Conductor curve

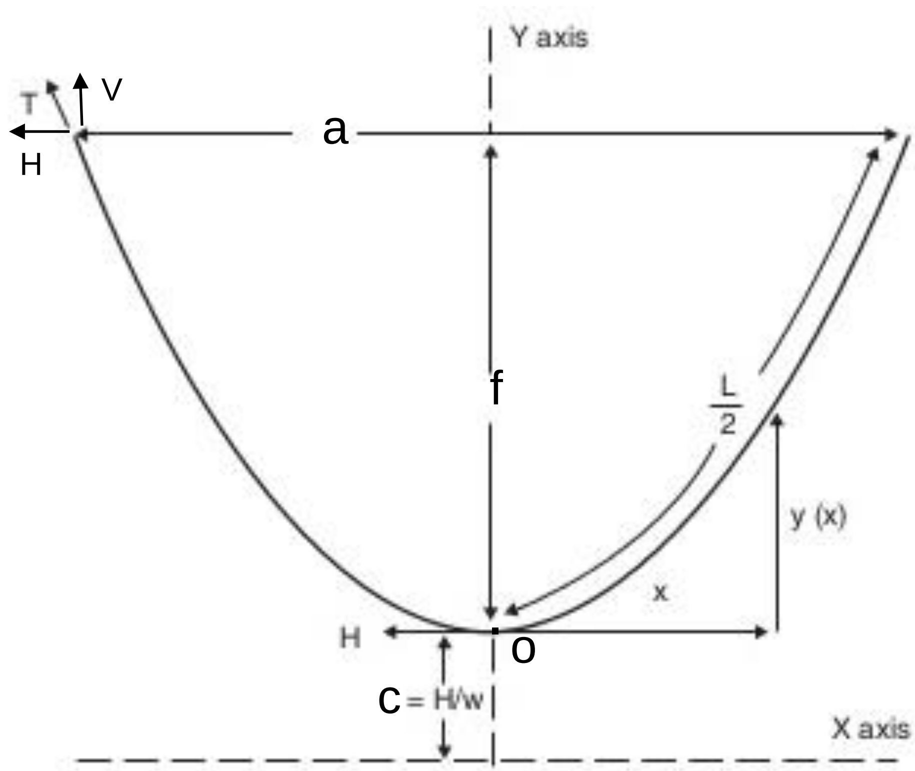
A bare stranded overhead conductor is normally held clear of the objects, people and other conductors. The conductor curve's shape has a distinct effect on the sag and tension of the conductor curve.

When the conductor is suspended between two supports at the same level, it takes the shape of catenary.

Catenary is the curve that an idealized hanging chain or cable assumes under its own weight when supported only at its ends.

If the sag is very small compared with the span, then sag-span curve is like a parabola.

<u>Level span</u> The conductor is suspended between two supports at the same level



T: Tension at any point on the conductor . It acts tangentially. (kg)
H: Horizontal component of the tension. It stays constant throughout the line. (kg)
V: Vertical component of the tension. It increases towards the support points to support the weight of the line. (kg)

O: origin (lowest point of the line)
Horizontal tangent point

c: catenary constant. Geometrically represented by the radius of curvature at the lowest point of the span (m).

$$H = cw$$

$$V = wl$$

w: total weight per unit length of the conductor (including ice and wind load) (kg/m)

l: length of the conductor measured along the conductor from the lowest point of the catenary in either direction. (m)

f: maximum sag. The maximum sag (for a level span where the weight is uniformly distributed) occurs at the midpoint of the span length.

