Application of the IEEE Guide for Improving the Lightning Performance of Electric Power Overhead Distribution Lines (Std. 1410-1997)

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http://www.pti-us.com/pti/consult/dist/ieee/lghtnwg/lghtnwg.htm

Prepared for the IEEE T&D Conference

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Working Group on the Lightning Performance of Distribution Lines

The Working Group is dedicated to investigating the effects of lightning on distribution circuits and educating the industry. The working group consists of experts from around the world.

The working group reports to the Lightning and Insulator Subcommittee within the T&D Committee of the IEEE Power Engineering Society. The working group normally meets during the Winter and Summer Power meetings. If you would like to become a member of the working group, contact Tom Short (meeting attendance is not required). A working group web page with meeting minutes and archives of some of the previous presentations is available at:

http://www.pti-us.com/pti/consult/dist/ieee/lghtnwg/lghtnwg.htm

Overview of the Guide

The introduction of the guide provides a good overview of the goals of the guide:

"Lightning is a major cause of faults on typical distribution lines. These faults may cause momentary or permanent interruptions on distribution circuits. Power quality concerns have created more interest in lightning. Improved lightning protection of overhead distribution lines against faults is being considered as a way of reducing the number of momentary interruptions and voltage sags.

On overhead distribution lines, lightning usually causes temporary faults. If the fault is cleared by a breaker or a recloser, the circuit may be successfully reclosed. In the past, this was acceptable, but now with the proliferation of sensitive loads, momentary interruptions are a major concern.

Lightning may also cause permanent faults. From 5 to 10% of lightning-caused faults are thought to cause permanent damage to equipment ([B22] recorded 9%). Temporary faults may also cause permanent interruptions if the fault is cleared by a one-shot protective device like a fuse.

Estimating the lightning performance of distribution lines contains many uncertainties. Even some of the basics such as lightning intensity measured by ground flash density or estimating the number of direct strikes to a distribution line may have significant error. Often, rough estimates or generally accepted practices are just as effective as detailed calculations. This guide is intended to provide straightforward estimates of lightning-caused faults.

The goal of this guide is to provide estimates of lightning-caused faults and the effectiveness of various improvement options. Estimates using this guide may be used to compare improved lightning protection with other methods of improving system reliability and power quality such as tree trimming programs or improved protection schemes such as the use of additional reclosers or sectionalizers. This guide should also be beneficial in evaluating design standards."

The scope of the guide is given below:

"This guide will identify factors which contribute to lightning-caused faults on overhead distribution lines and suggest improvements to existing and new constructions.

This guide is limited to the protection of overhead line insulation for system voltages 69 kV and below. Equipment protection considerations are covered in ANSI/IEEE C62.22-1991."

Contents

Common Questions

This section addresses how the guide answers several common questions regarding the lightning performance of distribution lines.

How can I improve the performance of a particular distribution line?

Lightning may cause flashovers from:

1. Direct strokes, and
2. Induced voltages from nearby strokes

Direct strokes are difficult to protect against because the overvoltages are very high (the voltage wants to go to megavolts, but the insulation is usually only capable of handling 100-500 kV). Direct strokes would be the main concern for lines out in the open. Direct stroke protection is possible using one of the following methods:

- Shield wire with good grounding and high insulation levels
- Arresters at tight spacings
- Combinations of the above

Induced voltages are usually less than 300 kV, so they are much easier to protect against. Induced voltages are more of a problem on lines with nearby trees (the trees bring strokes closer to the line) and on lines with low insulation levels. Several improvement options that the guide discusses include:

- Improving insulation level
- Adding surge arresters at a given spacing (they don't have to be as tight as direct-stroke protection)

- Adding surge arresters at weak-link poles (poles with lower than normal insulation)
- Adding a ground wire

How often do I need to space arresters?

This depends on the purpose of the arresters. Direct-stroke protection requires arresters at almost every pole (every other pole will help if insulation levels are kept high at the unprotected poles).

Induced voltage flashover improvement can be significant at much wider spacings (up to 6-8 spans). This can be further improved by applying the arresters at weak links such as cut-outs, dead-end poles or crossover poles.

Other situations such as underbuilt distribution circuits, top-phase arrester application, or use with a shield wire are more complicated.

What is the BIL of my structure?

The critical flashover voltage (CFO) more accurately specifies the lightning insulation capability of a distribution structure. The CFO is "The crest value of the impulse wave that, under specified conditions, causes flashover through the surrounding medium on 50 percent of the applications."

