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EFFECT ON TRANSMISSION LINE: REVIEW

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Abstract

Electrical design of overhead transmission line discusses everything that electrical engineering student as well as practicing engineers' needs to know effectively for the designing of overhead power lines. This paper presents a review regarding the "various effects" on the transmission line, due to the change in various parameters associated with the line. These various parameters may include the type of current (AC or DC); frequency; presence of another conductor in its vicinity; operation of the line in no load condition, etc. The parameter of the transmission line include Resistance, Capacitance, Inductance, Conductance (R, C, L, G) which are uniformly distributed over the length of transmission line and the performance of line is completely dependent upon these parameters. The performance of the transmission line can also be determined by the efficiency and regulation of line.

This paper provides a general conceptual view over the development of the effects (Skin Effect, Proximity Effect, Ferranti Effect) on line, and also certain methodologies to overcome such effects on the line, which generally results in increased voltage drop, transmission line (conductor loss)loss and decreased line efficiency. These methodologies may also have positive effect toward the betterment of the affected voltage regulation of the line. The particular focus here in is upon the Line Efficiency, Voltage Regulation, Power Factor, Skin Effect, Proximity Effect And Ferranti Effect.

Index Terms: *Transmission line, Line parameters, Line efficiency, Line regulation, Power factor, Skin effect, Proximity effect, Ferranti effect, etc…*

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1. INTRODUCTION.

Nowadays energy plays a very important role in day to day life. There are different types of energies available out there but the dependency on the electrical energy is such that without it life gets somewhat cumbersome. The use of electrical energy is in different fields such as it is used for domestic purpose, irrigation purpose, commercial complex, industries, etc…Thus, to satisfy everyone's need supply utilities provides electrical energy to them via. a network known as "**Power System".** Power-system is composed of five elements :

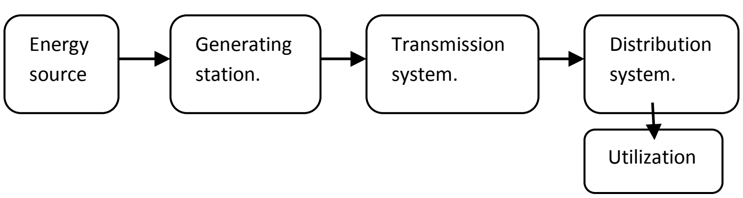


FIG. 1 :- Block diagram of power system.

According to the law of conservation, energy can neither be created nor be destroyed, it can be only transfer from one form to another and hence generating station converts this energy from any form of energy source available in the utilizable form of electrical energy. Then this high voltage electrical energy is transmitted by transmission line over a long distance and then it is stepped down in distribution substation to utilization level and then distributed to various consumers via. a Distribution System.

During this process of transmission, distribution and utilization of power numbers of losses are raised. This decreases efficiency and increase regulation, as a result transmission line experience number of effects which creates losses in lines. These losses mainly depends upon the line parameters. These parameters varies with their mechanical and electrical characteristics along with transmission line

1.1 TRANSMISSION LINE.

Transmission line is a set of conductor being run from one place to another and is supported by the transmission towers on both the ends.

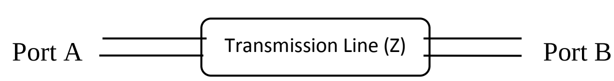
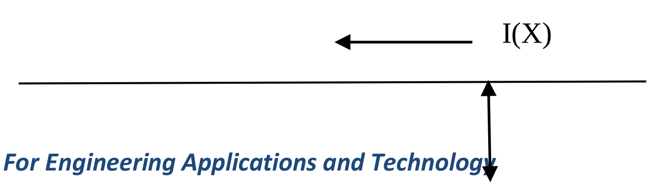


FIG. 2 :- Block diagram of transmission line.