Catenary equation

$$y(x) = c(\cosh(\frac{x}{c}) - 1)$$

Length of the conductor:

$$L = 2c \sinh \frac{a}{2c}$$

Maximum Sag:

$$f = 2c \sinh^2 \frac{a}{4c}$$

Conductor slack

S=L-a

Parabolic approximation:

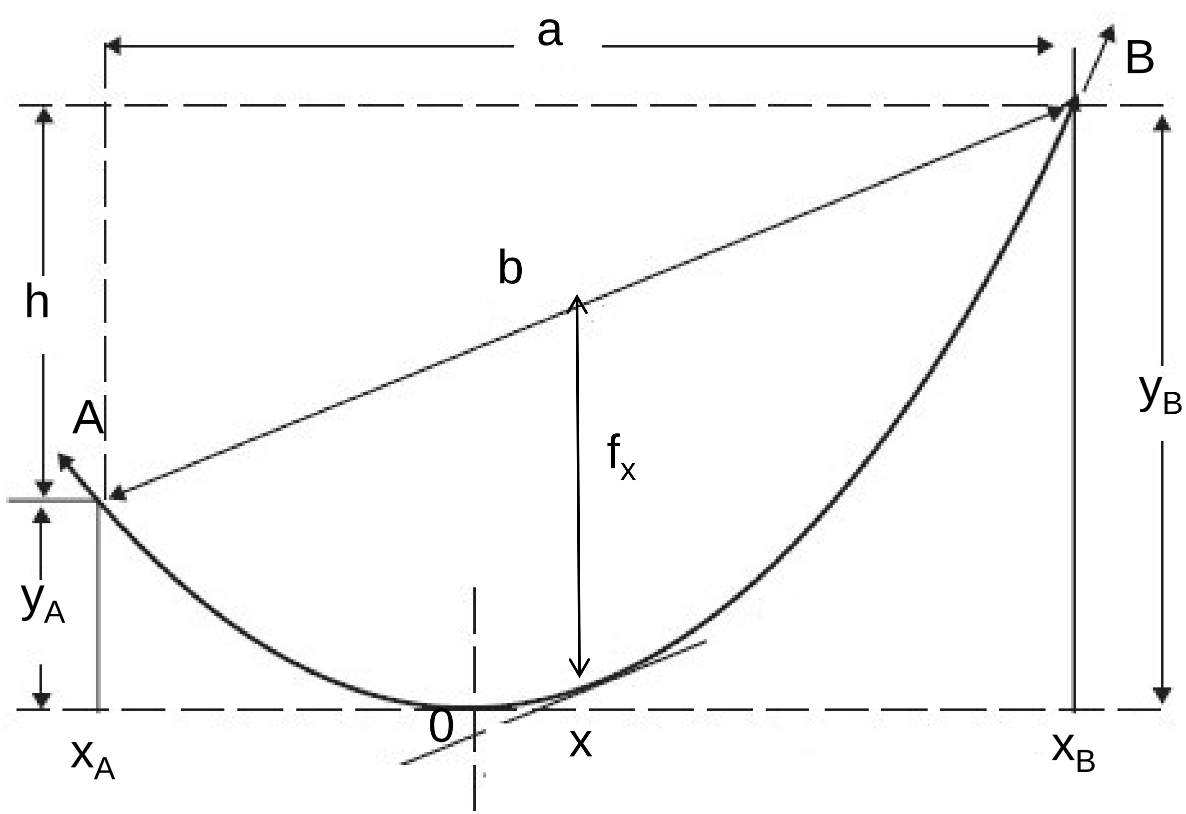
$$y(x) = \frac{x^2}{2c}$$

$$L = a + \frac{a^3}{24c^2}$$

Maximum Sag:

$$f = \frac{a^2}{8c}$$

<u>Inclined span</u> : There's an elevation difference between the supports. The elevation difference between the supporting structures doesn't affect the shape of the catenary.



x_A and x_B are x-coordinates of the lower and the higher supports.

y_A and y_B are y-coordinate of the lower and the higher supports.

$$x_B - x_A = a$$

$$y_B - y_A = h$$

h: vertical distance between the support points. (elevation difference)

b: straight line distance between support points. (sloping span length)

f_x : sag measured vertically from a straight line through the points of conductor support to a line tangent to the conductor x-distance from the lowest point.

