Module-I

Transmission Line Parameters

Conductor: Conductor is a physical medium to carry electrical energy form one place to other. It is an important component of overhead and underground electrical transmission and distribution systems. The choice of conductor depends on the cost and efficiency. An ideal conductor has following features.

1. It has maximum conductivity
2. It has high tensile strength
3. It has least specific gravity i.e. weight / unit volume
4. It has least cost without sacrificing other factors.

1.Types of Conductors:

In the early days conductor used on transmission lines were usually Copper, but Aluminum Conductors have Completely replaced Copper because of the much lower cost and lighter weight of Aluminum conductor compared with a Copper conductor of the same resistance. The fact that Aluminum conductor has a larger diameter than a Copper conductor of the same resistance is also an advantage. With a larger diameter the lines of electric flux originating on the conductor will be farther apart at the conductor surface for the same voltage. This means a lower voltage gradient at the conductor surface and less tendency to ionise the air around the conductor. Ionization produces the undesirable effect called **corona.**

The symbols identifying different types of Aluminium conductors are as follows:-

AAC: AllAluminiumconductors.

AAAC: AllAluminiumAlloyconductors

ACSR: Aluminiumconductors,Steel-Reinforced

ACAR : Aluminum conductor, Alloy-Reinforced

Aluminium alloy conductors have higher tensile strength than the conductor of EC grade Aluminium or AAC, ACSR consists of a central core of steel strands surrounded by layers of Aluminium strands. ACAR has a central core of higher strength Aluminium Alloy surrounded by layer of Electrical-Conductor-Grade Aluminium.

ACSR (Aluminum Conductor Steel Reinforced)

- Aluminum Conductor Steel Reinforced (ACSR) is concentrically stranded conductor with one or more layers of hard drawn 1350-H19 aluminum wire on galvanized steel wire core.
- The core can be single wire or stranded depending on the size.
- Steel wire core is available in Class A ,B or Class C galvanization for corrosion protection.
- Additional corrosion protection is available through the application of grease to the core or infusion of the complete cable with grease.
- The proportion of steel and aluminum in an ACSR conductor can be selected based on

the mechanical strength and current carrying capacity demanded by each application.

- ACSR conductors are recognized for their record of economy, dependability and favorable strength / weight ratio. ACSR conductors combine the light weight and good conductivity of aluminum with the high tensile strength and ruggedness of steel.
- In line design, this can provide higher tensions, less sag, and longer span lengths than obtainable with most other types of overhead conductors.
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- The steel strands are added as mechanical reinforcements.
- The cross sections above illustrate some common stranding.
- The steel core wires are protected from corrosion by galvanizing.
- The standard Class A zinc coating is usually adequate for ordinary environments.
- For greater protection, Class B and C galvanized coatings may be specified.
- The product is available with conductor corrosion resistant inhibitor treatment applied to the central steel component.
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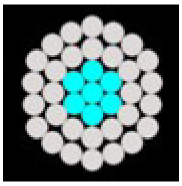


Features

- High Tensile strength
- Better sag properties
- Economic design
    - Suitable for remote applications involving long spans
    - Good Ampacity
    - Good Thermal Characteristics
    - High Strength to Weight Ratio
    - Low sag
    - High Tensile Strength

Typical Application

- Commonly used for both transmission and distribution circuits.
- Compact Aluminum Conductors, Steel Reinforced (ACSR) are used for overhead distribution and transmission lines.

BUNDLED CONDUCTORS:

Bundle conductors are widely use for transmission line and has its own advantages and disadvantages.

Bundle conductor is a conductor which consist several conductor cable which connected. Bundle conductors also will help to increase the current carried in the transmission line. The main disadvantage of Transmission line is its having high wind load compare to other conductors.

(Or)

The combination of more than one conductor per phase in parallel suitably spaced from each other used in overhead Transmission Line is defined as conductor bundle. The individual conductor in a bundle is defined as Sub-conductor.

At Extra High Voltage (EHV), i.e. voltage above 220 KV corona with its resultant power loss and particularly its interference with communication is excessive if the circuit has only one conductor per phase. The High-Voltage Gradient at the conductor in the EHV range is reduced considerably by having two or more conductors per phase in close proximity compared with the spacing between conductor-bundle spaced 450 mm is used in India

The three conductor bundle usually has the conductors at the vertices of an equilateral triangle and four conductors bundle usually has its conductors at the corners of a square.

