Tribhuvan University

KHWOPA COLLEGE OF ENGINEERING

An Undertaking of Bhaktapur Municipality
Libali-8, Bhaktapur
Nepal

A Report On

Transmission and Distribution Design

Submitted By:

Shubhanga Aryal
KCE078BEL038

Submitted To:

Er. Shreeshuva Maharjan
Er. Anil Bhatt

Department of Electrical Engineering
KHWOPA COLLEGE OF ENGINEERING
Libali, Bhaktapur

Contents

Transmission And Distribution Design

Design a transmission and distribution design that can transmit a power of $133MW$ for a length of $110Km$.

1 Calculation of the most Economical voltage

For a given power transmission, increasing the voltage reduces the current which reduces the overall copper loss and energy losses. Lower energy losses means less energy is wasted which allows us to use conductors with smaller cross sectional area, which improves conductor economy. However, transmitting at higher voltages requires better insulation, larger clearances, longer insulators which increases the insulator and construction cost.

To mitigate this issue, the most economical voltage is chosen. The most economical voltage can be defined as the voltage at which the reduction in power and energy loss and conductor cost just balances the increase in insulator and line construction cost, which gives us a minimum total annual cost for generating voltage. The empirical formula for the most economical voltage is given by:

$$V = 5.5\sqrt{\frac{L}{1.6} + \frac{P \times 1000}{150 \times N_c \times cos\phi}}(in\ KV) \tag{1}$$

where, L is the length of the transmission line in km, P is the power transmitted in MW, N_c is the number of circuit in the transmission line and $cos\phi$ is the power factor of the transmission line.

Since the most commonly used number of circuits(N_c) are 1 and 2, we now calculate the most economical voltage for $N_c = 1$ and $N_c = 2$.

For $Nc = 1$:

Taking the length and Power transmitted as given in the question and substituting the values in equation 1 and assuming power factor to be 0.9, we get

$$\begin{aligned} V_{eco1} &= 5.5\sqrt{\frac{110}{1.6} + \frac{133 \times 1000}{150 \times 1 \times 0.9}} \\ &= 178.55\ KV \end{aligned}$$

Similarly, for $N_c = 2$:

$$\begin{aligned} V_{eco2} &= 5.5\sqrt{\frac{110}{1.6} + \frac{133 \times 1000}{150 \times 2 \times 0.9}} \\ &= 130.3096\ KV \end{aligned}$$

2 Selection of Economical voltage Near the Standard Transmission Line Voltage

The most economical voltage can or may not be exactly the voltage that is used in standard transmission line design. Hence, we must choose the nearest standard voltage . The standard voltages used in transmission design are as follows: **55** kV, **132** kV, **220** kV, **400** kV . Since the economical voltage V_{eco1} is nearest to 220 KV and V_{eco2} is nearest to 132 KV, we choose $V_{eco1} = 220\ KV$ and $V_{eco2} = 132\ KV$.

3 Technical Analysis

To do the technical analysis of the transmission line, we must follow these three steps. They are as follows:

- Calculate multiplying factor(m_{funit}) for a given length.
- Calculate Surge Impeadance Loading(SIL) for both the cases($N_c = 1\ and\ N_c = 2$).
- Calculate the m_f value for both the cases.

The table to analyze the length and its corresponding limit of the multiplying factor is as shown below: Since the length is 110 Km, which is not available in the table given ,

Table 1: m_{flimit} for various lengths

Length(km)	m_{flimit}
80	2.75
160	2.25
240	1.75
320	1.35
480	1
640	0.75

we must interpolate the values to find the corresponding values. By using interpolation,

$$y - y_1 = \frac{y_2 - y_1}{x_2 - x_1}(x - x_1) \tag{2}$$

Taking the values of m_{flimit} column in y and Length column in x and putting it in equation 2:

$$y - 2.75 = \frac{2.25 - 2.75}{160 - 80}(110 - 80)$$
$$y = 2.5625$$

$\therefore m_{flimit}$ for 110 km is 2.5625. We know,

$$m_{flimit} = \frac{P_{capability}}{SIL} = 2.5625 \tag{3}$$

We now calculate the surge impedance loading for both the circuits, For $N_c = 1 \; and \; Nc = 2$. We know,

$$SIL = \frac{(V_{eco})^2}{Z_{nc}} \tag{4}$$

where Z_{nc} is the impedance of the number of circuits(400 for N_c=1 and 200 for $N_c = 2$. Substituting the values in equation 4:

$$SIL_1(N_c = 1) = \frac{(V_{eco1})^2}{Z_{nc1}} = \frac{220^2}{400} = 121 \; MW$$
$$SIL_2(N_c = 2) = \frac{(V_{eco2})^2}{Z_{nc2}} = \frac{132^2}{200} = 87.12 \; MW$$

