1. Calculation of continuous current carrying capacity of 2.5″ (0.0635mm) dia Aluminium tube.

Input Data:

System Voltage: 132 KV
Diameter of tube: 0.0635 m
Conductor wall thickness: 0.0127 m
Ambient Temperature: 35° C
= 308.15° K
Final operating temperature: 80° C
= 353° K
Temperature difference between conductor surface & ambient air ΔT= 45° C.
Emissivity/Absorption factor (ε) = 0.5
Cross-section area: $Ac = \pi r_o{}^2 - \pi r_i{}^2$

$$= 3.1416 \times 0.03175^2 - 3.1416 \times 0.0254^2$$

Derated current for allowable conductor temperature rise

$$I = \sqrt{\frac{q_c + q_r + q_{cond} - q_s}{RF}}$$

Where,
I = The current through the bus conductor
R = DC resistance at the operating temperature Ω/m
F = Skin effect co-efficient.
q_s = Solar heat gain
q_c = Convective heat loss
q_r = Radiant heat loss
q_{cond} = Conductive heat loss

a) Heat loss due to Convective is given by

$q_c = 4.0\ \rho_a^{0.5}\ D^{0.75}\ \Delta T^{1.25}$

$T_{film} = \frac{T_c + T_a}{2} = \frac{80+35}{2} = 57.5°$ C

ρ_a= 1.061 Kg/ m^3

Therefore, q_c = 4.0 x $1.061^{0.5}$ x $0.0635^{0.75}$ x $45^{1.25}$
= 60.745 W/m

b) Heat loss due to Radiation can be calculated by using the Stefan's Boltzman equation for radiation from a surface.

q_r = 5.6697 x 10^{-8} x ε $\pi D[(T_c + 273)^4 - (T_a + 273)^4]$
= 5.6697 x 10^{-8} x 0.5 x 3.1416 x 0.0635$[(80 + 273)^4 - (35 + 273)^4]$
Q_r = 36.92 W/m

c) The heat gain from solar Radiation is given by

q_s = ε' Q_s A'k sinθ

Where,

Qs	=	Total solar and sky radiated heat on a surface normal to sun's rays , W/m[2l]
A'	=	Projected area of conductor by unit length of conductor, m^2/m
K	=	Heat multiplying factors for high altitudes
H_c	=	The altitude of sun , degrees
Zc	=	The azimuth of sun , degrees
Z_I	=	The azimuth of conductor line , degrees
θ	=	Effective angle of incidence of sun , degrees
ζ	=	Angle between plane of conductor surface and sun's altitude

Degrees of Latitude (North) = 25°

Assuming the conductor axis laying East-West and maximum current at 12 noon.

$Z_c = 0°$

$H_c = 87°$

K = 1

Qs = 1035.18 W/ m^2

$Z_I = 90°$

$$\theta = cos^{-1}[\cos H_c \text{ x } \cos(Z_c - Z_1)]$$
$$= cos^{-1}[\cos 87 \text{ x } \cos(0 - 90)]$$
$$= 1.829$$

For Cylinder, A=D & Sinζ = 1

$$A' = A \text{ x } \sin\zeta$$
$$= 0.0635 \text{ x } 1$$
$$= 0.0635 \ m^2/\text{m}$$

Therefore,

$$q_s = 0.5 \text{ x } 1035.18 \text{ x } 0.0635 \text{ x } 1 \text{ x } \sin 1.83$$
$$= 1.05 \text{ W/m}$$

d) For aluminium alloy, the DC resistance is

$$R = \frac{1.724 \times 10^{-6}}{C' A_c}[1 + \frac{0.00403 \times C'}{61} \text{ x } (T_2 - 20)$$

C' = Conductivity as %IACS = 53%

$$R = \frac{1.724 \times 10^{-6}}{53 \times 0.00114}[1 + \frac{0.00403 \times 53}{61} \text{ x } (80 - 20)$$

$$= 0.0000345 \ \Omega/\text{m}$$

Skin Factor: 1

Derated current for allowable conductor temperature rise

$$I = \sqrt{\frac{60.745+36.92+0-1.05}{0.0000345 \times 1}}$$

= 1673.45 A

So, 2.5'' Aluminium tube will carry a current of 1250 A safely for operating temperature of 80° C.

