DESIGN OF 200 MW, 160 KM TRANSMISSION LINE

Most Economical Voltage Selection:

The most economical voltage is given by the following empirical formula:

Economical Voltage (V_{eco}) = $5.5 * \sqrt{(\frac{L}{1.6} + \frac{P*1000}{COS\emptyset*N_C*150})}$

Where,

Lt = length of transmission line = 160 Km

P = Power to be transmitted = 200 MW

$\cos\phi$ = Power factor = 0.95

Nc = number of circuit

Then, using the above formula the voltage for respective number of circuit is shown below:

Standard Voltage levels are:
66 KV
132 KV
220 KV
400 KV
500 KV
700 KV
750 KV

For Nc = 1 (Single Circuit)

$V_{eco} = 5.5 * \sqrt{(\frac{160}{1.6} + \frac{200*1000}{COS\emptyset*1*150})}$

= 213.81 KV

Nearest Standard Voltage will be = 220KV

For Nc = 2 (Double Circuit)

$V_{eco} = 5.5 * \sqrt{(\frac{160}{1.6} + \frac{200*1000}{COS\emptyset*2*150})}$

= 155.98 KV

Nearest Standard Voltage will be = 132KV

The MF Limit for the 160KM Line will be 2.25 from the standard table

Checking Technical Criteria

Surge Impedance Loading:

For Single Circuit line:

Zc = 400 ohms Veco = 220KV

SIL = $\frac{V^2}{Z_C}$

= 121MW

Multiplying Factor:

MF = $\frac{P}{SIL}$

= 1.65

MF < MF Limit

Line Length(Km)	**Mf**$_{Limit}$
80	2.75
160	2.25
240	1.75
320	1.35
480	1.0
640	0.75

For Double Circuit line:

Zc = 200 ohms   Veco = 132KV

SIL = $\frac{V^2}{Z_C}$

= 87.12MW

Multiplying Factor:

MF = $\frac{P}{SIL}$

= 2.34

MF > MF Limit

Thus, Criteria for Single circuit is fulfilled. Therefore we choose to use the Single Circuit Line.

Voltage Level for given Power Transmission	= 220 KV
Number of Circuit	= 1
Power Factor ($COS\emptyset$)	= 0.95
Length of Transmission Line (L)	= 160 Km

Calculation of Insulation Discs:

For all the calculations of number of insulator discs, we considered following value of different factor:

FOWR= Flashover withstand ratio =1.15

NACF= Non atmospheric condition factor = 1.1

FS= Factor of safety = 1.2

EF= Earthing factor = 0.8

Switching to impulse ratio = 1.2

I. Number of Insulator Discs Required to withstand Continuous operating voltage:

a) Voltage Level for dry condition = Equivalent dry 1 min. voltage*FOWR*NACF * FS

Where,

Equivalent dry 1 min voltage is taken from standard table = 435 KV

Equivalent Voltage Level = 435 * 1.15 * 1.1 *1.2= 660.33 kV

From Standard Table number of discs required to withstand above equivalent voltage level = 12

b) Voltage Level for wet condition = Equivalent wet 1 min. voltage*FOWR*NACF * FS

Where,

Equivalent dry 1 min voltage is taken from standard table = 395 KV

Equivalent Voltage Level = 395 * 1.15 * 1.1 *1.2= 599.61 kV

From Standard Table number of discs required to withstand above equivalent voltage level =16

II. Number of Insulator Discs Required for the temporary O/V :

Temporary O/V = Earth Factor (EF) * Maximum system voltage

= 0.88* (220* 1.1)

= 212.96 KV

Equivalent Voltage (V_{eq}) = Temporary O/V *√2 * FOWR *NACF * FS

Equivalent Voltage (V_{eq}) = 212.96* √2 *1.15 * 1.1 *1.2

= 457.17 KV

Since, In this case we have to see the worst case scenario i.e. in the wet condition .Thus, from standard table number of insulator discs required to withstand above equivalent voltage = 12

III. Number of Insulator Discs required for switching over voltage:

Voltage Level = switching o/v * Switching to impulse ratio * FOWR *NACF* FS

Where,

Switching to impulse ratio (SIR) = 1.15

SSR = Switching Surge Ratio =2.8 (For 220kV)

Switching O/V = ($\sqrt{2}$ / $\sqrt{3}$)*242*SSR

So Switching O/V = 553.25 KV

Voltage Level = 553.25*1.15*1.15*1.1*1.2

= 965.8 KV

From Standard Table number of discs required to withstand the above voltage level = 11

IV. Number of Insulator Discs required for over voltage due to Lightning:

Equivalent Impulse FOV = Impulse withstand (BIL) * FOWR* NACF * FS

From standard table Equivalent voltage level i.e. BIL for the given system voltage =900 KV

Voltage Level = 900* FOWR *NACF* FS

= 900*1.15*1.1*1.2

= 1366 kV

From Standard Table number of discs required to withstand the above voltage level = 16.

