3.1 SAG IN OVERHEAD LINES

While erecting an overhead line, it is very important that conductors are under safe tension. If the conductors are too much stretched between supports in a bid to save conductor material, the stress in the conductor may reach unsafe value and in certain cases the conductor may break due to excessive tension. In order to permit safe tension in the conductors, they are not fully stretched but are allowed to have a dip or sag. The difference in level between points of supports and the lowest point on the conductor is called sag. Following Fig. shows a conductor suspended between two equal level supports A and B. The conductor is not fully stretched but is allowed to have a dip. The lowest point on the conductor is O and the sag is S. The following points may be noted

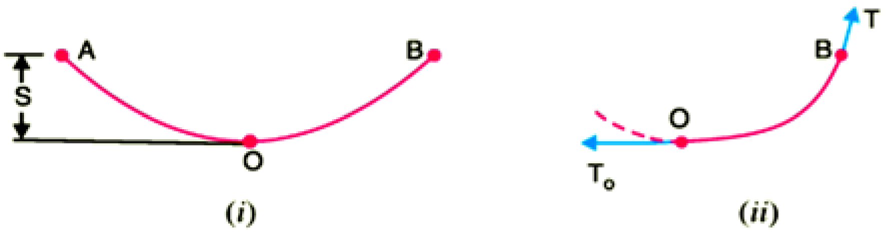

Figure 3.1 Sag in Overhead lines

[Source: "Principles of Power System" by V.K.Mehta Page: 187]

(i) When the conductor is suspended between two supports at the same level, it takes the shap e of catenary. However, if the sag is very small compared with the span, then sag-span curve is like a parabola.

(ii) The tension at any point on the conductor acts tangentially. Thus tension TO at the lowest Point O acts horizontally as shown in Fig. (ii).

(iii) The horizontal component of tension is constant throughout the length of the wire.

(iv) The tension at supports is approximately equal to the horizontal tension acting at any point on the wire. Thus if T is the tension at the support B, then T = TO

3.2 CALCULATION OF SAG

In an overhead line, the sag should be so adjusted that tension in the conductors is within safe limits. The tension is governed by conductor weight, effects of wind, ice loading and temperature variations. It is a standard practice to keep conductor tension less than 50% of its ultimate tensile strength i.e., minimum factor of safety in respect of conductor tension should be

We shall now calculate sag and tension of a conductor when

(i) supports are at equal levels and

(ii) supports are at unequal levels.

(i) When supports are at equal levels .Consider a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.8.2. It can be proved that lowest point will be at a conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.3.2.1 It can be proved that lowest point will be at the mid-span.

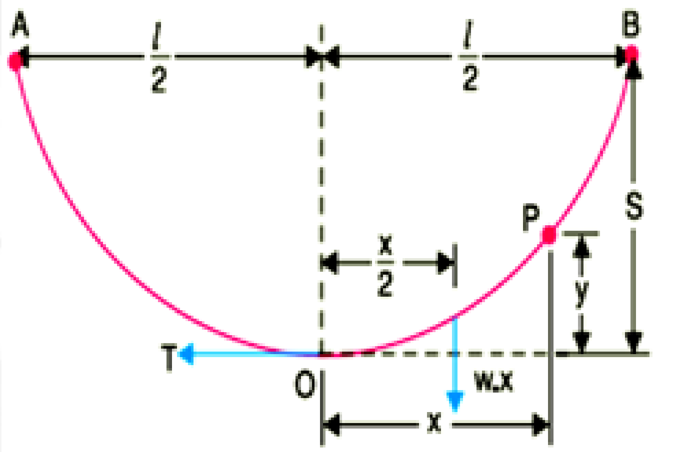

Figure 3.2.1 Supports are at Equal Levels

[Source: "Principles of Power System" by V.K.Mehta Page: 187]

conductor between two equilevel supports A and B with O as the lowest point as shown in Fig.3.2.1. It can be proved that lowest point will be at the mid-span.

Let

l = Length of span

w = Weight per unit length of conductor

T = Tension in the conductor.

Consider a point P on the conductor. Taking the lowest point O as the origin, let the co-ordinates of point P be x and y. Assuming that the curvature is so small that curved length is equal to its horizontal projection (i.e., OP = x), the two forces acting on the portion OP of the conductor are :

(a) The weight wx of conductor acting at a distance x/2 from O.