The current will not divide exactly between the conductor of the bundle unless there is a transposition of the conductors within the bundle, but the difference is of no practical importance.

Reduced reactance is the other equally important advantage of bundling. Increasing the number of conductor in a bundle reduces the effects of **corona** and reduces the reactance. The reduction of reactance results from the increased Geometric Mean Radius (GMR) of the bundle.

2. TRANSMISSION LINES:

The electric parameters of transmission lines (i.e. resistance, inductance, and capacitance) can be determined from the specifications for the conductors, and from the geometric arrangements of the conductors.

2.1 Transmission Line Resistance

Resistance to d.c. current is given by

$$R_{dc} = \rho \frac{\ell}{A}$$

where ρ is the resistivity at 20° C
ℓ is the length of the conductor
A is the cross sectional area of the conductor

Because of skin effect, the d.c. resistance is different from ac resistance. The ac resistance is referred to as effective resistance, and is found from power loss in the conductor

$$R = \frac{\text{power loss}}{I^2}$$

The variation of resistance with temperature is linear over the normal temperature range

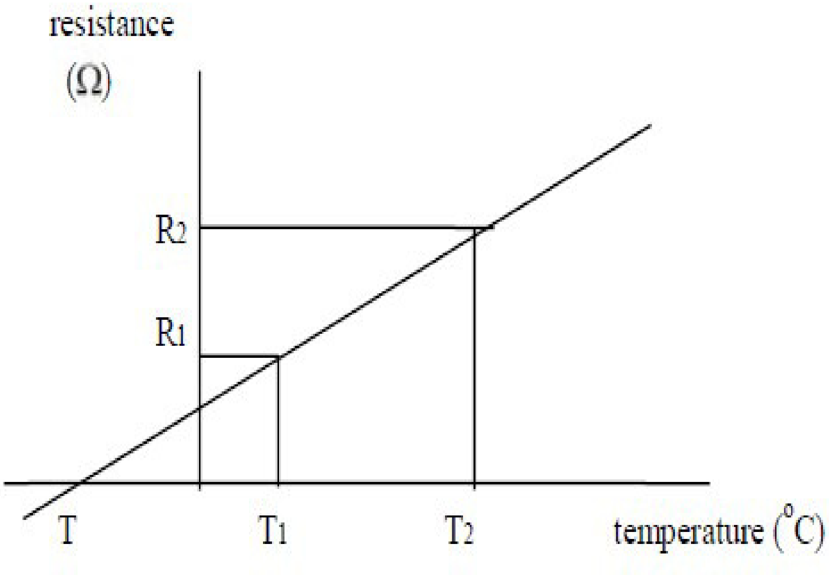


Figure 9 Graph of Resistance vs Temperature

$$R_2 = \frac{T_2 - T}{T_1 - T} R_1$$

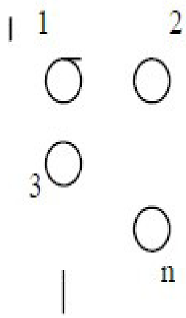
2.2 Transmission Line Inductive Reactance

Inductance of transmission lines is calculated per phase. It consists of self inductance of the phase conductor and mutual inductance between the conductors. It is given by:

$$L = 2 \times 10^{-7} \ln \frac{GMD}{GMR} \qquad [H/m]$$

where GMR is the geometric mean radius (available from manufacturer's tables)
GMD is the geometric mean distance (must be calculated for each line configuration)

Geometric Mean Radius: There are magnetic flux lines not only outside of the conductor, but also inside. GMR is a hypothetical radius that replaces the actual conductor with a hollow conductor of radius equal to GMR such that the self inductance of the inductor remains the same. If each phase consists of several conductors, the GMR is given by

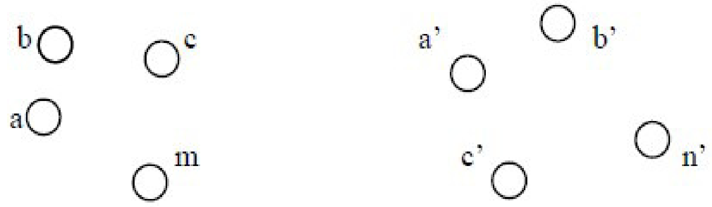


$$GMR = \sqrt[n^2]{(d_{11} d_{12} d_{13} \ldots d_{1n}).(d_{21}.d_{22} \ldots d_{2n}) \ldots\ldots (d_{n1}.d_{n2} \ldots d_{nn})}$$

where $d_{11} = GMR_1$
$d_{22} = GMR_2$
.
.
.
$d_{nn} = GMR_n$

Note: for a solid conductor, $GMR = r.e^{-1/4}$, where r is the radius of the conductor.