A transmission line can be represented as the **two port circuit using ABCD parameters** which determine the relationship between voltage and current in between the sending end and receiving end. The electrical performance of overhead transmission lines can be characterized by four parameters namely, **Resistance (R), Inductance (L), Capacitance (C), Conductance (G).**



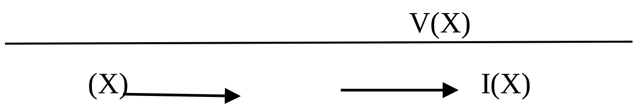


FIG. 3 :- Transmission line representation.

Let us consider a transmission line drawn as two black wires (shown in fig3). At a distance **" x"** in the line, there is current " **I(X)**" travelling through each wire as shown, and there is a voltage difference" **V(x)"** between the wires. If the current and voltage come from a single wave then,

$$\boldsymbol{Z} = \frac{V(X)}{I(X)}$$

Where,

Z is the characteristic impedance of the line in ohms(Ω).

Characteristics Impedance: - The effective resistance of any electric circuit or component to alternating current, arising from the combined effects of ohmic resistance& inductance or Capacitance. Generally denoted by **"Z".**

The performance of transmission line i.e. efficiency and the losses are completely dependent on It's to oppose constant\ parameters (R, L, C, G).

1.2 TRANSMISSION LINE PARAMETER.

Resistance:- It is the property of conductor to oppose the flow of current. It is represented by **"R"** and is measured in ohms (Ω). Resistance causes the conductor losses (I^2R) and reduce the transmission efficiency.

$$\boldsymbol{R} = \frac{\rho L}{A}$$

Where, ρ = resistivity of conductor. (it is constant)

L= length of conductor. (in meters)

A= cross sectional area of the conductor. (in m^{2})

Inductance:- The property of electric conductor or circuit that causes an electromotive force to be generated by the change in the current flowing through it is the "Inductance". Inductance is measured in Henry and it is denoted by **"L".**

$$\boldsymbol{L} = \frac{\mathbf{N\phi}}{\mathbf{I}}$$

Where, L = inductance in Henry.

N= No. of turns.

ϕ = flux link in Weber.

I = current through conductor in amp

Capacitance :- Capacitance is the ability of system to store electric charge. It is the ratio of change in electric charge in system+ to the corresponding change in its electric potential.

$$\boldsymbol{C} = \frac{Q}{V}$$

Where, Q = charge in coulombs.

V= voltage in volts.

Conductance:- The degree to which an object conducts electricity calculated as the ratio of the current which flows to the potential difference present. This is a reciprocal of resistance. And it is measured in simens and mho. Denoted by **"G".**

$$\boldsymbol{G} = \frac{\boldsymbol{R}}{\boldsymbol{Z^2}}$$

Where, R= Resistance
Z= impedance

2. TRANSMISSION LINE.

2.1 Transmission line efficiency.

In case of transmission line the end of the line where load is connected is known as receiving end and where supply is connected is known as the sending end. The power obtained at the receiving end of transmission line is generally less than the sending end power due to losses in line resistance.The ratio of receiving end power to the sending end power is known as **Transmission Line Efficiency.**

$$\boldsymbol{\eta}\% = \frac{\boldsymbol{RECEIVING\ END\ POWER}}{\boldsymbol{SENDING\ END\ POWER}} \times \mathbf{100}$$

Let sending end parameter be **Vs, Is, cosϕs and Ps**

Let receiving end parameters be **Vr, Ir, cosϕr and Pr**.

$$\boldsymbol{\eta}\% = \frac{(\mathbf{Vr*Ir*cos\phi r})}{(\mathbf{Vs*Is*cos\phi s})} \times \mathbf{100}$$

It is a desired parameter and it should be as high as possible and ideally infinite

2.2 Regulation.

When a transmission line is carrying current, there is a voltage drop in a line due to the resistance and the inductance of the line. The result is that the receiving end voltage **(Vr)** of the line is generally less than sending end voltage **(Vs).** This voltage drop **(Vs-Vr**) in the line is expressed as a percentage **(%)** of receiving end voltage **(Vr)** and is called **Voltage Regulation.**

% VOLTAGE REGULATION: - $\frac{VS-VR}{VR}$ ***100**

As transmission line current increases, efficiency decreases, and regulation increases. Regulation is an undesired parameter and supposed to be ideally nil.