2. Calculation of maximum allowable fault current of the 2.5'' dia Aluminium tube.

Maximum allowable (RMS) value of fault current is:

$$I = C \times 10^{6} \times A_c \times \sqrt{\frac{1}{t} log_{10}\left(\frac{T_f - 20 + \frac{15150}{G}}{T_i - 20 + \frac{15150}{G}}\right)}$$

Where,

C = 2.232 × 10^{-4} × $S_{0.5}$ / mm^2 for A_c in mm^2

I = Maximum allowable RMS value of fault current, A.

A_c = Conductor cross-sectional area, mm^2

G = Conductivity in percent IACS

t = Duration of fault, S

T_f = Allowable final conductor temperature, ° C

T_i = Conductor temperature at fault initiation, ° C

Therefore,

$$I = 2.232\times 10^{-4} \times 10^{6} \times 1140 \times \sqrt{\frac{1}{1} log_{10}(\frac{250-20+\frac{15150}{53}}{80-20+\frac{15150}{53}})}$$

= 106.03 KA

So, the maximum allowable fault current (106.03 KA) is more than the system fault current (31.5 KA).

3. Check for Surge Voltage Gradient

Equivalent distance from centre of conductor to ground plane for three phases,

$$h_e = \frac{hD}{\sqrt{4\,h^2 + D^2}} \text{ cm}$$

Where,

h = Conductor centre distance from ground

= 850 cm

d = Conductor diameter

= 6.35 cm

D = Phase to phase spacing

= 250 cm

V_1 = Line to ground test voltage

$= \frac{132 \times 1.1}{1.732}$

= 83.83 KV

Therefore,

$$h_e = \frac{hD}{\sqrt{4\ h^2 + D^2}}$$

$$= \frac{850 \times 250}{\sqrt{4 \times 850^2 + D^2}}$$

= 123.67 cm

Average voltage gradient at the surface of the conductor

$$E_a = \frac{V_1}{\frac{d}{2} \times ln(\frac{4h_e}{d})}$$

$$= \frac{83.83}{\frac{6.35}{2} \times ln(\frac{4 \times 123.67}{6.35})}$$

= 6.062 KV/cm

$$E_m = \frac{h_e}{h_e - (\frac{d}{2})} \times E_a$$

$$= \frac{123.67}{123.67 - (\frac{6.35}{2})} \times 6.062$$

= 6.22 KV/cm

The calculated value of maximum surface voltage gradient for selected conductor is 6.22 KV/cm which is less than breakdown strength of air is 21.2 KV/cm (RMS).

For satisfactory operation, $E_m < E_c$, The 64 mm (2.5 in) SPS, schedule 40 aluminium tube meets this criteria and is acceptable.

4. Calculation of maximum allowable span

a) Calculation of rigid bus loads

1. Force due to conductor weight is given by

$$F_c = \frac{\pi\, W_c}{4}\left(D_0^2 - D_1^2\right)$$

$$= \pi W_c\, T_c (D_o - t_c)$$

Where,

F_c = Conductor unit weight (N/m)

W_c = Specific conductor weight (N/ m^3)

for Aluminium W_c = 26500 N/ m^3

D_o = Conductor outside diameter (m)

D_i = Conductor inside diameter (m)

t_c = Conductor wall thickness (m)

Therefore,

$F_c = 3.1416 \times 26500 \times 0.0127\ (0.635 - 0.0127)$

= 53.71 N/m

2. **Force due to wind load is given by**

$$F_w = C\, V^2 D_o C_f K_z G_f I$$

Where,

F_w = Wind load by unit length N/m

C = Constant = 0.613

V = Extreme wind speed without ice (m/s) = 32.78 m/s

D_o = Conductor outside diameter or the height of the profile used as conductor (m) = 0.635 m