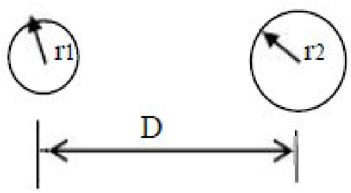
Geometric Mean Distance replaces the actual arrangement of conductors by a hypothetical mean distance such that the mutual inductance of the arrangement remains the same



$$GMD = \sqrt[mn']{(D_{aa'}D_{ab'}\ldots D_{an'}).(D_{ba'}D_{bb'}\ldots D_{bn'})\ldots\ldots(D_{ma'}D_{mb'}\ldots\ldots D_{mn'})}$$

where $D_{aa'}$ is the distance between conductors "a" and "a'" etc.

Inductance Between Two Single Phase Conductors



$$L_1 = 2\times10^{-7}\times\ln\frac{D}{r_1'} \qquad L_2 = 2\times10^{-7}\times\ln\frac{D}{r_2'}$$

where r_1' is GMR of conductor 1
r_2' is GMR of conductor 2
D is the GMD between the conductors

The total inductance of the line is then

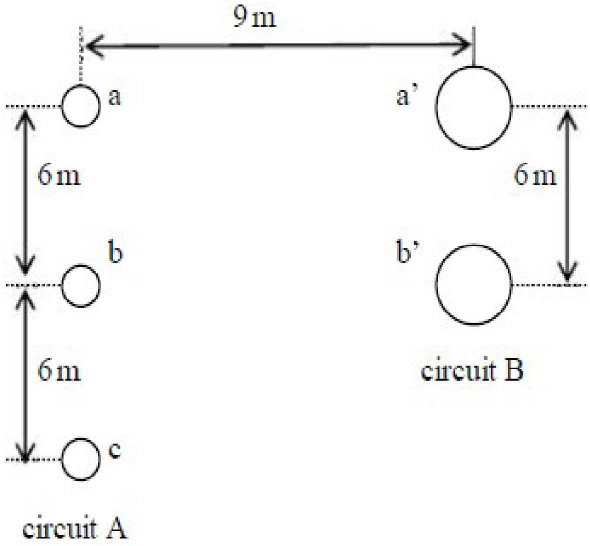
$$L_T = L_1 + L_2 = 2\times10^{-7}\times\left[\ln\frac{D}{r_1'}+\ln\frac{D}{r_2'}\right] = 2\times10^{-7}\times\ln\frac{D^2}{r_1'r_2'} = 2\times10^{-7}\times2\times\frac{1}{2}\times\ln\frac{D^2}{r_1'r_2'}$$

$$L_T = 4\times10^{-7}\times\ln\left[\frac{D^2}{r_1'r_2'}\right]^{1/2} = 4\times10^{-7}\times\ln\frac{D}{\sqrt{r_1'r_2'}}$$

If $r_1 = r_2$, then

$$L_T = 4\times10^{-7}\times\ln\frac{D}{r_1'}$$

Example: Find GMD, GMR for each circuit, inductance for each circuit, and total inductance per meter for two circuits that run parallel to each other. One circuit consists of three 0.25 cm radius conductors. The second circuit consists of two 0.5 cm radius conductor



Solution:

m = 3, n' = 2, ∴ m·n' = 6

$$GMD = \sqrt[6]{(D_{aa'}D_{ab'})(D_{ba'}B_{bb'})(D_{ca'}D_{cb'})}$$

where

$$D_{aa'} = D_{bb'} = 9 \text{ m}$$

$$D_{ab'} = D_{ba'} = D_{cb'} = \sqrt{6^2 + 9^2} = \sqrt{117} \text{ m}$$

$$D_{ca'} = \sqrt{12^2 + 9^2} = 15 \text{ m}$$

∴ GMD = 10.743 m

Geometric Mean Radius for Circuit A:

$$GMR_A = \sqrt[3^2]{D_{aa}D_{ab}D_{ac}D_{ba}D_{bb}D_{bc}D_{ca}D_{cb}D_{cc}} = \sqrt[9]{\left(0.25\times10^{-2}\times e^{-1/4}\right)^3\times6^4\times12^2} = 0.481\text{m}$$