SN	*Voltage Level Description*	*Voltage Level*	*Number of Discs*
I)	*Continuous voltage* *a) Continuous operating Voltage in Dry condition*	*660.33 KV*	*12*
		59.61 KV	*16*
II)	*b) Continuous operating Voltage in Wet condition*	*457.17 KV*	*12*
III)		*965.8 KV*	*11*
IV)		*1366.2 KV*	*16*

	Temporary O/V appearing across the insulator *Switching Over voltage* *O/V due to lightning*		

Hence from above table the required number of insulator discs to withstand all types voltage level in all condition for given system voltage = 16

Required Number of Insulator Discs =16

Air Clearance and Tower Specification:

The things for taking the parameters of air clearance for single circuit tower configuration are:

a = Minimum distance from a line conductor to any Earthed object and is given by the following relation.

a= $\left(V * \frac{\sqrt{2}}{\sqrt{3}}\right) * 1.1 + 30\ cms$ where, V = Transmission Voltage

After calculating the value of 'a' we can find the other Air Clearance parameters as follows:-

- Maximum swing angle $= \emptyset_{max} = 45°$
- Shield angle $= \emptyset_{sh} = 45°$
- String Length (l) = $asec\emptyset$.
- Tower width (b) = 1.5a.
- Cross Arm length (CL) =$a(1 + tan\emptyset)$.
- Distance of the earth wire form the Conductor (d) = $\sqrt{3}(CL + \frac{b}{2})$
- Vertical distance between two adjacent conductor (y) = $\frac{(l+a)}{\sqrt{(1-(\frac{x}{y})^2(\frac{l+a}{2a})^2}}$

  where 0.25<x/y<0.33

Air clearance from earthed object (a)	= 2.28 m
String Length (l)	= 3.224 m
Tower Width (b)	= 3.42 m
Cross Arm Length (CL)	= 4.56 m
Vertical distance between two adjacent line conductor (y)	= 5.7731 m
Horizontal distance between two adjacent line conductors	=12.54m
Height of Earth wire from top cross arm (d)	= 10.85 m

Conductor Selection

Continuous Current Carrying Capability:

P = 200 MW, Nc = 1, VL = 220 kV, Cosφ = 0.95
Line current is calculated as:

Line current (IL) = $\frac{P}{\sqrt{3}*V*COS\emptyset*Nc} = \frac{200*10^3}{\sqrt{3}*220*0.95*1} = 552.48$

Comparing the Value of the Current with the Current capacity form the given standard ACSR conductor table, the Conductor "KUNDAH" with current capacity 566 Amperes is selected.

I. Transmission efficiency Criteria

For Kundah Conductor:
Resistance at 20°C(R20) = 0.07311 Ώ/Km
Coefficient of Resistivity (α20) =0.004 /0C (For Aluminum)
So Resistance at 65°C(R65) = R20 (1 +α (65-20))
= 0.07311(1+0.004*45)
= 0.086270 Ώ/Km
Total Resistance of the line for 160 Km = Ώ
∴Total Power Loss (PL) = 3* I^2*R65 * Nc *L
= 3*552.48*0.0*1*160
= 12.636 MW
∴η = $1 - \frac{Pl}{P}$ = 0.9368 = 93.68 %

This efficiency is <94%. So this conductor cannot be used. To get the higher Efficiency we proceed in the same way and calculate efficiency for another Conductors

