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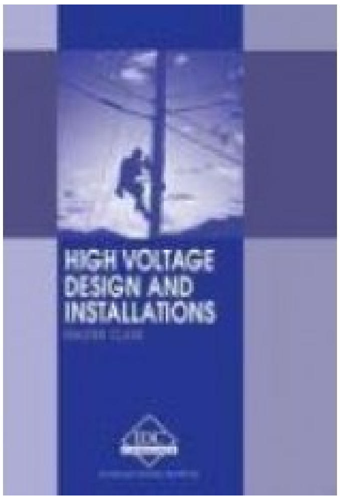
HI-E - High Voltage Design and Installations Master Class



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Short Description

This book is aimed at the private electrical installation designer. However, the topic HV design and installation could also be interpreted as possibly covering the electricity utility transmission and distribution sector (HV transmission and distribution network design) for which the HV design approach would be quite different, even though the technical fundamentals (and some of the technical standards such as AS 2067) are the same. This will not be the focus of this book.

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High Voltage Design and Installation Master Class - Overhead Conductor Design

1 Overhead Conductor Design

The design of each component of the OH line installation should be done with great care in view of the safety hazards associated with the bare overhead conductors and the necessity to minimize the risks of failure.

1.1 Inputs required for design

The following minimum criteria should be kept in mind while designing OH systems:

- Personnel safety of employees of the Utility company and the public
- Compliance with statutory Regulations
- Optimum costs (both installation and life time costs)
- Minimum environmental impacts

The design comprises of the following broad sections:

- Electrical design
- Mechanical design

1.2 Design of electrical specifications of OH conductors

1.2.1 Conductor sizing

The sizing of the conductor is based on several considerations as detailed below.

1. **a) Current carrying capacity**

The conductor should be able to carry the maximum full load current under maximum ambient temperature conditions within permissible temperature limits of the conductor. The conductor depending on the material of construction is designed to be able to withstand a maximum temperature without any reduction in its mechanical strength. The sizing of the conductor should also take into account any future loads planned to be connected to the OH line in the reasonably foreseeable future.

Another important input required for determination of the conductor size is the magnitude of fault level in the system. The conductor should be able to carry the short time fault currents in the system without sustaining any damage. Faults in the system can result in large flow of currents of the order of several thousands of amperes through the conductors producing enormous heating and magnetic effects. The conductors should be designed to withstand such large heating effects and magnetic forces. The three phase fault level at any point in an electrical system is given the following formula:

Fault level (MVA) = ?3 x System voltage(kV) x Maximum fault current(kA)

The fault level of the system is dependent on the following factors:

- The amount of power generation. More the capacity for generation, higher the ability to inject current into a fault and therefore higher is the fault level
- Type of network. More the interconnections and transformers connected at a location, higher the possibility to supply more fault current and hence higher the fault level at that location

It is generally assumed as a standard that the fault can exist for a maximum of three seconds during which time the protective devices will come into action and isolate the faulty section from the rest of the system. Hence, it is required to design the OH components and equipment to withstand the fault currents for a minimum period of three seconds. Flow of large magnitude fault currents, heat up the conductor beyond permissible limits and cause annealing or melting of the conductor which in turn reduce the strength of the conductor.

1. **b) Line voltage drop**

The selection of the conductor size is also based on the maximum allowable voltage drop (e.g. 5%) in the OH line. The voltage drop is dependent on the current in the conductor and the impedance of the line. The voltage drop is related to the total series impedance of the OH line and the current as follows:

$V_{drop} = I_{max} \times Z$

Where

- V_{drop} is the maximum permissible voltage drop
- I_{max} is the maximum load current (taking into consideration reasonably foreseeable future additional loads) and

$Z = R + jX$

Where

- R is the resistance of the conductor
- X is the reactance of the Line (Reactance depends on the conductor configuration and spacing)

The resistance of the conductor is a function of temperature. The relationship between resistance of the conductor and temperature is given by the formula:

R = ? x l/A

Where '?' is the resistivity of the conductor, 'l' is the length of the conductor and 'A' is the area of cross section of the conductor. The relationship between the resistances at different temperatures is given by the relation,

$R2/R1 = (T0 + T2)/(T0 + T1)$

R2 = Resistance at temperature T2

R1 = Resistance at temperature T1

T0 = Constant and is

= 234.5 for annealed copper of 100% conductivity

= 241 for hard drawn copper of 97.3% conductivity

= 228 for hard drawn aluminum of 61% conductivity

An important phenomenon to be considered in the resistance offered by the conductor is 'Skin effect'. Skin effect refers to the inclination of current to flow more readily towards the periphery of the conductor rather than in the centre of the conductor. This phenomenon therefore results in increasing the resistance of the conductor.