Moment of force due to weight = $wx \times x/2$

(b) The tension T acting at O .

Moment of force due to tension = Ty

Equating the moments of above two forces about point O, we get,

$$Ty = wx \times \frac{x}{2}$$

$$y = \frac{wx^2}{2T}$$

The maximum dip (sag) is represented by the value of *y* at either of the supports *A* and *B*. At support *A*, *x* = *l*/2 and *y* = *S*, Sag

$$S = \frac{w(l/2)^2}{2T}$$

$$= \frac{wl^2}{8T}$$

(ii) When supports are at unequal levels. In hilly areas, we generally come across conductors

suspended between supports at unequal levels. Fig. 3.2.2 shows a conductor suspended between two supports *A* and *B* which are at different levels. The lowest point on the conductor is *O*.

Let

l = Span length

h = Difference in levels between two supports

*x*1 = Distance of support at lower level (*i.e., A*) from *O*

*x*2 = Distance of support at higher level (*i.e. B*) from *O*

T = Tension in the conductor

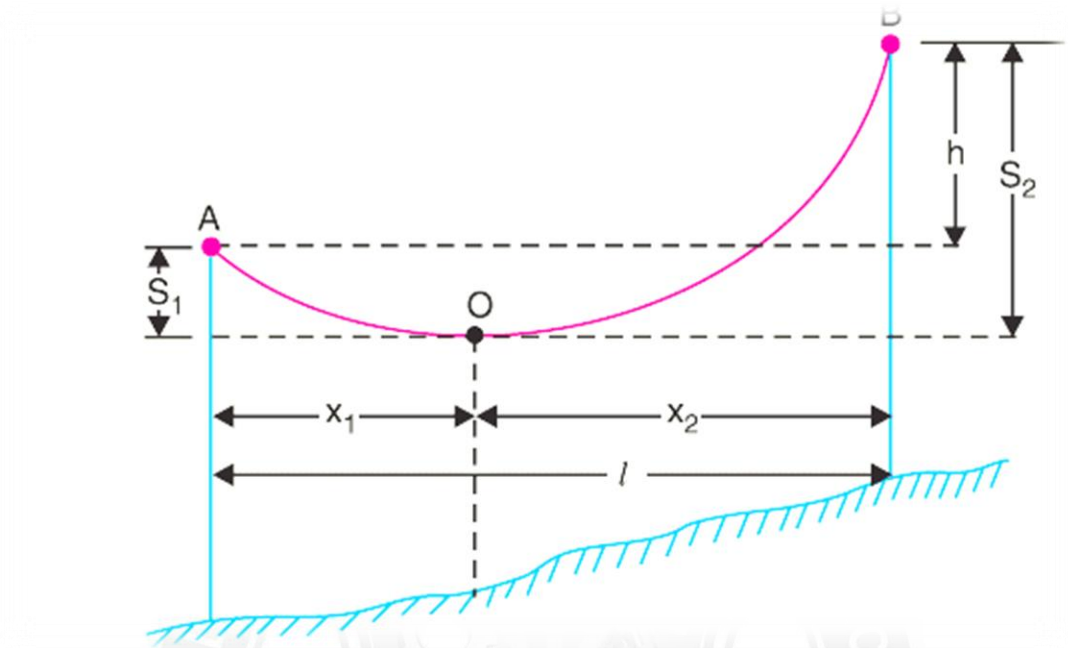

Figure 3.2.2 Supports are at UnEqual Levels

[Source: "Principles of Power System" by V.K.Mehta Page: 188]

$$S_1 = \frac{Wx_1^2}{2T}$$

$$S_2 = \frac{Wx_2^2}{2T}$$

$$x_1 + x_2 = l$$

$$S_2 - S_1 = \frac{W(x_2^2 - x_1^2)}{2T}$$

$$S_2 - S_1 = \frac{W(x_1 + x_2)(x_2 - x_1)}{2T}$$

$$S_2 - S_1 = \frac{Wl(x_2 - x_1)}{2T}$$

$$S_2 - S_1 = h$$

$$h = \frac{Wl(x_2 - x_1)}{2T}$$

$$x_2 - x_1 = \frac{2Th}{Wl}$$

$$x_1 = \frac{l}{2} - \frac{T\,h}{w\,l}$$

$$x_2 = \frac{l}{2} + \frac{T\,h}{w\,l}$$

3.2.1 Effect of wind and ice loading.

The above formulae for sag are true only in still air and at normal temperature when the conductor is acted by its weight only. However, in actual practice, a conductor may have ice coating and simultaneously subjected to wind pressure. The weight of ice acts vertically downwards *i.e.*, in the same direction as the weight of conductor. The force due to the wind is assumed to act horizontally *i.e.*, at right angle to the projected surface of the conductor.Hence, the total force on the conductor is the vector sum of horizontal and vertical forces as shown in Fig.3.2.3.

