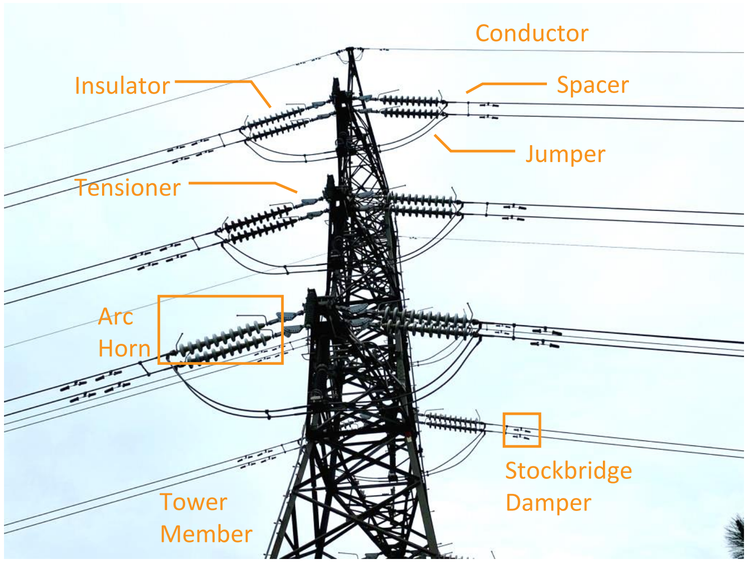
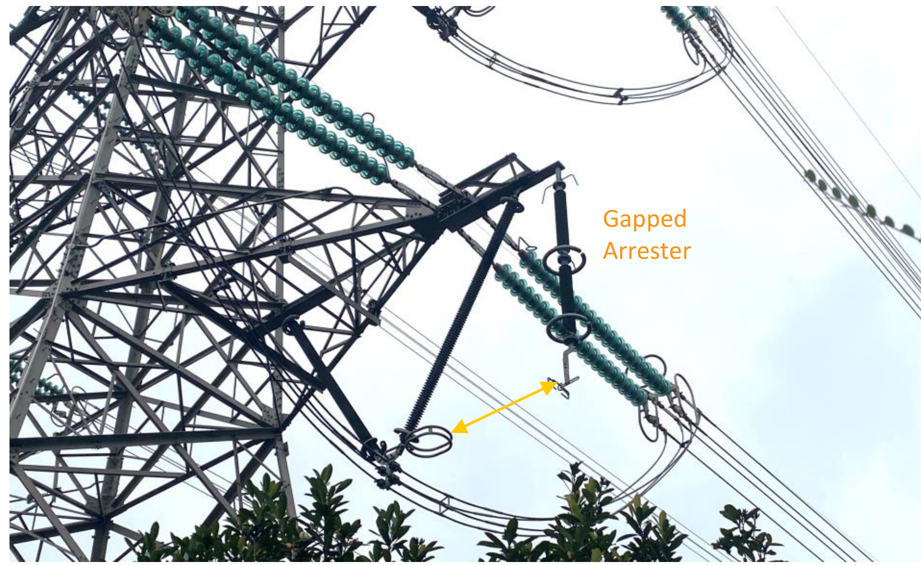
Chapter 1 Theory of Overhead Lines – Introduction

Overhead Lines, other than underground cables, are transmission lines which transmit power from power plant to customer ends with other supporting and auxiliary components. Higher voltage [>1000kV] is applied to transmit large power [>1GW] through the long corridor. Unlike underground cables, major problems tackling in overhead lines are mechanical problems due to meteorological condition, such as sag and tension due to weight of conductor and insulator, vibration due to vortex shedding with winds, tower member fatigue due to rusting or buckling due to rock impact, thermal creep due to poor heat transfer with surrounding. In this section, it aims to introduce basic in overhead lines for discussions in future chapters.

Components of Overhead Lines





Electrical Characteristics of AC Lines

Rated voltage kV	20	110	220	380	500	750
Highest operation voltage in kV	24	123	245	420	525	765
Rated aluminum area in mm^2	50	230	435	Bundle 2×572	Bundle 3×483	Bundle 4×658
Conductor diameter in mm	9,6	21,5	28,8	$2 \times 32{,}9$	$3 \times 29{,}6$	$4 \times 35{,}2$
Steady state current (at 80°C conductor temperature) in A	210	630	900	2100	2850	4380
Thermal limit power in MVA	7	120	340	1380	2470	5690
Surge impedance in Ω	400	375	365	284	276	259
Surge impedance load in MW	—	32	135	500	910	2170

Rated voltage in kV	110	220	380	500	750
Thermal limit[1)] (MVA)	100 to 350	300 to 1000	1400 to 2700	1800 to 3000	3000 to 5000
Economic power (MVA)	20 to 100	120 to 350	500 to 1200	700 to 1500	2000 to 3000
Right-of-way (m)	40 to 50	55 to 60	60 to 70	60 to 70	80 to 120
Tower weight (t/km)	15 to 25	25 to 35	45 to 65	16 to 25	28 to 50
Concrete volume (m^3/km)	100 to 200	120 to 250	150 to 300	120 to 250[3)]	150 to 250
Investment[2)] (kEUR/km)	125 to 200	150 to 400	650 to 1200	250 to 400	350 to 4500

[1)] for one circuit [2)] without indemnities [3)] 20 m^3/km for guyed towers

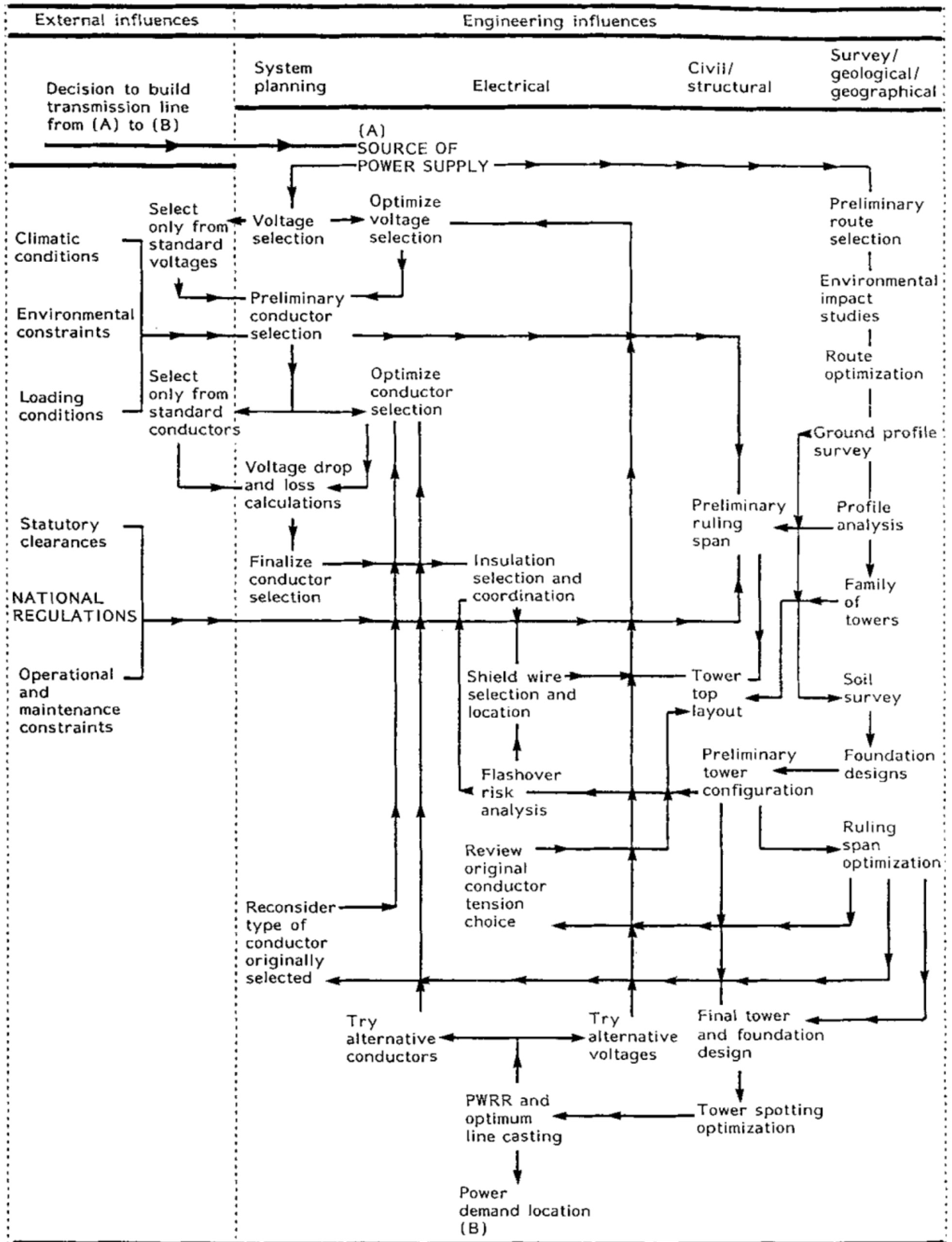
Comparison between Underground Cable and Overhead Lines