Now we calculate the multiplying factor for both the circuit:

$$m_{f1(N_{c1})} = \frac{P_{transfer}}{SIL_1} = \frac{133}{121} = 1.099$$
$$m_{f2(N_{c2})} = \frac{P_{transfer}}{SIL_2} = \frac{133}{87.12} = 1.5266$$

Hence the following can be analyzed with the help of table as shown:

Table 2: Comparison between the multiplying factor and its limit for both type of circuit

N_c	V_{eco}	$SIL(MW)$	m_f	m_{flimit}
1	220	121	1.099	2.5625
2	132	87.12	1.526	2.5625

It can be seen from the table that the value of m_f is less than m_{flimit} for both the circuits. And hence it is acceptable. Now we calculate the margin of m_f for both the circuits. Hence,

$$m_{f\ margin(N_{c1})} = |m_{flimit-m_{f1(N_{c1})}}| = |2.5625 - 1.099| = 1.466$$
$$m_{f\ margin(N_{c2})} = |m_{flimit-m_{f2(N_{c2})}}| = |2.5625 - 1.526| = 1.0372$$

The value of mf margin is minimum for $N_c = 2$. Hence we choose the most economical voltage of 132 KV as our main voltage(V) and move forward with our calculations.

4 Air Clearance Calculation

For the transmission of power, electrical energy is transmitted using transmission towers and conductors. Therefore, the transmission towers must be properly designed to ensure safe and reliable operation of the transmission line. For this purpose, various geometrical and electrical parameters of the tower need to be determined. The following parameters are required for the tower design:

$$\begin{aligned}
a &= \text{minimum air clearance} \\
l &= \text{length of string} \\
c_l &= \text{cross arm length} \\
b &= \text{width of the body} \\
c &= \text{total width of the tower} \\
d &= \text{length of earth wire from uppermost conductor} \\
\phi &= \text{swing angle} \\
\theta &= \text{shielding angle}
\end{aligned}$$

These parameters are selected to maintain the required clearances and structural dimensions of the tower under different operating conditions.

The minimum air clearance between live conductors and between conductor and earth is determined by the maximum operating voltage and safety requirements. It is given by

$$a = (1 \text{ cm per kV of maximum voltage}) + \text{factor of safety}$$

The factor of safety accounts for overvoltages, atmospheric variations, and non-uniform electric field effects. A value of 1.1 is used to consider the Ferranti effect for transmission lines up to 220 kV, where the receiving-end voltage may rise under light-load or no-load conditions. For higher voltage lines, up to 400 kV, the factor of safety is reduced to 1.05 due to improved design. This ensures sufficient air clearance to avoid flashover and maintain reliable and safe operation of the transmission line.

4.1 Calculation

4.1.1 Minimum Air Clearance

$$\begin{aligned} a &= \left(\frac{V}{\sqrt{3}} \times 1.1 \times \sqrt{2}\right) + 20cm \qquad (5)\\ &= \left(\frac{132}{\sqrt{3}} \times 1.1 \times \sqrt{2}\right) + 20cm \\ &= 139.5cm \end{aligned}$$

4.1.2 Length of cross arm(c_l)

$$\begin{aligned} c_l &= 2a \qquad (6)\\ &= 2 \times 138.55\ cm = 277.110\ cm \end{aligned}$$

4.1.3 Tower width(b)

$$\begin{aligned} b &= 2a \\ &= 277.110\ cm \end{aligned}$$

4.1.4 Insulator string length(l)

$$l = \sqrt{2}a = 195.93cm \qquad (7)$$

4.1.5 Horizontal separation between conductor(c)

It is given by:

$$\begin{aligned} c &= b + 2c_l \qquad (8)\\ &= 277.11 + 2 \times 277.11 \\ &= 831.33cm \qquad (9) \end{aligned}$$

4.1.6 Vertical separation between conductors(y)

$$\begin{aligned} y &= \frac{l+a}{\sqrt{1 - \frac{(l+a)^2}{c_l^2} \times (\frac{x^2}{y^2})}} \qquad (10)\\ &= 365.35cm \end{aligned}$$

The value of the ratio x/y should be taken between 1/4 and 2/3. i.e, $\frac{1}{4} < \frac{x}{y} < 1/3$. Taking the ratio to be 1/3 we get, y=464.215cm.

