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Design of Transmission Lines and Tower Structure at Different High Voltages to Transmit Power with Minimum Losses

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Abstract: ***When designing transmission lines, the basic data used in the design would be the power to be transmitted and the distance over which it is to be transmitted. After the transmission line designed to particular specifications, the construction and layout of the line start.Size of conductor, spacing of conductors, types of the poles or towers, span to be used, number of insulators per string, size of the ground wire, location of ground wire on towers, permissible tension in stringing the conductors, sags for different poles at equal or unequal height, grounding resistance, etc. In this paper, Analysis and Design of Transmission line considering multivoltage& multi circuit transmission of power has been carried out keeping in view to provide optimum electric supply and the efficient design of Tower Structure. The aim of this paper is to display the optimum design of the systems but because of the practical restrictions, this has been achieved through intuition, experience and repeated trials at different high voltages 132 Kv, 166Kv, 230Kv, maintaining the power loss and cost minimum.***

Keywords: Introduction , Selection of voltage for high voltage transmission line , line voltage of 166 kv and same size conductor , line voltage of 230 KV with smaller conductor ,Summarization of 230 kv line Results ,Conclusion

1. Introduction

The performance of the line can be determined by finding out the reactance, capacitance, etc. and solving the circuit for A,B,C and D constants of the line and then obtain the characteristics as shown in chapter 2, viz. the condition at the receiving end and the sending end under given conditions. By carefully studying the circle diagrams, the design of the line can be made by constructing the power circle diagram for the receiving end and the sending end under given conditions. By carefully studying the circle diagrams, the design of the line can be modified to obtain better performance under the given conditions or the special characteristics needed. The circle diagrams are very useful tools in the respect. Methods of improving the voltage regulation, reduction of losses and improvement in the power factor can also be devised by studying by the circle diagram.

Consider the following design problem

Design a transmission line to transmit three-phase 95,000 kw at 0.8 power factor lagging, over a distance of 180 km. the regulation of the line should be within 10% of the receiving end voltage. Efficiency 95% and corona loss not to exceed 0.6 kw/km.

Loading on the line = 85000 * 160 = 13.6 * 10^6KW km. from the table, the voltage required for this loading is 132 kV and above. From table as the length of the line is 160 km. the voltage of the line require would be 132 kV and above. It is, therefore desirable to choose a voltage from 132 kV, 166 kV or if necessary, 230 kV to obtain the required performance.

Selection of Voltage for High-Voltage Transmission Line

With increase in the power to be transmitted over long distances, use of high voltages for power transmission has been developed. However, a choice could be made out of standard voltages which are used in the country. The voltages have to be economical and depends on the cost of lines, cost of apparatus such as transformers, circuit breakers, insulators, etc.

The choice of voltages is also linked with the conductor size, the performance of the lines as expected within permissible percentage losses and the regulation of the lines or the receiving end voltage in relation to the sending end voltage, when transmitting the required power. The power to be transmitted and the distance of the transmission decide the voltage requirement for a certain extent.

The power to be transmitted and the distance over which it is to be transmitted together decide the voltage requirement to a certain extent. As a very rough preliminary guide, the following tables may be used.

Table 1.1

Line to line voltage kV	Line loading kW km
11	24 x 10^4
33	200 x 10^4
66	600 x10^4
110	11 x 10^7
132	20 x 10^7
166	35 x 10^7
230	90 x 10^7

Table 1.2

Line to line voltage kV	Length of line in km	
	Minimum	Maximum
66	40	120
110	50	140
132	50	160
166	80	180
230	100	300

For line voltage of 132 kV, the current at the receiving end,

$$Ir = \frac{85000}{\sqrt{3} * 132 * 0.9}$$
$$= 414 \,|-25.830°$$

From data sheet, the approximate equivalent spacing of the conductors for a 132 kV line is D_m = 6 m.

For high voltage lines, ACSR conductors will be used.

From data sheet, the conductor of nominal copper equivalent of 1.6125 cm^2 area gives a current carrying capacity of 505 A which is enough for the line under consideration. The nearest sizeof ACSR conductor chosen from table is, therefore 30/0.335 aluminium and 7/0.335 steel. The overall diameter is 2.347 cm. total number of strands is 37 and nominal copper equivalent area 1.613 cm^2.

Resistance of the line per km at 20^0 C = 0.1091Ω.

Resistance for 160 km line per phase = 17.456 Ω.

The receiving end voltage V_r per phase = 132/√3 kV = 76.4 kV, and is taken as the reference voltage phasor.
The equivalent spacing, D_m = 6m.
Self GMD for 37 strands wire = 0.768 R
Outer radius, $R = 2.347/2\ cm = 1.1735\ cm$
Self GMD $Ds = 0.768 * 1.1735 = 0.9\ cm$
Inductance per phase per meter = $2 * 10-7 * ln\left(\frac{Dm}{Ds}\right)$
Inductance per phase for 160 km line = $2 * 10-7 * 160 * 103 * ln\left(\frac{600}{0.9}\right)$
$= 320 * 10-6 * 2.3 * 2.8244 = 0.208\ H$
Reactance per phase, $X = 2\prod f\ L = 314 * 0.208 = 65.4\ \Omega$
Impedance per phase, $Z = 17.456 + j\,65.4 = 67.8 \llcorner 750$
The outer radius of the conductor, $R = 1.1735\ cm$
The ratio $Dm/R = 600/1.1735 = 511$
The capacitance per phase per meter = $1/(18 * 109 * ln\,511)$
The capacitance of 160 km line per phase
$$CN = 160 * 1000/(18 * 109 * 2.3 * 2.7084)$$
$$= 1.425 * 10-6\ F$$
Y per phase = $2\prod f\ CN\ 314 * 1.425 * 10-6$ ℧
$$Y = 0.000448 \,|90°\ ℧$$

