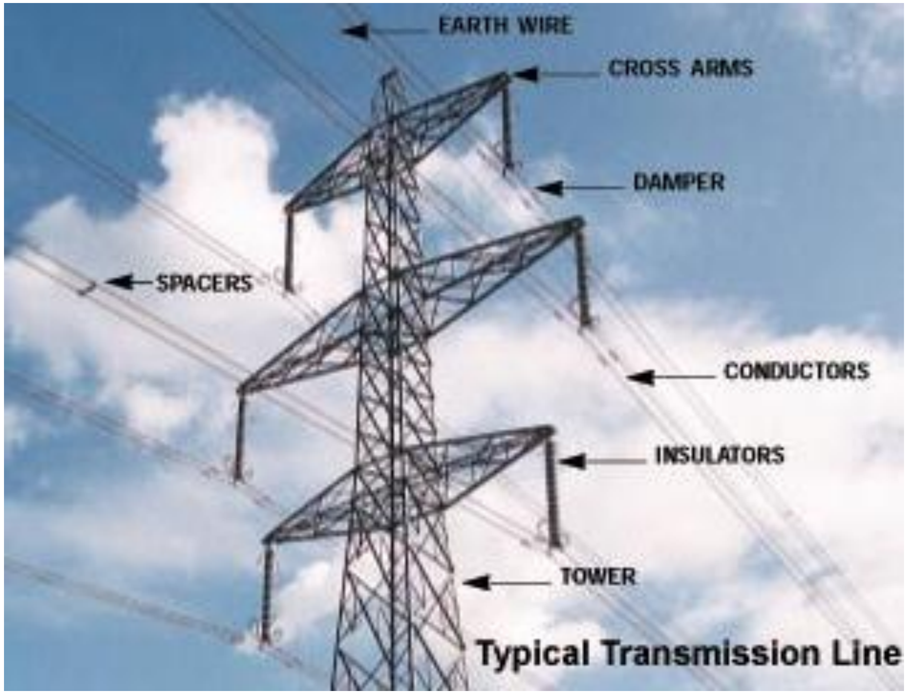
TRANSMISSION LINE

Gul Waqas Shahid

Component of Transmission Line

- Conductor
- Earth wire
- Insulator
- Transmission Tower
- Wave trap and other hardware(Clamp, Spacer, Vibration dampers, connectors etc.



Design Methodology

- Gather preliminary line design data and available climatic data
- Select reliability level in terms of return period of design
- Calculate climatic loading on components
- Calculate loads corresponding to security requirements (failure containment)
- Calculate loads related to safety during construction and maintenance
- Select appropriate correction factors, if applicable, to the design components such as use factor, strength factors related to numbers of components, strength coordination, quality control, and the characteristic strength.
- Design the components for the above loads and strength.

Reliability Levels

- Reliability Level ≥1(One)
- Higher the reliability level means higher safety factor and ultimately more cost.

Reliability Levels	1	2	3
T, Return period of climatic design loads, in years	50	150	300

Selection of Transmission Voltage

- **Standard Voltage - 66,110,132, 220, 400 KV**
  - **Tolerances** - ±10% up to 220 KV & ±5% for 400 KV

- **Selection Criterion of Economic Voltage –**
  - Quantum of power to be evacuated
  - Length of line
  - Voltage regulation
  - Power loss in Transmission
  - Initial and operating cost
  - Present and future voltage in neighborhood

Economic Voltage of Transmission of Power –

$$E = 5.5\sqrt{\frac{L}{1.6} + \frac{KVA}{150}}$$

E = Transmission voltage (KV) (L-L).
L = Distance of transmission line in KM
KVA=Power to be transferred