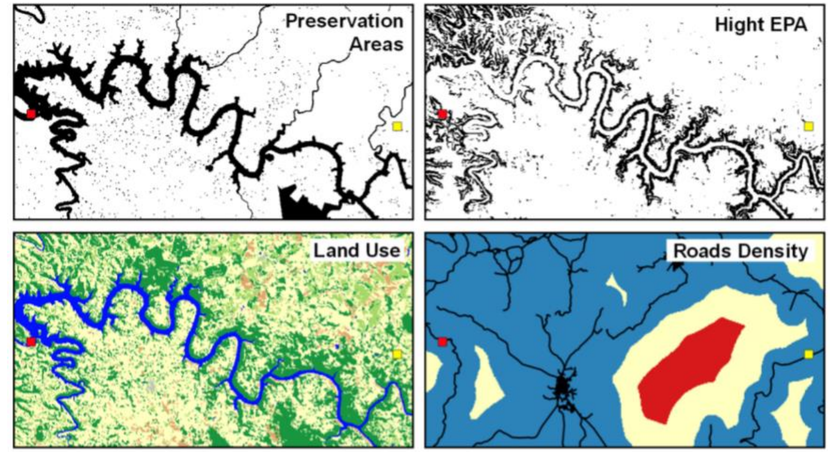
	Features	Overhead system	Underground system
1	Public safety	All the conductors with high voltages are placed overhead. Therefore, OHL is less safe compared to underground system.	All cables with high voltage is placed under the ground, hence it is safer.
2	Initial cost	Initial cost is less compared to underground system.	Initial cost is higher with high cost of trenching, conduits, manholes, and other special equipment.
3	Flexibility	Poles and conductors can be easily shifted to meet the changes in load conditions.	Manholes, ducts and cables are placed permanently once installed and the load expansion can be met by laying new lines only.
4	Faults	Higher chances of fault due to lightning, insulation failure, mechanical failures (abrasion, creeping, fatigue, buckling, corrosion, fretting)	The chances of faults here are less since all the wiring is underground and is provided with insulation.
5	Appearance	The appearance of overhead line is not so good.	All the distribution lines are kept underground. So it gives better appearance.
6	Fault Location and Repairs	The conductors are visible and are accessible so the fault can be located and repaired easily.	Generally, there are very less chances of faults in an underground system. But if at all any fault occurs, then it becomes difficult to locate it and repair.
7	Current Carrying Capacity and Voltage Drop	It has considerably higher current capability.	It has comparatively low current capability.
8	Life Cycle	25 years.	> 50 years
9	Maintenance Cost	Due to the chances of faults and service interruptions in an overhead system due to wind, ice, lighting as well as from traffic hazards , the maintenance cost of overhead system is high	As compared to the overhead system the maintenance cost is comparatively less due to less chances of faults
10	Interference with Communication Circuits	An overhead system causes electromagnetic interference with the telephone lines.	In underground system there is no such interference.

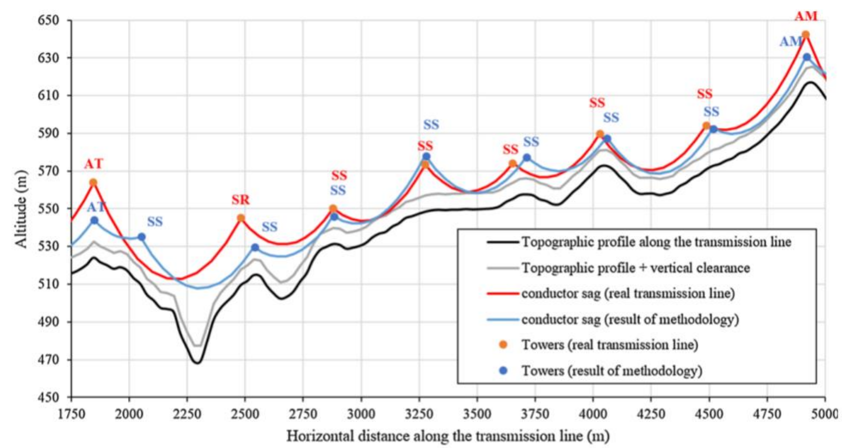
Planning Considerations:

1. When a new transmission line or uprating or upgrading of existing lines will be required?
2. Where is it required and what quality of supply or reliability is required?
3. What normal and emergency rating is required?
4. What type of transmission should be used? Overhead Lines or Underground Cables, DC or AC lines?
5. What voltage and how many circuits will be needed?

Overhead Lines Routing







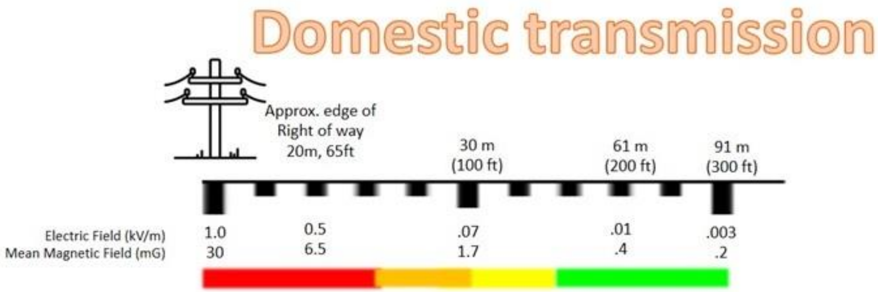
Topological Profile Optimization:

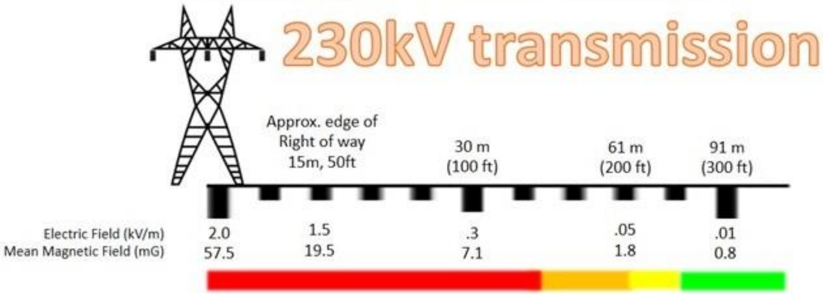
(i) TL route, represented as a point list containing information of elevation, slope, land use, geotechnical soil class, route deflection angles, and impediments;

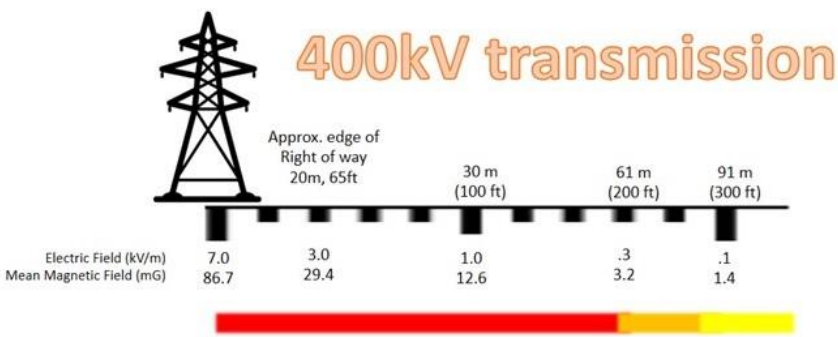
(ii) Towers and their characteristics: type, minimum and maximum heights, minimum and maximum weight span, maximum average span, foundation and structure costs;

(iii) Conductor and clearance parameters: weight, tension for maximum and minimum temperatures and vertical clearance distances according to the land use

Safety Distance







Line voltage (kV)	Safe distance from the ground fault (m)
10	0,4
20	0,9
110	7
220	14
400	21

Rated system voltage	**Safety distance from live high voltage conductors**
Up to 33kV	0.8 metres
110kV/ 132kV	1.4 metres
400kV	3.1 metres