Geometric Mean Radius for Circuit B:

$$GMR_B = \sqrt[2^2]{D_{a'a'}D_{a'b'}D_{b'b'}D_{b'a'}} = \sqrt[4]{\left(0.5\times10^{-2}\times e^{-1/4}\right)^2\times6^2} = 0.153\text{m}$$

Inductance of circuit A

$$L_A = 2\times10^{-7}\ln\frac{GMD}{GMR_A} = 2\times10^{-7}\ln\frac{10.743}{0.481} = 6.212\times10^{-7} \quad H/m$$

Inductance of circuit B

$$L_B = 2\times10^{-7}\ln\frac{GMD}{GMR_B} = 2\times10^{-7}\ln\frac{10.743}{0.153} = 8.503\times10^{-7} \quad H/m$$

The total inductance is then

$$L_T = L_A + L_B = 14.715\times10^{-7} \quad H/m$$

The Use of Tables

Since the cables for power transmission lines are usually supplied by U.S. manufacturers, the tables of cable characteristics are in American Standard System of units and the inductive reactance is given in Ω/mile.

$$X_L = 2\pi fL = 2\pi f\times2\times10^{-7}\ln\frac{GMD}{GMR} \quad \Omega/m$$

$$X_L = 4\pi f\times10^{-7}\ln\frac{GMD}{GMR} \quad \Omega/m$$

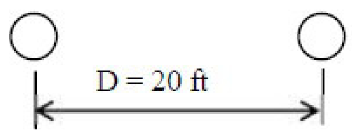
$$X_L = 4\pi f\times10^{-7}\times1609\times\ln\frac{GMD}{GMR} \quad \Omega/\text{mile}$$

$$X_L = 2.022\times10^{-3}\times f\times\ln\frac{GMD}{GMR} \quad \Omega/\text{mile}$$

$$X_L = \underbrace{2.022\times10^{-3}\times f\times\ln\frac{1}{GMR}}_{X_a} + \underbrace{2.022\times10^{-3}\times f\times\ln GMD}_{X_d} \quad \Omega/\text{mile}$$

If both, GMR and GMD are in feet, then X_a represents the inductive reactance at 1 ft spacing, and X_d is called the inductive reactance spacing factor.

Example: Find the inductive reactance per mile of a single phase line operating at 60 Hz. The conductor used is Partridge, with 20 ft spacings between the conductor centers.



Solution: From the Tables, for Partridge conductor, GMR = 0.0217 ft and inductive reactance at 1 ft spacing X_a= 0.465 Ω/mile. The spacing factor for 20 ft spacing is X_d = 0.3635 Ω/mile. The inductance of the line is then

$$X_L = X_a + X_d = 0.465 + 0.3635 = 0.8285\ \Omega/\text{mile}$$

Inductance of Balanced Three Phase Line

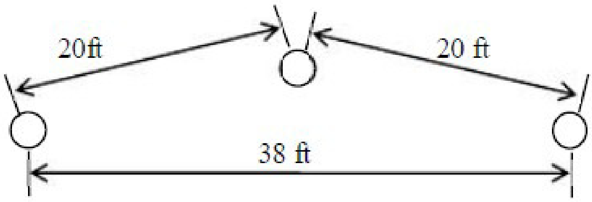
Average inductance per phase is given by:

$$L = 2\times10^{-7}\ln\frac{D_{eq}}{GMR}$$

where D_{eq} is the geometric mean of the three spacings of the three phase line.

$$D_{eq} = \sqrt[3]{D_{ab}D_{ac}D_{bc}}$$

Example: A three phase line operated at 60 Hz is arranged as shown. The conductors are ACSR Drake. Find the inductive reactance per mile.