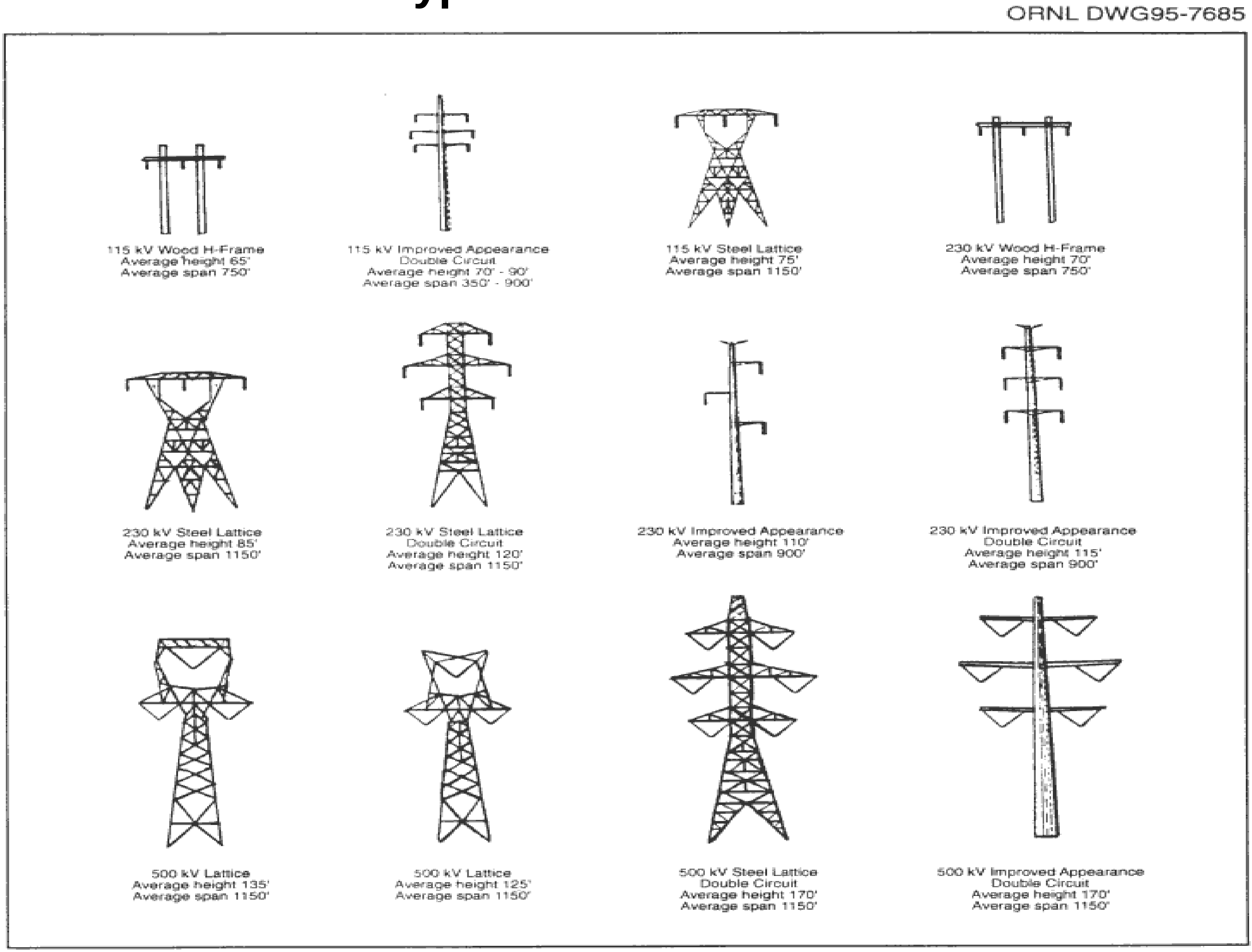
Table-1 shows the economic voltage level for efficient transmission.

Power Transfer Requirement (MW)	Distance (km)	Economic Voltage Level (KV)
3500	500	765
500	400	400
120	150	220
80	50	132

Types of Towers

- **Type A Tower** (Tangent Tower with suspension string)
  - Used on straight runs and up to 2° line diversion
- **Type B Tower** (Small Angle Tower with tension string)
  - Used for line deviation from 2° to 15°
- **Type C Tower** (Medium Angle Tower with tension string).
  - Used for line deviation from 15° to 30°.
- **Type D Tower** (Large angle tower with tension string)
  - Used for line deviation from 30° to 60°
- **Type E Tower** (Dead End Tower with tension string)
  - Used for line termination & starting
- **Special tower-**
  - **Suspension Tower** (Span ≈ 1000 m)
    - Used for River crossing, Mountain crossing etc.
  - **Transposition Tower**
    - Used for transposition of tower