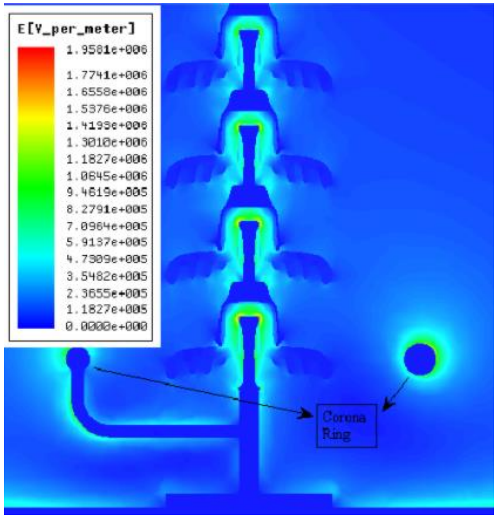
Highest voltage for installation	Standard rated short-duration power-frequency withstand voltage	Standard rated lightning impulse withstand voltage [a]	Minimum phase-to-earth and phase-to-phase clearance *N*	
U_m RMS	U_d RMS	U_p 1,2 μs/50 μs (peak value)	Indoor installations	Outdoor installations
kV	kV	kV	mm	mm
12	28	60	90	150
		75	120	150
		95	160	160
24	50	95	160	
		125	220	
		145	270	
36	70	145	270	
		170	320	
123	185 [b]	450 [b]	900	
	230	550	1 100	
	185 [b]	450 [b]	900	
145	230	550	1 100	
	275	650	1 300	

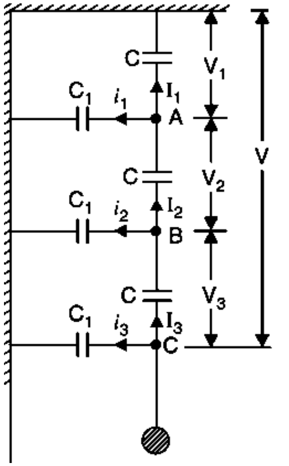
Highest voltage for installation	Standard rated lightning impulse withstand voltage [a]	Standard rated switching impulse withstand voltage	Minimum phase-to-earth clearance		Standard rated switching impulse withstand voltage	Minimum phase-to-phase clearance	
U_m RMS	U_p 1,2 μs/ 50 μs (peak value)	U_s Phase-to-earth 250 μs/2 500 μs (peak value)	Conductor – structure	Rod – structure *N*	U_s Phase-to-phase 250 μs/ 2 500 μs (peak value)	Conductor – conductor parallel	Rod – conductor
kV	kV	kV	mm		kV	mm	
300	850/950	750	1 600 1 700 [b]	1 900	1 125	2 300	2 600
	950/1 050	850	1 800 1 900 [b]	2 400	1 275	2 600	3 100
362	950/1 050	850	1 800 1 900 [b]	2 400	1 275	2 600	3 100
	1 050/1 175	950	2 200	2 900	1 425	3 100	3 600
420	1 050/1 175	850	1 900 2 200 [b]	2 400	1 360	2 900	3 400
	1 175/1 300	950	2 200 2 400 [b]	2 900	1 425	3 100	3 600
	1 300/1 425	1 050	2 600	3 400	1 575	3 600	4 200

Insulator

Nominal System Phase-to-Phase Voltage kV	BIL kV	Minimum Quantity of Suspension Insulators*
7.5	95	1
14.4	110	2
23	150	2
34.5	200	3
46	250	4
69	350	5
115	550	8
138	650	9
161	750	10
230	900	12
230	1050	14
345	1300	20

*For standard 14.6- x 25.4-centimeter (5 ¾- x 10-inch) suspension insulators.





The ratio of voltage across the whole string to the product of number of discs and voltage across the disc nearest to the conductor is known as string efficiency, i.e.

$$\text{String Efficiency} = \frac{\text{Voltage across string}}{n\ \times \text{Voltage across disc nearest to conductor}} \tag{1.1}$$

where n = number of discs in the string.

Apply KCL to node A, we get

$$I_2 = I_1 + i_1 \rightarrow V_2\omega C = V_1\omega C + V_1\omega C_1 = V_1\omega C(1+K) \rightarrow V_2 = V_1(1+K) \tag{1.2}$$

Apply KCL to node B, we get

$$I_3 = I_2 + i_2 \rightarrow V_3\omega C = V_2\omega C + (V_1+V_2)\omega C_1 = V_2\omega C + (V_1+V_2)\omega KC$$
$$V_3 = V_2 + (V_1+V_2)K = KV_1 + V_2(1+K) \tag{1.3}$$

Hence,

$$V_3 = V_1[1 + 3K + K^2] \tag{1.4}$$

Voltage between Conductor and earth is

$$V = V_1 + V_2 + V_3 = V_1 + V_1(1+K) + V_1(1+3K+K^2) \tag{1.5}$$

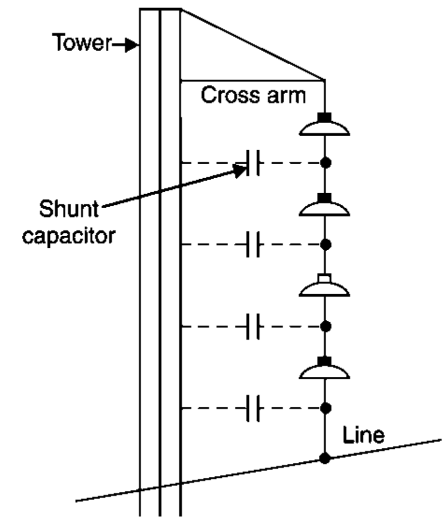
$$V = V_1(1+K)(3+K) \tag{1.6}$$

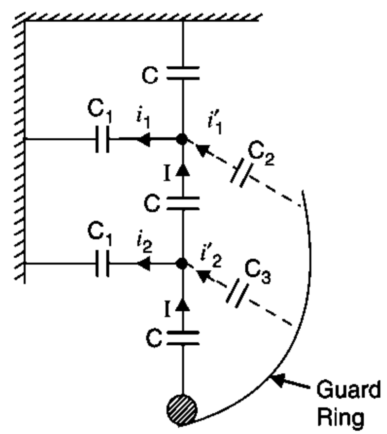
or

$$\boxed{V_1 = \frac{V}{(1+K)(3+K)}} \tag{1.7}$$

To improve String Efficiency,

1. By using longer cross-arms. The value of string efficiency depends upon the value of K i.e., ratio of shunt capacitance to mutual capacitance. The lesser the value of K, the greater is the string efficiency and more uniform is the voltage distribution. The value of K can be decreased by reducing the shunt capacitance. In order to reduce shunt capacitance, the distance of conductor from tower must be increased i.e., longer cross-arms should be used. However, limitations of cost and strength of tower do not allow the use of very long cross-arms. In practice, K = 0·1 is the limit that can be achieved by this method.
2. By grading the insulators. In this method, insulators of different dimensions are so chosen that each has a different capacitance. The insulators are capacitance graded i.e. they are assembled in the string in such a way that the top unit has the minimum capacitance, increasing progressively as the bottom unit (i.e., nearest to conductor) is reached. Since voltage is inversely proportional to capacitance, this method tends to equalize the potential distribution across the units in the string. This method has the disadvantage that a large number of different-sized insulators are required. However, good results can be obtained by using standard insulators for most of the string and larger units for that near to the line conductor.
3. By using a guard ring. The potential across each unit in a string can be equalised by using a guard ring which is a metal ring electrically connected to the conductor and surrounding the bottom insulator as shown in the figure. The guard ring introduces capacitance between metal fittings and the line conductor. The guard ring is contoured in such a way that shunt capacitance currents i_1, i_2 etc. are equal to metal fitting line capacitance currents i'_1, i'_2 etc. The result is that same charging current I flows through each unit of string. Consequently, there will be uniform potential distribution across the units.





Question 1:

In a 33 kV overhead line, there are three units in the string of insulators. If the capacitance between each insulator pin and earth is 11% of self-capacitance of each insulator, find

(a) Distribution of voltage over 3 insulators

(b) String efficiency

Question 2:

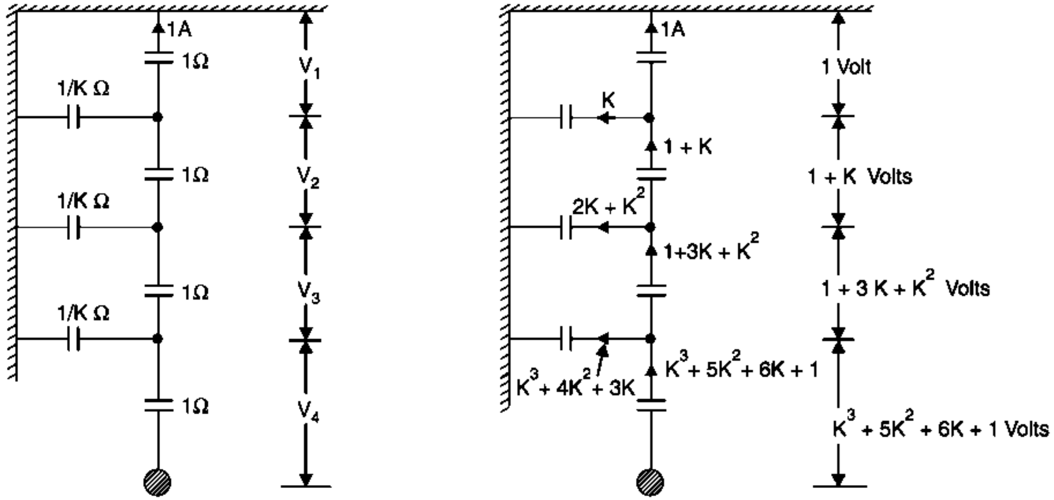
Each line of a 3-phase system is suspended by a string of 3 similar insulators.

