



Transmission Line Design (Volume III) - Hardware

An Online Continuing Education Course for Engineers

Course Number: E-4051

Credit: 4 Hours / 4 PDH / 4 CPD

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Introduction

The primary purpose of this series of courses is to furnish engineering information for use in designing transmission lines. Good line design should result in high continuity of service, long life of physical equipment, low maintenance costs, and safe operation. These courses present a generalized “how to” guide for the design of a high voltage transmission line.

The engineering information in this course is for use in design of transmission lines for voltages 230 kV and below. Designs should be adapted to various conditions and local requirements. Engineers should investigate local weather information, soil conditions, operation of existing lines, local regulations, and environmental requirements and evaluate known pertinent factors in arriving at design recommendations.

This course is based on the requirements of the National Electrical Safety Code® (NESC®). However, since the NESC is a safety code and not a design guide, additional information and design criteria are provided in this course as guidance to the engineer. The additional design criteria are based on practices of many utilities in the United States.

This series includes five volumes. For the best understanding of the material, they should be studied in order. The volumes are generally divided into the following categories.

Volume I. This volume is an introduction to transmission line design and addresses siting issues, plan and profile drawings, loading, and distribution underbuild.

Volume II. This volume is all about clearances. Ground clearances, horizontal clearances, clearances from other live parts, and clearances to supporting structures are addressed.

Volume III. This volume discusses the materials involved in transmission line design and construction including insulators, conductors and hardware.

Volume IV. This volume in the series is concerned with the structural aspects of transmission line design and includes foundations and guyed structures.

Volume V. The final volume in the series is concerned with the structural aspects of transmission line design and includes single-pole structures and H-frame structures.

Chapter 1

Insulation and Insulators

Insulation is the separation between conducting surfaces by means of a non-conducting (dielectric) material that would economically offer a high resistance to current. Insulators may be fabricated from ceramic, toughened glass, fiberglass rods and sheds of non-ceramic or silicone construction.

The main types of insulators used on transmission lines are suspension insulators using bells or non-ceramic strings, pin insulators, and vertical and horizontal posts. Several suspension bell units are connected in a string to achieve the insulation level desired. The non-ceramic suspension is one unit with an insulation level determined largely by its length. Horizontal post units are made of ceramic or non-ceramic material and are single units with a desired rating. See Figures 1 and 2.

Ceramic Suspension Insulator



Figure 1



Figure 2

Insulator Materials

Ceramic insulators have been the industry standard as specified by ANSI requirements for electrical and mechanical capacities. Although ceramic insulators have a history of long, useful lives, the strings are heavy and subject to breakage from gunshots. The connecting portions of ceramic insulators are metal components which are embedded in high strength cement as specified by ANSI standards. Strength ratings for ceramic insulators are verified by proof loading requirements of each manufactured unit, and stamped accordingly.

Toughened glass insulators are similar in construction to the ceramic insulator. They are heavy, and are also subject to vandalism exposure. ANSI fabrication standards are also available for toughened glass.

Non-ceramic (polymer) insulators typically consist of a fiberglass rod that is sheathed with weathershed 'bells' made of either rubber-based or silicone-based polymers. The connecting ends are typically compressed metal fittings. ANSI standards have been developed for suspension units.

Non-ceramic assemblies offer varieties of end fittings, lengths and strength capacities. They are much lighter in weight than their ceramic and glass counterparts. Non-ceramics may be subject to damage by corona voltage, ultraviolet radiation, or physical deterioration which may not be apparent. Deterioration of a fiberglass rod may result in a reduction in strength of the unit.

Insulation Levels Using Suspension Bells

Table 1 provides suggested insulation levels. However, circumstances such as high altitude, contamination, high isokeraunic levels, or high footing resistance, may warrant additional insulation. If wood structures with steel arms, steel structures, or concrete pole structures are used in areas where there is a high isokeraunic level, consideration should be given to using one additional suspension bell beyond the standard recommended insulation levels.

Table 1 indicates the recommended number of 5-3/4 x 10 in. suspension insulators to be used per phase on wood tangent and small angle structures. Also given are the electrical characteristics of the insulator strings.

For angle structures where the conductor tension is depended upon to pull the insulator string away from the structure, one more insulator bell should be added to the number of bells

recommended for tangent structures. The sole exception to this is 34.5 kV where no additional bells are needed.

In situations where the insulator string is in line with the conductor, the number of bells should be two more than is used for tangent structures. These situations occur at large angles, and tangent dead ends where the conductor is dead ended onto an insulator string. The sole exception to this is 34.5 kV where one additional bell is used.

Table 1 Recommended Insulation Levels at Sea Level (Ceramic Suspension at Tangent and Small Angle Structures) Flashover Characteristics in kV						
Nominal L-L Voltage in kV	No. of 5-3/4x10" Bells	60 Hz Low Freq Dry*	60 Hz Low Freq Wet	Impulse Positive	Impulse Negative	Total Leakage Distance inches
34.5	3	215	130	355	340	34.5
46	3	215	130	355	340	34.5
69	4	270	170	440	415	46
115	7	435	295	695	670	80.5
138	8	485	335	780	760	92
161	10	590	415	945	930	115
230	12	690	490	1105	1105	138

**See NESC Rule 273, Table 273-1 for minimum insulation level requirements*

Insulation Levels Using Post Insulators

Recommended electrical characteristics for horizontal post insulators are given in Table 2.

Table 2 Recommended Insulation Levels At Sea Level (Ceramic Posts at Tangent and Small Angle Structures) Flashover Characteristics in kV							
Design Type	ANSI C29.7 Class	60 Hz Dry Flashover	60 Hz Wet Flashover	Positive Critical Flashover	Negative Critical Flashover	Leakage Distance	Length (inches)
34.5	57-32	100	70	160	260	22	14
46	57-33	125	95	200	344	29	16.5
69	57-36	180	150	300	500	53	25
115						100	48
138						110	54
Note: Negative Critical Flashover values are 10% of Positive Critical Flashover values.							

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Electrical Characteristics

Because low frequency flashover values are generally the most conservative, these ratings are used for determining insulator ratings. However, 60 Hz flashover values are used under normal dry operating conditions, such as for determining insulator electrical characteristics. When comparing insulator electrical characteristics (e.g., suspension) to those of ceramic insulators, the same pattern as for ceramic insulators is used. Tables 1 and 2 are developed and provide both impulse and 60 Hz flashover values. For voltages up to 230 kV the most severe stress on the insulation is usually caused by lightning, and the most important flashover characteristic is the impulse flashover values. Insulation levels for non-ceramic insulators shall generally meet or exceed recommended insulation levels for ceramic insulators.

High Altitude Considerations

As altitude increases, the insulation value of air decreases and an insulator at a high elevation will flash over at a lower voltage than the same insulator at sea level. Figure 3 gives the derating factors for insulator flashover values as a function of altitude. These derating factors apply to both low frequency flashover values and impulse flashover values.