UNIT – 4

FACTORS GOVERNING THE PERFORMANCE OF TRANSMISSION LINES

SURGE IMPEDANCE:

The characteristic impedance or surge impedance (usually written Z_0) of a uniform transmission line is the ratio of the amplitudes of voltage and current of a single wave propagating along the line; that is, a wave travelling in one direction in the absence of reflections in the other direction. Characteristic impedance is determined by the geometry and materials of the transmission line and, for a uniform line, is not dependent on its length. The SI unit of characteristic impedance is the ohm.

The characteristic impedance of a lossless transmission line is purely real, with no reactive component. Energy supplied by a source at one end of such a line is transmitted through the line without being dissipated in the line itself. A transmission line of finite length (lossless or lossy) that is terminated at one end with an impedance equal to the characteristic impedance appears to the source like an infinitely long transmission line and produces no reflections.

THE SURGE IMPEDANCE LOADING:

The surge impedance loading (SIL) of a line is the power load at which the net reactive power is zero. So, if your transmission line wants to "absorb" reactive power, the SIL is the amount of reactive power you would have to produce to balance it out to zero. You can calculate it by dividing the square of the line-to-line voltage by the line's characteristic impedance. Transmission lines can be considered as, a small inductance in series and a small capacitance to earth, - a very large number of this combinations, in series. Whatever voltage drop occurs due to inductance gets compensated by capacitance. If this compensation is exact, you have surge impedance loading and no voltage drop occurs for an infinite length or, a finite length terminated by impedance of this value (SIL load). (Loss-less line assumed!). Impedance of this line (Zs) can be proved to be sq. root (L/C). If capacitive compensation is more than required, which may happen on an unloaded EHV line, and then you have voltage rise at the other end, the Ferranti effect. Although given in many books, it continues to remain an interesting discussion always.

The capacitive reactive power associated with a transmission line increases directly as the square of the voltage and is proportional to line capacitance and length.

Capacitance has two effects:

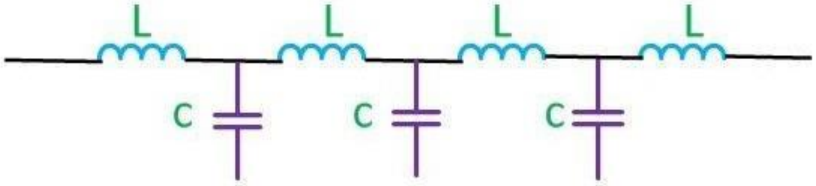
1 Ferranti effect

2 Rise in the voltage resulting from capacitive current of the line flowing through the source impedances at the terminations of the line.

SIL is Surge Impedance Loading and is calculated as (KV x KV) / Zs their units are megawatts.
Where Zs is the surge impedance....be aware...one thing is the surge impedance and other very different is the surge impedance loading.

SURGE IMPEDANCE LOADING

Capacitance and reactance are the main parameters of the transmission line. It is distributed uniformly along the line. These parameters are also called distributed parameters. When the voltage drops occur in transmission line due to inductance, it is compensated by the capacitance of the transmission line.

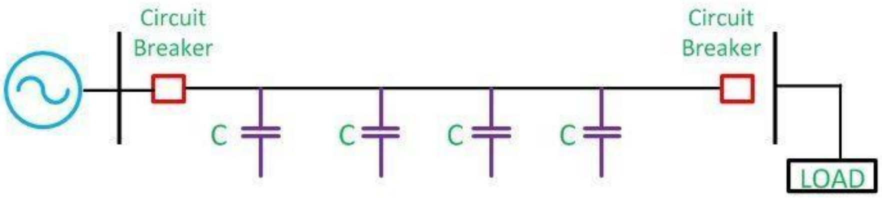


Distributed Parameters of transmission line Circuit Globe

The transmission line generates capacitive reactive volt-amperes in its shunt capacitance and absorbing reactive volt-amperes in its series inductance. The load at which the inductive and capacitive reactive volt-amperes are equal and opposite, such load is called surge impedance load.

It is also called natural load of the transmission line because power is not dissipated in transmission. In surge impedance loading, the voltage and current are in the same phase at all the point of the line. When the surge impedance of the line has terminated the power delivered by it is called surge impedance loading.

Shunt capacitance charges the transmission line when the circuit breaker at the sending end of the line is close. As shown below

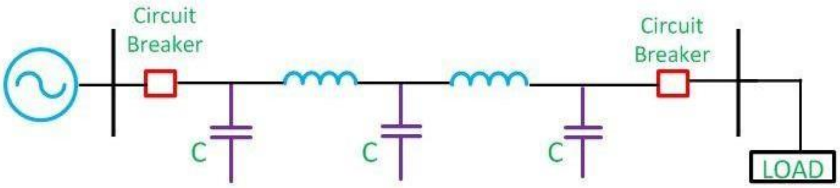


Shunt Capacitance Charges

Let V = phase voltage at the receiving end
L = series inductance per phase
X_L = series inductance reactance per phase
X_C = shunt capacitance reactance per phase
Z_o = surge impedance loading per phase
Capacitive volt-amperes (VAr) generated in the line

$$= \frac{V^2}{X_C} = V^2 wc \, per \, phase$$

The series inductance of the line consumes the electrical energy when the sending and receiving end terminals are closed.