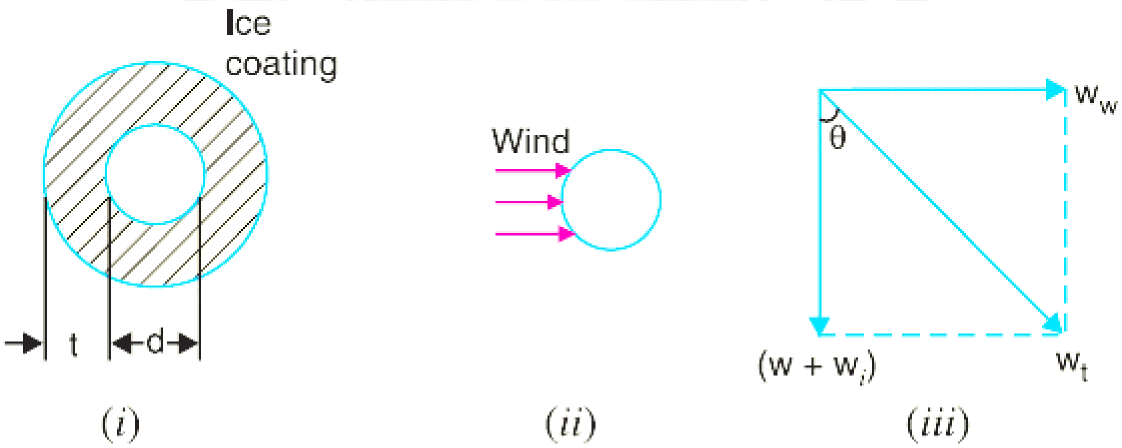

Figure 3.2.3 Effect of Wind and Ice Loading

[Source: "Principles of Power System" by V.K.Mehta Page: 189]

Total weight of conductor per unit length is,

$$w_t = \sqrt{(w + w_i)^2 + (w_w)^2}$$

w = weight of conductor per unit length

= conductor material density × volume per unit length

w_i = weight of ice per unit length

= density of ice × volume of ice per unit length

$$= \text{density of ice} \times \frac{\pi}{4}\,[(d+2t)^2 - d^2] \times 1$$

$$= \text{density of ice} \times \pi\, t\,(d+t)^*$$

w_w = *wind force per unit length*

= *wind pressure per unit area* × *projected area per unit length*

$$= \textit{wind pressure} \times [(d+2t)\times 1]$$

When the conductor has wind and ice loading also, the following points may be noted :

(i) The conductor sets itself in a plane at an angle θ to the vertical where

$$\tan\theta = \frac{w_w}{w+w_i}$$

(ii) The sag in the conductor is given by,

$$S = \frac{w_t l^2}{2T}$$

Hence S represents the slant sag in a direction making an angle θ to the vertical. If no specific mention is made in the problem, then slant slag is calculated by using the above formula.

(iii) The vertical sag = S cos θ

Problem 1

A 132 kV transmission line has the following data : Wt. of conductor = 680 kg/km ; Length of span = 260 m ; Ultimate strength = 3100 kg ; Safety factor = 2

Calculate the height above ground at which the conductor should be supported. Ground clearance required is 10 metres.

Solution:

Wt. of conductor/metre run, $w = 680/1000 = 0{\cdot}68$ kg

Working tension, $T = \dfrac{\text{Ultimate strength}}{\text{Safety factor}} = \dfrac{3100}{2} = 1550$ kg

Span length, $l = 260$ m

$$\therefore \quad \text{Sag} = \frac{w\,l^2}{8T} = \frac{0\cdot 68 \times (260)^2}{8 \times 1550} = 3{\cdot}7 \text{ m}$$

Problem 2

A transmission line has a span of 150 m between level supports. The conductor has a cross-sectional area of 2 cm2. The tension in the conductor is 2000 kg. If the specific gravity of the conductor material is 9·9 gm/cm3 and wind pressure is 1·5 kg/m length, calculate the sag. What is the vertical sag?