4.1.7 Height of earth wire from topmost conductor for double earth wire

Since we are using a double circuit line and not single circuit, the earth wire we will use is double circuit wire and not single circuit.
For single earth wire,

$$d = \sqrt{3}(\frac{b}{2} + a) \tag{11}$$
$$= 719.95cm$$

For double earth wire,

$$d = \sqrt{3} \times c_l \tag{12}$$
$$= 479.96cm$$

The figure of a three phase double circuit transmission tower is as shown below:

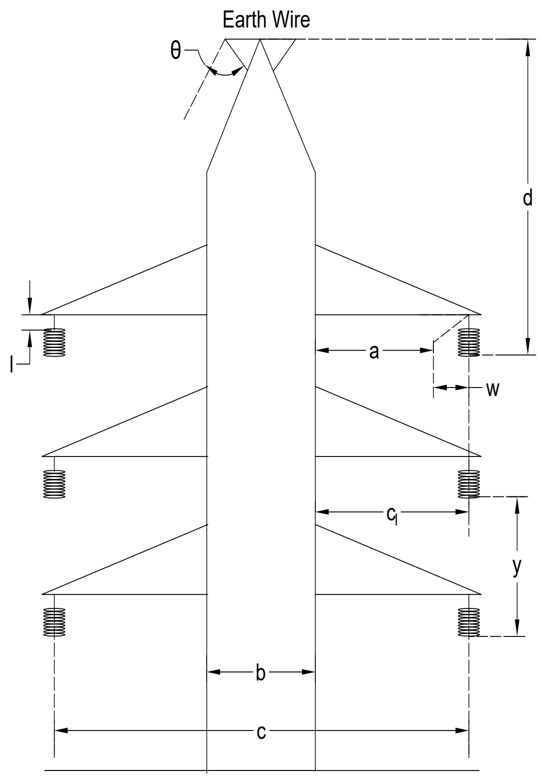

Figure 1: Transmission Tower of a Three Phase Double Circuit Transmission Line

5 Number of Insulator Disc Selection

For a 132 KV disc insulators the disc taken is a $(254\times154)mm^2$. The following parameters are assumed before conducting the tests:

$$\begin{aligned}
\text{Flashover Withstand Ratio}(FWR) &= 1.2 \\
\text{Non Standard Atmospheric Condition}(NAC) &= 1.1 \\
\text{Factor of safety}(FS) &= 1.2 \\
\text{Switching Surge Ratio}(SSR) &= 2.8 \\
\text{Switching Impulse Ratio}(SIR) &= 1.2 \\
\text{Earthing Factor} &= 0.8
\end{aligned}$$

5.1 Continuous Operating Voltage

- 1 min dry equivalent withstand test

$$\begin{aligned}
&= \textit{1 min dry withstand voltage(from table)} \times FWR \times NAC \times FS \qquad (13)\\
&= 265 * 1.15 * 1.1 * 1.2 \\
&= 402.27KV
\end{aligned}$$

According to the table, the number of discs required =7

- 1 min wet equivalent withstand test

$$\begin{aligned}
&= \textit{1 min wet withstand voltage(from table)} \times FWR \times NAC \times FS \qquad (14)\\
&= 230 * 1.15 * 1.1 * 1.2 \\
&= 349.14KV
\end{aligned}$$

According to the table, the number of discs required =9

5.2 Temporary Overvoltage Withstand test(V_{temp})

$$\begin{aligned}
&= \textit{EF} * \textit{maximum system voltage(L-L)*FWR*NAC*FS} \qquad (15)\\
&= 0.8 * \sqrt{2} * 145 * 1.15 * 1.1 * 1.2 \\
&= 249.026KV
\end{aligned}$$

According to the table, no of disc required=6

5.3 Lightning OverVoltage Withstand Test

$$\begin{aligned} &= Impulse\ Withstand(from\ table) * FWR * NAC * FS \\ &= 550 * 1.15 * 1.1 * 1.2 \\ &= 834.9KV \end{aligned} \tag{16}$$

According to the table, number of discs required=9.