Catenary approximation:

$$f_x = c(\cosh\frac{x_B}{c} - \cosh\frac{x}{c}) - \frac{h}{a}(x_B - x)$$

$$x_A = c\ln(h^* + \sqrt{{h^*}^2 + 1}) - \frac{a}{2}$$

$$h^* = \frac{h}{2c\sinh\frac{a}{2c}}$$

$$x_B = c\ln(h^* + \sqrt{{h^*}^2 + 1}) + \frac{a}{2}$$

If the lowest point is between the support points
$x_A<0$, $x_B>0$, $h>0$

If the lowest point is beyond the support points
$x_A>0$, $x_B>0$, $h>0$

$$x_A > 0 \quad if \quad h > 2c\sinh^2\frac{a}{2c}$$

$$L = \sqrt{h^2 + 4c^2\sinh^2\frac{a}{2c}}$$

Parabolic approximation:

$$f_x = \frac{(x_B{}^2 - x^2)}{2c} - \frac{h}{a}(x_B - x)$$

$$x_A = \frac{ch}{a} - \frac{a}{2}$$

$$x_B = \frac{ch}{a} + \frac{a}{2}$$

If the lowest point is between the support points
$x_A<0$, $x_B>0$, $h>0$

If the lowest point is beyond the support points
$x_A>0$, $x_B>0$, $h>0$

$$x_A > 0 \quad if \quad h > \frac{a^2}{2c}$$

$$L = \frac{a^2 + b^2}{2a} + \frac{a^3}{24c^2}$$

Tension and Stress

At any point, tension in the conductor can be calculated by using the equation given below

$$T = H + wy \quad \text{kg}$$

H: horizontal component of the tension (constant along the conductor length)
w: total weight per unit length acting on the conductor.
y: the vertical distance between the conductor and the lowest point.

Tension per unit area is called stress.

$$\sigma = \frac{T}{q} \quad kg/mm^2$$

$$\sigma_0 = \frac{H}{q}$$

Stress at the lowest point

Stress at any point on the conductor

$$\sigma = \sigma_0 + \gamma y$$

γ: specific weight (density) kg/m·mm^2

By using parabolic approximation, the average stress

$$\sigma_{AVG} = \sigma_0 + \frac{\sigma_0 h^2}{2a^2} + \frac{\gamma^2 a^2}{24\sigma_0}$$

Conductor Vibration

The failure of conductors under tensions that are much below maximum design stresses has been caused by fatigue due to very fast vertical vibrations of the conductor (from 15 to possibly 100 Hz) caused by steady winds blowing across the line.

In general, the mechanical vibrations in overhead conductors and ground wires are Aeolian Vibration, Swinging of Conductors Caused by Changes in Wind Pressure, Galloping (or Dancing), Conductor Ice Loading and Shedding, Subconductor Vibration.

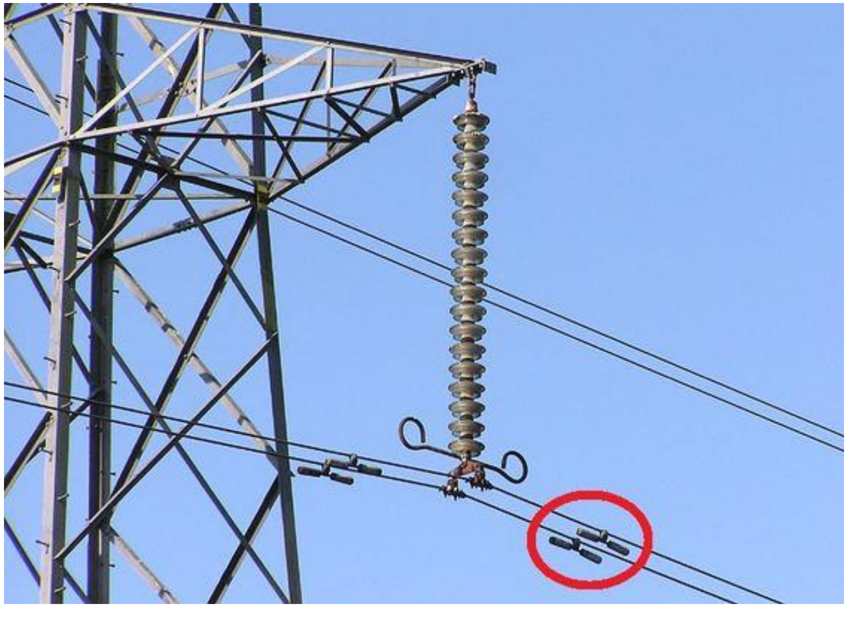
Aeolian Vibration: It is a resonant oscillation in a steady wind. Its amplitudes are of approximately one conductor diameter, with frequencies of oscillation on the order of 2-150 Hz.