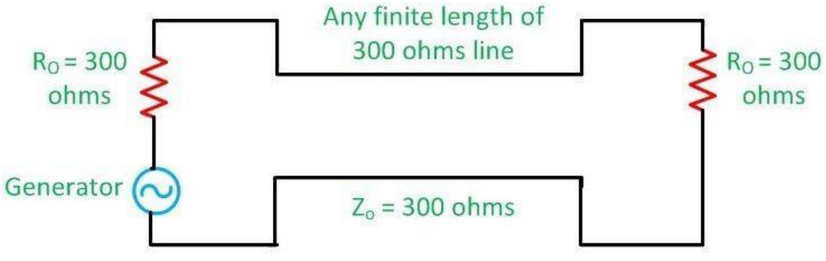


Series Inductance consume energy

Inductive reactive volt-amperes (VAr) absorbed by the line

$$= I^2 X_L = I^2 wL$$

Under natural load, the reactive power becomes terminated, and the load becomes purely resistive.



Surge Impedance Loading

Circuit Globe

And it is calculated by the formula given below

$$V^2wC = I^2wL$$

$$\frac{V}{I} = \frac{\sqrt{L}}{\sqrt{C}} = Z_0$$

Surge impedance loading is also defined as the power load in which the total reactive power of the lines becomes zero. The reactive power generated by the shunt capacitance is consumed by the series inductance of the line.

If Po is its natural load of the lines, $(SIL)_{1\emptyset}$ of the line per phase

$$(SIL)_{1\emptyset} = P_O = V_p I_p cos\emptyset$$

Since the load is purely resistive,

$$cos\emptyset = 1$$

$$P_O = V_P I_P = V_P \frac{V_P}{Z_O}$$

$$P_O = \frac{V_P^2}{Z_O} W/phase$$

Thus, per phase power transmitted under surge impedance loading is $(V_P^2)/Z_O$ watts, Where V_p is the phase voltage.

$$Line\ voltage\ V_L = \sqrt{3}V_P$$

$$(SIL)_{3\emptyset} = 3P_O = \frac{3V_P^2}{Z_O} = \frac{V_L^2}{Z_O}\ W$$

If kVL is the receiving end voltage in kV, then

$$(SIL)_{3\emptyset} = \frac{(kV_L)^2}{Z_O}\ \mathrm{MW}$$

Surge impedance loading depends on the voltage of the transmission line. Practically surge impedance loading always less than the maximum loading capacity of the line.

If the load is less than the SIL, reactive volt-amperes are generated, and the voltage at the receiving end is greater than the sending end voltage. On the other hand, if the SIL is greater than the load, the voltage at receiving end is smaller because the line absorbs reactive power.

If the shunt conductance and resistance are neglected and SIL is equal to the load than the voltage at both the ends will be equal.

Surge impedance load is the ideal load because the current and voltage are uniform along the line. The wave of current and voltage is also in phase because the reactive power consumed are equal to the reactive power generated by the transmission line.

CORONA

Electric-power transmission practically deals in the bulk transfer of electrical energy, from generating stations situated many kilometers away from the main consumption centers or the cities. For this reason the long distance transmission cables are of utmost necessity for effective power transfer, which in-evidently results in huge losses across the system. Minimizing those has been a major challenge for power engineers of late and to do that one should have a clear understanding of the type and nature of losses. One of them being the **corona effect in power system**, which has a predominant role in reducing the efficiency of EHV(extra high voltage lines) which we are going to concentrate on, in this article.

What is corona effect in power system and why it occurs?

For corona effect to occur effectively, two factors here are of prime importance as mentioned below:-

1) Alternating potential difference must be supplied across the line.
2) The spacing of the conductors, must be large enough compared to the line diameter.

Corona Effect in Transmission Line

When an alternating current is made to flow across two conductors of the transmission line whose spacing is large compared to their diameters, then air surrounding the conductors (composed of ions) is subjected to di-electric stress. At low values of supply end voltage, nothing really occurs as the stress is too less to ionize the air outside. But when the potential difference is made to increase beyond some threshold value of around 30 kV known as the critical disruptive voltage, then the field strength increases and then the air surrounding it experiences stress high enough to be dissociated into ions making the atmosphere conducting. This results in electric discharge around the conductors due to the flow of these ions, giving rise to a faint luminescent glow, along with the hissing sound accompanied by the liberation of ozone, which is readily identified due to its characteristic odor. This phenomena of electrical discharge occurring in transmission line for high values of voltage is known as the corona effect in power system. If the voltage across the lines is still increased the glow becomes more and more intense along with hissing noise, inducing very high power loss into the system which must be accounted for.

Factors Affecting Corona

The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends:

(i) *Atmosphere.* As corona is formed due to ionization of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.