To choose the final voltage and conductor size, it is necessary to calculate the regulation and to check whether it would be within the permissible limits. For this, it is necessary to find the constants of the line A,B,C and D.
$$ZY = 67.8 \,|75° * 0.000448 \,|90° = 0.0304|165°$$
$= 10^{-2} * 3.04\,(-0.9659 + j\,0.2588) = 10^{-2}\,(-2.94 + j\,0.787)$
$$ZY/2 = 10^{-3}(-1.47 + j\,0.3935)$$
$$ZY/6 = 10^{-2}(-0.49 + j\,0.1312)$$
$$Z^2Y^2 = 10^{-4} * 3.042 \llcorner 330$$
$$= 10^{-6} * 9.2\,(0.5660 - j\,0.5)$$
$$Z^2Y^2/120 = 10^{-6} * 0.766\,(0.8660 - j\,0.5)$$
$$= 10^{-6}\,(6.65 - j\,3.8)$$
$$A = D = 1 + ZY/2\ approx.$$
$$= 1 - 0.0147 + j\,0.003935 = 0.9853 + j\,0.003935$$
$$= 0.9853 \,|0.22°$$
$$B = Z\,(1 + ZY/6 + Z^2Y^2/120 + \ldots)$$
$$= (1 + ZY/6 + Z^2Y^2/120)$$
$$= 1 - 0.0049 + j\,0.001312 + 0.00000665 - j\,0.00000383$$
$$= 0.9951 + j\,0.002308 = 0.9951 \,|0.08°$$
Therefore,
$$B = 67.8 \,|750° * 0.9951 \,|0.080° = 67.5 \,|75.08°$$
$$C = Y\,(1 + ZY/6 + \ldots)$$
$$= 0.000448 \,|90°\,(1 - 0.0049 + j\,0.001312)$$
$$= 0.000448 \,|90° * 0.9951 \,|0.080° = 0.00045 \,|90.08°$$
$Vr\ per\ phase = 76.4 \,|0°\ kV$
$Ir = 414 \,|25.83°\ A$
To find out the sending end voltage and the regulation from the constants A, B, C and D.
$Vs = AVr + BIr$
$= 0.9553 \,|0.22° * 76400 \,|0° + 67.5 \,|75.08° * 414 \,|-25.83°$
$= 75150 \,|0.22° + 28600 \,|49.25°$
$= 75150 + j\,(75150 * 0.0038) + 28600\,(0.6541 + j\,0.7576)$
$= 93850 + j\,21936 = 96200 \,|13.2°\ V$
Thus, the sending end voltage is 96200 V per phase and the receiving end voltage per phase is 76400 V.
The voltage regulation = $(Vs - Vr)/Vr * 100\%$
$= (96200 - 76400)/76400 * 100\% = 25.9\%$
This is higher than permissible. Hence, we have to go in for higher voltage.

Summarising the results of 132 kV working,

Line voltage kV	Current in A	Spacing in m	Equivalent copper section cm^2	Current carrying capacity in A	Percentage regulation
132	484	6	1.0125	505	25.9

For line voltage 166 kV and conductor of same size,
Equivalent spacing, D_m = 8 m as obtained from data sheet.
V_m per phase = $\frac{166}{\sqrt{3}} = 95.5 \,|0°\ kV$
I_r per phase $= 85000/(\sqrt{3} * 166 * 0.90) = 329 \,|-25.83°\ A$
D_m = 0.9 cm since conductor size is same.
L per phase $= 2 * 10^{-7} * 160 * 102 * 2.3\ log\,(800/0.9)$
$$= 3.2 * 2.3 * 10^{-7} * 2.9494 = 0.217\ H$$
Reactance, X per phase = $314 * 0.217 = 68.3\ \Omega$
Resistance per phase = $17.456\ \Omega\ (as\ before)$
$$Z = 17.456 + j\,68.3 = 70.5|75.7°$$
$$\frac{Dm}{R} = \frac{800}{1.1735} = 682$$
$$CN = 1/(18 * 2.3 * 102\ log\ 682)\ F/m$$
C_N per phase = $(160 * 1000)/(18 * 102 * 2.3 * 2.8338) = 1.365 * 10-6\ F$
Y per phase = $314 * 1.365 * 10-6 = 0.000429 \,|90°$ ℧
$$ZY = 70.5 \,|75.7° * 0.000429 \,|90°$$
$$= 0.0302 \,|165.70 = 10^{-7}(-2.93 + j\,0.745)$$
$$ZY/2 = 10^{-2}(-1.465 + j\,0.3725)$$
$ZY/6 = 10^{-7}(-0.488 + j\,0.124)$ (for editing)
$$Z^2Y^2 = 10^{-4} * 3.022 \,|331.4°$$
$$= 9.51 * 10^{-4}(0.8813 - j\,0.4726)$$
$$Z^2Y^2/120 = 10^{-6} * 7.61\,(0.8813 - j\,0.4726)$$
$$= 10-6\,(6.7 - j\,3.6)$$
$$A = d = 1 + ZY/2 = 1 - 0.01465 + j\,0.003725$$
$$= 0.98535 + j\,0.003725$$

$$A = D = 0.9854\ |0.2^\circ$$
$$B = Z\,(1 + ZY/6 + Z^2Y^2/120 + \ldots)$$
$$= 1 + ZY/6 + Z^2Y^2/120$$
$$= 1 - 0.00488 + j\,0.00124 + 0.0000067 - j\,0.0000036$$
$$= 0.9951 + j\,0.000124 = 0.9951\ |0.06^\circ$$

