1B.7—Lightning and Other Overvoltage Protection

1. Scope

This engineering handbook document describes the overvoltage protection requirements for substations and transmission lines. These are general requirements and refer to company construction standards for more specific information. References are also made to pertinent industry standards where applicable. These protection policies are intended to cover overvoltages due to lightning, switching surges, ferroresonance, and temporary overvoltages caused by faults.

2. General

Recent reviews of distribution and substation lightning protection practices in the company have shown that additional overvoltage protection is warranted in some service areas. The latest revision of EA 111 describes new practices that apply to distribution. The substation guidelines put forth in this document will be further developed as the need arises with new construction, or when specific areas are identified for immediate attention to overvoltage potential. Standards for the most common substations, such as 138-12.47 kV, will be developed first.

3. References and Resource Documents

The reference and resource documents listed below apply to the extent specified in these policies and in the referenced standards:

IEEE 998, *Guide for Direct Lightning Stroke Shielding of Substations*

IEEE 1313.2, *Guide for the Application of Insulation Coordination*

IEEE 1410, *Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines*

Hileman, Andrew R., *Insulation Coordination for Power Systems* (New York: Taylor & Francis, 1999)

4. Ground Flash Density Levels

For systems 230 kV and below, some standard practices differ between Utah, Idaho, Wyoming, and other states in the service territory due to the higher incidence of lightning in the easternmost states. This is illustrated by the Ground Flash Density Map shown in Figure 1. This document will refer to Zones 1 and 2. Zone 1 is defined as an area with a ground flash density lower than .5 flashes/km2 /year. Zone 2 is an area with a ground flash density greater than .5 flashes/km2/year. Wyoming, Eastern Idaho, and Utah will all be considered Zone 2 for purposes of application of the practices described in this document.

For system voltages of 345 kV and above, overvoltage protection is more often necessary to protect against switching surges, rather than lightning. Therefore, the standards for higher voltage systems are uniform across the company.

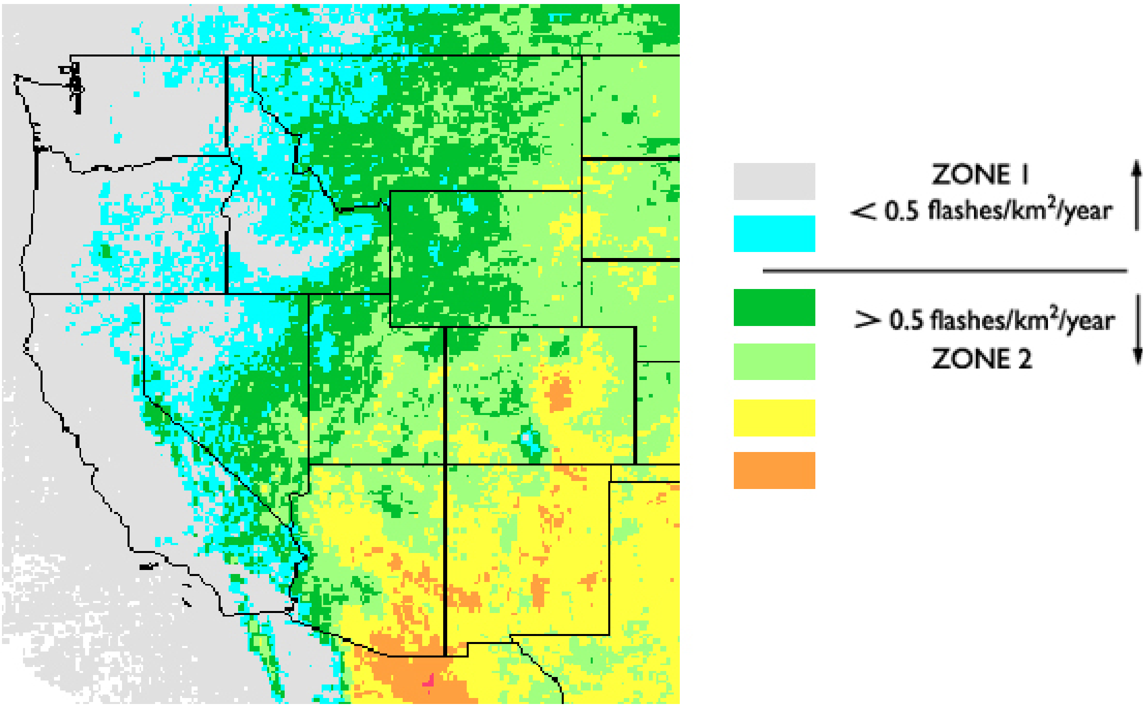

Figure 1—U. S. Flash Density Map

5. Substation Overvoltage Protection

Shield wires and lightning arresters are the primary means of overvoltage protection for substations and transmission lines. The practices in this document establish additional protection measures beyond those of past practices. Figure 2 illustrates the most significant changes to substations with high-side voltages of 138 kV and below.