Solution:

Span length, $l = 150$ m; Working tension, $T = 2000$ kg

Wind force/m length of conductor, $w_w = 1{\cdot}5$ kg

Wt. of conductor/m length, w = Sp. Gravity × Volume of 1 m conductor

$= 9{\cdot}9 \times 2 \times 100 = 1980 \text{ gm} = 1{\cdot}98 \text{ kg}$

Total weight of 1 m length of conductor is

$$w_t = \sqrt{w^2 + w_w^2} = \sqrt{(1\cdot98)^2 + (1\cdot5)^2} = 2{\cdot}48 \text{ kg}$$

$$\text{Sag,} \quad S = \frac{w_t l^2}{8T} = \frac{2\cdot48 \times (150)^2}{8 \times 2000}$$

$$= 3.48 \text{ m}$$

This is the value of slant sag in a direction making an angle θ with the vertical. Referring to Fig. 8.27, the value of θ is given by ;

$$\tan\theta = w_w/w = 1{\cdot}5/1{\cdot}98 = 0{\cdot}76$$

$$\theta = \tan^{-1} 0{\cdot}76 = 37{\cdot}23°$$

$$\text{Vertical sag} = S\cos\theta$$

$$= 3{\cdot}48 \times \cos 37{\cdot}23°$$

$$= 2.77 \text{ m}$$

Problem 3

A transmission line has a span of 275 m between level supports. The conductor has an effective diameter of 1·96 cm and weighs 0·865 kg/m. Its ultimate strength is 8060 kg. If the conductor has ice coating of radial thickness 1·27 cm and is subjected to a wind pressure of 3·9 gm/cm2 of projected area, calculate sag for a safety factor of 2. Weight of 1 c.c. of ice is 0·91 gm.

Solution:

Span length, l = 275 m ; Wt. of conductor/m length, w = 0·865 kg

Conductor diameter, d = 1·96 cm ; Ice coating thickness, t = 1·27 cm

Working tension, T = 8060/2 = 4030 kg

Volume of ice per metre (*i.e.*, 100 cm) length of conductor

$$= \pi\, t\,(d + t) \times 100 \text{ cm}^3$$

$$= \pi \times 1{\cdot}27 \times (1{\cdot}96 + 1{\cdot}27) \times 100 = 1288 \text{ cm}^3$$

Weight of ice per metre length of conductor is

$$w_i = 0{\cdot}91 \times 1288 = 1172 \text{ gm} = 1{\cdot}172 \text{ kg}$$

Wind force/m length of conductor is

$$w_w = [\text{Pressure}] \times [(d + 2t) \times 100]$$

$$= [3{\cdot}9] \times (1{\cdot}96 + 2 \times 1{\cdot}27) \times 100 \text{ gm}$$

$$= 1755 \text{ gm}$$

$$= 1{\cdot}755 \text{ kg}$$

Total weight of conductor per metre length of conductor is

$$w_i = \sqrt{(w + w_i)^2 + (w_w)^2}$$

$$w_i = \sqrt{(0.865 + 1.172)^2 + (1.755)^2}$$

$$= 2{\cdot}688 \text{ kg}$$

Sag ,

$$S = \frac{w_t l^2}{8T}$$

$$= \frac{2.688 \times (275)^2}{8 \times 4030}$$

$$= 6.8\ m$$

Problem 4

The towers of height 30 m and 90 m respectively support a transmission line conductor at water crossing. The horizontal distance betwen the towers is 500 m. If the tension in the conductor is 1600 kg, find the minimum clearance of the conductor and water and clearance mid-way between the supports. Weight of conductor is 1·5 kg/m. Bases of the towers can be considered to be at water level.

Solution:

Fig. 3.2.4 shows the conductor suspended between two supports *A* and *B* at different levels with *O* as the lowest point on the conductor.

Here, l = 500 m ; w = 1·5 kg ; T = 1600 kg.

Difference in levels between supports, h = 90 − 30 = 60 m. Let the lowest point O of the conductor be at a distance $x1$ from the support at lower level (*i.e.*, support A) and at a distance $x2$ from the support at higher level (*i.e.*, support B).