Therefore,

$B = 70.5 \angle 75.7^\circ * 0.9951 \angle 0.06^\circ = 70 \angle 75.76^\circ$

$C = Y\,(1 + ZY/6 + Z^2Y^2/120 + \ldots)$

$= 0.00429 \angle 90^\circ * 0.9951 \angle 0.06^\circ = 0.000427 \angle 90.06$

V_r per phase $= 95000 \angle 0^\circ\, V$

$Ir = 329 \angle -25.83^\circ\, A$

Now,

$Vs = AVr + BIr$

$Vs = 0.9854 \angle 0.2^\circ * 95000 \angle 0^\circ + 70 \angle 75.76^\circ * 329 \angle -25.83^\circ$

$= 94100 \angle 0.2^\circ + 23000 \angle 49.93^\circ$

$= 94100\,(1 + j\,0.0035) + 23000\,(0.6428 + j\,0.7660)$

$= 108850 + j\,17979\, V$

$Vs = 109300 \angle -9.4^\circ\, V$

Voltage regulation $= (109900 - 95500)/95500 * 100\%$

$= 13800/95500 * 100\% = 14.5\%$

This regulation is also higher than the permissible one. It is, therefore, necessary to go in for a higher voltage.

Summarising the result for the 166 kV line:

Line voltage kV	Current In A	Spacing in m	Equivalent copper section of conductor cm^2	Current carrying capacity A	Percentage regulation
166	329	8	1.6125	505	14.5

We now try a line voltage of 230 kV and a smaller conductor.

Choosing a conductor of equivalent copper section 0.805 cm^2

Then diameter of conductor = 1.654 cm

Outer radius R = 0.827

ACSR conductor 30/0.236, 7/0.236,

Current carrying capacity = 300 A

Resistance per kilometre = 0.22Ω

V_r per phase $= 230/\sqrt{3} = 133\, kV$

$Ir = 85000/\,(\sqrt{3} * 230 * 0.90) = 237 \angle 25.83^\circ$

Resistance of the line per kilometre = 0.22Ω

Resistance of the line per phase $= 160 * 0.22 = 35.2\,\Omega$

The spacing of conductors $= Dm = 10.2\, m$

$D = 0.768, R = 0.768 * 0.827 = 0.635\, cm$

X per phase $= 314 * 2 * 160 * 103 * 10^{-7} * 2.3\, log\,(1020/0.635)$

$= 0.314 * 32 * 2.3 * 3.2055 = 74\Omega$

Z per phase $= 35.2 + j\,85 = 82 \angle 64.43^\circ$

$Dm/R = 1020/0.827 = 1232;\ log\,(Dm/R) = 3.0906$

Y per phase $= 314 * 160 * 10^{-6}/\,(18 * 2.3 * 3.0906) = 0.000394 \angle 90^\circ\, \mho$

$ZY = 82 \angle 64.430 * 0.000394 \angle 90^\circ = 0.0323 \angle 154.43^\circ = 10^{-2} * 3.23 * (-0.9031 + j\,0.4316)$

$= 10^{-2}\,(-2.92 + j\,1.395)$

$Z^2Y^2 = 10^{-4} * 3.232 \angle 308.86^\circ$

$= 10^{-4} * 12.3\,(0.6284 - j\,0.7786)$

$Z^2Y^2/120 = 10^{-6} * 10.25\,(0.6284 - j\,0.7786)$

$= 10^{-6}(6.44 - j\,7.98)$

$ZY/2 = 10^{-2}(1.46 + j\,0.6975)$

$ZY/6 = 10^{-6}\,(-0.487 + j\,0.2325)$

$A = D = 1 + ZY/2$

$= 1 - 0.0146 + j\,0.006975 = 0.9854 + j\,0.006975$

$= 0.9855 \angle 0.4^\circ$

$B = Z\,(1 + ZY/6 + Z^2Y^2/120 + \ldots)$

$= (1 + ZY/6 + Z^2Y^2/120 + \cdots) * (1 - 0.00487 + j\,0.002325 + 0.00000644 - j\,0.00000798)$

$= 0.99514 + j\,0.002317 = 0.9951 \angle 0.13^\circ$ (neglecting the last two terms)

$B = 82 \angle 64.43^\circ * 0.9951 \angle 0.13^\circ = 81.5 \angle 64.56^\circ$

$C = Y\,(1 + ZY/6 + Z^2Y^2/120 + \ldots)$

$= 0.000394 \angle 90^\circ * 0.9951 \angle 0.13^\circ$

$= 0.000392 \angle 90.13^\circ$

$Vs = AVr + BIr$

$= 0.9855 \angle 0.4^\circ * 13300 \angle 0^\circ + 81.5 \angle 64.56^\circ * 237 \angle -25.83^\circ$

$= 131000 \angle 0.4^0 + 19300 \angle 38.73^0$

$= 131000\,(1 + j\,0.0070) + 19300\,(0.7808 + j\,0.6120)$

$= 146100 + j\,12720$

$V_s = 147000 \angle 5^0$ V

Regulation = (147000 – 13000)/ 133000 * 100% = 10.5%

Thus, the regulation for a conductor of this size and line voltage 230 kV is within the permissible limit of 12.5%. The next step is to check corona loss and find whether it is within the limits prescribed.

With the conductor radius 0.827 cm, and spacing 10.2 m, the disruptive voltage, E_d is given by,

$E_d = 21.1 * 0.82 * 0.827 * 2.3 * log\,(1020/0.827)$ kV line to neutral = 101.5 kV

The ratio, $E/E_d = 133/101.5 = 1.31$

The ratio is less than 1.8

From the table, this value of E/E_d, the constant F = 0.2,

By Peterson's formula, the corona loss is given by,

$P_s = 21 * 10^{-8} * f * E^2 * F * 3/\,(log\, D/r)^2$ kW per km for a three phase line

Here, $P_d = 21 * 10^{-8} * 10 * 133^2 * 0.2 * 3/\, 3.0906^2 = 1.65$ kW per km

This line, therefore gives a corona loss more than the permissible loss of 0.6 kW per km. the conductors, therefore, is not suitable and a bigger conductor should be tried to ensure that the corona loss is within the prescribed limit.