Different Types of Towers



Selection of Tower Structure

- Single circuit Tower/ double circuit Tower
- Length of the insulator assembly
- Minimum clearances to be maintained between ground conductors, and between conductors and tower
- Location of ground wire/wires with respect to the outermost conductor
- Mid-span clearance required from considerations of the dynamic behavior of conductors and lightning protection of the line
- Minimum clearance of the lowest conductor above ground level

Tower Design

- Tower height
- Base width
- Top damper width
- Cross arms length

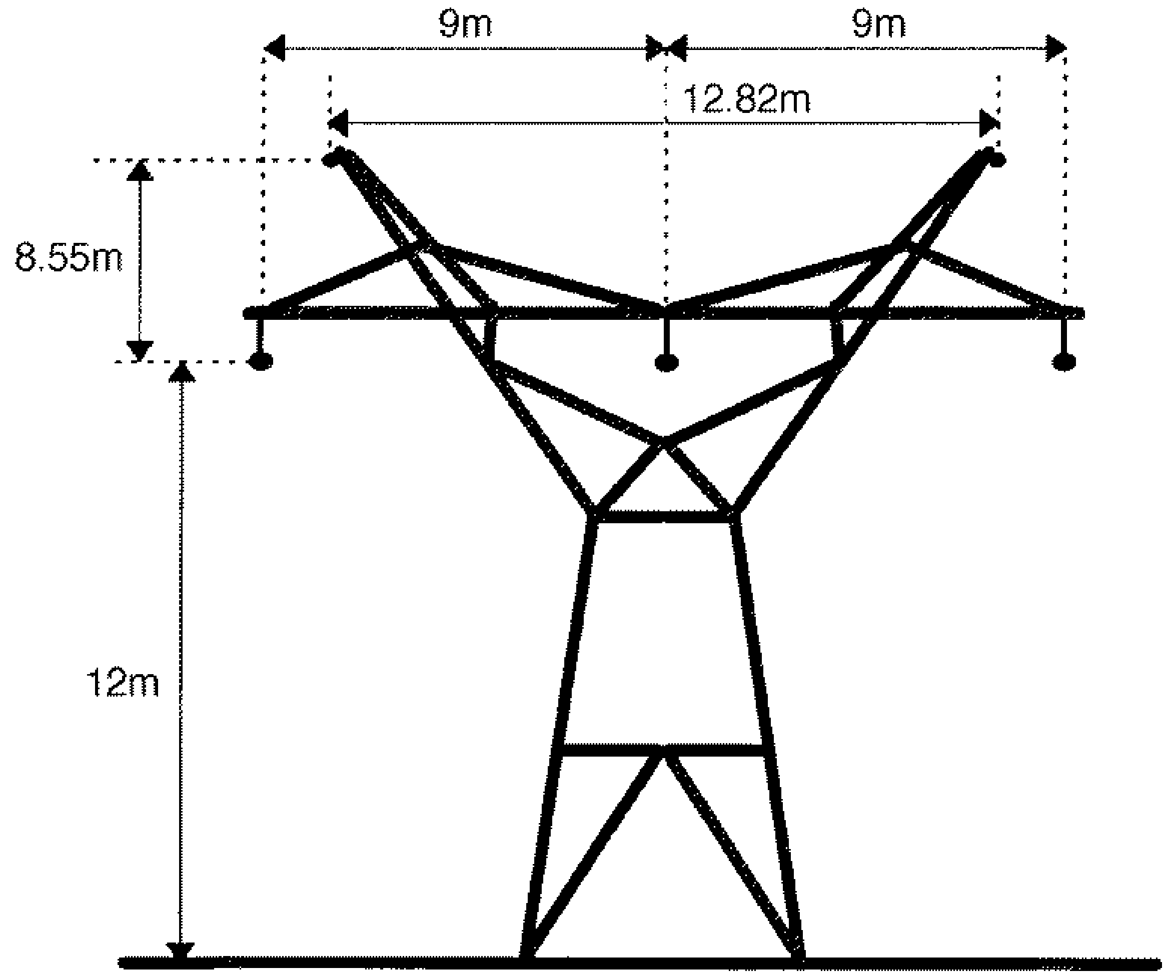
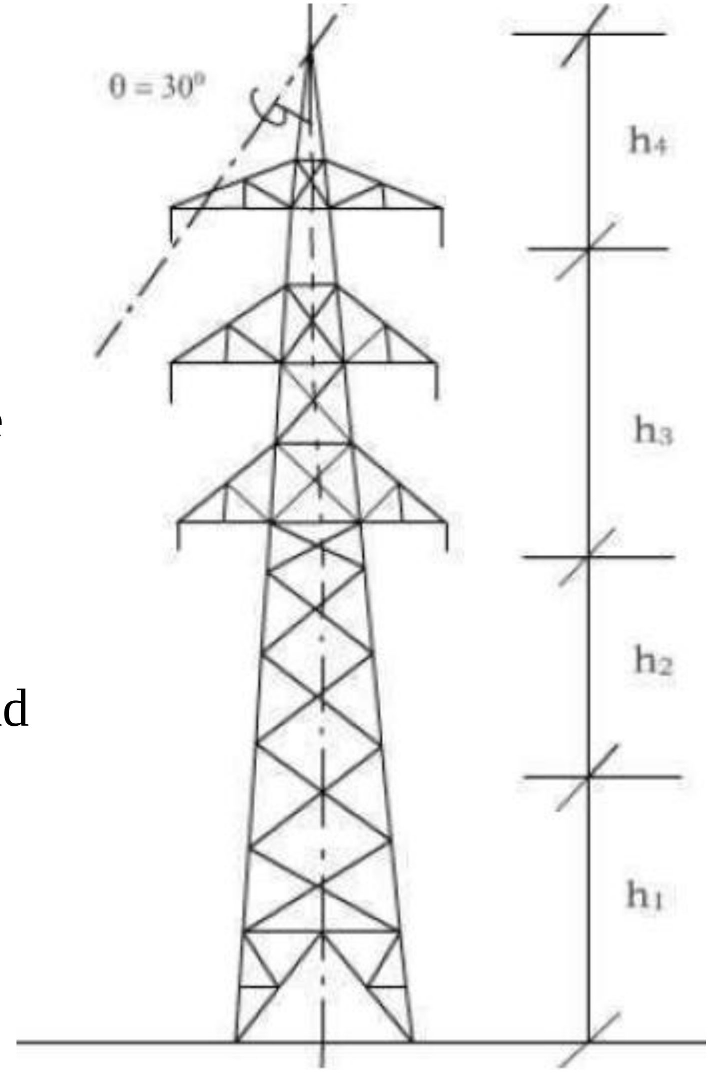