The CFO of a structure may be provided by several elements (the insulator, wood, fiberglass, etc.). It is difficult to estimate the CFO of a structure. The total CFO is less than the sum of the individual CFOs of each element. The structure CFO is dependent on the geometry's involved (this is why it is difficult). The CFO will also be less when the structure is wet.

The guide provides some tables and guidelines for estimating the CFO based on work done at Mississippi State University. The crudest approximation for a structure with an insulator and wood is to take the insulator CFO and add 250 kV per meter of wood.

The CFO is often degraded at "weak-link" poles where equipment on the poles reduces the CFO. The guide comments on the following situations:

- Guy Wires
- Fuse Cut-Outs
- Neutral Height
- Conducting Supports and Structures
- Multiple Circuits
- Spacer Cable Circuits
- Spark Gaps and Insulator Bonding

What is the lightning activity in my area?

The best measure of lightning intensity is ground flash density (GFD) that is measured with a lightning detection network or with flash counters. Unfortunately, many parts of the world do not have such equipment, or it has not been in service long enough. The guide offers advice on how to estimate GFD from other measures such as thunderstorm-day or thunderstorm-hour data. Because of the high variability in lightning and lightning-caused interruptions, it may take many years of data to accurately estimate a mean. The guide gives some advice on this.

The guide provides an isokeraunic map (giving the average annual days with thunderstorms) of the world and a ground flash density map of five years of data for the continental United States. These maps are provided if nothing else is available; for a particular location, better data is likely to be available.

How many hits will I get to a given line?

The flash collection rate *N*, in open ground (no significant trees or building nearby), is estimated by Eriksson's equation:

$$N = N_g\left(\frac{28h^{0.6} + b}{10}\right)$$

where
h = pole height, m
b = structure width, m
N_g = ground density, flashes/ km^2 / year
N = flashes/ 100 km/ year

For a typical distribution line height of 10 m, $N = 11$ flashes to the line/100 km/year for N_g=1 flash/km^2/year.

Trees and buildings may play a major role in the lightning performance of distribution lines. Trees and buildings may intercept many lightning flashes that otherwise would have hit a line. The guide offers some curves and advice on how to take this into account.

Case Study

The guide has the following case studies:

- Example 1: 15-kV wood crossarm design
- Example 2: 35-kV line with a shield wire

An additional case study is provided below:

Example: 15-kV Circuit Underbuilt on a Pole with a 69-kV Circuit Above

Problem: Excessive outages have been occurring on a circuit with 10 km of 12.47-kV distribution line mains built under a 69-kV circuit. The utility is investigating options for increasing performance. The pole structure is shown in Figure 1. The 12.47-kV insulators have a CFO of 90 kV. The distance from the insulator to the transmission ground lead is 30 cm. The average ground on the poles is 50 ohms. The average height of the pole is 15 m. The ground flash density is 5 flashes/km^2/year.

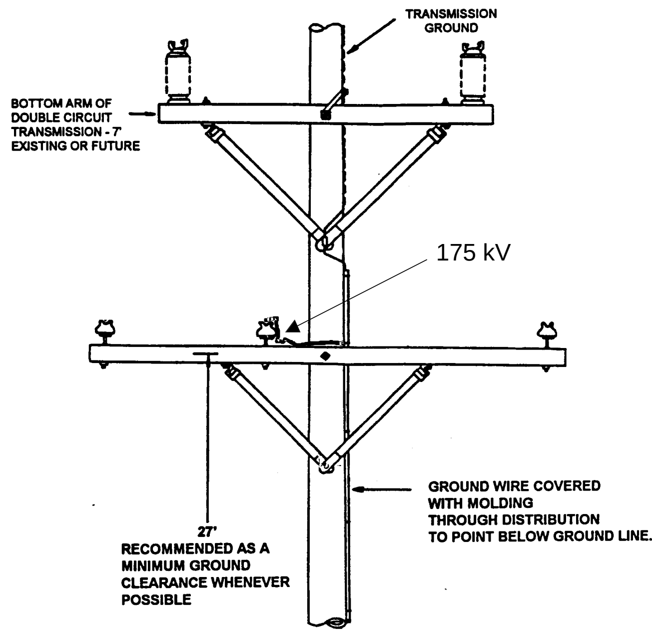

Figure 1. 15-kV Circuit Underbuilt on a Pole with a 69-kV Circuit Above.

Insulation level. The lowest flashover path is from the transmission ground to the middle pin insulator. The CFO along this path is 175 kV. This is the insulator CFO (100 kV) plus the CFO-added second component of 0.3 m of a wood crossarm that provides an additional 75 kV of CFO (this comes from using 250 kV/m for a 2nd component in Table 3 of the guide).