Summarising the results of 230 kV line

Line voltage in kV	Current in A	Current carrying capacity in A	Equivalent copper section of conductor in cm^2	Spacing in m	Percentage regulation	Corona loss in kW per km
230	237	300	0.805	10.25	10.5	10165

It is seen that the voltage is suitable but the size of the conductor should be larger to reduce the corona loss. We choose a 37 stranded conductor of strand diameter 0.259 cm. the overall diameter is 1.814 cm (radius = 0.907).
Line voltage in 230 kV as before. We first check the corona loss and then work out the regulation again.

The disruptive voltage E_d = 21.1 * m * r * ln (D/r) kV
= 21.1 * 0.82 * 0.907 * 2.3 ln (1020/0.907)
= 21.1 * 0.82 * 0.907 * 2.3 * 3.0512 = 110 kV

Line to neutral voltage, E_{rms} = 133 kV
E/E_d = 133/110 = 1.21. This ratio is less than 1.8.
From the table in sec 3.5.1, the value of the constant in Peterson's formula, F = 0.08, and the corona loss is given by,
$P_s = 21 * 10^{-6} * 50 * 133^2 * 0.08 * 3/ 3.0512^2$ kW per km of three phase line.
P_s = 0.48 kW per km of the three phase line.

This is within the permissible limit of 0.6 kW per km of the three phase line. The size of the conductor is, therefore, suitable and should be selected.
Total corona loss for this line = 0.48 * 160 = 76.8 kW
With this conductor size, we now check the regulation.
We have 230 kV line voltage, ACSR conductor of diameter 1.814 cm (radius 0.907 cm), 30/0.259 aluminium conductor strands, 7/0.259 steel strands and equivalent copper section of 0.968 cm^2.
Resistance of the conductor per km = 0.1832 Ω
Current carrying capacity = 350 A
V_s per phase = 230/√3 = 133 kV
$I_s = 237 ∟-25.83^0$ A as before
Resistance for 160 km line = 160 * 0.1832 = 29.4 Ω
D_m = 10.2 m, D_s = 0.768 * R = 0.768 * 0.907 = 0.695 cm
Resistance per phase,
$X = 314 * 2 * 10^{-7} * 160 * 10^2 * 2.3 \log (1020/0.695) = 73.2$ Ω
Z per phase = 29.4 + j 73.2 = $79 ∟68.1^0$ Ω
R = 0.907 cm

D_m/R = 1020/0.907 = 1125; log 1125 = 3.0512
$Y = 314 * 160 * 10^{-6}/ (18 * 2.3\ 3.0512) = 0.000398 ∟90^0$ ℧
$ZY = 79 ∟68.1^0 * 0.000398 ∟90^0 = 0.0315 ∟158.1^0$
$= 10^{-8} * 3.15 (-0.9278 + j\ 0.9730)= 10^{-8} (-2.92 + j\ 1.175)$
$ZY/2 = 10^{-2} * (-1.46 + j\ 0.5875)$
$ZY/6 = 10^{-2} (-0.486 + j\ 0.196)$
$Z^2Y^2 = 10^{-4} * 3.15^2 ∟316.2^0 = 10^{-4} * 9.95 (0.7218 – j\ 0.6921)$
$Z^2Y^2/120 = 10^{-6} * 8.3 (0.7218 – j\ 0.6921) = 10^{-6} (5.99 – j\ 5.74)$
A = D = 1 + ZY/2 = 1 – 0.0146 + j 0.005875 = 0.9854 + j 0.005875 = $0.9855 ∟0.34^0$
$B = Z (1 + ZY/6 + Z^2Y^2/120 + …)$
$= 79 ∟68.1^0 (1 – 0.00486 + j\ 0.00196 + 0.00000599 – j\ 0.00000574)$
$= 79 (0.9951 + j\ 0.00195) = 79∟68.1^0 * 0.9951 ∟0.12^0 = 78.5 ∟68.22^0$
$C = Y (1 + ZY/6 + Z^2Y^2/120 + …)$
$= 0.000398∟90^0 * 0.9951 ∟0.12^0 = 0.000396 ∟90.12^0$
$V_s = A\ V_r + B\ I_r = 0.9855 ∟0.34^0 * 13000 ∟0^0 + 78.5∟68.22^0 * 237 ∟-25.83^0$
$= 131000 ∟0.34^0 + 18600 ∟42.39^0$
= 131000 (1 + j 0.005875) + 18600 (0.7386 + j 0.6741)
= 131000 + j 770 + 13710 + j 12510 = $145300 ∟5.23^0$ V
Regulation = (145300 – 133000)/ 133000 * 100% = 9.26 %

The voltage regulation is within the permissible limit of 12.5 %. Therefore, the size of the conductor and the voltage is suitable for the line.

Summarising the results of 230 kV lines with this conductor,

Line voltage in kV	Current in A	Current carrying capacity in A	Equivalent copper section of conductor cm^2	Spacing in m	Percentage regulation	Corona loss in kW per km
230	23	350	0.968	10.2	9.26	0.48

Summarising the results of all the alternatives considered,

Line voltage in kV	Current in A	Current carrying capacity in A	Equivalent copper section of conductor cm^2	Spacing in m	Percentage regulation	Corona loss in kW per km
132	414	505	1.6125	6	25.9	-
166	329	505	1.6125	8	14.5	-
230	237	300	0.805	10.2	10.5	1.165
230	237	350	0.968	10.2	9.26	0.48

The final choice of voltage and conductor size is thus made. To predict the efficiency of the transmission line, once the voltage and the conductor size have been decided and the receiving end conditions are given, the sending end conditions can be worked out, knowing the circuit constants.

