Analysis of Overhead Transmission Lines

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***Abstract*—This document explores how the overhead transmission lines work, and present an idea on the simplified circuit of the network. Also we will analyze the workings and the equations governing the network.**

I. Introduction

In this report, we present a detailed analysis of the overhead transmission lines' circuit, conducted through the lens of an engineer. Our focus lies in scrutinizing the circuit's performance and classifying the various types of overhead transmission lines present. This comprehensive examination aims to provide a nuanced understanding, contributing to a better understanding of the network at hand.

II. What are Overhead Transmission Lines?

A. Definition :-

Overhead transmission lines are integral components of electrical power systems, designed for the efficient transfer of electricity over long distances. These lines consist of conductors supported by towers or poles above the ground, distinguishing them from underground alternatives.

B. History and Evolution :-

The history of overhead transmission lines dates back to the late 19th century when pioneers like Nikola Tesla and George Westinghouse championed alternating current (AC) transmission. The famous Niagara Falls hydroelectric project in 1896 marked a milestone, demonstrating the viability of long-distance transmission, setting the stage for the widespread adoption of overhead lines. Over the years, technological advancements have led to the development of High Voltage Direct Current (HVDC) transmission, enabling more efficient and controlled power transfer over vast distances. Today, overhead transmission lines play a crucial role in supplying electricity from power plants to distribution networks, contributing to the global interconnected grid system. Despite their efficiency, overhead transmission lines face challenges such as environmental impact, visual aesthetics, and susceptibility to weather conditions. Ongoing innovations include the integration of smart grid technologies, improved conductor materials, and enhanced monitoring systems to address these challenges.

C. Types :-

The transmission lines are categorised into two categorizing systems -
1) Based on the Voltage supplied, and
2) Based on the Distance between which the power is transmitted.

1) Based on Voltage Supplied:

- LOW VOLTAGE
- MEDIUM VOLTAGE
- HIGH VOLTAGE

2) Based on Distance:

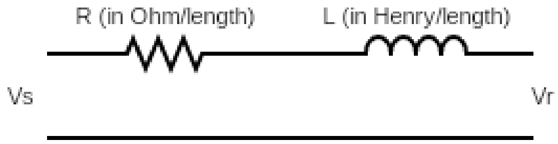
- SHORT LENGTH
- MEDIUM LENGTH
- LONG LENGTH

Here we start our analysis of the transmission lines. We will be studying the categorization on the basis of distance.

III. ANALYSIS OF SHORT LENGTH TRANSMISSION LINES

In this section we discuss and analyze the short length transmission lines. Short-distance transmission lines refer to electrical power transmission lines that cover relatively short distances, typically less than 60 kilometers. These lines are considered short in comparison to longer transmission lines, which can span several hundreds or even thousands of kilometers. The characteristics and behaviors of short-distance transmission lines differ from those of longer lines, and they are often used to connect power generation sources to local distribution networks or to interconnect different parts of a power system.

A. Equivalent Circuit :-



this is the equivalent circuit diagram for the short line transmission lines. As the line is short, capacitance can be ignored as it will have negligible effect on the overall circuit.

B. Equations :-

We assume that the signal transmission occurs at the speed of light and the frequency of transmission is 50 Hz. Then,

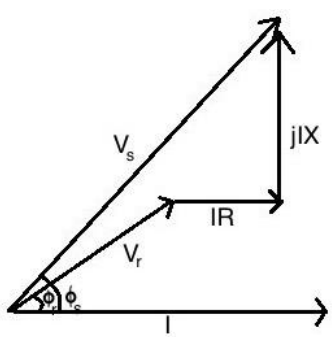
$$c = 3 * 10^8 m/s$$

$$f = 50Hz$$

$$c = f\lambda => \lambda = c/f$$

$$\lambda = 6000km$$

Here, λ is the wavelength of the transmission,f is the frequency and c is the speed of light.
We also know the current going into the circuit is same as the current going out of the circuit (using Kirchhoff's current law), let it be I. The reactance of the inductor is X which would be $2\pi fL$. Then, the angle made by Vs and Vr with respect to I are,