If uncorrected, these vibrations can cause chafing and fatigue failures of conductor strands, typically at oscillation nodes such as splices and suspension points.

Aeolian vibrations can be controlled by adding energy-dissipating vibrations dampers (usually Stockbridge), which are attached to the conductor. Such dampers detune the vibrating conductor and absorbs enough of the the energy to stop or greatly lessen vibration.

The effectiveness evaluation of Stockbridge dampers can be performed as stated in the international standard IEC 61897 by means of one of the following methods:

- laboratory test
- field test
- analytical method



The most vulnerable section of the cable is where it is clamped to the end of an insulator string, so dampers are typically installed at the nearest points of maximum displacement either side of the clamp. There are thus normally two dampers per span, though more can be installed if necessary on longer spans.

Aeolian vibration can also be prevented by the use of self-damped conductors such as

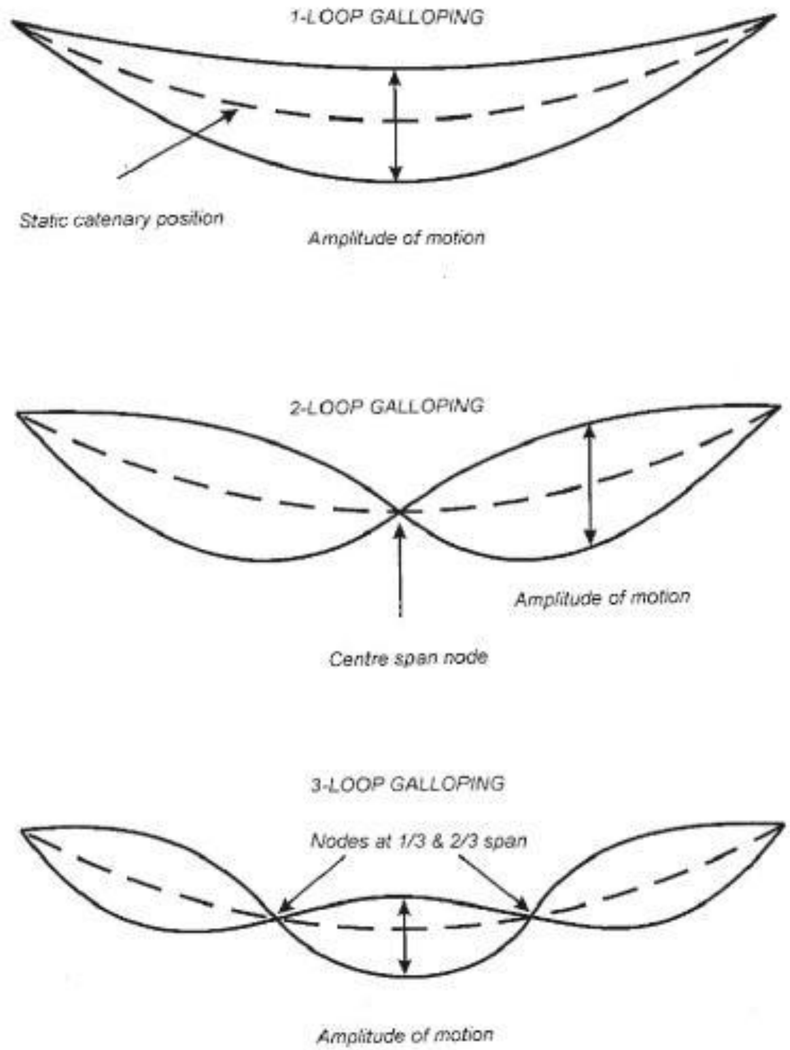
- ACSS :Aluminum Conductor Steel Supported
- SDC : Self-damping conductors
- VR : Vibration resistant conductors