(a) If the voltage across the line unit is 17.5 kV, calculate the line to neutral voltage.

(b) Assume that the shunt capacitance between each insulator and earth is 1/8th of the capacitance of the insulator itself. Find the string efficiency.

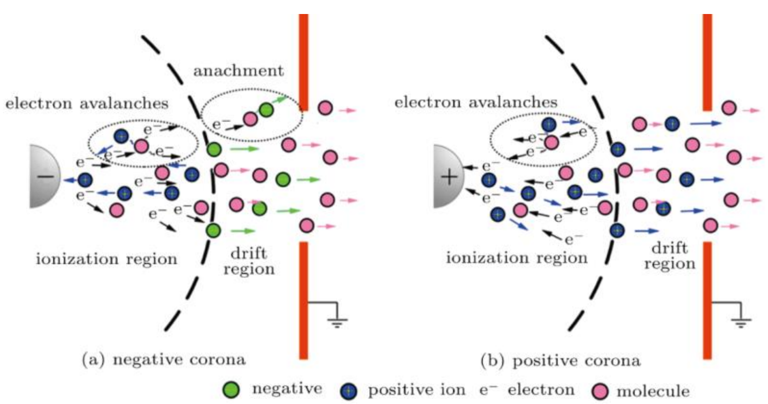
Question 3:

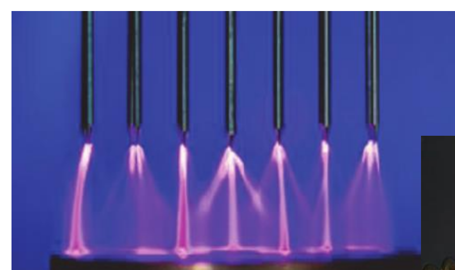
Derive the equivalent voltage at the first insulator in terms of applied voltage (V) and K. Also derive the disc efficiency.

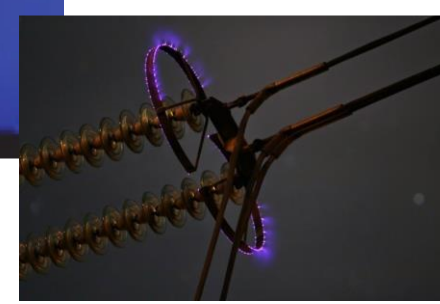


Corona

When an alternating potential difference is applied across two conductors whose spacing is large as compared to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the applied voltage is low. However, when the applied voltage exceeds a certain value, called critical disruptive voltage, the conductors are surrounded by a faint violet glow called corona. The phenomenon of corona is accompanied by a hissing sound, production of ozone, power loss and radio interference. The higher the voltage is raised, the larger and higher the luminous envelope becomes, and greater are the sound, the power loss and the radio noise. If the applied voltage is increased to breakdown value, a flash-over will occur between the conductors due to the breakdown of air insulation. If the conductors are polished and smooth, the corona glow will be uniform throughout the length of the conductors, otherwise the rough points will appear brighter. With d.c. voltage, there is difference in the appearance of the two wires. The positive wire has uniform glow about it, while the negative conductor has spotty glow.







Factor affecting corona:

The phenomenon of corona is affected by the physical state of the atmosphere as well as by the conditions of the line. The following are the factors upon which corona depends on:

1. Atmosphere. As corona is formed due to ionsiation of air surrounding the conductors, therefore, it is affected by the physical state of atmosphere. In the stormy weather, the number of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.
2. Conductor size. The corona effect depends upon the shape and conditions of the conductors. The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage. Thus a stranded conductor has irregular surface and hence gives rise to more corona that a solid conductor.
3. Spacing between conductors. If the spacing between the conductors is made very large as compared to their diameters, there may not be any corona effect. It is because larger distance between conductors reduces the electro-static stresses at the conductor surface, thus avoiding corona formation.
4. Line voltage. The line voltage greatly affects corona. If it is low, there is no change in the condition of air surrounding the conductors and hence no corona is formed. However, if the line voltage has such a value that electrostatic stresses developed at the conductor surface make the air around the conductor conducting, then corona is formed.

Calculation:

1. Critical Disruptive Voltage is the minimum phase voltage at which corona occurs. Consider two conductor of radii *r* cm and spaced *d* cm apart. If *V* is the phase potential, then potential gradient at the conductor surface is given by:

$$g_0 = \frac{V_c}{r \ln \frac{d}{r}} = 30\text{kV/cm (max.) or } 21.2 \text{ kV/cm (r.m.s)} \tag{1.8}$$

Critical Disruptive Voltage is given by

$$V_c = m_0 g_0 \delta r \ln \frac{d}{r}, \qquad \delta = \frac{3.92b}{273 + T} \tag{1.9}$$

where δ is air density factor depending on b, barometric pressure b [cmHg] and temperature T[°C], and m_0 is irregularity factor with m_0 = 1 for polished conductor, 0.8 for stranded conductors.

2. Visual Critical Voltage is the minimum phase voltage at which corona glow appears all along the line conductors. It is higher than the critical disruptive voltage with formula

$$V_v = m_v g_0 \delta r \left(1 + \frac{0.3}{\sqrt{\delta r}}\right) \ln \frac{d}{r} \text{ [kV/phase]} \tag{1.10}$$

where m_v is another irregularity factor with 1.0 for polished conductor and 0.72 for rough conductors.

3. Power Loss due to corona, dissipated in form of light, heat, sound and chemical action when disruptive voltage exceeded, is given by [kW/km/phase]

$$P = 242.2 \frac{f + 25}{8} \sqrt{\frac{r}{d}} (V - V_c)^2 \times 10^{-5} \tag{1.11}$$

Question 4:

(a) A 3-phase line has conductors 2 cm in diameter spaced equilaterally 1 m apart. If the dielectric strength of air is 30 kV (max) per cm, find the disruptive critical voltage for the line. Take air density factor $\delta = 0{\cdot}952$ and irregularity factor $m_o = 0{\cdot}9$.

(b) A 3-phase, 220 kV, 50Hz transmission line consists of 1.5 cm radius conductor spaced 2 m apart in equilateral triangular formation. If the temperature is 40ºC and atmospheric pressure is 76 cm, calculate the corona loss per km of the line. Take $m_o = 0{\cdot}85$.

Question 5:

A certain 3-phase equilateral transmission line has a total corona loss of 53 kW at 106 kV and a loss of 98 kW at 110·9 kV.

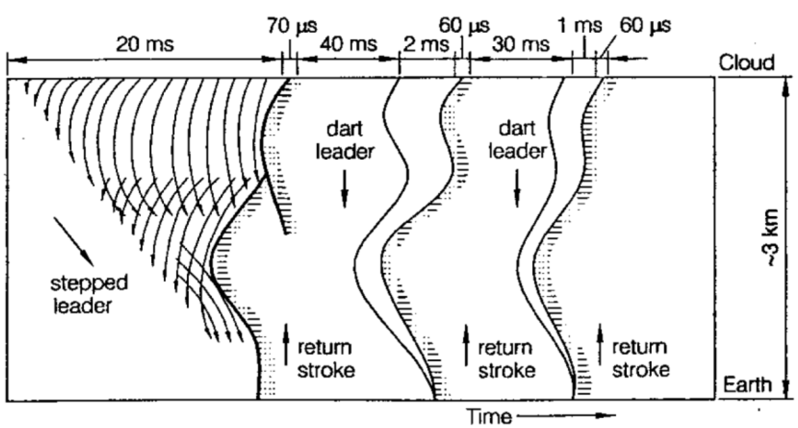
(a) What is the disruptive critical voltage?