C_f = Force co-efficient = 1

K_z = Height & exposure factor = 0.70

G_f = Gust response factor = 0.85

I = Importance factor of the structure = 1.15

Therefore,

$$F_w = 0.613 \times 32.78^2 \times 0.0635 \times 1 \times 0.70 \times 0.85 \times 1.15$$

$$= 28.62 \text{ N/m}$$

3. **Force due to wind load is given by**

$$F_{sc} = D_f{}^2 K_f \frac{16 \times \Gamma \times I_{sc}{}^2}{D \times 10^7}$$

Where,

K_f = Mounting structure flexibility factor = 0.85

Γ = Constant based on type of fault and conductor location = 0.866

I_{sc} = Short circuit current = 31.5 KA = 31500 A

D = Phase to phase spacing = 2.5 m

D_f = Half-cycle decrement factor to account for the momentary peak factor effect

$$D_f = \frac{1+e^{-\frac{1}{2fTa}}}{2}$$

$$T_a = \frac{X}{R}\,\frac{1}{2\pi f}$$

f = 50 Hz,

$\frac{X}{R}$ = 10, Assumption

So,

T_a = 0.0318, D_f = 0.865, $D_f{}^2$ = 0.749

Therefore,

$$F_{sc} = 0.749 \times 0.85 \times \frac{16 \times 0.866 \times 31500^2}{2.5 \times 10^7}$$

= 350.12 N/m

4. **Total gravitational force**

$$F_G = F_C$$

$$= 53.71 \text{ N/m}$$

5. **Total force is given by the vector sum of the vertical and horizontal forces.**

$$F_t = \sqrt{{F_G}^2 + (F_w + F_{sc})^2}$$

$$= \sqrt{53.71^2 + (28.62 + 350.12)^2}$$

= 382.53 N/m

b) Calculation of allowable span

1. **Allowable span based on deflection limit is given by**

$$L_V = \sqrt[3]{\frac{384 \times E \times J_n}{5F_G}}$$

Where,

E = Youngs modulus of the conductor materials

= 68.9 × 10^9 N/m^2

J = Bending moment of inertia

$$= \pi \frac{(0.0635^4 - 0.0508^4)}{64}$$

= 4.712 × 10^{-7} m^4

η = Fraction of the allowable span limit = 0.0067

Therefore,

$$L_V = \sqrt[3]{\frac{384 \times 68.9 \times 10^9 \times 4.712 \times 10^{-7} \times 0.0067}{5 \times 53.71}}$$

= 6.7754 m

2. **Allowable span based on fiber stress is given by**

$$L_s = \sqrt{\frac{16\, J\sigma_{allowable}}{F_T D_o}}$$

Where,

$\sigma_{allowable}$ = Allowable stress of material accounting for welds

= 170 M ρ_a

Therefore,

$$L_s = \sqrt{\frac{16 \times 4.712 \times 10^{-7} \times 170 \times 10^6}{F_T D_o}}$$

= 7.26 m

The maximum span will be the lesser of the lengths based on deflection and fiber stress.

Therefore, Maximum allowable span is 6.8 meter.

5. Calculation of Vibration Frequency

a) Natural frequency of bus span is given by

$$f_b = \frac{\pi k^2}{2L^2}\sqrt{\frac{EJ}{m}}$$

Where,

m = $\frac{F_C}{9.81} = \frac{53.71}{9.81}$ = 5.475 Kg/m

L = 6.8 meter, K = 1.51

Therefore,

$$f_b = \frac{3.1416 \times 1.51^2}{2 \times 6.8^2} \sqrt{\frac{68.9 \times 10^9 \times 4.712 \times 10^{-7}}{5.475}}$$

= 5.96 Hz

b) Wind induced vibration is given by

$$f_a = \frac{C \times V}{D_o}$$

Where,

C = Strouhal number = 0.19

V = Wind velocity = 72 kmph = 20 m/s

Therefore,

$$f_a = \frac{0.19 \times 20}{0.0635}$$

= 59.84 Hz

If twice the calculated natural frequency of the bus span is less than the Aeolian force frequency, the design is safe.

$$2f_b < f_a$$

Hence, the design is safe.

So, 2.5″ Aluminium Tubular conductor is selected for 132 KV common bus.