From here we apply 2 port model using 2x2 matrices

$$V_s = AV_r + BI$$

$$I = CV_r + DI$$

Here, A,B,C and D are constants which can be calculated by

$$I = 0 => A = V_s/V_r$$

$$V_r = 0 => B = V_s/I$$

$$I = 0 => C = I/V_r$$

$$V_r = 0 => D = I/I$$

Applying Kirchhoff's Voltage law on the given circuit we find,

$$V_s = I(R + jX) + V_r$$

Here the net impedance will be $Z = R+jX$. Now comparing this equation with the one we got before, we find;
$A = 1$
$B = Z$
$C = 0$
$D = 1$
Hence we find that the conditions for a passive network are met, which are; $AD - BC = 1$ and $A = D$

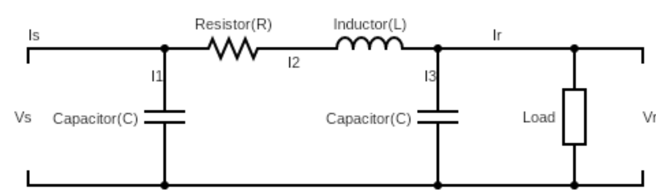
IV. ANALYSIS OF MEDIUM LENGTH TRANSMISSION LINES

In this section we discuss and analyze the medium length transmission lines. Medium-distance transmission lines refer to electrical power transmission lines that cover relatively medium distances, typically between 60 to 150 kilometers. The characteristics and behaviors of medium-distance transmission lines differ from those of short and medium lines, and they are often used to interconnect different parts of a power system. They are studied under two circuits -

1) Nominal Π
2) Nominal **T**

A. Nominal Π :-

1) Equivalent Circuit Diagram:



This is the equivalent circuit diagram for medium length transmission line in a nominal pi configuration, here each of capacitor would be equated with a shunt admittance equal to Y/2.

2) Equations: -

First we define shunt admittance across each capacitors -

$$\frac{Y}{2} = 2\pi fC$$

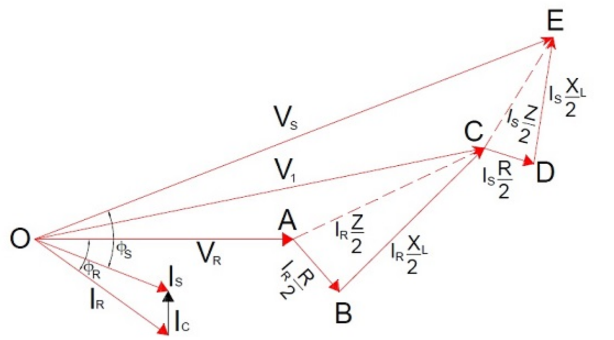
Then the impedence across inductor is -

$$X_L = 2\pi fL$$

Now we define Z as a series impedence across resistor and inductor

$$Z = R + X_L = R + 2\pi fL$$

The phasor representation of the various components is as follows :-



Now applying Nodal Analysis on each node we find the following set of equations -

- $I_s = I_1 + I_2$
- $I_2 = I_r + I_3$
- $I_s = I_1 + I_3 + I_r$

Also we find that,

- $I_1 = V_s \frac{Y}{2}$
- $I_3 = V_r \frac{Y}{2}$
- $I_2 = \frac{V_s - V_r}{Z}$

then,

$$V_s = I_2 Z + V_r$$

$$V_s = (I_r + I_3)Z + V_r = I_r Z + V_r(1 + \frac{YZ}{2})$$

and,

$$I_s = V_s \frac{Y}{2} + V_r \frac{Y}{2} + I_r$$

$$I_s = Y(1 + \frac{YZ}{4})V_r + (1 + \frac{YZ}{2})I_r$$

From here we apply 2 port model using 2x2 matrices

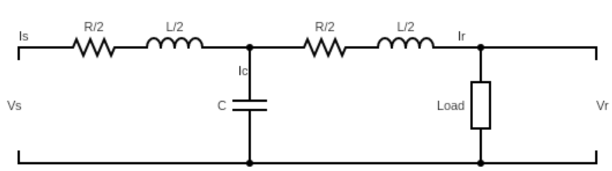
$$V_s = AV_r + BI_r$$

$$I_s = CV_r + DI_r$$

Here, A,B,C and D are constants which can be calculated by direct comparison and the values are :-
$A = (1 + \frac{YZ}{2})$
$B = Z$
$C = Y(1 + \frac{YZ}{4})$
$D = (1 + \frac{YZ}{2})$
Hence we find that the conditions for a passive network are met, which are; $AD - BC = 1$ and $A = D$