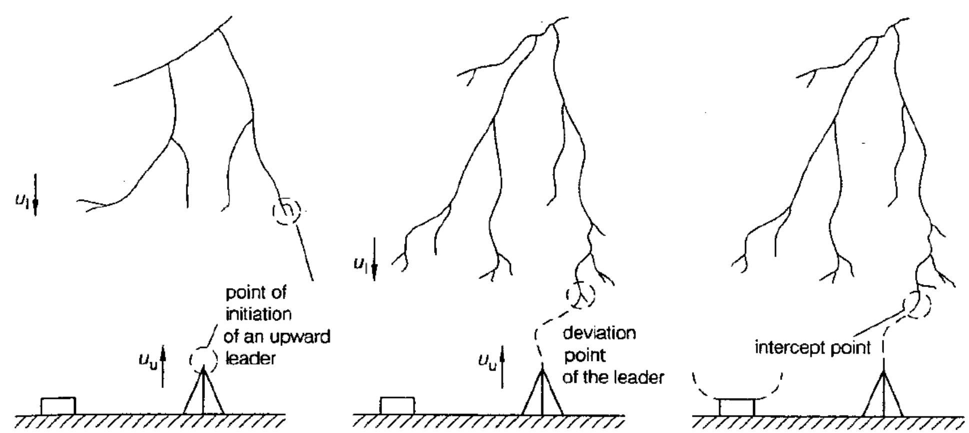
(b) What is the corona loss at 113 kV?

To reduce corona effect:

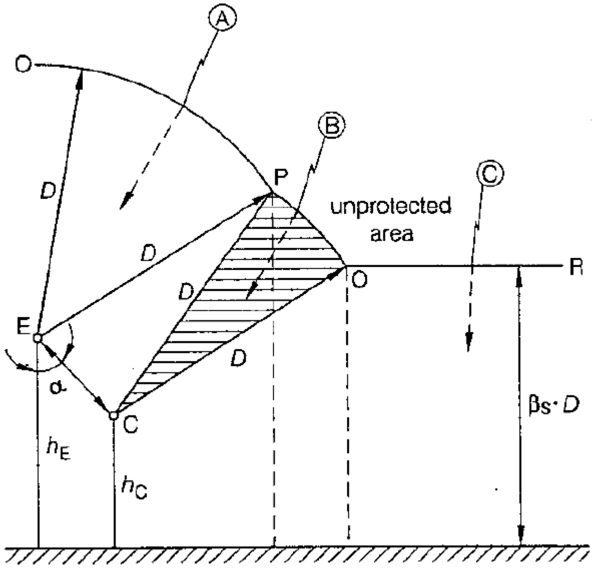
1. By increasing conductor size. By increasing conductor size, the voltage at which corona occurs is raised and hence corona effects are considerably reduced. This is one of the reasons that ACSR conductors which have a larger cross-sectional area are used in transmission lines.
2. By increasing conductor spacing. By increasing the spacing between conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated. However, spacing cannot be increased too much otherwise the cost of supporting structure (e.g., bigger cross arms and supports) may increase to a considerable extent.

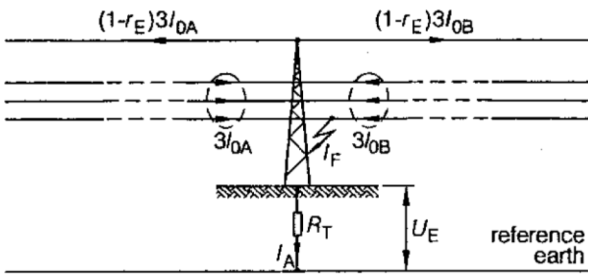
Lightning

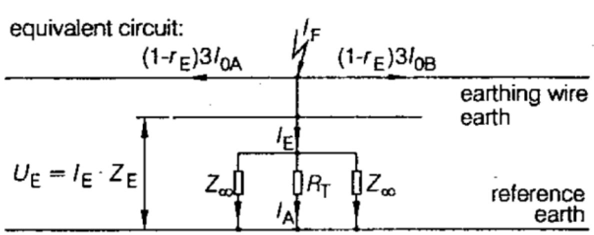


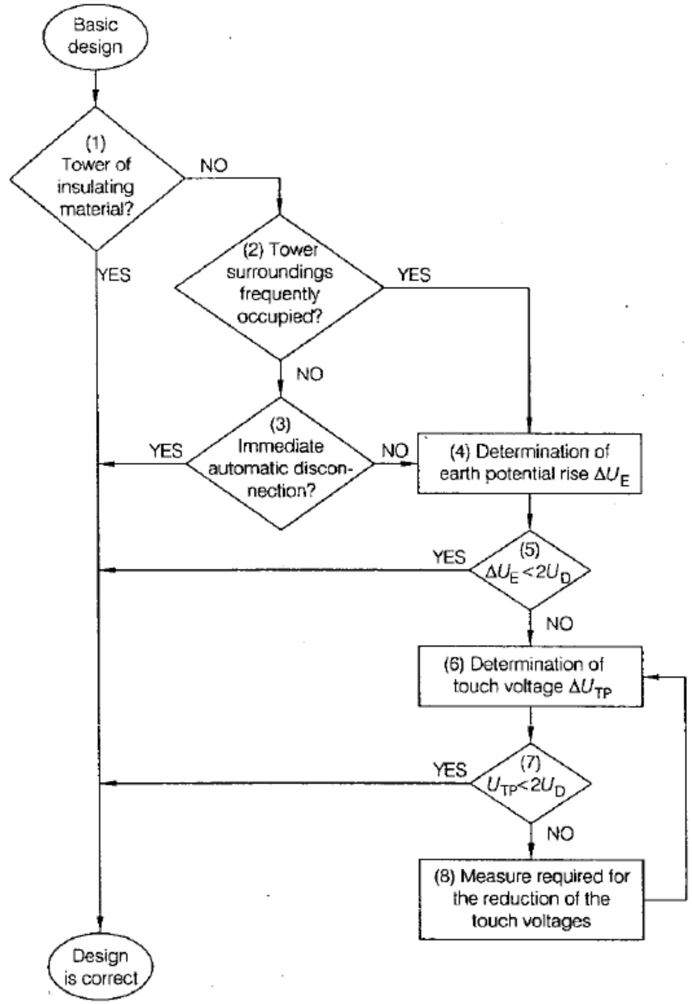


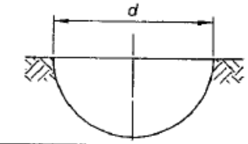
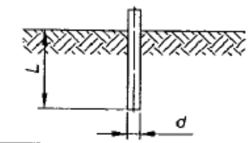
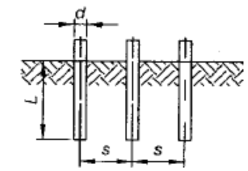
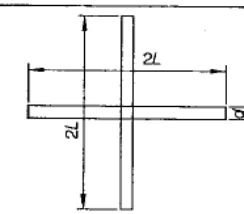
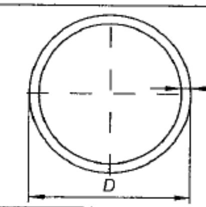
Shielding, Earth Wire and Electrode

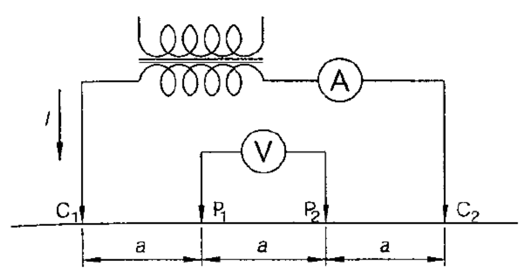


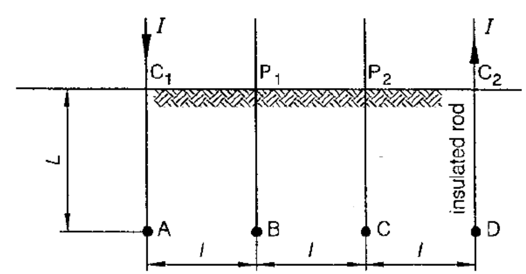






Type of earth electrode	Schematic representation
Hemisphere diameter d	
One earthing rod	
Several earthing rods	
Horizontally burried electrodes, circular cross section, independent of depth t	
Horizontally burried electrodes, crosswise arranged, depth t	
Ring electrode, ring diameter D, independent of depth t	





Earth Wire Selection

Consider conductor temperature with adiabatic process based on the heat balance at the conductor.

$$m_c\, c\frac{dT}{dt} = N_{I^2R} + N_{solar} + N_B - N_{conv} - N_{rad} \tag{1.12}$$

Heat produced by the short circuit current through Joule's Law will be fully employed in increasing conductor temperature until a balance is reached without heat dissipation by convection or radiation. From (1.12),

$$A_2\gamma\, c\frac{dT}{dt} = N_{I^2R} \tag{1.13}$$

where A_2 is the cross section contributing to heat storage and γ is specific mass.
Consider also the thermal effect to the resistance,

$$A_2\gamma\, c\frac{dT}{dt} = I^2[R(1+\alpha(T-20)] \rightarrow \frac{dT}{dt} = I^2\frac{R(1+\alpha(T-20))}{A_2\gamma c} \tag{1.13}$$