(ii) *Conductor size.* The corona effect depends upon the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thus a stranded conductor has irregular surface and hence gives rise to more corona that a solid conductor.

(iii) *Spacing between conductors.* If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.

(iv) *Line voltage.* The line voltage greatly affects corona. If it is low, there is no change in the condition of air surrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that electrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is formed.

The phenomenon of corona plays an important role in the design of an overhead transmission line. Therefore, it is profitable to consider the following terms much used in the analysis of corona effects:

*(i) Critical disruptive voltage***.** It is the minimum phase-neutral voltage at which corona *occurs*. Consider two conductors of radii *r* cm and spaced *d* cm apart. If *V* is the phase-

$$g = \frac{V}{r \log_e \frac{d}{r}} \text{ volts / cm}$$

neutral potential, then potential gradient at the conductor surface is given by:

In order that corona is formed, the value of *g* must be made equal to the breakdown strength of air. The breakdown strength of air at 76 cm pressure and temperature of 25ºC is 30 kV/cm (*max*) or 21·2 kV/cm (*r.m.s.*) and is denoted by *go*. If *Vc* is the phase-neutral potential required under these conditions, then,

$$g_o = \frac{V_c}{r \log_e \frac{d}{r}}$$

where g_o = breakdown strength of air at 76 cm of mercury and 25°C
= 30 kV/cm (*max*) or 21·2 kV/cm (*r.m.s.*)

$$\therefore \quad \text{Critical disruptive voltage, } V_c = g_o\, r \log_e \frac{d}{r}$$

The above expression for disruptive voltage is under standard conditions *i.e.*, at 76 cm of Hg and 25ºC. However, if these conditions vary, the air density also changes, thus altering the value of *go*. The value of *go* is directly proportional to air density. Thus the breakdown strength of air at a barometric pressure of *b* cm of mercury and temperature of *t*ºC becomes

™ *go* where

$$\delta = \text{air density factor} = \frac{3 \cdot 92b}{273 + t}$$

Under standard conditions, the value of $\delta = 1$.

$\therefore$ Critical disruptive voltage, $V_c = g_o \, \delta \, r \log_e \frac{d}{r}$

Correction must also be made for the surface condition of the conductor. This is accounted for by multiplying the above expression by irregularity factor m_o.

$\therefore$ Critical disruptive voltage, $V_c = m_o \, g_o \, \delta \, r \log_e \frac{d}{r}$ kV/phase

where m_o = 1 for polished conductors
= 0·98 to 0·92 for dirty conductors
= 0·87 to 0·8 for stranded conductors

***(ii)* Visual critical voltage.** *It is the minimum phase-neutral voltage at which corona glow appears all along the line conductors.*

It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage V_c but at a higher voltage V_v, called *visual critical voltage.* The phase-neutral effective value of visual critical voltage is given by the following empirical formula :

$$V_v = m_v \, g_o \, \delta \, r \left(1 + \frac{0 \cdot 3}{\sqrt{\delta \, r}}\right) \log_e \frac{d}{r} \text{ kV/phase}$$

where m_v is another irregularity factor having a value of 1·0 for polished conductors and 0·72 to 0·82 for rough conductors.

***(iii)* Power loss due to corona.** Formation of corona is always accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action. When disruptive voltage is exceeded, the power loss due to corona is given by :

$$P = 242 \cdot 2 \left(\frac{f + 25}{\delta}\right) \sqrt{\frac{r}{d}} \, (V - V_c)^2 \times 10^{-5} \text{ kW / km / phase}$$

where f = supply frequency in Hz
V = phase-neutral voltage (*r.m.s.*)
V_c = disruptive voltage (*r.m.s.*) per phase

Advantages and Disadvantages of Corona

Corona has many advantages and disadvantages. In the correct design of a high voltage overhead line, a balance should be struck between the advantages and disadvantages.

Advantages

(i) Due to corona formation, the air surrounding the conductor becomes conducting andhence virtual diameter of the conductor is increased. The increased diameter reduces the electrostatic stresses between the conductors.

(ii) Corona reduces the effects of transients produced by surges.

Disadvantages

(i) Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

(ii) Ozone is produced by corona and may cause corrosion of the conductor due to chemical action.

(iii) The current drawn by the line due to corona is non-sinusoidal and hence non-sinusoidal voltage drop occurs in the line. This may cause inductive interference with neighboring communication lines.

Methods of Reducing Corona Effect

It has been seen that intense corona effects are observed at a working voltage of 33 kV or above. Therefore, careful design should be made to avoid corona on the sub-stations or bus- bars rated for 33 kV and higher voltages otherwise highly ionized air may cause flash-over in the insulators or between the phases, causing considerable damage to the equipment. The corona effects can be reduced by the following methods:

(i) *By increasing conductor size.* By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that *ACSR* conductors which have a larger cross-sectional area are used in transmission lines.

(ii) *By increasing conductor spacing.* By increasing the spacing between conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated. However, spacing cannot be increased too much otherwise the cost of supporting structure (*e.g.*, bigger cross arms and supports) may increase to a considerable extent.