Fig. Typical 765 KV Tower Structure

Height of Tower Structure

Height of tower is determine by-

$$H = h_1 + h_2 + h_3 + h_4$$



h_1=Minimum permissible ground clearance

h_2=Maximum sag

h_3=Vertical spacing between conductors

h_4=Vertical clearance between earthwire and top conductor

Determination of Base Width

The base width(at the concrete level) **is the distance between the centre of gravity at one corner leg and the centre of gravity of the adjacent corner leg.**

- A particular base width which gives the minimum total cost of the tower and

  foun

$$B = 0.42\sqrt{M} \text{ or } 0.013\sqrt{m}$$

Ryle Formula

Where
B = Base width in meters,
M = Overturning moment about the ground level in tonne-meters, and
m= Overturning moment about the ground level in kg.meters.

- The ratio of base width to total tower height for most towers is generally about one-fifth to one-tenth.

Spacing and Clearances

Ground Clearances

$$CL = 5.182 + 0.305 * K$$

Where- $K = \left(\frac{V - 33}{33} \right)$

Minimum permissible ground clearance as per IE Rules, 1956,Rule 77(4)

S.No.	Voltage level	Ground clearance(m)
1.	≤33 KV	5.20
2.	66 KV	5.49
3.	132KV	6.10
4.	220 KV	7.01
5.	400 KV	8.84

Clearance for Power Line Crossings

- **Crossing over rivers:**
    - 3.05m above maximum flood level.