In the case under study, the data are
$V_r = 133 ∟0^0$ kV
$V_s = 145.3 ∟5.23^0$ kV
$I_r = 237 ∟-25.83^0$ A
Corona = 76.8 kW
Z = = 29.4 + j 73.2 = $79 ∟68.1^0$
$Y = 0.000398 ∟90^0$
$A = D\ 0.9855 ∟0.34^0$
$B = 78.5 ∟68.22^0$
$C = 0.000396 ∟90.12^0$
$I_s = C\ V_r + D\ I_r$
$= 0.000396 ∟90.12^0 * 133000 ∟0^0 + 0.9855 ∟0.34^0 * 237 ∟-25.83^0$
$= 52.6 ∟90.12^0 + 233.5∟-25.49^0$
= 52.6 (-0.002 + j 1) + 233.5 (0.9027 – j 0.4303) = 209.8948 – j 47.4
$I_r = 215.5 ∟-12.73^0$
$\cos\varphi_A$ = power factor at the sending end = $\cos (5.23^0 + 12.73^0)$
$= \cos 17.96^0$ = 0.952 lagging.

Sending end power = 3 $V_s I_s \cos\varphi_A$
P_s = 3 * 145.3 * 215.5 * 0.952 kW = 89500 kW

Transmission line efficiency = 85000/ (89500 + 76.8) * 100% = 95%
The charging current of the line per phase = VY=133000 * 0.000398 = 53 A
Charging kVA per phase = 133 * 53 = 7050
Charging kVA per 100 km of the line = 7050/1.6 = 4400 kVA per phase (as the length of the line is 160 km)
The surge impedance loading of the line per phase = 2.5 * 133^2 = 44200 kW
12.5% of the surge impedance loading of the line = 12.5/100 * 44200 = 5525 kVA per phase
Thus, the charging kVA of the line per phase for 100 km is less than 12.5% of the surge impedance loading of the line per phase.

This is as per general requirement of the line per phase.

We use 16 insulators in suspension string, each insulator being of 25 cm disc diameter. If the capacitance between the insulator and the earth is taken as 0.125 times the capacitance between the units i.e. $C_p = 0.125\ C_0$ and then the voltage e_1, across the insulator nearest to the conductor is given by (Ref. 3.2),
e_1 = E 2sinh (1/2 √0.125) cosh (√0.125(16 – ½)) / sinh (16√0.125)

Where, E is the maximum conductor to earth voltage. From this, the ratio e_1/E and then the string efficiency E/(n e_1) can be found out.
e_1/E = 2 sinh (0.5 * 0.354) cosh (0.354 * 15.5)/ sinh (16 * 0.354)
= 2 sinh 0.177 cosh 5.49 / sinh 5.66 = 2 * 0.178 * 121 / 143.5 = 0.3 = 30%

And string efficiency = E/ (n e_1) = 1/(16 * 0.30) = 20.8 %

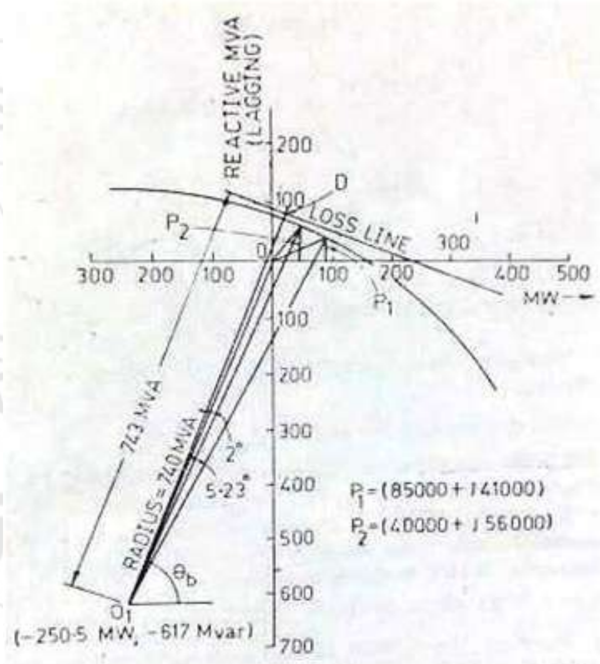
This must be increased. This can be done by shielding and grading the suspension type insulators. The voltage distribution along the insulators in the string can be improved by increasing the value of K where C = KCe. If K is made 16, C_n = 0.0625 C.

Capacitive grading is used to make the voltage across the unit nearest to the line as low as possible, because this unit has the maximum voltage distribution across it. Earth capacitance can be practically eliminated means of an antenna shield from the line conductor.
Therefore,
e_1/E = 2 sinh (0.5 √0.0625) cosh (√0.0625 (16 – ½)) / sinh (16 √0.0625)
= 2 sinh (0.5 * 0.25) cosh (0.25 * 15.5)= 2 * 0.1253 * 21.9/ 27.29 = 20%
And string efficiency = E/(n e_1) = 1/(16 * 0.2) = 31.5 %

If each insulator can stand 40000 V, the string of 16 insulators can stand 40000 * 100/ 0.20 = 200000 V. line to line voltage = √3 * 200 kV = 346 kV maximum while the line to line voltage in this case = √2 * 230 = 324 kV maximum. The number of insulators chosen would therefore be suitable.

