) and helps dissipate lightning energy directly to the earth ground electrodes (the station ground grid in this example). Normally, the magnitude of the GPR is less than the firing voltage of the arrestor, and therefore the arrestor does nothing. Its purpose is to provide a secondary path for extreme lightning energy should the substation side experience an unusually high lightning event. Additionally, the arrester limits the voltage across the HVI, thus protecting the HVI from voltages exceeding its insulation capability.

The copper cable-type HVI accomplishes circuit isolation two ways; either through high dielectric strength transformer action (coupling through electromagnetics) or short-reach fiber optics (coupling through an optical interface).

Transformer HVI

The HVI equipment can be composed of transformer isolation, where the LV CO side is isolated from the HV station side through specially designed HV isolation transformers. These special transformers provide circuit isolation up to about 90 kV (asymmetrical peak voltage, which is defined later in this book).

Fiber HVI

When a short 6-inch section of fiber optics telecommunications equipment is used to bridge an air gap between the CO side of the HVI and the station side of the HVI, about the same 90 kV level of isolation is provided. The insulation properties of a short section of glass are used to isolate the HV potentials.

Optical Fiber Cables Crossing the ZOI (IEEE 1590-2009)

Optical fiber cables provide inherent isolation because of the fact that glass and plastic are nonconductors of electricity. In this application, the all-dielectric optical fiber cable itself serves as the HVI isolator, provided the conversion from copper cable to optical fiber cable is located outside the ZOI, and the conversion of optical fiber cable back to copper cable is located at the ESL (substation). The all dielectric optical fiber cable must traverse the entire ZOI (between the 300-V point and station ground grid) to conform to IEEE Std. 1590-2009.

Figure 1.5 shows the optical fiber cable isolation method. When optical fiber cables are used across the ZOI as the isolation method, the copper-to-fiber and the fiber-to-copper transition points are referred to as the following:

- copper fiber junction (CFJ): implying the CO side of the installation
- optical electrical interface (OEI): implying the station side.

Note that the figure shows that the optical fiber cable is not of the metallic shielded type. Only all dielectric optical fiber cable is recommended, where there is *no* copper or conductive shield present in the optical fiber cable (as recommended by IEEE 1590-2009). Should a metallic shield-type optical fiber cable be desired, then the HVI design and installation procedures must follow the standards recommended for copper cables crossing the ZOI (IEEE Std. 487-2007).