2.3 Power Factor.

Power factor is defined as the factor by which the apparent power (S) must be multiplied so as to obtain the true power (P) OR it is the ratio of the true power and apparent power generally, denoted by "cosϕ**".** Ideally power factor should be one and practically it should be as high as possible.

$$\text{Powerfactor} = \frac{\text{true power}}{\text{apparent power}} = \frac{V*I*COS\phi}{V*I} = \cos\phi$$

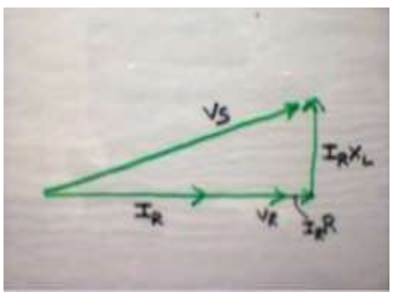
The power factor can also be defined as the ratio of impedance as follows. From the impedance triangle the resistance is given by;

$$\boldsymbol{R} = Z * \cos\phi$$

Hence,power factor = cosϕ= $\frac{R}{Z}$

The value of power factor will be confined between +1 and -1 because it is basically the cosine of the phase difference ϕ. The nature of power factor is dependent on the type of circuit as illustrated below,

(1). Purely resistive



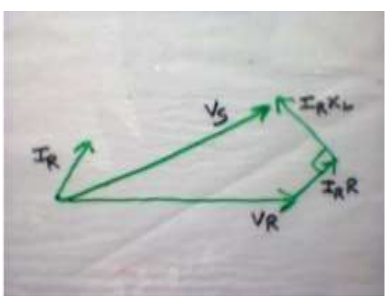
ϕ = 0

Cos ϕ = 1.

Neither leading nor lagging.

FIG.4:- vector diagram for unity power factor.

(2). Purely inductive.



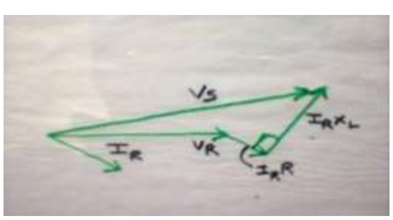
ϕ = -90°

Cos ϕ = 0.

FIG.6 :- vector diagram for lagging power factor.

The power factor is said to be zero lagging due to negative sign of ϕ.

(3). Purely capacitive.



ϕ = +90°

cos ϕ = 0.

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FIG.7:- vector diagram for leading power factor.

The power is said to be zero leading due to positive sign of ϕ.

3. EFFECTS ON TRANSMISSION LINE.

3.1 Skin Effect:-

The alternating current is used in preference with the direct current due to the fact that alternating voltage can conveniently change in magnitude by means of transformer.

Hence direct current flows in the conductor, the current is uniformly distributed across the section of the conductor. But when an alternating current passes through a conductor it tends to distribute itself non uniformly throughout the cross section of the conductor ; those portion of the conductor situated near the surface carry a major portion of the total amount current the phenomenon is known as "**skin effect"**.

As an example consider a solid current carrying conductor of circle cross section (as shown in fig.4.1.1) we can replace this conductor by large no. of small element in parallel, bunched together and occupying the same space such that the total area of cross section remains unchanged (as shown in fig.4.1.2).

Each small element now carries a fraction of total current and now these current set up their own magnetic fields. There is a difference in the flux set up by the inner and outer element. Thus flux due to element "A" links with itself but not with any of the outer element. Whereas, the flux due to an outer element like "B" links with all inner elements upto "B".