5.4 Switching OverVoltage Withstand Test

$$\begin{aligned} &= Switching\ overvoltage * SIR * FWR * NAC * FS \\ or, &Maximum\ per\ phase\ peak\ voltage * SSR * SIR * FWR * NAC * FS \\ &= \frac{132}{\sqrt{3}} * 1.1 * \sqrt{2} * 2.8 * 1.2 * 1.15 * 1.1 * 1.2 \\ &= 604.6689KV \end{aligned} \tag{17}$$

According to the table, number of discs required=6.

Since the maximum number of insulators is 9 which will withstand all the overvoltage tests. Hence, the number of insulators required is 9.

6 Conductor Selection

6.1 Conductor Selection and Current Calculation

The line current is calculated as follows:

$$Line\ Current(I) = \frac{P_{transfer}}{\sqrt{3} * cos\phi * V_{L-L} * N_c * N_b} \tag{18}$$

where, N_b is the number of bundle in the given conductor which is taken as 1. Hence,

$$\begin{aligned} or, I &= \frac{133}{\sqrt{3} * 0.9 * 132 * 2 * 1} \\ &= 0.3231KA\ or\ 323.1A \end{aligned}$$

Comparing this value of the current with the current carrying capacity from the given ACSR conductor table, conductor "CAT" is selected. Then, it must meet the efficiency criteria which must be greater than 94% and the voltage regulation must be less than 12% and the corona inception voltage must be greater than the maximum system voltage.

6.1.1 Efficiency Criteria

Initially, the **CAT** conductor of the current carrying capacity at 65° is 323.1 A.
From the table,

$$\text{Total cross sectional area(A)} = 111.33\ mm^2$$
$$\text{Overall diameter(r)} = 13.50mm$$
$$\text{Resistance at } 20°C(R_{20}) = 0.3077\ \Omega/km$$

For 110 km,
The coefficient of Resistivity(α_{20})=0.004/$°C$
The resistance at 65$°C$ is given by:

$$\begin{aligned} R_f &= R_0(1 + \alpha_i(\theta_f - \theta_i)) \\ &= 0.3007(1 + 0.004(65 - 20)) \\ &= 0.354826\ \Omega/Km \\ &= 0.354826 * 110 \\ &= 39.03086\ \Omega \end{aligned} \tag{19}$$

We know the transmission efficiency is given by:

$$Efficiency(\eta) = 1 - \frac{P_{loss}}{P_{transfer}} \tag{20}$$

where,

- $P_{loss} = 3 \times I^2 \times R_{65} \times * N_c = 3 * 323.1^2 * 39.03086 * 2 = 24447434.260W = 24.474\ MW$
- $P_{transfer}$ = Power to be transferred=133 MW

Thus, Transmission efficiency is :

$$\begin{aligned} &= 1 - \frac{24.447}{133} \\ &= 0.8182\ or\ 81.618\% \end{aligned}$$

Since, the transmission efficiency is less than required efficiency , we increase the current rating of conductor used and repeat it until we got the desired efficiency. The iterative process was done with efficiencies corresponding to conductors shown below:
If the efficiency had not been greater than 94% up to the very end of the table, we would have increased the number of bundles in the conductor and calculated the current and started the process again.

Hence, we select the **GOAT** conductor moving forward.