- **Crossing over telecommunication lines**

  Minimum clearances between the conductors of a power line and telecommunication wires are-

Voltage Level	Minimum Clearance(mm)
≤33 KV	2440
66KV	2440
132 KV	2740
220 KV	3050
400 KV	4880

❑ Power line Crossing over railway tracks

under maximum sag condition minimum clearance over rail level stipulated in the regulations for Electrical Crossings of Railway Tracks, 1963

Table. For un-electrified tracks or tracks electrified on 1,500 volts D.C. system

System Voltage Level	Broad Gauge		Meter & Narrow Gauge	
	Inside station limits(m)	Out side station limits(m)	Inside station limits(m)	Out side station limits(m)
≤66 KV	10.3	7.9	9.1	6.7
132 KV	10.9	8.5	9.8	7.3
220 KV	11.2	8.8	10.0	7.6
400 KV	13.6	11.2	12.4	10.0

Table. Tracks electrified on 25 kV A.C. system

System Voltage Level	Broad Gauge	
	Inside station limits(m)	Out side station limits(m)
≤ 66 KV	10.3	7.9
132 KV	10.9	8.5
220 KV	11.2	8.8
400 KV	13.6	11.2

❑ Power line Crossing another Power line

System Voltage Level	Clearance(m)
≤ 66 KV	2.40
132 KV	2.75
220KV	4.55
400 KV	6.00

❑ Spacing Between Conductor(Phases)

1) Mecomb's formula

$$Spacing\,(cm) = 0.3048 * V + 4.010 \frac{D}{W} \sqrt{S}$$

Where-

V= Voltage of system in KV

D= Diameter of Conductor in cm

S= Sag in cm

W= weight of conductor in Kg/m

1) VDE formula

$$Spacing\,(cm) = 7.5\sqrt{S} + \frac{V^2}{2000}$$

Where-

V= Voltage of system in KV

S= Sag in cm

Still's formula

$$Spacing\,(cm) = 5.08 + 1.814 * V + \left[\frac{l}{27.8}\right]^2$$

Where-

l = Average span length(m)

NESC formula

$$Spacing\,(cm) = 0.762 * V + 3.681\sqrt{S} + \frac{L}{\sqrt{2}}$$

Where-

V= Voltage of system in KV

S= Sag in cm

L= Length of insulator string in cm

- Swedish formula

$$Spacing\,(cm) = 6.5\sqrt{S} + 0.7 * E$$

Where-

E= Line Voltage in KV

S= Sag in cm

- French formula

$$Spacing\,(cm) = 8.0\sqrt{S + L} + \frac{E}{1.5}$$

Where-

E= Line Voltage in KV

S= Sag in cm

L= length of insulating string(cm)

- Offset of conductors (under ice-loading conditions)

Sleet Jump:

The jump of the conductor, resulting from ice dropping off one span of an ice-covered line, has been the cause of many serious outages on long-span lines where conductors are arranged in the same vertical plane.

Offset in cm = 60 + Span in cm / 400

Clearances b/n Conductors

SYSTEM VOLTAGE	TYPE OF TOWER		Vertical spacing b/n conductors(mm)	Horizontal spacing b/n conductors(mm)
66 kV	SINGLE CIRCUIT	A(0-2°)	1080	4040
		B(2-30°)	1080	4270
		C(30-60°)	1220	4880
	DOUBLE CIRCUIT	A(0-2°)	2170	4270
		B(2-30°)	2060	4880
		C(30-60°)	2440	6000
132 KV	SINGLE CIRCUIT	A(0-2°)	4200	7140
		B(2-30°)	4200	6290
		C(30-60°)	4200	7150
		D(30-60°)	4200	8820
	DOUBLE CIRCUIT	A(0-2°)	3965	7020
		B(2-15°)	3965	7320
		C(15-30°)	3965	7320
		D(30-60°)	4270	8540

220 kV	**SINGLE CIRCUIT**	**A(0-2°)**	**5200**	**8500**
		B(2-15°)	5250	10500
		C(15-30°)	6700	12600
		D(30-60°)	7800	14000
	DOUBLE CIRCUIT	A(0-2°)	5200	9900
		B(2-15°)	5200	10100
		C(15-30°)	5200	10500
		D(30-60°)	6750	12600
400 KV	**SINGLE CIRCUIT**	A(0-2°)	7800	12760
		B(2-15°)	7800	12760
		C(15-30°)	7800	14000
		D(30-60°)	8100	16200