DISRUPTIVE CRITICAL VOLTAGE:

- The critical disruptive voltage is defined as the minimum phase to neutral voltage at which Corona occurs. It is denoted as Vd.

VISUAL CRITICAL VOLTAGE:

- The critical visual disruptive voltage is the minimum phase to neutral voltage at which corona glow appears and visible along the conductors.
- In parallel conductors, the corona glow does not begin at the disruptive voltage Vc but a higher voltage Vv called visual critical voltage.

CORONA POWER LOSS:

The corona effect due to which several losses occur in transmission lines. These losses decrease the efficiency of transmission lines. Out of all the losses the corona power loss is the one which affects most, the proficiency of lines.

The power dissipated in the system due to corona discharges is called corona loss. Accurate estimation of corona loss is difficult because of its variable nature. It has been found that the corona loss under fair weather condition is less than under foul weather conditions. The corona loss under appropriate weather conditions is given below by the Peek’s formula;

$$P_C = \frac{244}{\delta}(f+25)(E_n - E_O)^2 \frac{\sqrt{r}}{\sqrt{D}} 10^{-5}\, kW/km/phase$$

Where P_c – corona power loss
f – frequency of supply in Hz
δ – air density factor
E_n – r.m.s phase voltage in kV
E_o – disruptive critical voltage per phase in kV
r – radius of the conductor in meters
D – spacing between conductors in meters

It is also to be noticed that for a single –phase line,

E_n=1/2×line voltage

and for a three phase line,

E_n = 1/(√3)×line voltage

Peek's formula is applicable for decided visual corona. This formula the gives the inaccurate result when the losses are low, and En/Eo is less than 1.8. It is superseded by Peterson's formula given below;

$$P_C = 2.1fF\frac{E_n^2}{(log_{10}\frac{D}{r})^2} \times 10^{-5}$$

Where,
P_c – corona power loss
f – frequency of supply in Hz
E_n – voltage per phase
r – radius of the conductor
D – spacing between conductors in meters
Factor F is called the corona loss function. It varies with the ratio (En/Eo). Eo is calculated by the formula given below,

$$E_o = G_o m_o r \delta^{\frac{2}{3}} In \frac{Deq}{r} V/phase$$

Where,
G_o – maximum value of disruptive critical voltage gradient in V/m.
m_o= irregularity factor

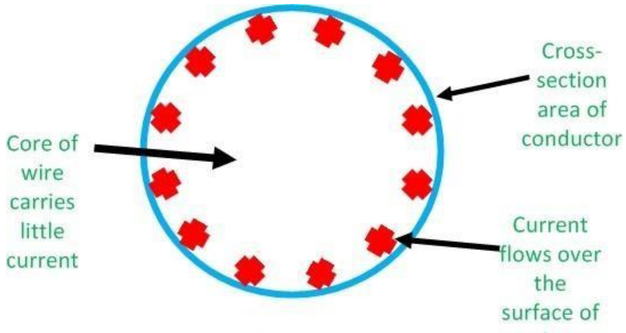
Factors Affecting Corona Loss
The following are the factors which affect the corona loss:

- **Effect of system voltage** – The electric field intensity around the conductor depends on the potential difference between the conductors. If the potential difference is high, electric field intensity is also high, and hence corona loss is also high.
- **Effect of Frequency** – The corona loss is directly proportional to system frequency.
- **Effect of Density of Air –** The corona loss is inversely proportional to air density factor. The corona loss increases with the decreases in density of air. The corona loss of the hilly area is more than that of the plains because plain have low density of air.
- **Effect of Conductor Radius** – If the wire area has high surface area, then their surface field intensity is low, and hence corona loss is less.

SKIN EFFECT

The non-uniform distribution of electric current over the surface or skin of the conductor carrying is called the skin effect. In other words, the concentration of charge is more near the surface as compared to the core of the conductor. The ohmic resistance of the conductor is increased due to the concentration of current on the surface of the conductor.

Skin effect increases with the increase in frequency. At low frequency, such as 50Hz, there is a small increase in the current density near the surface of the conductor; but, at high frequencies, such as radio frequency, practically the whole of the currents flows on the surface of the conductor. If d.c current (frequency=0) is passed in a conductor, the current is uniformly distributed over the cross-section of the conductors



Skin Effect

Circuit Globe

WHY SKIN EFFECT OCCURS?

Let us consider the conductor is made up of a number of concentric cylinders. When A.C is passed in a conductor, the magnetic flux induces in it. The magnetic flux linking a cylindrical element near the center is greater than that linking another cylindrical element near the surface of the conductor. This is due to the fact that the center cylindrical element is surrounded by both the internal as well as the external flux, while the external cylindrical element is surrounded by the external flux only.

The self-inductance in the inner cylindrical element is more and, therefore, will offer a greater inductive reactance than the outer cylindrical element. This difference in the inductive reactance gives a tendency to the current to concentrate towards the surface or skin of the conductor.