6.1.2 GMD and GMR calculation

We know, for GOAT conductor:

Table 3: Efficiencies At Different Conductor Rating

Conductor	Ampacity(A)	$R_{65^\circ C}(\Omega)$	Loss(MW)	$\eta\%$
CAT	340	39.03086	24.44743426	81.618
HARE	360	35.47434	22.21976649	83.293
DOG	360	35.47434	22.21976649	83.293
HYENA	360	35.00706	21.92708021	83.513
LEOPARD	410	28.34832	17.75630077	86.649
COYOTE	420	39.3943	24.67507914	81.447
TIGER	420	28.58196	17.90264391	86.539
WOLF	470	23.72744	14.86195871	88.826
LYNX	520	20.45648	12.81315477	90.366
PANTHER	560	17.69174	11.08142763	91.668
LION	610	15.74474	9.861901483	92.585
BEAR	650	14.18714	8.886280561	93.319
GOAT	730	11.56518	7.243985343	94.553

- Total sectional area(A)=399.98 mm^2
- Overall diameter(d_c)=25.97 mm
- Overall radius(r)=12.985 mm

The calculation of GMD and GMR for a double circuit transmission line is as follows:

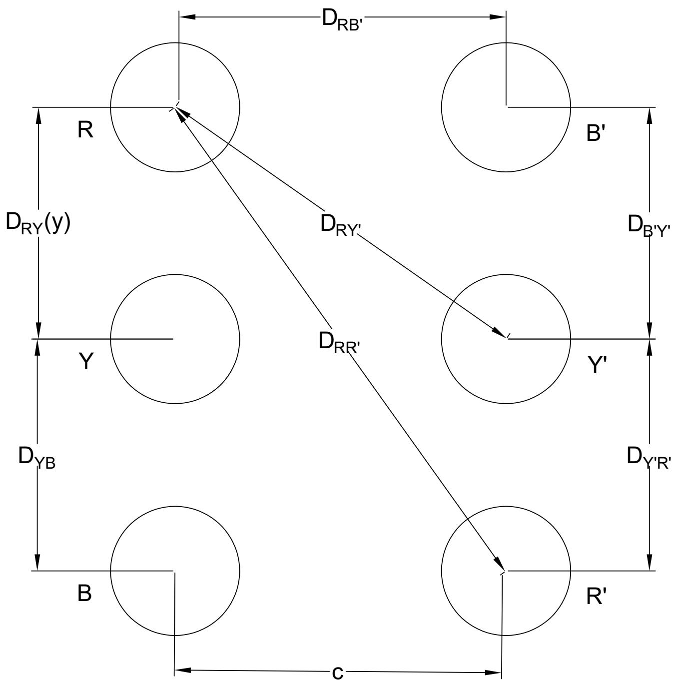

Figure 2: Three Phase Double Circuit Transmission Line

The vertical separation(y) and the horizontal separation between conductors(c) of each of the phases has been already been calculated above as y=3.6535m and c=8.3133m.

$$D_{RY} = D_{YB} = D_{Y'R'} = D_{B'Y'} = y = 3.6535m$$
$$D_{RB'} = D_{YY'} = D_{BR'} = c = 8.3133m$$
$$D_{RR'} = D_{BB'} = \sqrt{(2y)^2 + c^2} = 9.778m$$
$$D_{YR'} = D_{RY'} = D_{BY'} = D_{YB'} = \sqrt{y^2 + c^2} = 9.080m$$
$$D_{RB} = D_{R'B'} = 2y = 7.307m$$

GMD Calculation

The GMD of a three-phase double circuit line is given by:

$$GMD = \sqrt[3]{GMD_{RY} * GMD_{YB} * GMD_{BR}} \tag{21}$$

where,

$$GMD_{RY} = \sqrt[4]{D_{RY} * D_{RY'} * D_{R'Y} * D_{R'Y'}} = 5.7596m$$
$$GMD_{YB} = \sqrt[4]{D_{YB} * D_{YB'} * D_{Y'B} * D_{Y'B'}} = 5.7596m$$

$$GMD_{BR} = \sqrt[4]{D_{BR} * D_{BR'} * D_{B'R} * D_{B'R'}} = 7.7939m$$

From equation 21:

$$GMD = \sqrt[3]{5.7596 * 5.7596 * 7.7939} = 6.370m$$

GMR Calculation

We know:
GMR of self conductor$(r') = 0.7788r = 0.7788 * 0.012985m = 0.0101m$

The GMR in a three-phase double circuit line is given by:

$$GMR_L = \sqrt[3]{GMR_{R_L} * GMR_{Y_L} * GMR_{B_L}} \tag{22}$$

where,

$$GMR_{R_L} = \sqrt[4]{D_{RR} * D_{RR'} * D_{R'R} * D_{R'R'}} = \sqrt[4]{r' * D_{RR'} * D_{R'R} * r'} = 0.3142m$$
$$GMR_{Y_L} = \sqrt[4]{D_{YY} * D_{YY'} * D_{Y'Y} * D_{Y'Y'}} = \sqrt[4]{r' * D_{YY'} * D_{Y'Y} * r'} = 0.2897m$$
$$GMR_{B_L} = \sqrt[4]{D_{BB} * D_{BB'} * D_{B'B} * D_{B'B'}} = \sqrt[4]{r' * D_{BB'} * D_{B'B} * r'} = 0.3142m$$

Thus from equation 22:

$$GMR_L = \sqrt[3]{0.3142 * 0.2897 * 0.3142} = 0.3058m$$

To calculate GMR_C, $r' = r = 0.012985m$ and we repeat the same process again:

$$GMR_C = \sqrt[3]{GMR_{R_c} * GMR_{Y_c} * GMR_{B_c}} \tag{23}$$

where,

$$\begin{aligned} GMR_{R_c} &= \sqrt[4]{D_{RR} * D_{RR'} * D_{R'R} * D_{R'R'}} = \sqrt[4]{r * D_{RR'} * D_{R'R} * r} = 0.3563m \\ GMR_{Y_c} &= \sqrt[4]{D_{YY} * D_{YY'} * D_{Y'Y} * D_{Y'Y'}} = \sqrt[4]{r * D_{YY'} * D_{Y'Y} * r} = 0.3285m \\ GMR_{B_c} &= \sqrt[4]{D_{BB} * D_{BB'} * D_{B'B} * D_{B'B'}} = \sqrt[4]{r * D_{BB'} * D_{B'B} * r} = 0.3563m \end{aligned}$$

Thus from equation 23:

$$GMR_C = \sqrt[3]{0.3563 * 0.3285 * 0.3563} = 0.3467m$$

6.1.3 Inductance And Capacitance Calculation

The value of inductance can be calculated with the following formula:

$$Inductance(L) = 2 * 10^{-7} * ln\left(\frac{GMD}{GMR_L}\right) \tag{24}$$

The value of capacitance can be calculated with the following formula:

$$Capacitance(C) = 2\pi\epsilon_o \left(\frac{1}{ln\frac{GMD}{GMR_C}}\right) \tag{25}$$

From equation 24 and 25:

$$\begin{aligned} L &= 2 * 10^{-7} * ln\left(\frac{6.370}{0.3058}\right) = 6.072 * 10^{-7} H/phase\ m = 6.072 * 10^{-4} H/phase\ Km \\ C &= 2\pi\epsilon_o * \left(\frac{1}{ln\frac{6.370}{0.3467}}\right) = 1.910 * 10^{-11} F/phase\ m = 1.910 * 10^{-8} F/phase\ km \end{aligned}$$

The total inductance and capacitance is therefore:

- $L_{total} = L * 110 = 0.066792 H/phase$
- $C_{total} = C * 110 = 2.101 * 10^{-6} F/phase$

7 Voltage Regulation

7.1 Calculation Of ABCD parameters

The sending end voltage and current can be related to the receiving end voltage and current as:

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{26}$$

where,

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 + \frac{YZ}{2} & Z \\ Y\left(1 + \frac{YZ}{4}\right) & 1 + \frac{YZ}{2} \end{bmatrix}$$

The equivalent π model of a transmission line as shown below:

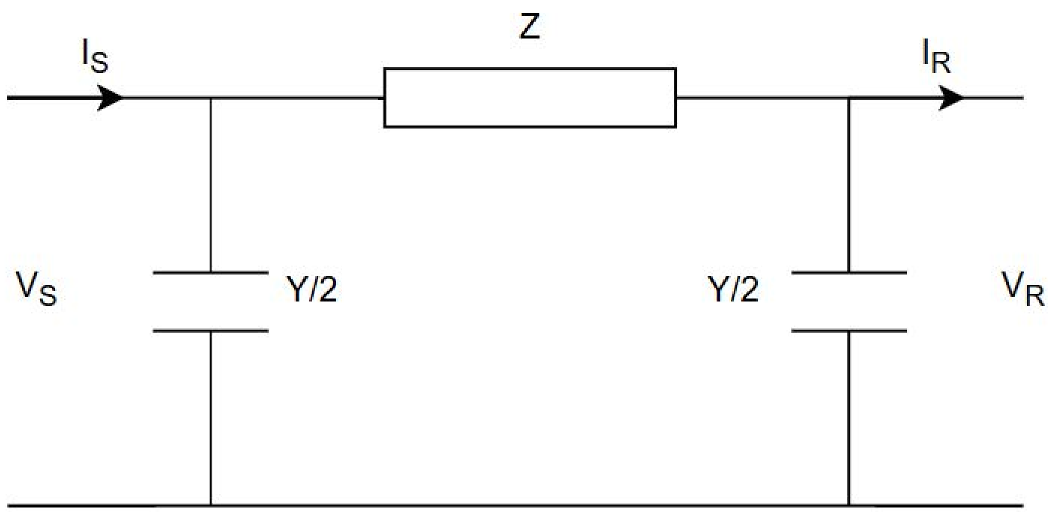

Figure 3: π model of a transmission line

We know,

$$\begin{aligned} Z &= R_{65} + jX_L \\ &= R_{65} + j(2\pi f L_{total}) \\ &= 11.56518 + j(2\pi \cdot 50 \cdot 0.066792) \\ &= 11.565 + 20.983j = 23.959\angle 61.13^\circ \end{aligned} \tag{27}$$

$$\begin{aligned} Y &= j\omega C_{total} \\ &= j2\pi f C_{total} \\ &= 2\pi \cdot 50 \cdot 2.101 \times 10^{-6} j \\ &= 6.600 \times 10^{-4} j \ \Omega^{-1} \end{aligned} \tag{28}$$

For the π model circuit:

$$
\begin{aligned}
A = D &= 1 + \frac{ZY}{2} = 1 + \frac{(11.565 + 20.983j)(6.600 * 10^{-4}j)}{2} = 0.9930\angle 0.220^\circ \\
C &= Y\left(1 + \frac{YZ}{4}\right) = 6.600 * 10^{-4}\left(1 + \frac{(11.565 + 20.983j)(6.600 * 10^{-4}j)}{4}\right) \\
&= 6.5771 * 10^{-4}\angle 90.10^\circ
\end{aligned}
$$

From equation 26:

$$
\begin{aligned}
V_S &= AV_R + BI_R = (0.9930\angle 0.220^\circ)V_R + (23.959\angle 61.13^\circ)I_R \\
I_S &= CV_R + DI_R = (6.5771 * 10^{-4}\angle 90.10^\circ)V_R + (0.9930\angle 0.220^\circ)I_R \\
V_{R(FL)} &= \frac{132}{\sqrt{3}}\angle 0^\circ = 76.210\angle 0^\circ\ KV \\
I_R &= 323.1\angle - cos^{-1}(0.9) = 323.1\angle(-25.84^\circ)\ A
\end{aligned}
$$

The full load Source Voltage from equation 26 is given by:

$$
\begin{aligned}
V_{S(FL)} &= (0.9930\angle 0.220^\circ) * (76.210\angle 0^\circ) + (23.959\angle 61.13^\circ) * 323.1\angle(-25.84^\circ) \\
&= 82.132\angle 3.324^\circ
\end{aligned}
$$

The negative sign in the current denotes that the line is operating at a lagging power factor.
At no load $I_R = 0$:

$$
\begin{aligned}
V_{R(NL)} &= \frac{V_{S(FL)}}{A} \\
&= \frac{82.132\angle 3.324^\circ}{(0.9930\angle 0.220^\circ)} \\
&= 82.71\angle 3.104\ KV
\end{aligned}
$$

The voltage regulation of the conductor is given by:

$$
\begin{aligned}
Voltage\ Regulation(V_R) &= \frac{|V_{R(NL)}| - |V_{R(FL)}|}{|V_{R(FL)}|} \times 100\% \qquad (29) \\
&= \frac{82.71 - 76.21}{76.21} \times 100\% \\
&= 8.52\%
\end{aligned}
$$

Since the voltage regulation is less than 12% and efficiency is greater than 94% both the transmission efficiency and voltage regulation criteria is satisfied.