Consider R' = ρ'/A_1.

$$\int_{T_1}^{T_2}\frac{dT}{1+\alpha(T-20)} = \int_0^{t_K}\frac{\rho' I^2}{A_1A_2\gamma c}\,dt \tag{1.14}$$

where ρ' is the resistivity of well conducting part and A_1 is its cross section.
After integration,

$$\frac{1}{\alpha}\ln\frac{1+\alpha(T_2-20)}{1+\alpha(T_1-20)} = \frac{\rho' I^2 t_K}{A_1A_2\gamma c} \tag{1.15}$$

where t_K is the short-circuit duration and T_1 and T_2 are the initial and final temperature. The final earth wire temperature for a thermally equivalent short-circuit network is then obtained

$$T_2 = 20 + \frac{1}{\alpha}\left(\big(1+\alpha(T_1-20)\big)\exp\frac{\rho' I^2 t_K}{A_1A_2\gamma c} - 1\right) \tag{1.15}$$

The short circuit current equivalent to final temperature T_2 is determined by:

$$I_{th} = \sqrt{\frac{\gamma c}{\rho\alpha}\ln\frac{1+\alpha(T_2-20)}{1+\alpha(T_1-20)}} \times \sqrt{\frac{A_1A_2}{t_K}} \tag{1.16}$$

Assumption:

A. Earth wire is considered as a homogeneous Al conductor and only the conducting component is considered neglecting the steel portion. $A_1 = A_2 = A_{al}$
B. Mass and conductivity of steel portion is considered with $A_1 = A_2 = A_{Al} + A_{fe}$.
C. The conductivity of steel is NOT considered, yet its mass is taken into account. Then, $A_1 = A_{Al}$, $A_2 = A_{Al} + A_{Fe}$ α_{Al}; ρ_{Al}; γ_{tot} and c_{tot}

Given that the thermal equivalent short-circuit current I_{th} and initial alternating short-circuit current I_k''

$$I_{th} = I_k''\sqrt{m+n} \tag{1.17}$$

where m considers the DC component while n considers AC component in heating process. In usual case, n = 1, and

$$m = \frac{\exp(4ft_K \ln(\kappa_S - 1) - 1}{2ft_K \ln(\kappa_S - 1)} \tag{1.18}$$

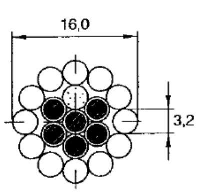
where κ_S = 1.8 for OHL which is factor considering the initial short-circuit current and f is nominal frequency of alternating current component.

Question 6:
Determine the permissible short-circuit current of the conductor 264-AL1/34ST1A for a duration of 1s. Assumptions A, B and C should be considered.

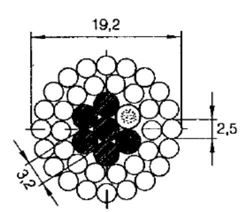
Permissible short circuit current of 264AL1/34ST1A with duration 1s:

Input data and results		Assumption A	Assumption B	Assumption C
Cross section A_1	mm^2	263,7	297,8	263,7
Cross section A_2	mm^2	263,7	297,8	297,8
Specific heat c	Ws/(kg·K)	897	772	772
Specific mass γ	kg/(m· mm^2)	0,002703	0,00328	0,00328
Temperature coefficient of resistance α	1/K	0,00403	0,00403	0,00403
Resistivity ϱ	Ωmm^2/m	0,0283	0,0326	0,0283
Initial temperature T_1	°C	40	40	40
Final temperature T_2	°C	160	160	160
Nominal frequency f	Hz	50	50	50
Factor κ_S	—	1,8	1,8	1,8
Factor m	—	0,0448	0,0448	0,0448
I_{th}	kA	23,4	25,2	25,4
I_k''	kA	22,9	24,6	24,8

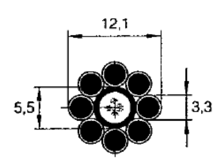
	97-AL1/ 48-A20SA	167-AL3/ 43-A20SA	OPGW 68-A20SA
Rated tensile strength (kN)	82	103	81
Modulus of elasticity (kN/mm^2)	96	79	162
Expansion coefficient ($10^{-6}/K$)	17,4	18,8	13,0
Conductor diameter (mm)	16,0	19,2	12,1
Tube diameter (mm)	3,2	3,0	5,5
Wire diameter (mm)	3,2	2,5/3,0	3,3
Everyday stress (N/mm)	85	78,0	137
Long-term stress (N/mm)	400	340	1110
OPGW with stainless steel tube			
Number of fibres	16	36	36
Mass (kg/km)	615	788	505
Short-circuit capacity $I^2 \cdot t([\text{kA}]^2 \cdot s)$	112	425	38
DC resistance (Ω/km)	0,265	0,182	0,88