- A conductor carries a steady D.C current. This current is uniformly distributed over the whole cross- section of the conductor.
- The current distribution is non – uniform if conductor carries alternating current.
- The current density is higher at the surface than at the surface than at its centre
- This behavior of alternating current to concentrate near the surface of the conductor is known as skin effect.

Factors affecting skin effect

1. **Frequency** – Skin effect increases with the increase in frequency.
2. **Diameter** – It increases with the increase in diameter of the conductor.
3. **The shape of the conductor** – Skin effect is more in the solid conductor and less in the stranded conductor because the surface area of the solid conductor is more.
4. **Type of material** – Skin effect increase with the increase in the permeability of the material (Permeability is the ability of material to support the formation of the magnetic field).

Points-to-remember

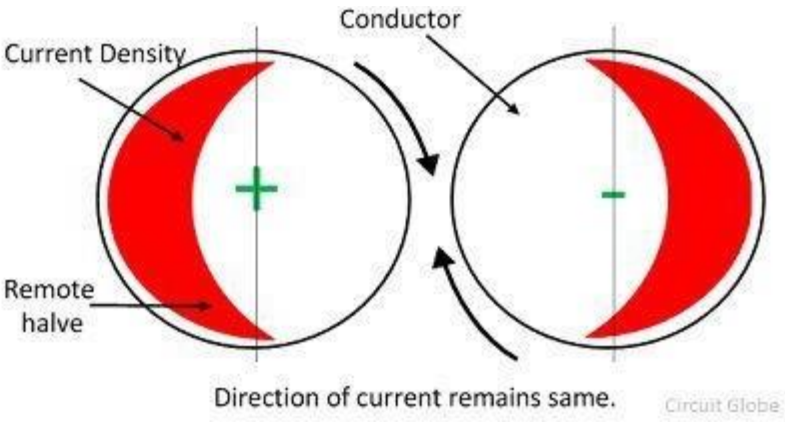
1. The Skin effect is negligible if the frequency is less than the 50Hz and the diameter of the conductor is less than the 1cm.
2. In the stranded conductors like ACSR (Aluminium Conductor Steel Reinforced) the current flows mostly in the outer layer made of aluminum, while the steel near the center carries no current and gives high tensile strength to the conductor. The concentration of current near the surface enabled the use of ACSR conductor.

PROXIMITY EFFECT

Definition: When the conductors carry the high alternating voltage then the currents are non-uniformly distributed on the cross-section area of the conductor. This effect is called proximity effect. The proximity effect results in the increment of the apparent resistance of the conductor due to the presence of the other conductors carrying current in its vicinity.

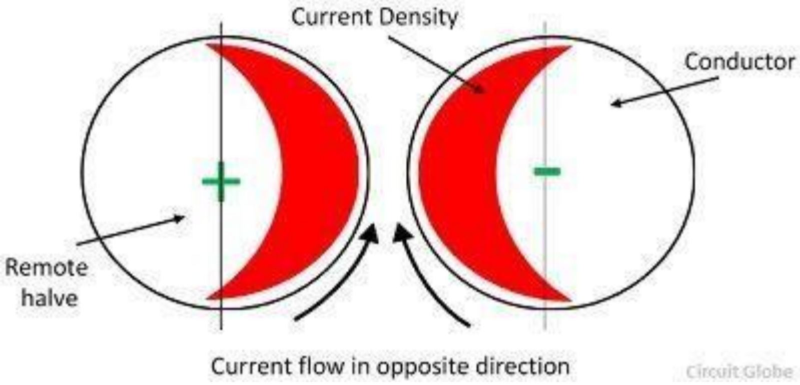
When two or more conductors are placed near to each other, then their electromagnetic fields interact with each other. Due to this interaction, the current in each of them is redistributed such that the greater current density is concentrated in that part of the strand most remote from the interfering conductor.

If the conductors carry the current in the same direction, then the magnetic field of the halves of the conductors which are close to each other is cancelling each other and hence no current flow through that halves portion of the conductor. The current is crowded in the remote half portion of the conductor.



Direction of current remains same.

When the conductors carry the current in the opposite direction, then the close part of the conductor carries, the more current and the magnetic field of the far off half of the conductor cancel each other. Thus, the current is zero in the remote half of the conductor and crowded at the nearer part of the conductor.



Current flow in opposite direction

If DC flows on the surface of the conductor, then the current are uniformly distributed around the cross section area of the conductor. Hence, no proximity effect occurs on the surface of the conductor.

The proximity effect is important only for conductor sizes greater than 125 mm^2.Correction factors are to be applied to take this fact into account.

If R_{dc} – uncorrected DC level of the core
Y_s – skin effect factor, i.e., the fractional increment in resistance to allowing for skin effect.
y_p – proximity effect factor, i.e., the fractional increment in resistance to allowing for skin effect.
R_e – effective or corrected ohmic resistance of the core.
The allowance for proximity effect is made, the AC resistance of the conductor becomes

$$R_e = R_{dc}\left(1 + y_{dc} + y_p\right)$$

The resistance R_{dc} is known from stranded tables.