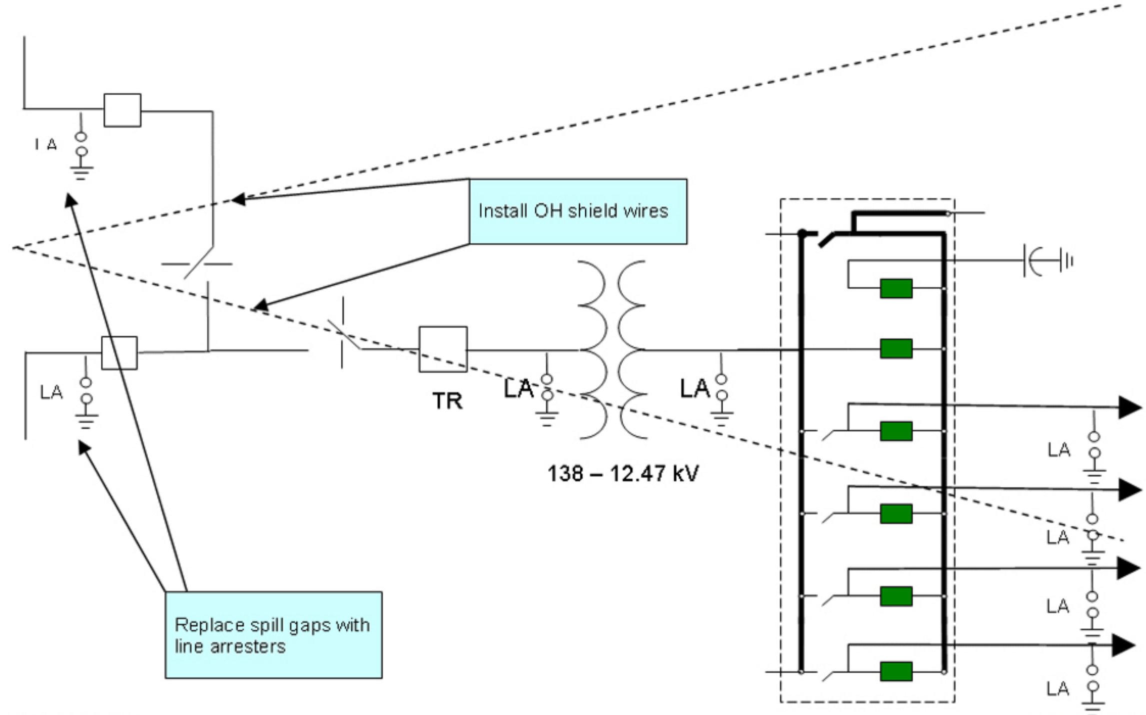

Figure 2—Distribution Substation Overvoltage Protection (Zone 2)

5.1. Substations with High-Side Voltages of 138 kV and Below

5.1.1. Substation Shielding

Substations located in Zone 2 shall be shielded with overhead shield wires or lightning masts. The fixed angle method, per IEEE 998, shall be used with a 45-degree angle for heights up to 60 feet, and a 30-degree angle for heights above 60 feet.

Substations located in Zone 1 shall not be shielded unless the incoming transmission lines are shielded over the entire length.

5.1.2. Transformer Protection

All power transformers shall be protected with high- and low-side lightning arresters. Refer to Table 1, and company material specification BHE PX-S01 for arrester sizes.

Table 1—Transformer Surge Arrester Rating Guide

Transformer Nameplate Voltage	Transformer Winding BIL	Arrester Duty Cycle Rating		Stock Item #		MCOV
		Grounded Systems	Ungrounded Systems	Grounded Systems	Ungrounded Systems	
525 kV	1425 kV	420 kV	n/a	(TBD)	n/a	335 kV
345 kV	1050 kV	264 kV	n/a	7882325	n/a	212 kV
230 kV	750 kV	180 kV	n/a	9600416	n/a	144 kV
161 kV	650 kV	132 kV	n/a	7887345	n/a	106 kV
138 kV	550 kV	120 kV	n/a	8100175	n/a	98 kV
115 kV	450 kV	96 kV		9600160		76 kV
			120 kV		7887373	98 kV
69 kV	350 kV	60 kV		9602189		48 kV
			72 kV		1003204	57 kV
46 kV	250 kV	39 kV		1004075		31.5 kV
			48 kV		7887346	39 kV
34.5 kV	200 kV	30 kV		7887347		24.4 kV
			36 kV		7887348	29 kV
25.0 kV	150 kV	21 kV		7887095		17 kV
			27 kV		7887349	22 kV
20.8 kV	150 kV	21 kV		7887095		17 kV
			27 kV		7887349	22 kV
13.8 kV	110 kV	12 kV		7887171		10.2 kV
			15 kV		1008491	12.7 kV
13.2 kV	110 kV	12 kV		7887171		10.2 kV
			15 kV		1008491	12.7 kV
13.09 kV	110 kV	12 kV		7887171		10.2 kV
			15 kV		1008491	12.7 kV
12.5 kV	110 kV	12 kV		7887171		10.2 kV
			15 kV		1008491	12.7 kV