Obviously, $x1 + x2$ = 500 m

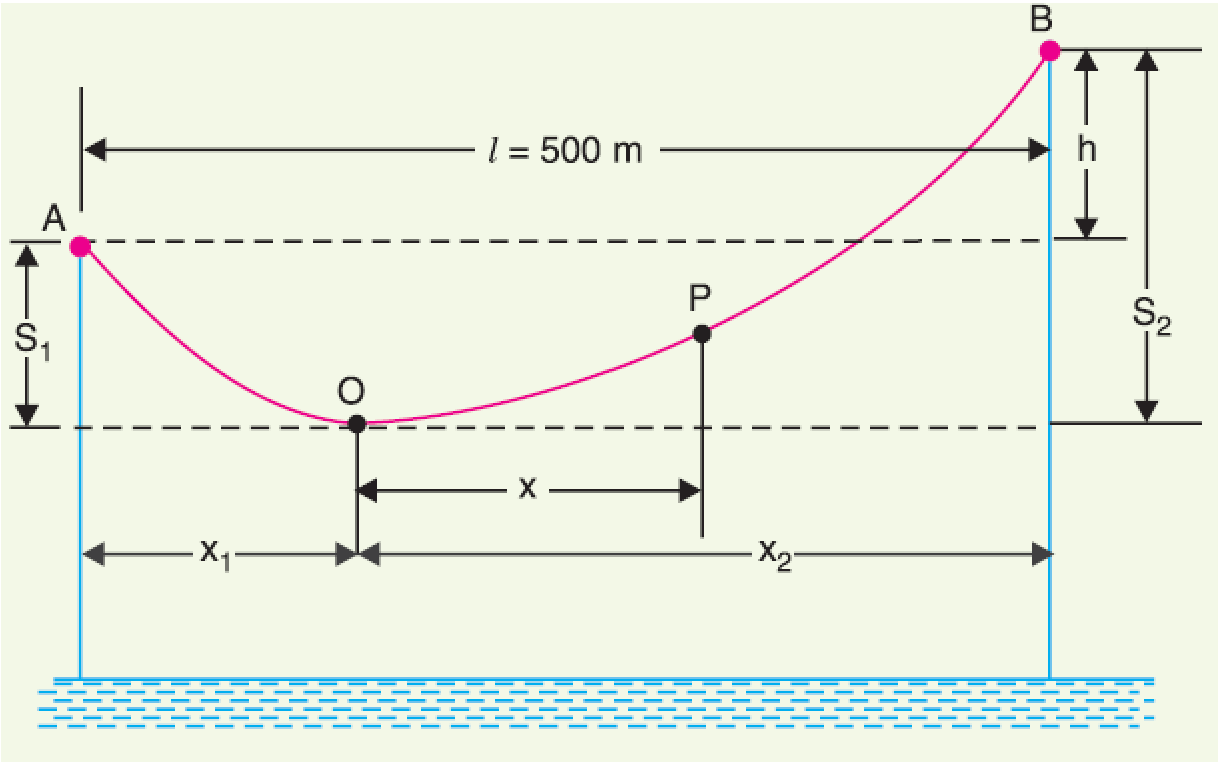

Figure 3.2.4 Conductor b/w two Supports

[Source: "Principles of Power System" by V.K.Mehta Page: 193]

$$\text{Sag } S_1 = \frac{w\,x_1^2}{2T} \quad \text{and} \quad \text{Sag } S_2 = \frac{w\,x_2^2}{2T}$$

$$h = S_2 - S_1 = \frac{w\,x_2^2}{2T} - \frac{w\,x_1^2}{2T}$$

$$60 = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$x_2 - x_1 = \frac{60 \times 2 \times 1600}{1\cdot 5 \times 500} = 256 \text{ m}$$

we get, x_1 = 122 m ; x_2 = 378 m

$$S = \frac{w_t l^2}{2T}$$

$$= \frac{1.5 \times (122)^2}{2 \times 1600}$$

$$= 7m$$

Clearance of the lowest point *O* from water level

= 30 − 7 = **23 m**

Let the mid-point *P* be at a distance *x* from the lowest point *O*.

Clearly,

$x = 250 - x1$

$= 250 - 122$

$= 128$ m

Sag at mid-point *P*,

$$S_{mid} = \frac{wx^2}{2T}$$

$$= \frac{1.5 \times (128)^2}{2 \times 1600}$$

$$= 7.68\, m$$

Clearance of mid-point *P* from water level

= 23 + 7·68

= 30·68 m