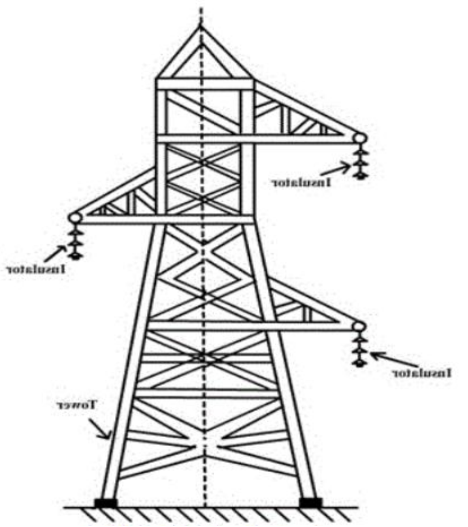
Table 1 Efficiency Table

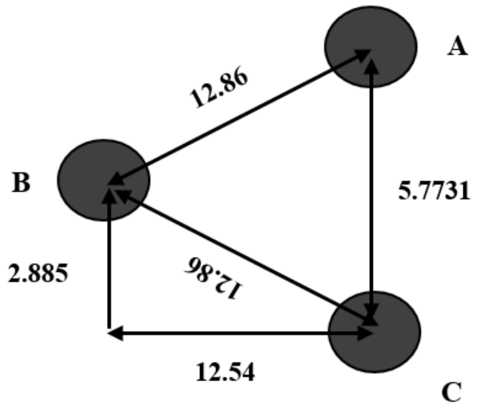
Conductors	Resistance(20°C)	Resistance(65°C)	Efficiency (%)
Sheep	0.07730	0.091214	94.023
Zebra	0.06868	0.081042	94.063
Moose	0.05595	0.066021	95.163
Deer	0.06786	0.080075	94.134
Elk	0.06110	0.072098	94.710

From the above conductors lets select, Conductor 'SHEEP' for the further criteria.

II. Voltage Regulation Criteria

The SHEEP conductor has 37 strands (30 Aluminum strands and 7 steel strands).
Diameter of conductor (D) =27.93mm
Radius of the conductor(R) =13.965mm
GMR for inductance (r’) =0.768R =0.778 * 13.965 =10.72mm = 1.086 cm
GMR for capacitance (r) = R = 13.965 mm. = 1.3965 cm





Vertical distance between two conductors (y) = 5.77 m = Dac
Horizontal distance between two conductors = 12.54 m
Applying Pythagoras theorem,

Dab = $\sqrt{(\frac{Dac}{2} + 12.54^2)}$ = 12.86 m

Now,

GMD = $\sqrt[3]{(Dab * Dbc * Dac)}$ = $\sqrt[3]{(12.86 * 12.86 * 5.77)}$ = 9.846 m

Inductance per unit length (L) = $2 * 10^{-7} * \ln\left(\frac{GMD}{GMRl}\right)$ H/m

= 1.3618*10^{-6} H/m = 1.3618*10^{-3} H/Km

Capacitance per unit length(C) = $\frac{2\pi\varepsilon}{\ln\left(\frac{GMD}{GMRc}\right)}$ F/m

= 8.4735*10^{-12} F/m = 8.4735*10^{-9} F/Km

Total Inductance of Whole length = 0.21838 H

Total Capacitance of Whole length = 1.35665 uF =0.000001F

Impedance of the Line (Z) = R + j2*pi*f*L

= 14.59 +j68.4514

Susceptance of the Line(Y) = j*2*pi*C

= j0.0004

III. A, B, C, D Parameters Calculation

Using Pi – model,

A = $1 + \frac{ZY}{2}$ = 0.9854 + j0.00031

B = Z = 14.5942 + j68.581

C = $Y(1 + \frac{ZY}{4})$ = -0.000 + j0.0004

D = A = 0.9854 + j0.00031

Ir = $I(cos\emptyset - jsin\emptyset)$ = 552.48<-18.19

Sending End Voltage (Vs) = A*Vr +B*Ir
= (0.9854 + j0.00031)*(220/√3) + (14.5942 + j68.581)*(552.48√-18.19 *e-03)
=1.4464e+02 + j3.3875
= 144.6423 KV

Now Voltage Regulation = $\frac{(|Vs|/A - |Vr|)}{|Vr|}$ = 15.64 %

Voltage regulation > 11% so this conductor cannot be used. To get lower voltage regulation we proceed in same way and calculate the voltage regulation for other conductors.

Conductors	Voltage Regulation (%)
Zebra	14.917
Moose	13.751
Deer	14.798
Elk	14.183

Finally we cannot get the conductor for which voltage regulation less than 11 % (voltage regulation criterion) for a single conductor for the given system voltage i.e.220 KV. So to obtain Voltage Regulation criterion we go for Bundle conductor.