Direct strokes. The number of flashes to the structure is:

$$N = 5\,(28(15)^{0.6})/10 = 71.1 \text{ flashes/100 km/year}$$

Direct stroke flashovers. Because the line is underbuilt, the shield wire on the 69-kV circuit provides a shield wire for the 12.47-kV circuit too. This means that the insulation and grounding of the structure are critical to the performance of the line. Using Figure 8 (reproduced below) of the guide, the circuit will flashover for about 80% of direct strokes, so the flashover rate of the line is:

$$N_{fl} = 71.1(.8) = 56.9 \text{ flashes/100 km/year}$$

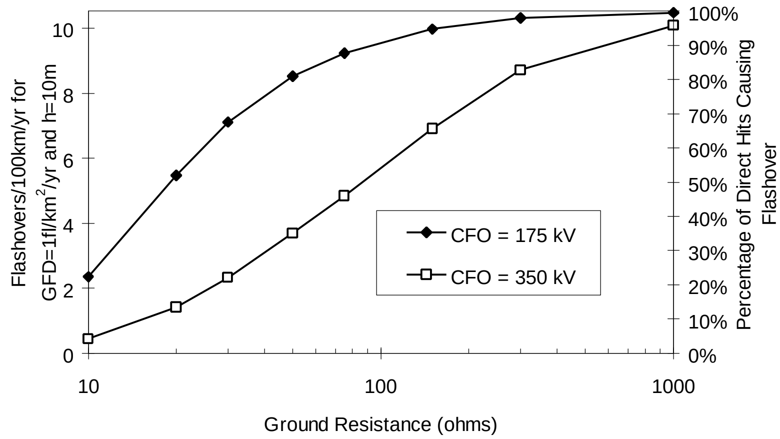

Figure 2. Effect of grounding resistance on shield wire performance (direct strokes)
[Figure 8 of IEEE Std. 1410-1997]

Induced flashovers. Using Figure 5 of the guide, the number of induced flashovers is estimated as 0.9 flashovers/100 km/year for N_g=5 flashes/km^2/year. This number is small relative to the number of direct stroke flashovers, so solution efforts will be concentrated on direct strokes.

Improvement efforts could include:

- Better grounding
- Higher CFO
- Arrester on the middle phase

The guide could be used to address all of these options. The simplest solution is probably to put the transmission ground on fiberglass standoffs to hold it away from the center insulator and increase CFO. The limit of increase in insulation is about 300 kV. The ground should be positioned such that it falls between the middle and right insulator. This leaves about 0.5 meters of distance from the ground to one of the phase wires. The CFO path straight through the air is then 300 kV (using 600 kV/m as the primary insulation path through air given in Table 2 of the guide). With a 300 kV CFO, the flashovers will be reduced by about 40% (you have to interpolate Figure 8 of the guide).

To get the same effect (40% reduction in flashovers) by reducing grounding, the grounds would have to be reduced to 20 ohms. Another thing to look at would be poles that have poor or missing grounds (with an average of 50 ohms, some may be much worse). Improvements may be most economical in areas with the worst grounding. To get reductions larger than 40% would probably require the use of surge arresters.

Future Work

At recent working group meetings, several suggestions have been made for improvements to the guide. These include:

- Consolidation of Eriksson's model and the electrogeometric model: The Eriksson equation is a shadow method (the line attracts flashes within a given shadow width). Some of the other theoretical underpinnings (for induced voltages and for calculations of shielding factors) in the guide are based on an electrogeometric model. It can be argued that these are incompatible.

- Better induced voltage model: The Rusck model for induced voltage is a simplified model. The Rusck model seems to break down for close strikes (as discussed in B.2.4 in the guide). A more detailed model may be included in the future. The biggest holdup is that there are not enough experimental measurements to verify that the more detailed models give more accurate results.

- Better model of insulation under induced voltages: The guide contains a fudge factor of 1.5 to account for the fact that induced voltages do not stress insulators as much as a standard 1.2/50-μs wave (because they are short duration spikes). If a better model becomes available, it will be used.

- Covered wire performance: There is no discussion of covered wire in the guide. Covered wire burndowns are often associated with lightning-caused faults (it is actually the power-frequency fault current that causes the wire damage, so it is really more of an overcurrent protection issue).

- Grounding: It has been suggested that the guide offer more practical guidance on how to provide better pole grounding.

- Down ground connections: More guidance on connections of down grounds has been requested.

- Insulated down grounds: The guide does not consider using insulated down grounds on shield wire structures.

The working group will be addressing these items and others that come up in the future. To be involved, please contact the chair to join the working group or attend working group meetings.