Sag and Tension Calculation

Span ≤300 m ← **Sag & Tension** → **Span >300 m**

- Parabolic formula:

$$L = S + \frac{S^3 . q^2}{24 . H^2}$$

$$D = \frac{S^2 . q}{8H}$$

$$\frac{T}{q} = \frac{S^2 . q}{8H} + \frac{H}{q}$$

$$q = \sqrt{w^2 + p^2}$$

- Catenary formula:

$$L = \frac{2H}{q} Sinh \frac{Sq}{2H}$$

$$D = \frac{H}{q}\left(Cosh \frac{Sq}{2H} - 1 \right)$$

$$\frac{T}{q} = D + \frac{H}{q}$$

$$q = \sqrt{w^2 + p^2}$$

Where:

q = resultant load on the conductor per unit length
S = Span length
D = Sag of conductor at its lowest point
L = length of the conductor in span
T = Tension at either point of support
H = horizontal tension at the lowest point

Types of Conductors

- ACSR Conductor(Aluminium Conductor Steel Reinforced)
- AAC(All Aluminium Conductor)
- AAAC(All Alloy Aluminium Conductor)

TECHNICAL DATA OF ACSR CONDUCTORS COMMONLY USED ON EHV LINES

CODE NAME	NOMINAL Cu AREA mm2	STRANDING & WIRE DIA. AL/ST, mm.	SECTIONAL AREA OF AL in mm2	TOTAL AREA IN mm2	OVERALL DIA IN mm	UNIT WEIGHT Kg/Km	RESISTANCE AT 20°C Ohms/Km	APPROX. ULTIMATE STRENGTH KN (BREAKING LOAD)	APPROX. CURRENT CARRYING CAPACITY IN AMPS AT 40°C AMBIENT, AND AIR VELOCITY AT 0.6 M/Sec. FOR RISE OF	
									30°C	35°C
PANTHER	129.0	30/7/3.0	212.0	261.5	21.0	974.0	0.14000	90	460	490
DEER	258.1	30/7/4.27	429.5	529.8	29.89	1970.5	0.06918	179	725	775
ZEBRA	258.1	54/7/3.18	428.9	484.5	28.62	1620.0	0.06915	132	730	780
MOOSE	322.6	54/7/3.53	528.5	597.0	31.77	2000	0.05633	160	820	875

Selection of Conductor Size

- **Mechanical Requirement**
- **Electrical Requirement**

Mechanical Requirement

- Tensile Strength(For Tension)
- Strain Strength(For Vibration)

Use vibration damper for vibration control.

Electrical Requirement

- Continuous current rating.
- Short time current carrying rating.
- Voltage drop
- Power loss
- Minimum dia to avoid corona
- Length of line
- Charging current

Continuous Current Rating.

$$I_2 = I_1 * \sqrt{\frac{\Delta t_2 * R_1}{\Delta t_1 * R_2}}$$

I_1=current rating for temp rise Δt_1

I_2=current rating required to produced temp rise Δt_2

R_1= conductor resistance at conductor total temp T_1(say 75°C)

R_2= conductor resistance at required conductor total temp T_2

Short Time Rating

According to short time rating conductor size is given by-

$$A = 7.58 * I_F * t$$

Where **A**=area of conductor(mm^2)

I_F= fault current(KA)

t= fault duration(1 sec.)

Corona

Visual corona voltage in fair weather condition is given by-

$$V_0 = 21.1 * m \frac{\delta * r(1+0.3)}{\sqrt{r}} \log_n\left(\frac{D}{r}\right)$$

- V_0= corona starting voltage, KV(rms)
- r= radius of conductor in cm
- D= GMD equivalent spacing b/n conductors in cm
- m= roughness factor

  = 1.0 for clean smooth conductor

  =0.85 for stranded conductor

Voltage gradient at the surface of conductor at operating voltage-

$$g_0 = \frac{V/\sqrt{3}}{Log_n\left(\frac{D}{r}\right)}$$ (rms kv/cm)