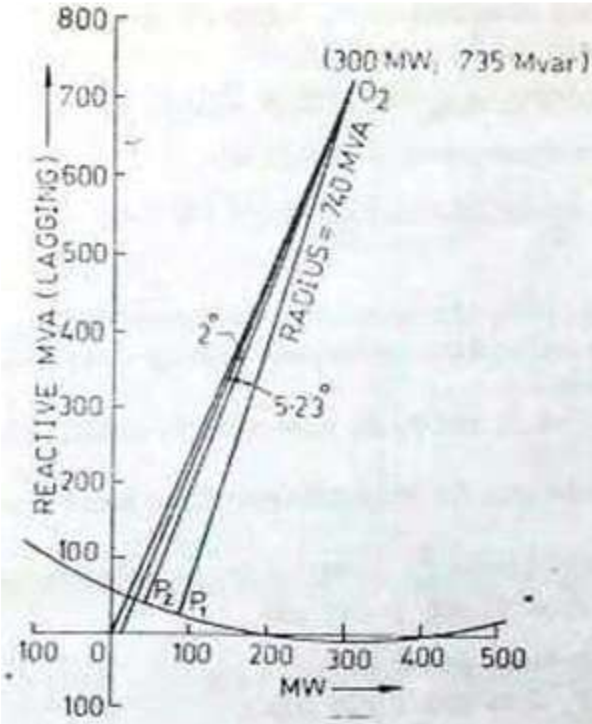
For the receiving end power circle diagram, the coordinates of the centre of the diagram are,
-0.003 V_r^2 a/b cos ($\theta_b – \theta_a$) kW and
-0.003 V_t^2 a/b sin ($\theta_b – \theta_a$) kvar
i.e. -0.003 * 133^2 * $10^6/10^2$ * 0.9855/78.5 * cos (68.22^0 – 0.34^0)
= -666 cos (67.88^0) = -666 * 0.3762 = -250.5 MW
And -0.003 * 133^2 * $10^6/10^2$ * 0.9855/78.5 * sin (68.22^0 – 0.34^0)
= -666 * 0.9265 = -617 Mvar
And the radius of the receiving end power circle diagram is,
= 0.003 $V_b V_a$/b kVA = 0.003 * 133 * 145.3 10^4/(78.5 * 10^2)MVA = 740 MVA
(-250.5 MW; -617 Mvar; radius 740 MVA)

The receiving end power circle diagram is shown in the figure.



The coordinates of the centre of the sending end power circle diagram are,
0.003 Va^2 d/b cos ($\theta_b – \theta_a$) kW and
0.003 V_s^2 d/b sin ($\theta_b – \theta_a$) kvar
i.e. 0.003 * 145.3^2 * $10^6/10^2$ * 0.9855/78.5 cos (68.22^0 – 0.34^0)
= 300MW
And 0.003 * 145.3^2 * 0.9855/78.5 sin (68.22^0 - 0.34^0) * $10^6/10^2$ = 735 Mvar
The radius of the sending end power circle diagram is,
0.003 $V_a V_r$/b kVA = 0.003 * 133 *145.3 10^6/(78.5 * 10^2) = 740 MVA
(300 MW; 735 Mvar; radius 740 MVA)

The sending end power circle diagram is showing in figure,



Lagging reactive kVA is taken as positive.
At P_1 power = (89500 +
At P_2 power = (41500 +

The construction of loss line is shown in fig. 3.6. Draw the line O_1D of length given by,
$O_1D = 0.003\ V_a^2\ d/b \cos(\theta_b - \theta_a) + 0.003\ V_r^2\ a/b \cos(\theta_b - \theta_a)$
$= 300 + 250.5/(2 \cos 68.22^0) = 350.5/0.7422 = 743$ MVA

Draw a line perpendicular to O_1D. The distance between the line and the points on the power circle diagram represent the loss at those points of operation. The scale of the loss measurement is 2 $\cos\theta_b$ (or 0.7422) times the scale of the power circle diagram.

The scale of the main diagram in 1 unit = 100 MVA
Loss line scale in 1 unit = 100 * 0.422 = 74.22 MVA

The point P_1 on the diagram represents full load condition at the receiving end, viz. load of 85000 kW at a power factor of 0.9 lagging. The perpendicular distance from P_1 to the loss line represents the loss during transmission. Measured on the loss scale, this is 4500 kW.

The load condition when 40000 kW is supplied at the receiving end is represented by the point P_2.
At point $P_2 \cos\theta_r = \cos 54.5^0 = 0.58$ lagging.
Loss in transmission = 1500 kW
Transmission efficiency at 40000 kW load = 40000/(40000 + 1500) * 100% = 96%

This is from the receiving end power circle diagram drawn for the receiving end and the sending end voltage conditions as calculated in the design problem.

The points P_1 and P_2 are shown on the sending end power circle diagram also (fig. 3.9)

The following conditions for the sending end and receiving end operations are as follows:
At full load point P_1, power at the receiving end P_r is
$P_r = 85000 + j\ 41100$

And that at sending end P_s is
$P_s = 89500 + j\ 29100$

Receiving end power factor = 0.9 lagging
Sending end power factor = 0.952 lagging
At a load of 40000 kW at the receiving end at point P_s power
$P_r = 40000 + j\ 56000$

Power at sending end
$P_s = 41500 + j\ 41500$

Receiving end power factor = 0.58 lagging
Sending end power factor = 0.707 lagging

From the power circle diagram, the maximum theoretical load on the line is 489.5 MW. However, under this condition, the angle between the sending end and receiving end voltages will be so large that stability will be lost. The losses will also be excessive and the loading completely impractical. Another way to find the maximum permissible loading is by finding out the surge impedance of the line and

The surge impedance of the line = $\sqrt{L/C}$
The impedance Z = 29.4 + j 73.2
Y = 0.000398 ∟90^0
$L = 73.2/314 = 0.233 = 233 * 10^{-3}$ H
$C = 0.000398/314 = 0.00000127 = 127 * 10^{-8}$ F
$L/C = 233 * 10^5 / 127 = 18.35 * 10^4$
Surge impedance = $\sqrt{L/C}$ = 100 * 4.28 = 123 MW
Surge impedance loading = (line kV)^2/428 = 230^2/428 = 123 MW
When the receiving end load is 85000 kW and the power factor is 0.9 lagging.
The relative end kVA = 41000
When the power factor is improved to 0.93 lagging, $\varphi = 21.5^0$, the relative kVA = 41000
The relative kVA that must be added at the receiving end by the installation of synchronous compensator would be given by the difference of the two reactive kVA at the receiving end.
i.e. 41000 – 34000 = 7100 kVA

Therefore, the capacity of the synchronous compensator required at the receiving end for improving the power factor is given by 7100 kVA. This can also be represented on the power circle diagram.