5.1.3. Breaker Protection—69 kV to 138 kV

In both Zones 1 and 2, the high-side breakers shall be protected by lightning arresters installed on the line side of the breakers (Refer to Table 2 for arrester sizes). In some cases, the breaker may be protected by the arrester on the transformer if they are very close (30 ft. for 138 kV) to one another. Check with substation standards engineering for any question regarding the need for arresters at the breaker.

Table 2—Line Entrance Surge Arrester Rating Guide

Nominal System Voltage	Breaker/Trans. Line BIL	Arrester Duty Cycle Rating		Stock Item Number		MCOV	Arrester Minimum Energy Capability Based on One
		Grounded Systems	Ungrounded Systems	Grounded Systems	Ungrounded Systems		
525 kV	1800/1800 kV	420 kV	n/a	(TBD)	n/a	335 kV	13KJ/KV of MCOV
345 KV	1300/1300 KV	276 kV	n/a	(TBD)	n/a	220 kV	9KJ/KV of MCOV
230 kV	900/900 kV	180 kV	n/a	9600416	n/a	144 kV	5kJ/KV of MCOV
161 kV	750/750 kV	132 kV	n/a	7887345	n/a	106 kV	5KJ/KV of MCOV
138 kV	650/650 kV	120 kV	n/a	8100175	n/a	98 kV	5KJ/KV of MCOV
115 kV	650/550 kV	96 kV		9600160		76 kV	5KJ/KV of MCOV
			120 kV		7887373	98 kV	5KJ/KV of MCOV
69 kV	350/350 kV	60 kV		9602189		48 kV	5KJ/KV of MCOV
			72 kV		1003204	57 kV	5KJ/KV of MCOV
46 kV	350/250 kV	39 kV		1004075		31.5 kV	5KJ/KV of MCOV
			48 kV		7887346	39 kV	5KJ/KV of MCOV

Notes

The length of 525 and 345 kV transmission lines was assumed to be 300 miles or less.

The length of 230 and 169 kV transmission lines was assumed to be 200 miles or less.

The length of 138 to 46 kV transmission lines was assumed to be 150 miles or less.

5.1.4. High-Side Bus Protection

If there are no high-side breakers, spill gaps shall be installed at the transmission line terminals in both Zones 1 and 2. Table 3 lists the requirements for spill gaps.

Table 3—Spill Gap Settings

Maximum System Voltage Phase-to-phase (kV)	Basic Impulse Insulation Level (BIL) (kV)	Spill gap spacing S at sea level (inches)
48	250	7.5
72.5	350	11
121	550	19
145	650	23
169	750	27
242	900	40

Table 4—Altitude Correction Factors

Altitude (ft)	500	1000	1500	2000	2500	3000	3500
Correction Factor δ (Note 3)	0.982	0.965	0.948	0.931	0.915	0.899	0.883
Altitude (ft)	**4000**	**4500**	**5000**	**5500**	**6000**	**6500**	**7000**
Correction Factor δ (Note 3)	0.868	0.852	0.837	0.823	0.808	0.794	0.780

Note 1. The spill gaps are set to withstand a 2.5 pu switching surge at sea level, using the formula:

$$S = \frac{8}{\frac{3400 \times k_g}{CFO} - 1}$$

(IEEE Std.1313.2 Eq. 27), where k_g = the gap factor given in Table 10 (IEEE 1313.2). For rod-to-rod (vertical) gaps, the value = 1.30, and CFO is the switching surge.

Note 2. Switching surge line-to-ground at sea level is calculated using the formula:

$$\frac{E\,max \times \sqrt{2}}{\sqrt{3}} \times pu$$

where E_{max} = the system's maximum voltage and pu = the per unit switching surge factor.

Note 3. To find spill gap setting at different altitude, use the values listed in Table 4, which were
developed with the formula:

$$\delta = 1.000 \times e^{\wedge \frac{-A}{8.59}}$$

where A = the altitude in kilometers. The setting at sea level should be divided by the altitude correction factor to get the gap setting at the desired altitude.