The innermost element "A" is concentrated with more flux , thus the inductance of it is much more than that of an outer element "B" which is near to the surface. As we know that the current always follow through path of a low resistance\ reactance. Thus here, the current would have the tendency to concentrate itself to the path nearer to the conductors surface rather than from the middle due to higher reactance of inner elements and hence this reduces the effective cross sectional area of the conductor. This causes increase in effective resistance of the path through which current is flowing. The distribution of current is non-uniform. The typical distribution of current as shown;

Fig. 8 :- cross sectional view of conductor
a)single conductor
b) bundle conductor

The skin effect is due to opposing eddy currents induced by the changing magnetic field resulting from the alternating current. Skin depth is due to the circulating eddy current (arising from a change in H field) cancelling the current flow in the centre of conductor and reinforcing it in th skin.

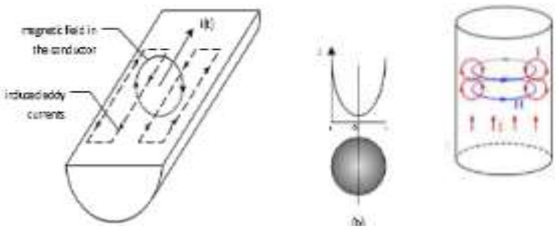


FIG.9 :- Sectional View of conductor

Dependency:-

Skin effect is directly proportional with the frequency, diameter of the conductor i.e. with the increased value of frequency and diameter the skin effect increases. Whereas, the skin effect is less for standard conductors and more for solid conductors. Similarly, on the other hand for the frequencies less than 50HZ and diameter less than 1cm the skin effect negligible.

Calculation of skin effect:-

We can derive a formula for skin depth as follows

$$\delta = \sqrt{\frac{2p}{(2\pi f)(\mu 0 \mu r)}} \approx 503\sqrt{\frac{p}{\mu r f}}$$

Where
ϱ = resistivity of conductor 10^{-8}
ω = angular frequency
ɥr =relative magnetic permeability of the conductor
ɥ0 = the permeability of free space

Whenever skin effect rises in conductor, it depends on frequency of supply and conductor material. As given, data of frequency and material, formulate the skin depth when current flows through it.

Table1:- variation of skin depth with frequency

Table2:- variation of skin depth with Conductor Material

Conductor	Skin depth (ɥm)
Aluminium	0.80
copper	0.65
gold	0.79
silver	0.64

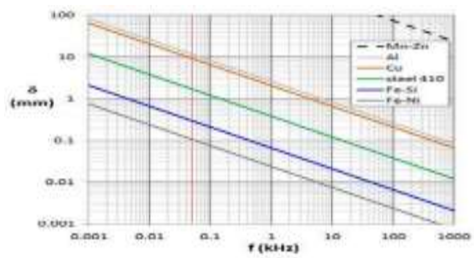


FIG.10:- Graph of freq v/s skin effect

Example to find skin effect ((σ):-

Aluminium is a good conductor with a resistivity of $2.65*10^{-8}$ ohm m and is essentially nonmagnetic Ɥr = 1, so its skin depth at frequency 60HZ is given by

$$\sigma = 503\sqrt{\frac{2.65*10^{-8}}{1*60}} = 11.57\,mm.$$

Factor Affecting "σ":-

1.Frequency of the conductor.

2.Electrical and magnetic properties of the conductor.

Effects of skin effect on Transmission line:-

Since, the effective cross section of the conductor reduces, therefore **resistance of the conductor increases**. Increased resistance of conductor causes increase in **copper loss of the transmission line**. Also **voltage drop value increases.** This two effect **reduces the transmission efficiency** and **affect the voltage regulation** respectively.