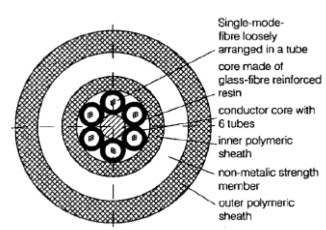
97-AL1/
48-A20SA

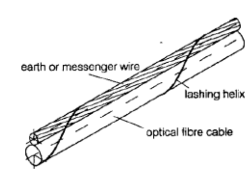


167-AL3/
43-A20SA

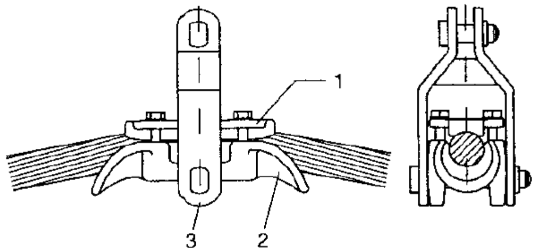


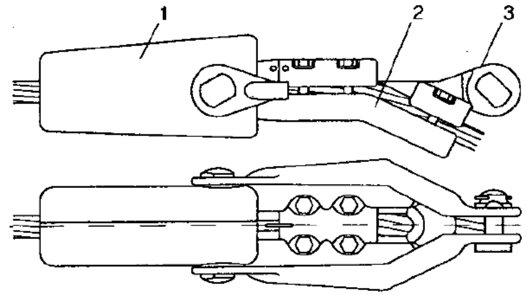
68-A20SA

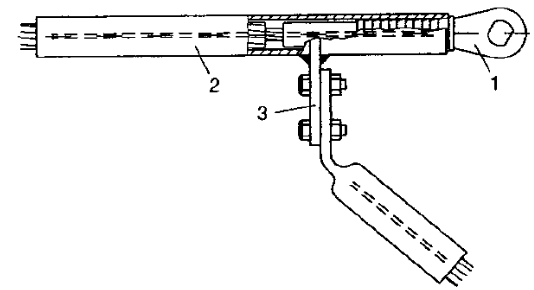


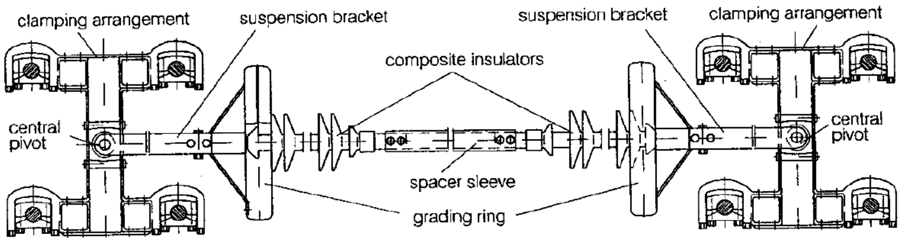


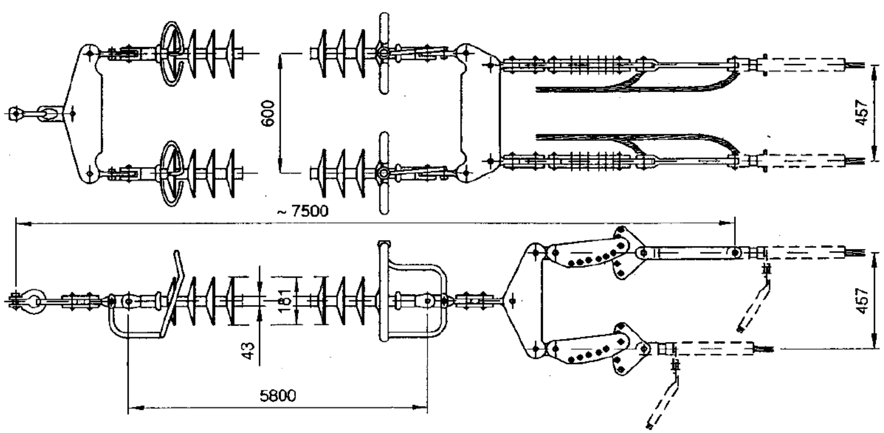
Overhead Line Fitting

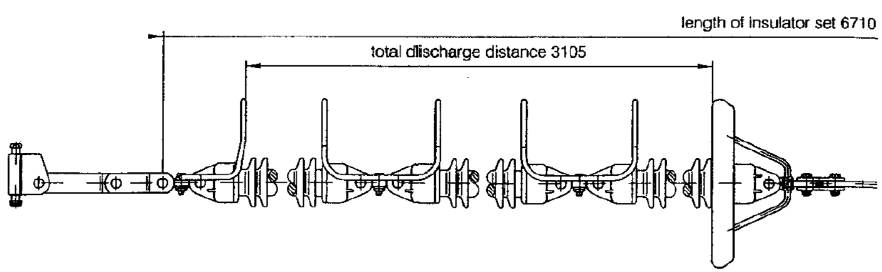












	Type of test	Visual examination	Verfication of dimensions and material	Hot-dip galvanizing	Non-destructive testing	Damage and failure load test	Slip test	Clamp bolt tightning test	Tensile test	Test of attachment point	Magnetic loss test	Heat cycle test	Corona and RIV test
Insulator and earth wire fittings	T	x	x	x [3]	x [3]	x	–	–	–	x	–	–	x [3],[6]
	S	x [2]	x	x	x [3]	x	–	–	–	x [3]	–	–	–
	R	x [3]	x [3]	–	x [3]	x [3],[4]	–	–	–	–	–	–	–
Suspension clamps	T	x	x	x [3]	x [3]	x	x	x	–	–	x [3]	–	x [3],[6]
	S	x [2]	x	x	x [3]	x	x	x [2]	–	–	–	–	–
	R	x [3]	x [3]	–	x [3]	x [3],[4]	–	–	–	–	–	–	–
Tension-proof joints and clamps	T	x	x	x [3]	x [3]	x	–	x	x	x	x [3]	x [5]	x [3]
	S	x [2]	x	x	x [3]	x [3]	–	x [2]	x	x [3]	–	–	–
	R	x [3]	x [3]	–	x [3]	–	–	–	–	x [3],[4]	–	–	–
Partial tension-proof fittings	T	x	x	x [3]	x [3]	–	–	–	x	–	–	x [5]	x [3]
	S	x [2]	x	x	x [3]	–	–	–	–	–	–	–	–
	R	x [3]	x [3]	–	–	–	–	–	–	–	–	–	–
Repair sleeves	T	x	x	x [3]	–	–	–	–	x	–	–	–	x [3]
	S	x [2]	x	–	–	–	–	–	x	–	–	–	–
	R	x [3]	x [3]	–	–	–	–	–	–	–	–	–	–
Insulator protective fittings	T	x	x	x [3]	x [3]	x [3]	–	–	–	–	–	–	x [3],[6]
	S	x [2]	x	x	x [3]	x [3]	–	–	–	–	–	–	–
	R	x [3]	x [3]	–	x [3]	x [3]	–	–	–	–	–	–	–

T type tests; S sample tests; R routine tests

[2] Inspection by attributes only

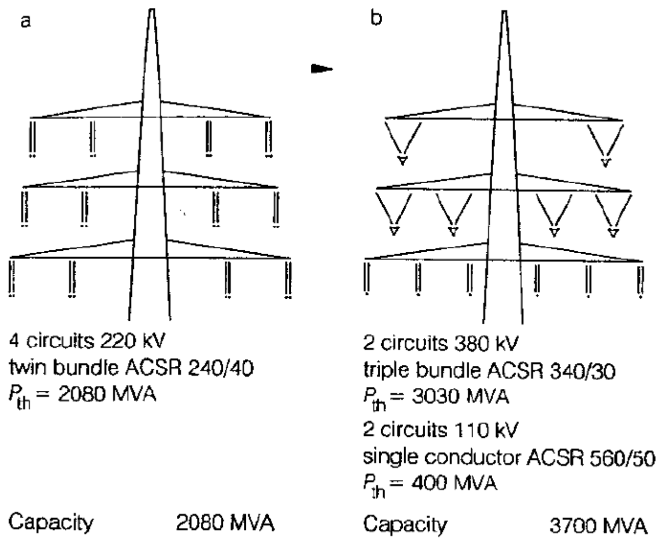
[3] By agreement between purchaser and supplier

[4] Only as regards damage load test

[5] Only for current-carrying joints

[6] Only in connection with complete insulator set

Uprating and Upgrading

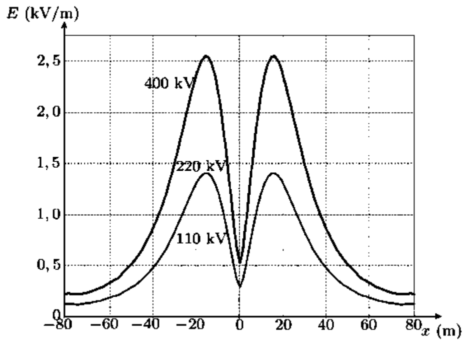


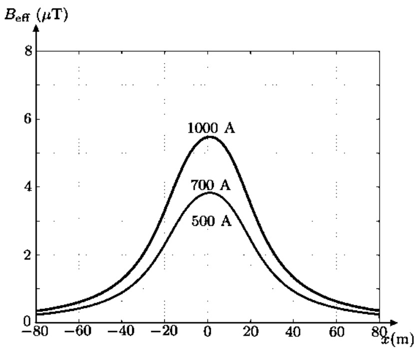
Voltage Upgrading

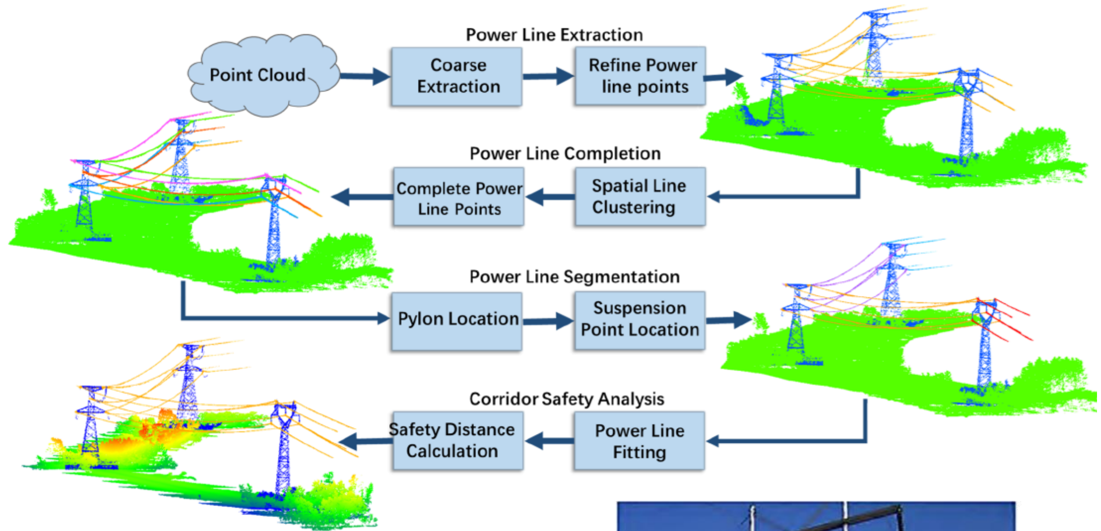
Country	The Original Level of Voltage (kV)	The New Level of Voltage (kV)	Technique
Norway	300	420	• Reinsulation (different types of insulator)
UK	275	400	• Adjusting insulator length
Japan	66	154	• Insulator supported jumper devices and compact phase-to-phase spacers
USA	41.6	115	• Reinsulation, pole-top bracket, midspan spacers, and reconductor
South Africa	275	400	• Reinsulation (phase assembly insulator)
Norway	300	420	• Rearrangement of insulator string and additional insulator discs