Design with Bundle (2) Conductor

Current (I) = 552.48

I/2 = 276.4

Comparing this value of the current with the current carrying capacity from the given standard ASCR conductor table, Conductor "OTTER" is selected.

For Otter conductor, From ASCR conductor table,

Resistance at 20^0C (R_{20}) = 0.3434 Ώ/Km

Coefficient of Resistivity (α_{20}) =0.004

So Resistance at 65^0C (R_{65}) = R_{20} (1 + α_{20}(65-20))

= 0.3434 (1+.004*45)

= 0.4052 Ώ/Km

I. Transmission Efficiency Criterion

Power loss = I^2*R*L*6

= $(276.4)^2$*0.4052 *160*6

= 29 MW

Transmission Efficiency (ή) = 200 / (200+29)

= 0.873

= 87.3%

Transmission Efficiency < 94 % so this conductor cannot be used .To get higher efficiency we proceed in same way and calculate efficiency.

Finally we got the conductor "Bear" which has efficiency greater than 94 %.

II.Voltage Regulation Criteria

For Conductor Bear,

This conductor has 37 strands 30 Aluminum strands and 7 steel strands.

GMR for inductance (GMR_l) = $\sqrt[4]{(0.7788 * r * d^2)}$ where d, is the distance between the bundled Conductor which 10 to 12 times the diameter of the conductor

GMR for inductance (GMR_l) = $\sqrt[4]{(0.7788 * 11.725 * (10 * 23.45)^2)}$ = 46.27mm = 0.046275 m

GMR for Capacitance (GMRc) = $\sqrt{(r * d)}$ = $\sqrt{(11.725 * 10 * 23.45)}$ = 52.43 mm = 0.052436 m

Inductance per unit length (L) = $2 * 10^{-7} * \ln\left(\frac{GMD}{GMRl}\right)$ H/m

= $1.0712*10^{-6}$ H/m = $1.0712*10^{-3}$ H/Km

Capacitance per unit length(C) = $\frac{2\pi\varepsilon}{\ln\left(\frac{GMD}{GMRc}\right)}$ F/m

= $1.0622*10^{-11}$ F/m = $1.0622*10^{-8}$ F/Km

Total Inductance of Whole length = 0.171524 H

Total Capacitance of Whole length = 1.6999 uF =0.000002F

Impedance of the Line (Z) = (R/2) + j2*pi*f*L

= 10.5728 +j53.884

Susceptance of the Line(Y) = j*2*pi*C

= j0.0005

III.A, B, C, D Parameters Calculation

A = $1 + \frac{ZY}{2}$ = 0.9856 + j0.0028

B = Z = 10.572 + j53.884

C = $Y(1 + \frac{ZY}{4})$ = -0.000 + j0.0005

D = A = 0.9856 + j0.0028

Ir = $I(cos\emptyset - jsin\emptyset)$ = 552.48<-18.19

Sending End Voltage (Vs) = A*Vr +B*Ir

= (0.9854 + j0.0028)*(220/√3) + (10.572 + j53.884)*(552.48√-18.19 *e-03)

=1.4003e+02 + j2.6818e+01

= 140.0274 KV

Now Voltage Regulation = $\frac{(|Vs|/A - |Vr|)}{|Vr|}$ = 11.85%

Voltage regulation > 11% so this conductor cannot be used. To get lower voltage regulation we proceed in same way and calculate the voltage regulation for other conductors.

For Conductor Sheep

This conductor has 37 strands 30 Aluminum strands and 7 steel strands.

GMR for inductance (GMR_l) = $\sqrt[4]{(0.7788 * r * d^2)}$ where d, is the distance between the bundled Conductor which 10 to 12 times the diameter of the conductor

GMR for inductance (GMR_l) = $\sqrt[4]{(0.7788 * 11.725 * (10 * 23.45)^2)}$ = 55.11mm = 0.055115 m

GMR for Capacitance (GMRc) = $\sqrt{(r * d)}$ = $\sqrt{(11.725 * 10 * 23.45)}$ = 62.45 mm = 0.06245 m

Inductance per unit length (L) = $2 * 10^{-7} * \ln\left(\frac{GMD}{GMRl}\right)$ H/m