Factors Affecting the Proximity Effect

The proximity effect mainly depends on the factors like conductor's material, conductor diameter, frequency and conductor structure. The factors are explained below in details

1. **Frequency** – The proximity increases with the increases in the frequency.
2. **Diameter –** The proximity effect increases with the increase in the conductor.
3. **Structure –** This effect is more on the solid conductor as compared to the stranded conductor (i.e., ASCR) because the surface area of the stranded conductor is smaller than the solid conductor.
4. **Material –** If the material is made up of high ferromagnetic material then the proximity effect is more on their surface.

How to reduce Proximity Effect?

The proximity effect can be reduced by using the ACSR (Aluminum Core Steel Reinforced) conductor. In ACSR conductor the steel is placed at the centre of the conductor and the aluminium conductor is positioned around steel wire.

The steel increased the strength of the conductor but reduced the surface area of the conductor. Thus, the current flow mostly in the outer layer of the conductor and no current is carried in the centre of the conductor. Thus, reduced the proximity effect on the conductor.

- The current distribution may be non-uniform because of another effect known as proximity effect. Consider a two wire line as shown in fig. below

- ➢ Let each of the line conductor is assumed to be divided into 3 sections having equal Cross-sectional area. These parallel loops are formed by the pairs xx', yy' and zz'.
- ➢ The inductance of inter loop is less. Thus, the current density is highest at inner edges of the conductor.
- ➢ Due to this non uniform distribution of current, the effective conductor resistance increases.
- ➢ The proximity effect also depends on the same factors as that of skin effect.

FERRANTI EFFECT

Ferranti Effect in Transmission Lines and Its Calculation

Generally, we know that the flow of current in every electrical system will be from the higher potential area to lower potential area, to reimburse for the difference that lives in the system. In practical, the voltage at the transmitting end is superior to the voltage at the receiving end due to line losses, so the flow of current will be from the supply to the load. In the year 1989, Sir S.Z. Ferranti came up with a theory, namely astonishing theory. The main concept of this theory is all about "Medium Distance Transmission Line" or Long Distance Transmission Lines proposing that in case of no-load operation of the transmission system. The voltage at the receiving end frequently enhances beyond the transmitting end. This is the Ferranti Effect in power system

What is a Ferranti Effect?

The Ferranti effect definition is, the voltage effect on the collecting end of the transmission line is higher than the transmitting end is called as "Ferranti Effect". Generally, this sort of effect happens due to an open circuit, light load at the collecting end or charging-current of the transmission line. Here, charging current can be defined as, whenever an exchanging voltage is connected, the current will flows through the capacitor, and it is also called as "capacitive current". When the voltage at the collecting end of the line is superior to the transmitting end, then the charging current rises in the line.

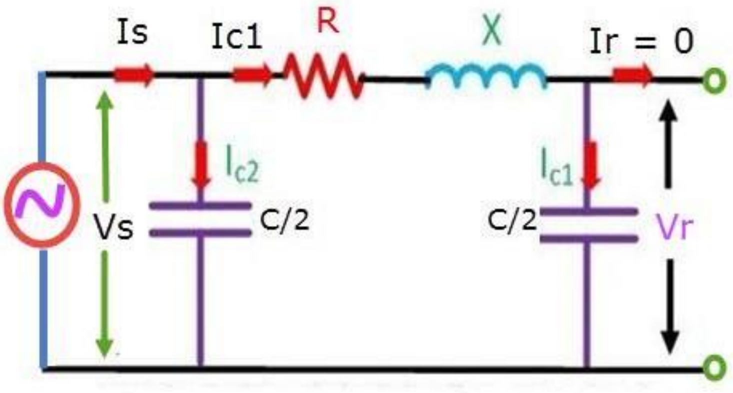
Parameters of Ferranti Effect

Ferranti effect mainly occurs due to the charging current, and couples with the line capacitance. In addition, the following parameters must be noticed.
Capacitance depends on composition and length of a line. In capacitance, cables have more capacitance than bare conductor per length. Whereas in line length, long lines have higher capacitance than short lines.

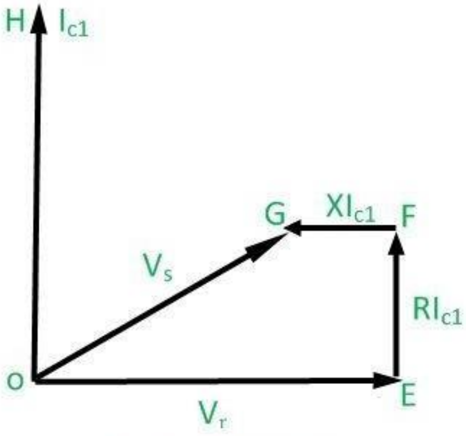
Charging current turns into more important as load current decreases, and it Increases with the voltage of the system given the similar capacitive charge. As a result, the Ferranti effect happens only for long lightly loaded or open-circuited energized lines. In addition, the fact becomes clearer with higher applied voltage and underground cables.