Design domain in mechanical features for the transmission line details of the line is as follows:

Voltage	Current	Current carrying capacity	Equivalent copper section	Equivalent spacing
230 kV	237 A	350 A	0.968 cm^2	10.2 m

Conductor used in ACSR 30/0.259 AI strands ,7/0.259 steel strands overall diameter 1.814cm,weight per kilometre 728 kg breaking strength of conductor is 6883kg.

Thermal liner coefficient of expansion for aluminium per degree centigrade at C at 20°C=23 x 10^- 4 and of steel =11.5 x 10^-8 degree. C at 20°C. The modulus of ASCR a may be taken as 11.5×10^-2 per °C. At 20°C.
The modulus of elasticity E for ASCR conductor may be taken as 0.85x 10^8 kg/ cm^2.
If a typical span is chosen 200 m long find the sag and the length of the conductor in span.(a)Under maximum loading ice covering of the projected area of the conductor,(b) the vertical sag (c)if the maximum permissible sag is 3.5m and occurs at 0°c with 1cm thick ice and no wind, at maximum temperature 60°c and no wind find:

1) Length of conductor at maximum sag.
2) Upstretched length at zero degree centigrade with Ice and no wind.
3) Upstretched length at 60 degree centigrade with no wind
4) The condition under which the sag will be maximum.

Tofind the maximum permissible tension and maximum loading and to find the factor of safety,choose the height of the tower in preliminary dimension, designEarth Wires for the line and suggest location of the tower. Find the side of the earth wire under heavy loading condition the tension in the earth wire and the factor of safety.

Loading in the line parameter is calculated as following:
Area of ice coating or covering =pi/4{(1.814+2)^2* 1.814^2} = 8.875cm^2
Volume of ice covering per metre length of 8.875 x10^{-4} x 1m^2
Density of ice=915kg m-1
Weight of ice metre length of conductor=8.87x10^{-4} 1x915kg=0.81kg
Load due to wind pressure on projected area of conductor=(1.814+2)/100x39 kg m $^{-1}$
Thus the load of ice of line is due to:
Weight of the conductor =0.728 kg/m
Weight of the ice= 0.810kg/m
Wind pressure=1.490 kg/m
The vertical loading v= 0.728+0.810=1.5 kg/m
The total load W=√1.538+√1.49=2.14 kg/m
The breaking load=6883 kg. The permissible tension is assumed to be 3500kg.

(a)W=2.14 mg/m
T = 3500 kg , Span = 2 l- 215 m
Or half span l = 107.5 m
H = T – w^2 l^2/ 2T = 3500 – (2.14^2 * 107.5^2) / 2 * 3500
= 3500 – 7.1 = 3493 kg

The total sag,
D = H/W {cosh Wl/H - 1}
= 3493/2.14 {cosh (2.14 * 107.5) / 3493 - 1 }
=1630(cosh 0.066 - 1) = 1630 (1.0023 - 1)
=3.75 m

Half-lengthof conductor = H/Wsinh (Wl/H)= 1630 sinh 0.066
=1630 * 0.066 = 107.6 m
Length of the conductor L = 215.2m

(b) The vertical sag is,
d * 1.538/2.14 = 3.75 * 1538/2.14 = 2.7m

(c) d =3.5 m; and 2l = 215m
The length of the conductor L is given by,
L = 2l (1 + 2d^2/ 3l^2- 1 4d^2/49l^2+ ……)
= 215 {1 + 2/3 (3.5)^2/(107.5)^2 - …..)
=215 (1+ 0.000705)
L = 215.1515 m

Unscratched length at 0^0 Cwith ice and no wind:
La$_a$ = L – vl^2/AEd (1 + 5/3 * d^2/l^2 + ……………)
Area of conductor = ∏/4 (30* 0.259^2 + 7 * 0.259^2)
=∏/4 *37 * 0.259^2 = 1.95 cm^2
E = 0.85 * 10^6 kg/cm^2
V =1.538 kg/m; l = 107.5 m
Vl^2/AEd = (1.538 * 107.5^2)/(0.85 * 10^4 * 1.95 *3.5) = 0.332
Therefore,
Vl^2/AEd (1 + 5/3 * d^2/l^2 + ……………) = 0.332 (1 + 0.005 25) = 0.333 666.
La$_a$ = 215.1515 – 0.333 66 * 0.728/1.538
= 215.1515 – 0.158 = 214.935 m.

Comparing the unstretched lengths in 2 and 3, it is seen that the unstretched length of the line with ice and no wind load condition is shorter than at the other condition. Hence, the maximum sag will occur under the loading condition with ice and no wind.

(d) Taking unstretched length at 0^{0}c, find L with maximum load on the line, viz, weight of conductor, weight of ice and wind pressure.
L = La$_a$ + Wl^2/AEd (1 + 5d^2/ 3l^2 + 4d^2/9l^2 + ……)
=214.817 84 + 0.333 66 * 2.14/1.538=214.817 84 + 0.464 = 215.281 84 m
Assuming maximum tension to be 3000kg,
L = 2l {1 – 1/6 (wl/T)^2 + …….}
= 215 {1 + 1/6 ((2.14*107.5)/3000)^2 + …….}
=215(1.000988)=215.212 m

This length is less than 215.28184 m
Therefore, the tension used is less than 3000 kg.
Assuming a tension of 2500 kg,
L = 215 {1 + 1/6 ((2.14*107.5)/2500)^2 + …….}
= 215 + 0.308 = 215.308 m

This is slightly less than 215.281 84 m. The tension of the line thus lies between 2500 and 2700 kg, and is assumed to be 2600 kg.