Solution:

For ACSR Drake conductor, GMR = 0.0373 ft

$$D_{eq} = \sqrt[3]{20\times20\times38} = 24.8\ \text{ft}$$

$$L = 2\times10^{-7}\ln\frac{24.8}{\ } = \quad\times\quad^{-}\quad H/m$$

13 10 7

$$X_L = 2\pi\times60\times1609\times13\times10^{-} = 0.788\ \Omega/\text{mile}$$

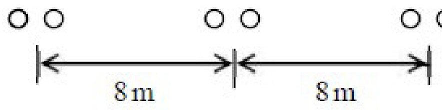
OR

from the tables $X_a = 0.399\ \Omega/\text{mile}$

The spacing factor is calculated for spacing equal the geometric mean distance between the conductors, that is, $X_d = 2.022\times10^{-3}\times60\ln24.8 = 0.389\ \Omega/\text{mile}$

Then the line inductance is $X_{line} = X_a + X_d = 0.788 \quad \Omega / \text{mile} \quad$ per phase

Example: Each conductor of the bundled conductor line shown in the figure is 1272 MCM Pheasant. Find:
a) the inductive reactance in Ω/km and Ω/mile per phase for d = 45 cm
b) the p.u. series reactance if the length of the line is 160 km and the base is 100 MVA, 345 kV.



Solution:

a) The distances in ft are

$$d = \frac{0.45}{0.3048} = 1.476 \quad \text{ft}$$

$$D = \frac{8}{0.3048} = 26.25 \quad \text{ft}$$

For Pheasant conductors, GMR = 0.0466 ft.

GMR_b for a bundle of conductors is

$$GMR_b = \sqrt{GMR \times d} = \sqrt{0.0466 \times 1.476} = 0.2623 \quad \text{ft}$$

The geometric mean of the phase conductor spacing is

$$D_{eq} = \sqrt[3]{26.25 \times 26.25 \times 52.49} = 3307 \quad \text{ft}$$

The inductance of the line is then

$$L = 2 \times 10^{-7} \ln \frac{D_{eq}}{GMR_b} = 2 \times 10^{-7} \ln \frac{33.07}{0.2623} = 9.674 \times 10^{-7} \quad \text{H / m}$$

The inductive reactance is

$$X_L = 2\pi f L = 2\pi \times 60 \times 9.674 \times 10^{-7} = 3.647 \times 10^{4} \quad \Omega / \text{m} = 0.3647 \quad \Omega / \text{km} = 0.5868 \quad \Omega / \text{mile}$$

b) Base impedance $Z_b = \dfrac{V_b^2}{S_b} = \dfrac{345^2}{100} = 1190 \quad \Omega$

Total impedance of the 160 km line is

Reactive power to charge the line is

$$Q_C = \sqrt{3} V_{LL} I_C = \sqrt{3} \times 220k \times 119 = 45.45 \quad \text{MVAr}$$

2.5 Transmission Line Losses and Thermal Limits

The power losses of a transmission line are proportional to the value of resistance of the line. The value of the resistance is determined by the type and length of the conductor. The current in the line is given by the power being delivered by the transmission line.

$$P_R = E_R I_{equiv} \cos\Phi_R \qquad \therefore \qquad I_{equiv} = \frac{P_R}{E_R \cos\Phi_R}$$

From that,

$$P_{loss} = I_{equiv}^2 R = \left(\frac{P_R}{E_R \cos\Phi_R} \right)^2 R$$

Power utilities usually strive to maintain the receiving end voltage constant. The power delivered by the transmission line is determined by the load connected to the line and cannot be changed without changing the load. The only term in the above equation that can be regulated is the power factor. If the power factor can be adjusted to be equal to 1, the power losses will be minimum.

Efficiency of the transmission line is given by

$$\eta_{\%} = \frac{P_R}{P_S} \cdot 100\%$$

Thermal Limits on equipment and conductors depend on the material of the insulation of conductors. The I^2R losses are converted into heat. The heat increases the temperature of the conductors and the insulation surrounding it. Some equipment can be cooled by introducing circulation of cooling media, other must depend on natural cooling. If the temperature exceeds the rated value, the insulation will deteriorate faster and at higher temperatures more immediate damage will occur.

The power losses increase with the load. It follows that the rated load is given by the temperature limits. The consequence of exceeding the rated load for short periods of time or by small amounts is a raised temperature that does not destroy the equipment but shortens its service life. Many utilities routinely allow short time overloads on their equipment - for example transformers are often overloaded by up to 15% during peak periods that may last only 15 or 30 minutes.