The resistance data of the conductor is invariably provided by the manufacturer of the conductor in the form of tables. Safety margin is always provided in sizing the conductor, however the cost implications due to conductor size must be taken into consideration in the selection of the conductor.

1.3 Design of mechanical specifications of OH conductors

In the earlier section, the various factors going into the design of the electrical specifications of the OH conductor were discussed. In addition to the electrical specifications, there is a need to look into the mechanical properties to be possessed by the conductor for the specific application. In this section, the various mechanical specification requirements of the OH conductors are discussed.

The decision on the mechanical properties of the conductor at a minimum is based on the following:

- Required Sag in the conductor
- Span of the conductor
- Environmental conditions (corrosive atmosphere, pollution, winds, storms, ice formation etc)

In order to decide the mechanical specifications of the conductor, it is necessary to understand the various mechanical terms associated with OH conductors.

1.3.1 Parabola

Parabola is defined as the shape assumed by a cable suspended between two support points, when the cable is supporting a uniform horizontal load. For example, the cables used for supporting the deck in a suspension type bridge take the form of a parabola.

1.3.2 Catenary

Catenary is the natural shape assumed by a conductor whose weight is constant per unit of arc length, when the conductor is suspended freely between two support points. The shape assumed by OH conductors therefore is a catenary. However, the formulae related to the calculations of catenary are more involved and complex than that of a parabola. If the Sag (described later in the section) of the conductor is less than 9% of the span length, then the difference between a parabola and a catenary is observed to be less than 1%. Hence, for all practical purposes of calculation, the shape of the OH line is assumed to be that of a parabola.

1.3.3 Span

Span is the horizontal distance between the two supporting points of the overhead conductor. The Span of the section is dependent on:

- Nature of Terrain
- Adequate clearance between the conductors
- Permissible tension under maximum mechanical loads

In general, smaller spans are used in urban areas attributable to reasons of conductor clearances, right of way, pole locations and constraints in providing stays. Longer spans are mostly used in rural areas.

In practical situations all the spans of an OH line are hardly of the same length, hence the use of the Ruling span. Ruling span is defined as the assumed uniform span which would most closely resemble the variety of spans in a particular section of the line. Sag and clearances are calculated based on the Ruling span and used for spotting the structures. The condition that needs to be satisfied is that the spans in the line should not be more than twice or less than half of the Ruling span.

Ruling span is given by the equation:

Wind span is defined as the length of span that determines the transverse load on the support structure due to force of wind on the conductor. Wind span is equal to half of the sum of the adjacent spans. Refer to Figure 1.1.

Weight span is defined as the length of span between the lowest points of the catenaries on either side of a structure. Weight span determines the vertical loading on the structure due to the weight of the conductor. Refer to Figure 1.1.

Figure 1.1

Wind span and weight span

1.3.4 Sag

Sag is defined as the vertical distance between the point where the overhead conductor is attached to the support poles and the lowest point in the conductor as shown in the Figure 1.2.

Figure 1.2

Sag

Factors affecting Sag are:

- Conductor load per unit length (including wind and ice loads)
- Span
- Conductor tension
- Temperature
- Levels of conductor supports

Sag is given by the formula:

$$S = WL^2/8T$$

Where:

S is the Sag of the conductor at mid span (m)

W is the weight of the conductor per unit length (N/m) including wind and ice loads.

Conductor weight is normally provided by the manufacturer in terms of Kg/km. This should be converted to N/m using the formula $W_N = (9.81 \text{ X } W_{Kg})/1000$

L is the horizontal span length between supports

T is the tension of the conductor at the lowest point of conductor (N)

Calculation 1:

Consider a conductor strung between two support poles having a span of 200 mts. The tension of the conductor is 5368 N and the weight of the conductor per unit length is 1.893 N/m. Calculate the Sag of the conductor.

Importance of Sag

Adequate amount of Sag should be provided in the OH line during installation due to the following reasons. An excess amount of Sag can result in reduction of safety clearances due to expansion of the conductor during hot weather, ice loading during winter season and any tilting of the poles. A low value of Sag on the other hand will result in increased conductor tension due to contraction of the conductor during cold weather conditions and may result in snapping of the conductor. Safety clearances below the conductor should be observed in calculation of Sag design values.

Stringing tables are used for selecting the minimum amount of Sag of the conductor at a specified temperature based on the type of conductor and the span length. In actual construction, overhead conductors are not installed and sagged as a single dead end span between adjacent rigid supports. The conductor is installed and sagged in one operation in a line section of may be several unequal spans. Freewheeling stringing sheaves are installed in the structures in between the dead end supports which permit the conductor to move freely between the spans.