Swinging of Conductors Caused by Changes in Wind Pressure*:* This type vibration is not harmful provided there is enough clearance left between conductors to prevent flashover.

Galloping (or Dancing): It is usually created by a nonuniform airfoil surface formed around the conductor by ice. It can be very severe, is of a very low frequency, and is extremely difficult to control since the shapes of the ice and the wind velocity combine to result in a critical stability condition. Therefore, winds from 25 km/h upwards can create violent conductor motion with amplitudes measuring up to two times the amount of conductor sag.

Cases have occurred where this galloping has displaced the phase conductor all the way up to the ground wires, causing multiple trip-outs. It has also resulted in damage to conductors, spacers, and towers.

Although galloping produces severe motions, it is almost always limited to areas of icing and is dependent on terrain and wind exposure.



Galloping types

Interphase spacers

***Conductor Ice Loading and Shedding**:* Conductor icing and the subsequent shedding of ice loads can cause large vertical conductor motions (i.e., jumping). The worst jumping takes place when ice melts from the center span of a section after it has fallen from the other spans. Serious jumping also occurs when ice slips down the conductor toward midspan.

The conductor jumping can be controlled by fitting special insulator assemblies at the suspension points and by increasing the mass per-unit length of line at midspan.

Vertical motion of the conductor due to ice shedding is dependent on span length, tension, conductor size, ice thickness, and the amount of ice shed at anyone time.

Subconductor Vibration*:* It is only possible on bundled conductor arrangements. Subconductor vibration occurs at lower frequency (2-4 Hz) than aeolian vibration and is more difficult to control. It may lead to the ultimate breaking of spacers and, in some cases, destruction of suspension points at the insulators.
In general, it can be controlled by the use of vibration dampers and the spacing of subconductors as far apart as practical.

Spacer damper

Conductor tension limits

The national regulation recommends limits on the tension of bare overhead conductors as a percentage of the conductor's rated breaking strength.

1. The maximum tension (or stress) at which a structure is designed to operate is the allowable or working tension (or stress).

$$H_{max} \leq 0.45 H_{breaking\ tensile\ strength}$$

The ratio of the ultimate stength (beaking strength) to the working strength of the material is the design safety factor.

$$safety\ factor = \frac{1}{0.45} = 2.2$$

In Europe it is 1.5-3.

2. Transmission-line conductors are normally not covered with ice, and wind loads on the conductor are usually much lower than those used in maximum load calculations.

Under such everyday conditions, tension limits are specified to limit aeolian vibration to safe levels. Everyday lower tension levels at 15ºC,

$$H_{+15} \leq 0.15 H_{\text{breaking tensile strength}}$$

If there are dampers,

$$H_{+15} \leq 0.22 H_{\text{breaking tensile strength}}$$

3. At -5 ºC, with double ice load, the resultant tension at the support points

$$\sqrt{H^{2}_{+2ice} + V^{2}_{+2ice}} \leq 0.7 H_{breaking\,tensile strength}$$

The maximum resultant tension occurs in maximum span length or at maximum elevation difference.