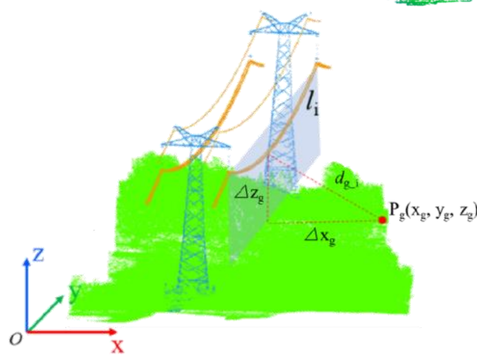
Mechanism	Method	Technique	Process
Increase Voltage Rating	Increase Electrical Clearance	Increase Insulation Electrical Strength	• Adding/ Replacing Insulator • Crossarm Modification
		Improve Conductor Air Clearance	• Structure Body Extension • Interspaced Structure • Conversion of Two to One circuit
Increase Current Rating by Reconductoring (HTLS)	Increase Thermal Rating	Apply Material with High Creeping Resistance	• Conductor Replacement
Increase Current Rating by Adding New Circuit	Increase Current Carrying Capacity	Increase Conductor Cross-Section	• Conductor Replacement
Dynamic Line Rating	Optimize Thermal Rating Limit	Real time data harvesting and optimization	• Application of Phasor Measurement Unit (PMU) and Sensor Network
Replacement to HVDC	Reduce Joules Heat Loss	Add HVDC Converter S/S	• Optimal Placement of HVDC S/S

EM Interference and Remote Sensing

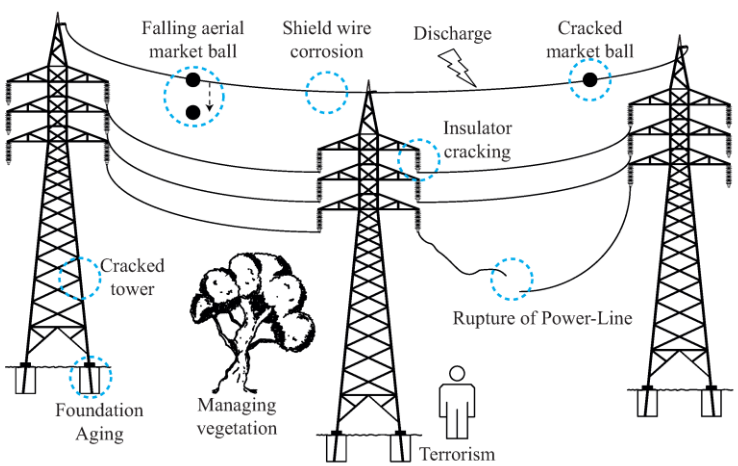


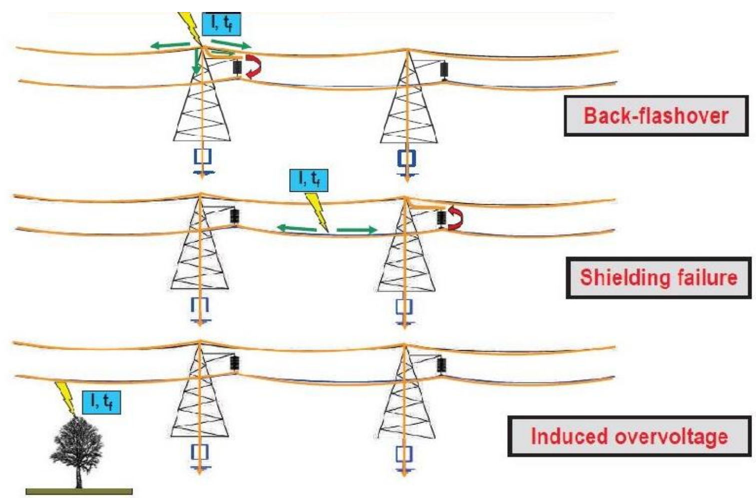




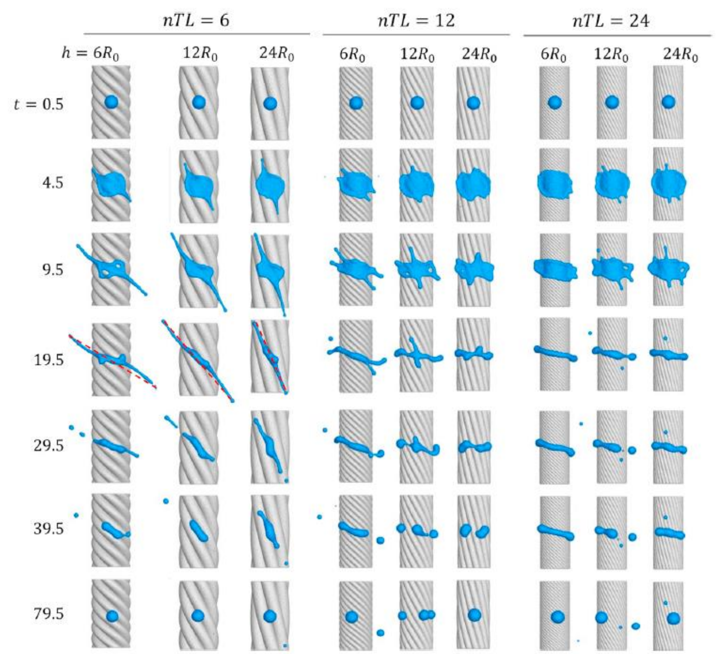


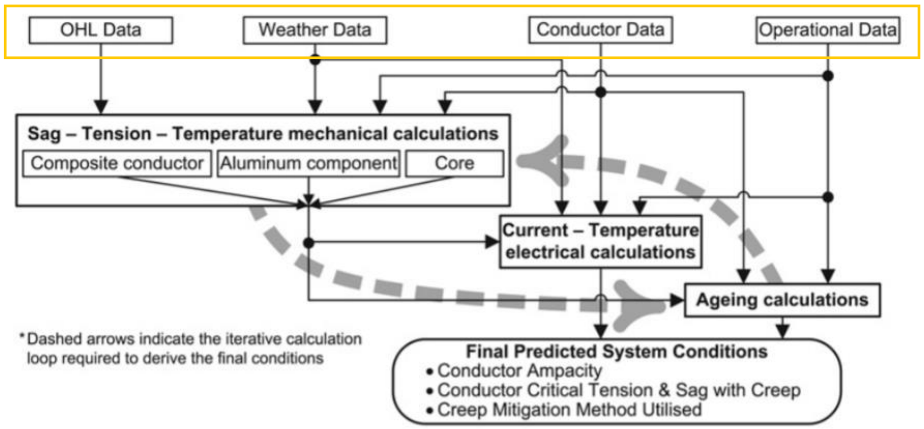
Overhead Line Fault

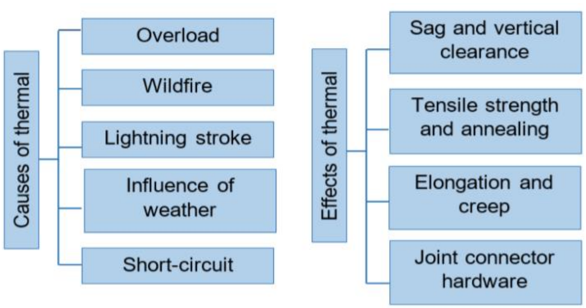




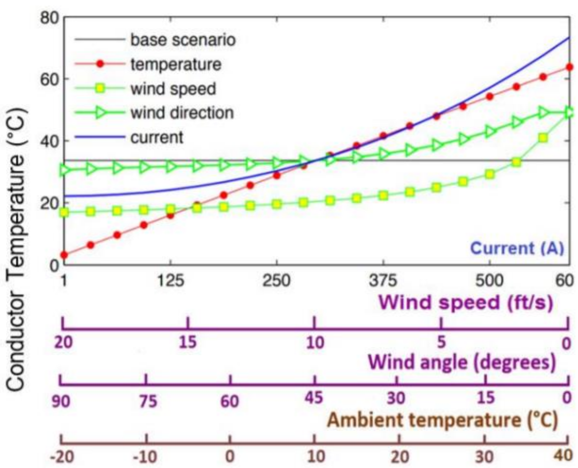
Effect of Meteorological Conditions







Monitoring	Devices/Method
Weather measurement	Thermal rate Weather sensors Weather model
Surface conductor temperature	Power donut SMT Distributed temperature sensor and wide monitoring systems Surface acoustic wave (SAW) sensor Conductor temperature model (CTM)
Vertical ground clearance and sag	Laser distance and laser scanning
Sag and conductor temperature	Current induced in resistive wire Fiber optic-based sensors
Sag monitoring	Global positioning system (GPS) Ampacimon Sagometer Magnetic field sensor Tension ampacity monitoring (TAM)
Tension monitoring	CAT-1



Summary:

This set of notes provides introductory information to the application and theory of overhead lines, including:

- OHL Components
- Comparison of OHL to Underground Cable
- Thermal Limit
- Surge Impedance
- OHL Routing
- Safety Distance and Clearance
- Insulator (and Grading Ring)
- Corona
- Earth Wire and Shielding
- Lightning Failure
- Sag and Tension
- Thermal Monitoring