*B. Nominal **T** :-*

1) Equivalent Circuit Diagram:



This is the equivalent circuit diagram for medium length transmission line in a nominal T configuration, here the impedence across the resistor and inductor is equal to Z/2.

2) Equations: -

First we define shunt admittance across capacitor -

$$Y = 2\pi f C$$

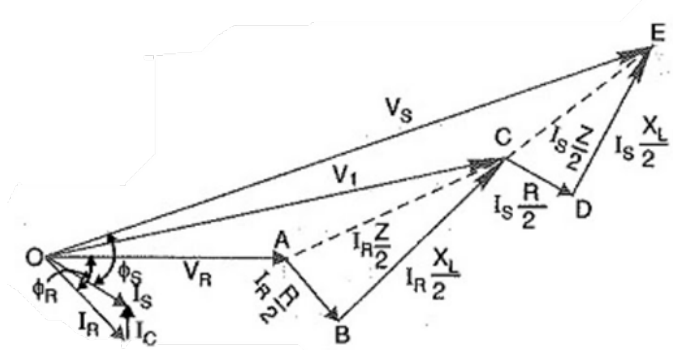
Then the impedence across each inductor is -

$$X_L = 2\pi f \frac{L}{2}$$

Now we define Z/2 as a series impedence across resistor and inductor

$$\frac{Z}{2} = \frac{R}{2} + X_L = \frac{R}{2} + 2\pi f \frac{L}{2}$$

The phasor representation of the various components is as follows :-



Now we start writing equations governing the systems - let us define the voltage at the T junction to be V_1

$$V_1 = I_r \frac{Z}{2} + V_2$$

also we know from Kirchhoff's current law -

$$I_s = I_c + I_r$$

$$I_c = V_1 Y$$

from these we can conclude -

$$I_s = I_r(1 + \frac{ZY}{2}) + V_r Y$$

Now,

$$V_s = I_s \frac{Z}{2} + V_1$$

on simplifying we get,

$$V_s = Z(1 + \frac{YZ}{4})I_r + V_r(1 + \frac{YZ}{2})$$

From here we apply 2 port model using 2x2 matrices

$$V_s = AV_r + BI_r$$

$$I = CV_r + DI_r$$

Here, A,B,C and D are constants which can be calculated by direct comparison and the values are :-
$A = (1 + \frac{YZ}{2})$

$B = Z(1 + \frac{YZ}{4})$
$C = Y$
$D = (1 + \frac{YZ}{2})$
Hence we find that the conditions for a passive network are met, which are; $AD - BC = 1$ and $A = D$

C. Conclusion :-

We can conclude that we can regulate the voltage using these network, using the formulas -

$$\%\,Voltage\,Regulation = \frac{V_r(no\,load) - V_r(full\,load)}{V_r(full\,load)} * 100$$

we also know, $V_s = AV_r(no\,load) + BI$ but $I = 0$ for no load, then $V_r = V_s$ in no load condition, then :

$$\%\,Voltage\,Regulation = \frac{V_s - V_r}{V_r} * 100$$

where everything is measured in full load conditions.
We can also calculate the efficiency of the circuit by using :

$$efficiency\,\eta = \frac{Power\,Recieved}{Power\,Sent} * 100$$

but power sent can be calculated as
$Power\,Sent = Power\,Recieved + I^2R$ as there is a loss across the wires length. Hence, the final equation is as follows:

$$efficiency\,\eta = \frac{Power\,Recieved}{Power\,Recvieved + I^2R} * 100$$

Here we haven't considered the long range transmission lines as their were some concepts which were beyond our scope and hence we end our project here.
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