Corona discharge form at the surface of conductor if $g_0 \geq$ corona starting gradient i.e.

$$g_0 \geq 21.1 * m * \delta * r \frac{(1+0.3)}{\sqrt{r}}$$

- **Conductor size will be so chosen that normal gradient of conductor should not exceed 17.5 KV/cm.**
- **For EHV transmission line 400KV and above use bundle conductor from point view of corona.**

Optimization of Conductor

When more than one conductor satisfied the requirement of current capacity and corona performance than study required for conductor optimization

C= cost in Rs. Per Km of 3-ø line

A= Annual fixed charge on capital in Rs./ Rupees of capital cost(interest 14%+depreciation 5%+ operation and maintenance cost 1-3%)

P_m= Maximum demand(KW)

V= Line voltage(KV)

R= Resistance of conductor/Km/phase

Cosø=Power factor

H= Loss load factor

= $0.3[LF+0.7(LF)^2]$ (For normal load variation)

= $0.2[LF+0.8(LF)^2]$ (For more uniform load variation)

$$LF = \frac{\text{Annual energy generated}}{8760 * \text{maximum demand}}$$

L= Energy charge in Rs/Kwh

M= Demand charge in Rs/Kwh

$$J = \frac{12M(LF)^2 + 8760 * L * H}{1000}$$

Total annual fixed charge **(C_1)=C*A**

Total annual running charges**(C_2)= (P^2_m*R*J)/(V^2 Cos^2 ø)**

Total charges**(T)= C*A + (P^2_m*R*J)/(V^2 Cos^2 ø)**

Conductor giving minimum T will be optimum

Cost/KW/Km will be minimum i.e. **T/P_m** will be minimum when

$$P_m = V\cos\phi \frac{[C*A]^{1/2}}{R}$$

Some Others Consideration in Conductor Selection

- **AL/St Area** (For longer span & less sag with economic consider)
- **River crossing** (Span≥1000 m use AAAC conductor because of more tendency to vibration and twisting)
- **Weight/ Dia** (Less Weight/Dia ratio conductor swing more hence require longer cross arms witch increase torsional load. Consider optimum value W/d in design.)

INSULATOR

Insulator are required to support the line conductor and provide clearance from ground and structure.

- **Insulator material-**
  - High grade Electrical Porcelain
  - Toughened Glass
  - Fiber Glass

- Choice of insulator material is govern by availability, price and ease of maintenance.
- Porcelain insulator are largely used in India.

Type of Insulator-

- Disc Type
- Strut Type

Disc type Insulator

- It consist of central suitable shaped porcelain/ glass body like a disc with an metal clamp on one side and metal ball pin on other side
- Cap is made of malleable cost iron and the ball pins is of forged steel.

Strut Type Insulator

- It consist of several insulator disc cemented altogether without any link.
- It is rigid and can take both tension and compression load.
- These are used for holding the conductor out of way of structure.

Long Rod Insulator

INSULATOR STRING

- Disc insulator are joint by their ball pins and socket in their caps to form string.
- No of insulator disc is decided by system voltage, switching and lighting over voltage amplitude and pollution level.
- Insulator string can be used either suspension or tension.
- Two suspension string in parallel used at railways, road and river crossing as statutory requirement.
- Swing of suspension string due to wind has to be taken into consider.