Note 4. The settings were checked to be below the withstand capabilities of the station post insulator, determined with the formula:

$$BSL = 1.07 \times \frac{3400}{1 + \frac{8}{Hi}}$$

This formula is from IEEE 1313.2, Eq. 23, where H_i is the insulator height in meters, and BSL is the basic switching level.

5.1.5. Feeder Getaway Protection

Underground Getaways—Riser pole arresters shall be installed on both ends of underground getaways in open-bus substations. For underground getaways exiting from metalclad switchgear, an arrester shall only be installed at the riser pole on the load side of the getaway.

Overhead Getaways—Distribution class arresters shall be installed as close as possible to the getaway conductors where they attach to the substation bus structure.

5.2. Substations with Voltages of 161 kV and Above

5.2.1. Substation Shielding

All transmission substations shall be shielded. The fixed angle method, per IEEE 998, shall be used with a 45-degree angle for heights up to 60 feet, and 30-degree angle for heights above 60 feet.

5.2.2. Transformer Protection

All power transformers shall be protected with high- and low-side lightning arresters. Refer to Table 1, and company material specification PX-S01A for arrester sizes.

5.2.3. Breaker Protection

All breakers, at voltages of 69 kV and above, shall be protected by line entrance arresters. The example in Figure 3 illustrates that 138 and 230 kV line terminals with breakers, previously protected by spill gaps, will now have arresters installed. Refer to Table 2 for arrester sizes.

5.2.4. High-Side Bus Protection

If there are no high-side breakers, spill gaps shall be installed at the transmission line terminals. Table 3 lists the requirements for spill gaps.

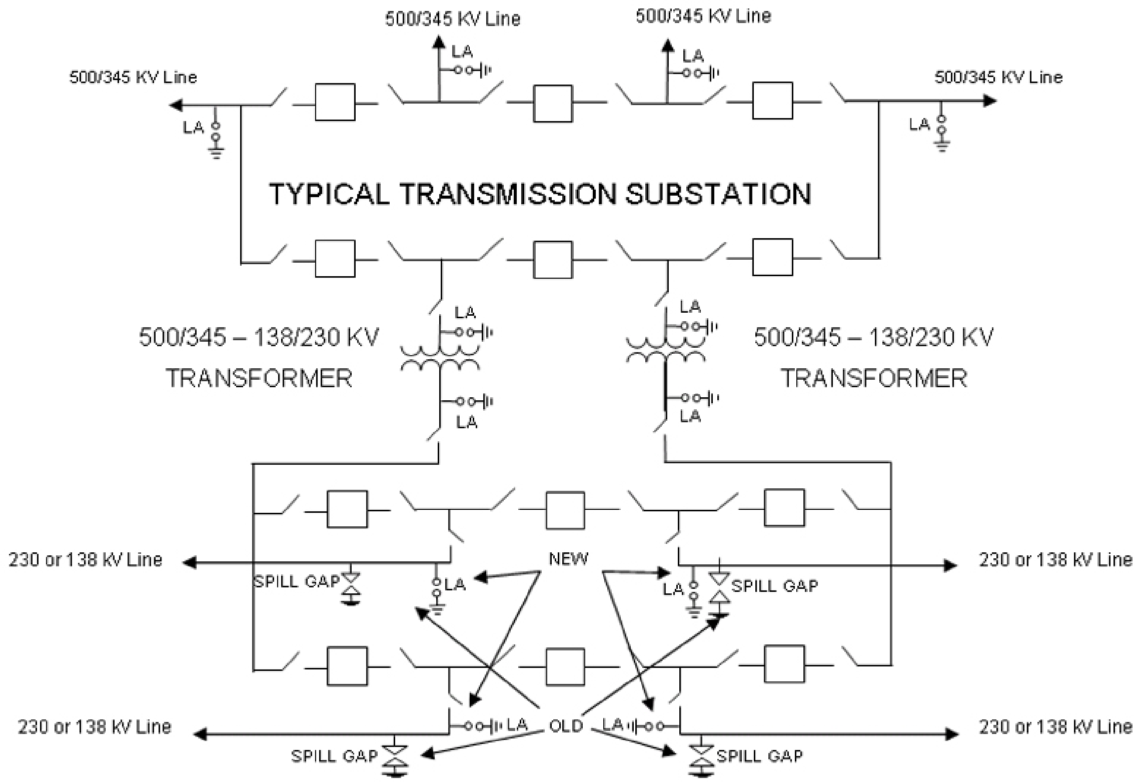

Figure 3—Typical Transmission Substation Overvoltage Protection

6. Transmission Line Overvoltage Protection

6.1. Shield Wire

Refer to company transmission construction standard TD 201, *Shield Wire—Lightning Protection Locations*.