Frequency	Skin depth (ɥm)
60 Hz	8470
10 kHz	660
100 KHz	210
1 MHz	66
10 MHz	21
100 MHz	6.6

How to overcome skin effect:-

1. By using bundle conductors
2. By using litz wire
3. Using good conductor
4. Decreasing frequency

3.2 Ferranti Effect :-

When a long transmission line is operating under no-load or light load condition , the receiving end voltage become greater than sending end voltage". There are many factors affecting temporary over voltage that may be considered in insulation. The Ferranti effect is an phenomenon where the steady voltage at the open end of an uncompensated transmission line is always higher than the voltage at the sending end. It occurs as a result of the capacitive charging current flowing through the inductance of the line and resulting over voltage increases according to the increase in line length. This phenomenon is known as **Ferranti effect**.

On one installation of ac transmission system Ferranti observed alerted by the installers that by adding additional distribution sections, i.e. by increasing the total length of transmission line, the voltage on the line increase locally. Infact they observed first on the Deptford – London line luminosity of some carbon fibre lamps increase , when they attached an additional distribution section. In this case it should be noted that they had a load of only a couple of low power bulbs while having an effective generator power exceeding slightly 935kw. Thus ferranti had approximately an open ended transmission line. As a result today the Ferranti effect is very known in the field of power transmission over long distances at relatively low frequencies.

Transmission line simulator :-

The transmission line simulator is design to have length adjustment facility (200,300,400……m) such that the study can be extended for short, medium and long lines. The simulators Is fed at the sending end using a 3phase 400V (L-L) various equivalent to 1.0pu at the sending end. The sending end is connected the different meters for measuring all lines and phase quantities. A frequency meter is also provided at the sending end.

The sending end is connected to the line unit house in a steel enclosure. The line units are modelled as "∏"circuits and have variable lengths facilities. The receiving end system serves as a major load centre with a variety of static impedance load. The receiving end bus consist of bus, metering, loading and variac for voltage control . The auxiliary bus is connected with the receiving end through 100km line. The auxiliary bus also has independent metering and external loads can be connected with auxiliary bus.

Simulator Rating:

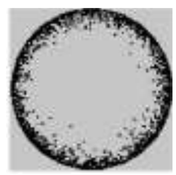
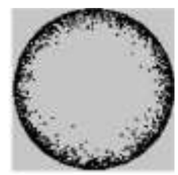
Voltage	:	400 V (L-L)
Current	:	2 A (max 3A) continuous
Frequency	:	50HZ
Power	:	1400 VA
Line unit	:	'∏ ' equivalent with 400 KV , single circuit on H-tower (simulated) and having, 1 = 1 mH\km c = 10nF/ Km , r = 0.01 ohm/Km.

The over voltage can be confirmed due to Ferranti effect along the transmission line length. It occurs when line is energised but there is a very light load or the load is disconnected. the effects is due to the voltage drop across the inductance being in phase with the sending end voltages, therefore inductance is responsible for producing this phenomenon. The Ferranti effect will be more pronounced the longer the line and the higher the voltage applied. From the knowledge of ferranti effect the temporary over voltage in transmission line can be reduced and thus the line can be protected.

3.3 Proximity Effect:-

This is an another electromagnetic effect which result in the gradual increment of the apparent resistance of the conductor due to presence of the other conductor carrying current in its vicinity. When two or more conductors are in proximity their electromagnetic field interacts with each other which results that current in each of them is redistributed such that the greater current density concentrated in that part of the strand which is most remote from the interfering area of the conductor.

Suppose there is two conductors A and B placed near each other as shown:

Conductor-"A" **Conductor-"B"**

When one conductor A carries current, its flux link with the other conductor "B" more flux link with the nearer half portion of conductor "B" (dark shaded portion)than with other half portion farther away.

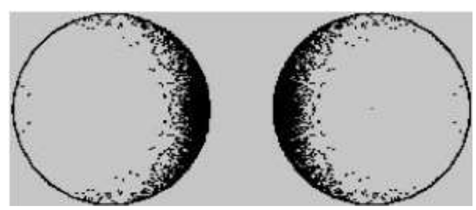


FIG.11 current distribution for proximity effect with current flow both in same direction.