= 1.0297*10^{-6} H/m = 1.0297*10^{-3} H/Km

Capacitance per unit length(C) = $\frac{2\pi\varepsilon}{\ln\left(\frac{GMD}{GMRc}\right)}$ F/m

= 1.0989*10^{-11} F/m = 1.098*10^{-8} F/Km

Total Inductance of Whole length = 0.165930H

Total Capacitance of Whole length = 1.758 uF =0.000002F

Impedance of the Line (Z) = (R/2) + j2*pi*f*L

= 7.2971 +j52.12

Susceptance of the Line(Y) = j*2*pi*C

= 5.52*10^-4 <90 = j0.0006

A, B, C, D Parameters Calculation

A = $1 + \frac{ZY}{2}$ = 0.9856 + j0.0020

B = Z = 7.2971 + j52.1268

C = $Y(1 + \frac{ZY}{4})$ = -0.000 + j0.0005

D = A = 0.9856 + j0.0020

Ir = $I(cos\emptyset - jsin\emptyset)$ = 552.48<-18.19

Sending End Voltage (Vs) = A*Vr +B*Ir

= (0.9854 + j0.0020)*(220/√3) + (7.2971 + j52.12)*(552.48√-18.19 *e-03)

=1.3800e+02 + j2.6357e+01

= 138.0037 KV

Now Voltage Regulation = $\frac{(|Vs|/A - |Vr|)}{|Vr|}$ = 10.2365%

Voltage regulation <11% so this conductor can be used. Voltage regulation Criteria has also been fulfilled.

Corona Inception Voltage

For Sheep conductor,

Maximum system voltage = 220 * 1.1 = 242kV (rms) Corona inception voltage (Vci) = √3 $*$ Air dielectric strength * GMRC * m * δ * ln ($/GMRc$)

Where,
Air dielectric strength = 21.21 kV/ cm (rms)
GMRc = 6.245 cm
GMD = 984.6 cm
m = Roughness factor = 0.9
δ = Relative density of air = 0.95

$\therefore$Vci= $\sqrt{3} * 21.21 * 6.254 * 0.9 * 0.95 * \ln \frac{(984.6)}{6.254}$ = 287.66 KV

Since Vci> Maximum system voltage (242.2 kV), there is no corona effect on BEER conductor. So, Corona Inception Voltage criterion is satisfied and all the technical criteria is met by the Conductor.

Hence the five best bundled conductors which satisfy all the criteria are:

1. Sheep
2. Deer
3. Zebra
4. Elk
5. Moose

Tension Calculation For different Conductors

1. Toughest condition -T1 tension and Sag is minimum (Dmin). - Wt. of conductor (w1)
2. Normal Operating Condition (Stringing Condition) – T2 tension and S2 sag - Wt. of conductor (w2)
3. Easiest condition – T3 tension and Sag is maximum (Dmax). - Wt. of conductor (w3)

Let Wc = weight of conductor per unit length
Ww = weight per unit length due to wind
Wice = weight per unit length due to ice

∴ Weight during toughest condition = W1 = $\sqrt{(Wc + Wice)^{2} + Ww^{2}}$

Calculation of Tension @ toughest condition (T1)

T1≤ $UTS\ FS$

Where, UTS = Ultimate Tensile Strength of the conductor
FS = Factor of safety = 2

Calculation of Tension at Normal condition (T2)

T2 is given by stringing equation

$$T_2^2(T_2 + K_1) - K_2 = 0$$

Where,

$$K_1 = -T_1 + \propto (\theta_2 - \theta_1)A \in + \frac{(W_1^2 L^2)}{24T_1^2}$$

k2 = $\frac{(W_2^2 L^2)}{24} A \in$

∊= Modulus of Elasticity
α= Coefficient of linear expansion
A = Cross-section area of conductor
θ2 = Temperature at normal condition = 270C
θ1 = Temperature at toughest condition = 00C
w1 = per unit length conductor weight @ toughest condition
w2 = per unit length conductor weight @ stringing condition

Calculation of Tension @ Easiest condition (T3)

T3 is given by stringing equation

$$T_3^2(T_3 + K_1') - K_2' = 0$$

Where,

$$K_1' = -T_2 + \propto (\theta_3 - \theta_2)A \in + \frac{(W_1^2 L^2)}{24T_2^2}$$

k2’ = $\frac{(W_2^2 L^2)}{24} A \in$

θ3 = Temperature @ easiest condition = 650C

Four Different conductors below conductor Sheep in ASCR conductor table is chosen. Hence Tension calculation will be done for conductor "Sheep, Deer, Zebra, Elk, and Moose" with Span length 250 m, 275 m, 300 m, 325 m, and 350 m. Tensions for Toughest, Stringing and Easiest condition are calculated and tabulated below.