Ferranti Effect In Transmission Line, Calculation

Let us think the Ferrenki Effect in extensive transmission line where OE-signifies the collecting end voltage, OH-signifies the flow of current in the capacitor at the collecting end. The FE-phasor signifies a decrease in a voltage across the resistance R. FG-signifies a decrease in a voltage across the (X) inductance. The OG-phasor signifies the transmitting end voltage in a no-load state. The nominal Pi model of the transmission line at no load condition circuit is shown below.



In the following phasor graphical representation that OE is greater than OG (OE>OG). In other terms, the voltage at the receiving end is superior to the voltage at the transmitting end when the transmission line is at no load condition. Here the **Ferranti effect phasor diagram** is shown below.



Phasor Diagram Circuit Globe

For a nominal pi (п) model

$$V_s = \left(1 + \frac{ZY}{2}\right)V_r + ZI_r$$

At no load, Ir = 0

$$V_s = \left(1 + \frac{ZY}{2}\right) V_r$$

$$V_s - V_r = \left(1 + \frac{ZY}{2}\right) V_r - V_r$$

$$V_s - V_r = V_r \left[1 + \frac{YZ}{2} - 1\right]$$

$$V_S - V_r = \frac{YZ}{2} V_r$$

$$Z = (r + jwl)S, Y = (jwc)S$$

If the resistance of the line is neglected,

$$Z = jwlS$$

$$V_S - V_r = \frac{1}{2}(jwlS)(jwcS)V_r$$

$$V_S - V_r = -\frac{1}{2}(w^2 S^2) lc V_r$$

For overhead lines, $1/\sqrt{lc}$ = velocity of propagation of electromagnetic waves on the transmission lines = 3×10^8m/s.

$$\sqrt{lc} = \frac{1}{3 \times 10^8}$$

$$lc = \frac{1}{(3 \times 10^8)^2}$$

$$V_S - V_R = -\frac{1}{2}w^2S^2.\frac{1}{(3 \times 10^8)^2}V_r$$

$$w = 2\pi f$$

$$V_S - V_R = -\left(\frac{4\pi^2}{18} \times 10^{-16}\right)f^2S^2V_r$$

Above equation shows that (VS-Vr) is negative. That is Vr>VS. This equation also shows that Ferranti effect also depends on frequency and the electrical length of the lines.

In general, for any line

$$V_S = AV_r + BI_r$$

At no load

$$I_r = 0, V_{r=}V_{rnl}$$

$$V_S = AV_{rnl}$$

$$|V_{rnl}| = \frac{|V_s|}{|A|}$$

For a long line, A is less than unity, and it decrease with the increase in the length of the line. Hence, the voltage at no load is greater than the voltage at no load (Vrnl > Vs). As the line length increases the rise in the voltage at the receiving end at no load becomes more predominant.

How to reduce Ferranti effect:

Electrical devices are designed to work at some particular voltage. If the voltages are high at the user ends their equipment get damaged, and their windings burn because of high voltage. Ferranti effect on long transmission lines at low load or no load increases the receiving end voltage.This voltage can be controlled by placing the shunt reactors at the receiving end of the lines.

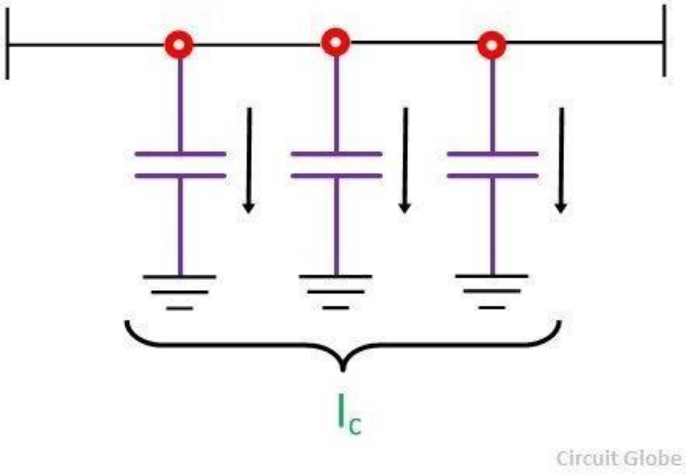
Shunt reactor is an inductive current element connected between line and neutral to compensate the capacitive current from transmission lines. When this effect occurs in long transmission lines, shunt reactors compensate the capacitive VAr of the lines and therefore the voltage is regulated within the prescribed limits.

Note:

- Voltage rise is directly proportional to the square of the length of a line.
- Ferranti effect is more occurs in short transmission cables because their capacitance is high.

CHARGING CURRENT IN TRANSMISSION LINE

In a transmission line, air acts as a dielectric medium between the conductors. When the voltage is applied across the sending end of the transmission line, current starts flowing between the conductors (due to imperfections of the dielectric medium). This current is called the **charging current in the transmission line**.



In other words, we can say, the current associated with the capacitance of a line is known as the charging current.The strength of the charging current depends on the voltage, frequency, and capacitance of the line. It is given by the equations shown below.