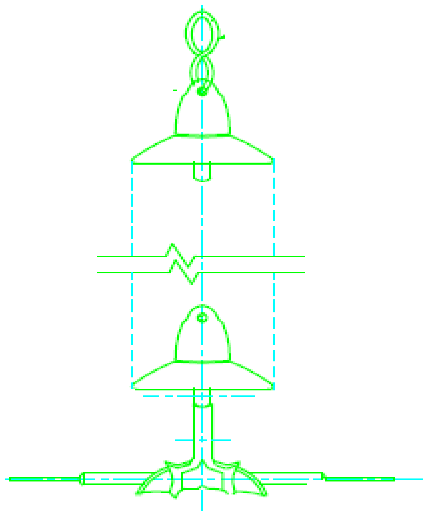


Fig. single string

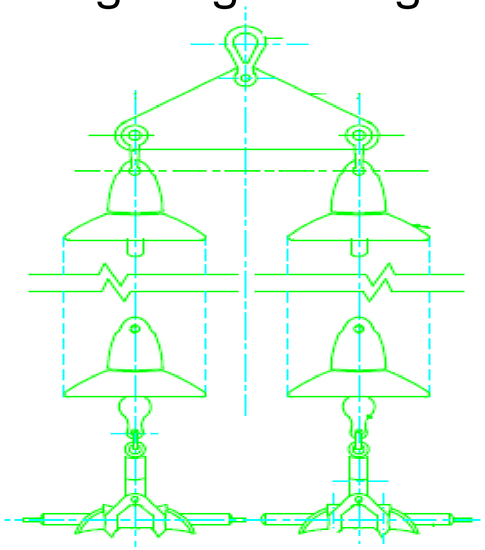


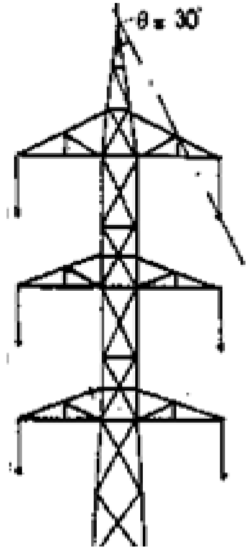
Fig. Double string

Earth Wire

Earth wire provided above the phase conductor across the line and grounded at every tower.

- It shield the line conductor from direct strokes
- Reduces voltage stress across the insulating strings during lightning strokes

Design criterion:



- **Shield angle**
  - 25°-30° up to 220 KV
  - 20° for 400 KV and above
- Earth wire should be adequate to carry very short duration lightning surge current of 100 KA without excessive over heating
  - Duration should be consider as 200 μ-sec
  - Safe temp rise limited to 300°C

$$A = 5 * I * \sqrt{t}$$

A= Area(in mm^2) of cu conductor
I =current in KA
t = Time insecond

Area of Steel Wire = 3*A(cu mm^2)

- From mechanical consideration, size become higher than required for current carrying rating.
- For EHV line it is suggested as 70 mm^2 (7/3.66 mm).
- ACSR is used as earth wire (12/3.0 mm AL+7/3.0 mm steel) in consideration of corrosion and resistance.

Mid span clearance:

Direct distance b/n earth wire and top power conductor.

As per IS 5613 following value of mid span clearance should be considered

System voltage	Mid span clearance(m)
≤ 66 KV	3.0
110 KV	4.5
132 KV	6.1
220 KV	8.5
400 KV	9.0

Tower Grounding

Used to reduce earth wire potential and stress on insulators at the time of stroke and also for safety

- Tower footing resistance will be 10Ω and should not be more than 20 Ω under any condition throughout the year.
- Earth resistance depend upon soil resistivity(general 100 Ω-m)

Method of Tower Grounding

- **Buried Conductor**

  One or more conductor are connected to tower lags and buried in back filled of tower foundation.

  - Used where soil resistivity is low

- **Counterpoise Wire**

  A length of wire/ Strip of 50 m is buried horizontally at depth of 0.5 m bellow ground. This wire is connected to tower lags.

  - Used when earth resistance is very high and soil conductivity is mostly confined to upper layer)

- **Rod Pipe**

  Pipe/Rod of 3 to 4 m is driven into ground near the tower and top of rod is connected to tower by suitable wire/strip

  - Used where ground conductivity increase with depth

- **Treated Earth Pits**

  Pipe/Rod of 3 to 4 m are buried in treated earth pits and top of rod is connected to tower by suitable wire/strip.

  - Used in very high resistivity near tower

Reference Standards

IS-398	Specification of Aluminium Conductor for Over Head Transmission Line(ACSR)
IS-802	Code of Practice for use of Structural Steel in over head Transmission Line Tower
IS 3853	Specification of Aluminium Steel Core Wire for Aluminium Conductor
IS 4091	Code Practice for Design and Construction of Foundation of Transmission Line Tower and Pole
IS 5613	Specification of Design, Installation and Maintenance of Line above 11 KV and up to 220 KV
CBIP	Manual on Transmission Line Tower, Technical Report N0. 9, March 1977
IE Rules, 1956	

Thank You….