Sample Calculation

For **Conductor Sheep (250 m span)**

Area of conductor (A) = 462.60 mm2

Coefficient of linear expansion (α) = 17.73*10-6 / 0C

Modulus of Elasticity (ε) = 0.789*10^6 kg/cm2

Ultimate Tensile Strength (UTS) = 15910 kg

Wt. of conductor per unit length (wc) = 1726 kg/km

Wind Pressure (wp) = 100 kg/m2

Conductor diameter (d) = 27.93 mm

Thickness of ice (t) = 10 mm = 0.01 m ∴

Wt due to wind (Ww) per km = (wp*1000)*(d*2/3) kg/km

= 100*1000*27.93*10-3*2/3

= 1862kg/km

Wt due to ice loading (Wi) = π t (d+t) ρice *1000 kg/km

= π * 0.01 (0.02793+0.01) * 950 *1000

= 1132.02 kg/km

∴Wt. @ toughest condition (w1) = $\sqrt{(Wc + Wice)^2 + Ww^2}$

= 3411.063 kg/km ∴

Wt. @ Stringing Condition (w2) = Wc = 1726 kg/km ∴

Wt. @ Easiest Condition (w3) = Wc = 1726 kg/ km

Temperature @ Toughest condition (ɵ1) = 0℃

Temperature @ Normal Condition (ɵ2) = 27℃

Temperature @ Easiest Condition (ɵ3) = 65℃

Calculation of T1

T1 = UTS/ FS = 15910 2 = 7595kg

Calculation of T2

$$K_1 = -T_1 + \propto (\theta_2 - \theta_1) A \in + \frac{(W_1^2 L^2)}{24 T_1^2}$$

= -3939.80

k2 = $\frac{(W_2^2 L^2)}{24} A \in$

= 28244293719.56

From stringing equation,

$T_2^2(T_2 + K_1) - K_2 = 0$

Solving the above equation by putting the value of k1 and k2 we get

$\boldsymbol{T_2}$ **= 5048.133 Kg**

<u>Calculation of T_3</u>

$K_1{}' = -T_2 + \propto (\theta_3 - \theta_2)A \in + \frac{(W_1^2 L^2)}{24T_2^2}$

= 1733.52

k2' = $\frac{(W_2^2 L^2)}{24} A \in$

= 28244293719.56

T3 is given by stringing equation

$T_3^2(T_3 + K_1{}') - K_2{}' = 0$

$\boldsymbol{T_3}$ **= 2563.71 Kg**

Table 2 Calculation of Weight @ Toughest Condition

S.NO	Conductor	Wc	Ww	W1	W2	T1(Kg)
1	Sheep	1726	1862	3411.06	1726	7595
2	Deer	1977	1992.66	3742.18	1977	9115
3	Zebra	1623	19.08	3368.16	1623	6658
4	Elk	2196	2100	4025.70	2196	10120
5	Moose	1998	2118	3874	1998	7175

Table 3 Calculation of T3

S.no	Conductor	Span	K1	K2=K2_	T2	K1_	T3
1	Sheep	0.250	-3939.80	2.824*e10	5048.13	1733.53	2563.17
		0.275	-3538.20	3.417*e10	4939.12	2985.34	2496.79
		0.300	-3098.35	4.067*e10	4836.83	4406.02	2437.79
		0.325	-2620.26	4.773*e10	4742.52	5999.24	2385.90
		0.350	-2103.92	5.535*e10	4656.74	7766.71	2340.35

S.no	Conductor	Span	K1	K2=K2_	T2	K1_	T3
2	Deer	0.250	-5333.00	4.260*e10	6379.74	70.312	3469.31
		0.275	-4888.22	5.155*e10	6220.46	1372.90	3315.80
		0.300	-4465.65	6.134*e10	6109.33	2599.90	3240.90
		0.325	-4006.34	7.199*e10	6003.80	3972.97	3173.98