For a single-phase line, the charging current

$$I_c = \frac{V_n}{-jX_c} = \frac{V}{-j/wC} = j2\pi f C V A$$

Where,

C= line-to-line in farads
X_c= capacitive reactance in ohms
V= line voltage in volts

$$Charging\ voltamperes = VI_c = \frac{V.V}{X_C} = \frac{V^2}{X_c}\ VAr$$

Also, reactive volt-ampere generated by the line = charging volt-amperes of the lines

$$Q = VI_c = \frac{V^2}{X_c} VAr$$

For a three phase line, the charging current phase

$$I = \frac{V_n}{-jX_c} = \frac{V_n}{-j/wC} = jwC_nV_n\ A$$

where V_n =voltage to neutral in volts = phase voltages in volts
C_n = capacitance to neutral in farads

C_n = capacitance to neutral in farads

$$Charging\ voltamperes\ per\ phase = V_nI_c = V_n \times \frac{V_n}{X_c} = \frac{V_n^2}{X_c} VAr$$

$$Total\ three\ phase\ charging\ voltamperes = 3V_nI_c = \frac{V_n^2}{X_C}\text{VAr}$$

Reactive volt-ampere generated by the line = charging volt-amperes of the lines

$$Q_c = \frac{3V_nI_n}{X_c} = \frac{3}{X_c}\left(\frac{V_t}{\sqrt{3}}\right)^2 = \frac{V_t^2}{X_c} VAr$$

where V_t = line-to-line voltage in volts.

Significance of charging current

1. It reduces the load current, due to which line losses decreases, and hence the efficiency of the line is increased.
2. It improves the power factor of the transmission line.
3. Charging current improves the load capacity of the line.
4. It improves the voltage regulation of the line because the voltage drop is quite small.

INDUCTIVE INTERFERENCE WITH NEIGHBOURING COMMUNICATION CIRCUITS

It is usual practice to run telephone lines along the same route as the power lines. The transmission lines transmit bulk power at relatively high voltages and, therefore, these lines give rise to electro-magnetic and electrostatic fields of sufficient magnitude which induce are superposed on the true speech currents in the neighboring telephone wires and set up distortion while the voltage so induced raise the potential of the communication circuit as a whole. In extreme cases the effect of these may make it impossible to transmit any message faithfully and may raise the potential of the telephone receiver above the ground to such an extent to render the handling of the telephone receiver extremely dangerous and in such cases elaborate precautions are required to be observed to avoid this danger.

In practice it is observed that the power lines and the communication lines run along the same path. Sometimes it can also be seen that both these lines run on same supports along the same route. The transmission lines transmit bulk power with relatively high voltage. Electromagnetic and electrostatic fields are produced by these lines having sufficient magnitude. Because of these fields, voltages and currents are induced in the neighboring communication lines. Thus it gives rise to interference of power line with communication circuit.

Due to electromagnetic effect, currents are induced which is superimposed on speech current of the neighboring communication line which results into distortion. The potential of the communication circuit as a whole is raised because of electrostatic effect and the communication apparatus and the equipments may get damaged due to extraneous voltages. In the worst situation, the faithful transmission of message becomes impossible due to effect of these fields. Also the potential of the apparatus is raised above the ground to such an extent that the handling of telephone receiver becomes extremely dangerous.

The electromagnetic and the electrostatic effects mainly depend on what is the distance between power and communication circuits and the length of the route over which they are parallel. Thus it can be noted that if the distortion effect and potential rise effect are within permissible limits then the communication will be proper. The unacceptable disturbance which is produced in the telephone communication because of power lines is called Telephone Interference.

There are various factors influencing the telephone interference. These factors are as follows

1) Because of harmonics in power circuit, their frequency range and magnitudes.

2) Electromagnetic coupling between power and telephone conductor.

The electric coupling is in the form of capacitive coupling between power and telephone conductor whereas the magnetic coupling is through space and is generally expressed in terms of mutual inductance at harmonic frequencies.

3) Due to unbalance in power circuits and in telephone circuits.

4) Type of return telephone circuit i.e. either metallic or ground return.

5) Screening effects.

Steps for Reducing Telephone Interference

There are various ways that can reduce the telephone interference. Some of them are as listed below

i) The harmonics at the source can be reduced with the use of A.C. harmonic filters, D.C. harmonic filters and smoothing rectors.
ii) Use greater spacing between power and telephone lines.
iii) The parallel run between telephone line and power line is avoided.
iv) Instead of using overhead telephone wires, underground telephone cables may be used.
v) If the telephone circuit is ground return then replace it with metallic return.
vi) Use microwave or carrier communication instead of telephone communication.

The balance of AC power line is improved by using transposition. Transposition of lines reduces the induced voltages to a considerable extent. The capacitance of the lines is balanced by transposition leading to balance in electro statically induced voltages. Using transposition the fluxes due to positive and negative phase sequence currents cancel out so the electromagnetically induced e.m.f’s is diminished. For zero sequence currents the telephone lines are also transposed