1.3.5 Slack

Slack is defined as the difference in the lengths between the straight line across the conductor supports and the distance along the conductor length. For a level span, the slack is given by:

$$K = (8 \times S^2) / (3 \times L)$$

Where

K = Slack (m)

S = Mid span Sag (m)

L = Length of Span (m)

Calculation 2:

Calculate the Slack for the data provided in the above problem.

1.3.6 Conductor length

The length of the conductor is given by the equation:

$$L = S \times (1 + (W \times D)/ (3 \times T))$$

Where

S is the horizontal length of the Span

D is the Sag of the conductor

W is the weight of the conductor per unit length (including wind and ice loads)

T is the tension at the lowest point of the conductor

Calculation 3:

Calculate the length of the conductor for the case given in the earlier calculations.

1.3.7 Swing of conductor

The horizontal swing is provided by the following equation:

$$S_W = P \times D \times L^2 /8 \times T$$

Where S_W is the horizontal swing at mid span in m

W is the conductor weight in N/m

P is the wind pressure under final conditions in Pa

D is the conductor diameter in m

L is the length of the span in m

T is the final tension in N

1.3.8 Conductor Tension

Conductor tension is affected by the various following factors;

1. **a) Temperature**

An increase in the temperature of the conductor results in an increase in length of the conductor. The increase in conductor length is given by the formula:

?L = ? x T x S

Where ? is the coefficient of thermal expansion of the conductor

T is the increase in temperature in deg C

S is the length of the conductor in m

Calculation 4:

Calculate the increase in length of the conductor for the case given in the earlier calculations.

Effect of increase in temperature of conductor

An increase in temperature therefore results in an increase in conductor Sag and a reduction in tension. The conductor tension is given by the formula

$$T = (W \times L^2) /(8 \times S)$$

Where

T is the tension

W is the weight of the conductor per unit length (N/m)

L is the horizontal span length between supports

S is the vertical Sag at the mid span of the conductor

1. **b) Wind**

The second significant factor affecting tension is wind. The wind load acting on the conductor results in an increase in tension of the conductor. This increase in tension results in stretching of the conductor defined by the formula;

$?L = (T_O - T_I)/ (E \times A)$

Where

T_I is the initial tension in Newtons

T_O is the final tension in Newtons

E is the coefficient of elasticity

A is the cross section of the conductor in metres

The wind load on the conductor would cause an inclined Sag on the conductor.

1. **c) Ice**

In locations prone for snow fall and ice formation, the buildup of ice on the conductor has a significant bearing on the tension of the conductor. Ice buildup results in an increase in weight of the conductor. The buildup also increases the area of the conductor subjected to wind force. Both of these phenomena result in increased Sag of the conductor.

1. **d) Age**

Sag of the conductor tends to increase over a period of time due to settling of strands and metallurgical creep. Hence a higher tension may be kept during installation of the conductor to compensate for the effects of aging.

Tension of the conductors should be carefully set during the installation since tension values exceeding the strength of the conductor can result in the breaking of the conductor.

The calculations required to predict the Sag and tension behaviour of an overhead line conductor are complex and are usually performed with sophisticated computer programs. These calculations involve the simultaneous applications of equations for Sag-Tension relationships, conductor stress strain characteristics and change in conductor length as a function of conductor temperature. The program calculates the change in tension of a conductor given its initial stringing condition and nominated operating conditions. The horizontal swing and vertical sag at mid span under this tension are also calculated.

The tension under the operating conditions is calculated using the equation given below:

$$(c_1wl/ T)^2 – T = (c_1w_0l/ T_0)^2 - T_0 + c_2t$$

Where c_1 = ? EA/ 24, c_2 = ?ÉA

l is the ruling span in metres

T is the tension under initial conditions in N

W is the weight of the conductor under initial conditions in N/m

T_0 is the tension under the operating conditions in N

w_0 is the weight of the conductor under the operating conditions in N/m

t is the temperature under the initial conditions less the temperature under operating conditions in °C

E is the final Modulus of Elasticity in Pa

A is the total sectional area of the conductor in sq.m

?’ is the coefficient of linear expansion per °C

The following are the inputs required to be fed into the computer program:

- The ruling span
- The span length
- Conductor temperatures and loading
- Conductor limiting tension condition
- Specific Sag and Tension characteristics of the conductor

The program then determines:

- Which limiting conductor tension will control the design

- Whether final Sags will be controlled by the maximum tension or by conductor creep
- The initial and final Sags for all specified conductors

The computed data from the computer is then used for preparing the Sag-Tension and stringing table. By changing one or more input variables, it is possible to obtain alternative conductor designs which in turn can be used to determine the most practical design for a particular distribution line. Sag-Tension table is then used for the installation of the conductor.

The conductor’s calculated Sag and Tension are based on the span, the type and size of the conductor, the loading conditions and specified tension limit.