	0.350	-3510.28	8.350*e10	5905.20	5495.14	3114.31

S.no	Conductor	Span	K1	K2=K2_	T2	K1_	T3
3	Zebra	0.250	-2844.01	2.284*e10	4162.56	3760.03	1992.81
		0.275	-2377.88	2.764*e10	4057.24	5419.23	1938.35
		0.300	-1867.37	3.289*e10	3962.57	7304.88	1891.90
		0.325	-1312.46	3.861*e10	3878.79	9417.67	1851.03
		0.350	-713.16	4.477*e10	3805.40	11756.04	1816.38

S.no	Conductor	Span	K1	K2=K2_	T2	K1_	T3
4	Elk	0.250	-5988.65	5.824*e10	7133.28	-161.94	3931.01
		0.275	-5587.31	7.047*e10	7018.13	914.99	3846.98
		0.300	-5147.73	8.387*e10	6906.18	2127.97	3770.72
		0.325	-4669.94	9.843*e10	6799.16	3481.00	3701.83
		0.350	-4153.92	11.41*e10	6698.26	4976.98	3639.80

S.no	Conductor	Span	K1	K2=K2_	T2	K1_	T3
5	Moose	0.250	-3756.39	4.263*e10	5283.56	3216.86	2687.16
		0.275	-3248.21	5.158*e10	5174.66	4826.17	2630.17
		0.300	-2691.63	6.139*e10	5075.10	6644.02	2579.84
		0.325	-2086.64	7.204*e10	4985.44	8670.64	2535.60
		0.350	-1433.27	8.355*e10	4905.56	10906.18	2496.86

Sag and Tower Height Calculation

The maximum sag between two towers is given by
We have the relation,

Maximum sag (D_{max}) = (W L^2)/ (8*T_3);

Where, W = weight of conductor.

L = length of span.

T_3 = tension at easiest condition.

Minimum ground clearance = hg = $\frac{(Vsmax-33)}{13}$+ 17 ft

Height of lower conductor (H_1) = hg+ D_{max}

Height of middle conductor (H_2) = H1+y/2

Height of top most conductor (H3) = H1+y

Total height of tower (H_t) = H3+y+d

Sample calculation:

For sheep, W = 1726 kg/km.

L = 0.25 Km.

T_3 =2563.17 Kg.

Using the above equation, D_{max} = 5.260m.

Let the minimum ground clearance (hg) = 10.08m.

Height of lower conductor (H_1) = hg+ D_{max} =15.34m.

Height of middle conductor (H_2) = H1+y/2 = 18.22m.

Height of top most conductor (H3) = H1+y = 21.11m.

Total height of tower (H_t) = H3+y+d = 31.96m.

Similarly, the maximum sag, H1, H2, H3 and the total height of the tower are calculated and presented in the table below:

Table 4 Sag and Height of Tower

S.no	Conductor	Span(Km)	H1(m)	H2(m)	H3(m)	Ht(m)
1	Sheep	0.250	15.34	18.22	21.11	31.96
		0.275	16.61	19.50	22.38	33.23
		0.300	18.04	20.93	23.82	34.67
		0.325	19.63	22.51	25.40	36.25
		0.350	21.37	24.26	27.14	37.99
2	Deer	0.250	14.53	17.42	20.30	31.15
		0.275	15.71	18.60	21.49	32.34
		0.300	16.94	19.83	22.71	33.56
		0.325	18.30	21.19	24.07	34.92
		0.350	19.80	22.68	25.57	36.42
		0.250	14.53	17.42	20.30	31.15

3	Zebra	0.250	16.44	19.33	22.21	33.06
		0.275	17.99	20.88	23.77	34.62
		0.300	19.73	22.61	25.50	36.35
		0.325	21.65	24.54	27.43	38.28
		0.350	23.76	26.65	29.53	40.38
4	Elk	0.250	14.44	17.33	20.21	31.06
		0.275	15.47	18.36	21.25	32.10
		0.300	16.63	19.52	22.40	33.25
		0.325	17.91	20.80	23.68	34.53
		0.350	19.32	22.20	25.09	35.94
5	Moose	0.250	15.89	18.77	21.66	32.51
		0.275	17.26	20.14	23.03	33.88
		0.300	18.79	21.68	24.56	35.41
		0.325	20.48	23.37	26.25	37.10
		0.350	22.33	25.22	28.10	38.95

Design of 220KV Tower in AutoCAD Electrical