Breaking strength of the conductor =6883 k.
Therefore the factor of safety = 6883/2600=2.64

(e) Preliminary design of tower:
For a 230kv line, a steel tower is chosen. The spacing of the conductors is horizontal, the equivalent spacing being 10.2 m or horizontal distance between adjacent conductors is 8m. If the normal span is as used in the calculation, viz.215 m and the minimum height of the conductor at midspan is taken as 6m + 0.01m per kV, i.e. 6 + 2.3 or 6.3 m and if the supports are assumed at the same label, the sag is as already calculated

For the 230kv line 16 suspension type insulators are used each of 25 cm diameter, disc spacing 14.6 cm with respect to each other. Length of the insulator string = 16 / 14.6 cm =233.6 cm or about 2.35 m.

For horizontal spacing, two ground or earth wires are used on top of the tower. Minimum space between each wire and conductor for insulation level of 18000 kV = 7m. It can be increased to, say about 9m. For best protection the angle formed by a line through the earth wire and the outer phase wire and the vertical should not exceed 30^0.

The minimum vertical height of earth wire above the level of the conductor = 9 cos 30^0 = 9 * 0.866 = 7.794. It is rounded off to 8 m, so that the angle will be less than 30^0.

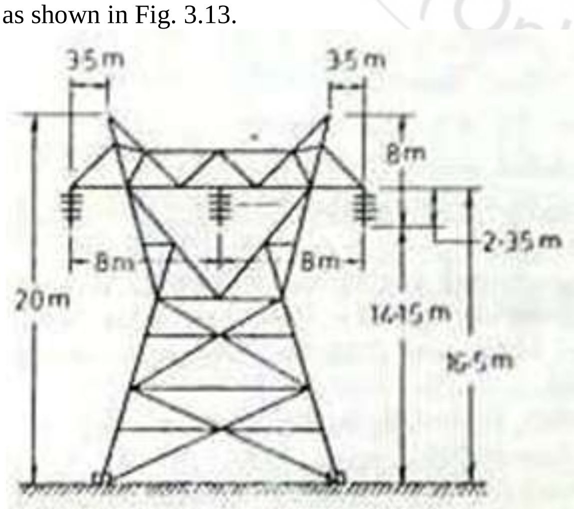
For insulation level of 18000 kV, the tower footing ground impedance should be about 10 Ω.

The overall dimension of the tower required can be now calculated approximately with the data.

Minimum height of conductor at mid span = 8.3 m.
Sag = 3.5 m.

Insulator string length = 2.35 m
Minimum height up to cross arm = 8.3 + 3.5 + 2.35 = 14.15 m
Height of earth wire location above conductor = 8.0 m
Overall height of tower = 14.15 + 8.00 – 2.35 = 19.80 = 20 m
Distance of earth wire from the end of the tower each way = 3.5 m
The distance is less than 8 tan 30^0 or 5.775 m thus the earth wires are between the protection zone of 30^0 angle with vertical.
Distance of earth wire from conductor = $\sqrt{(8^2 + 3.5^2)}$ = 8.72 m
The tower is shown in fig.3.10.

(f) Earth wires
For this design with horizontal spacing of conductors on the tower, two earth wires are provided on the tower and located as shown in Fig. 3.13.



The size may be 1.1 cm diameter copper weld w = 0.607 kg/m. to find loading conditions similar to the main line conductors, ice and wind loading at the same rate should be considered.

Area of ice = ∏/4 $((1.1 + 2)^2 – 1.1^2)$ = 6.6 cm^2
Volume of ice = 6.6 * 10^{-4} * 1 m^2
Weight of ice per metre of wire = 6.6 * 10^{-4} * 915 kg = 0.604 kg.
Vertical weight, v = 0.607 + 0.604 = 1.211 kg/m
Wind pressure = (2 * 1 + 1.11 * 1) * 39/100 = 1.21 kg/m
Total weight per metre W = $\sqrt{(1.211^2 + 1.21^2)}$ =1.71 kg/m
Assuming the same sag as allowed for the transmission line conductors, viz. 3.5 m.

$$T = Wl (1/2 + l/d + 7/6 – d/l + \ldots)$$
$$T = 1.71 * 107.5 (1/2 * 107.5/3.5 + 7/6 * 3.5/107.5 + \ldots)$$
$$= 184 (15.35 + 0.038) = 2900 \text{ kg.}$$

The factor of safety = Breaking strength/T
= 6309/2900 = 2.18

2. Conclusion

In this paper 230 KV Transmission Line and Steel tower is Considered in from design point of view at first Voltage regulation in sending end and Receiving end of the Transmission Line is measured . Then sending end power receiving end power, sending end power factor and receiving end power is calculated. Then Sag, Breaking Strength and Factor of Safety of conductors and Earth wires are measured as well as String efficiency of each insulator is measured .minimum height upto cross arm of the tower, distance of earth wire from the conductor is measured which gives one overall overview of the Design of the transmission line and Tower

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Author Profile

Mr. Deepak Bhattacharjee has done his BSC Hons from Calcutta University in the year 1980, has done his BEE From Jadavpur University in year in the year 1984, M. Tech from Calcutta university in the year 1988. Has 18 years of industrial experience, and current teaching at Siliguri Institute of technology and has 14 years of Academic Experience . currently living in Subhas Pally Siliguri . Received award in the organization India Foils Ltd for best planning and designing of Splitting Machine

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