If conductors carry current in the opposite direction the magnetic field set up will tend to cause an increase in the current density in the adjacent portion of the conductors.

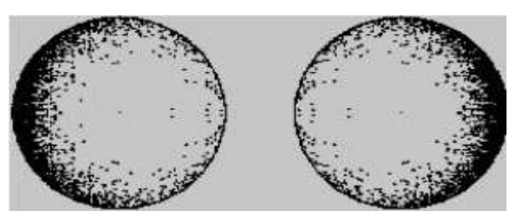


FIG.12 current distribution for proximity effect with current flow both in opposite direction.

On the other hand if the current are in the same direction, the current density is increased in the remote part of the conductor.

The result is that there is an increase in the losses in the conductor since the effective resistance (A.C resistance) is more than the ohmic resistance (DC resistance).

Proximity losses in AC conductors and Magnetic devices:-

Proximity effect is an AC power system phenomenon that can greatly increase magnetic losses over dc resistance or skin effect values alone. Closed from analysis in the form of set of hyperbolic equation is possible without resulting 3-D finite analysis programs. However, a full harmonic analysis must be used on the governing equations or loss estimates may be off by orders of magnitude. As a result, EASI uses a proprietary computer program in order to quickly calculated the result of design changes upon facility distribution system losses.

Even with the aid of all referenced paper, the analysis is not straightforward. Using concept developed from the paper, the following equation are governs the losses in the individual layer at one frequency ;

$$LOSS = AREA\ \frac{(H^2)}{2\delta\sigma}[(1 + H_r M_n) - 4H_r D_n]$$

Area is the total conductor surface area = (winding width) (winding length)

H is the high side magnetic field intensity (in ampere turns per length)

Hr is the field ratio for one winding (high side to low side)

Dependency :-

It depends on conductor size , frequency of current , resistance of conductor and aslo the permeability of material .

Effects:-

Since the effective cross section of the conductor reduces, therefore resistance of the conductor to flow the current increases. This causes the increase in power loss of the transmission line. Also it increases the voltage drop in line. This also reduce the line efficiency and also affect the Regulation respectively.

Result Analysis:-

The overall common effect recognised is the "increased resistance of the conductor because of reduction in the cross section area of the conductor", the increase in the resistance of the conductor, causes the increase in the loss of transmission line (I^2R).

These effects causes increase in the voltage drop of the line. Also decrease the overall transmission efficiency which is one of the desirable parameter, the voltage regulation also gets affected.

Method to overcome these effects:-

1. The skin effect can be reduced by using standard conductor rather than solid conductor.
   Because each strand has very small sectional area and is insulated from its adjacent conductors, therefore the skin effect is negligible compared with a solid conductor, also due to this the effective surface area of the wire increases for a given wire gauge.
2. Tinned wire should be avoided because tin has higher resistance copper or aluminium should be preferred as its resistance is low in comparison with tin.
3. A.C resistance of a conductor is somewhat higher than D.C resistance, hence comparatively skin effect is absent in case of D.C hence H.V.D.C line can use for transmission of power.
4. Actually, the skin effect cannot be reduced in ordinary conductors, for the sake of economy tubular conductor are also used. Tubular conductor does not reduce the skin effect, but merely saves copper.
5. Whereas, the proximity effect can be reduced by increasing the gap between two conductor of transmission line wires. Generally the proximity effect for 50 HZ frequency is considered to be negligible.
6. As available parameter of line R, L, C, G, reduction of resistance offers less inductance, which is also depend on length and spacing of conductor. This can easily formulate where the spacing between lines can increases. The capacitance is also controlled by spacing between conductors. As these parameter can be reduces the affects where power loss may happen.

5. Conclusion:-

As the paper provides a overall common problem rises due to affect, also it provides the skin depth which can be Improved by with proper manufacturing of conductor material Some method are also provides the overcome of these problem in easy manner.

Transmission line simulator provides electrical essential which can affect the system. So design can improved before commissioning.

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