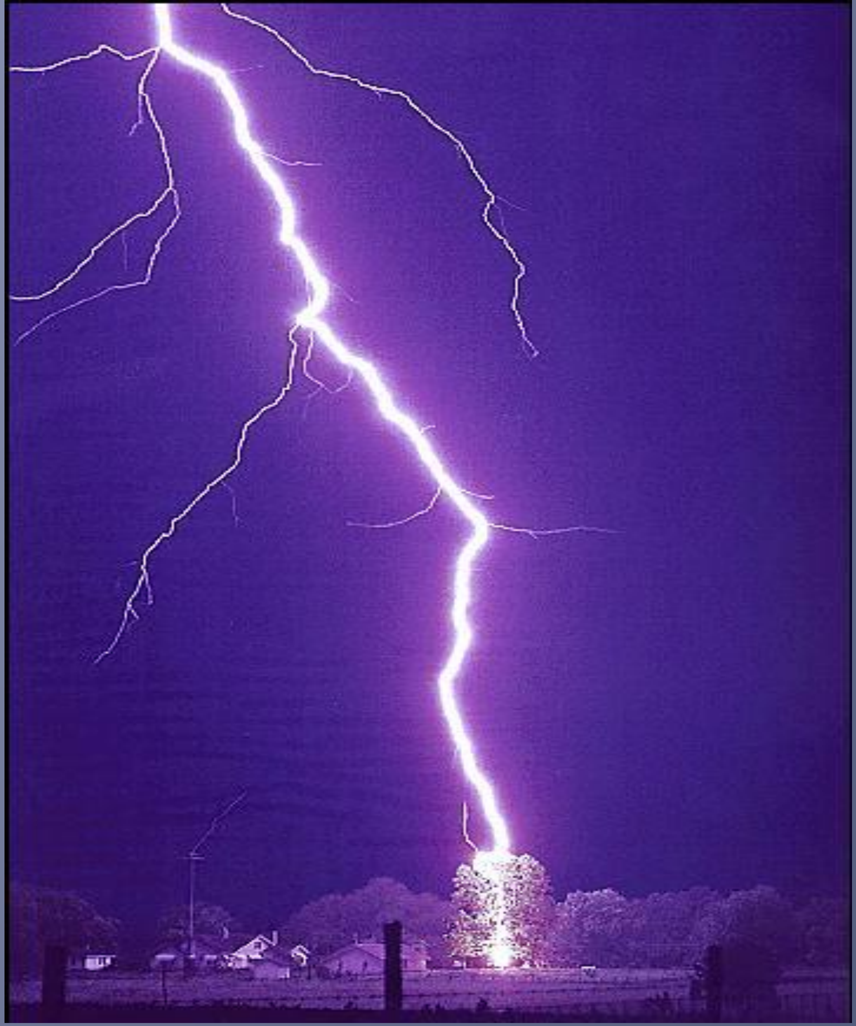
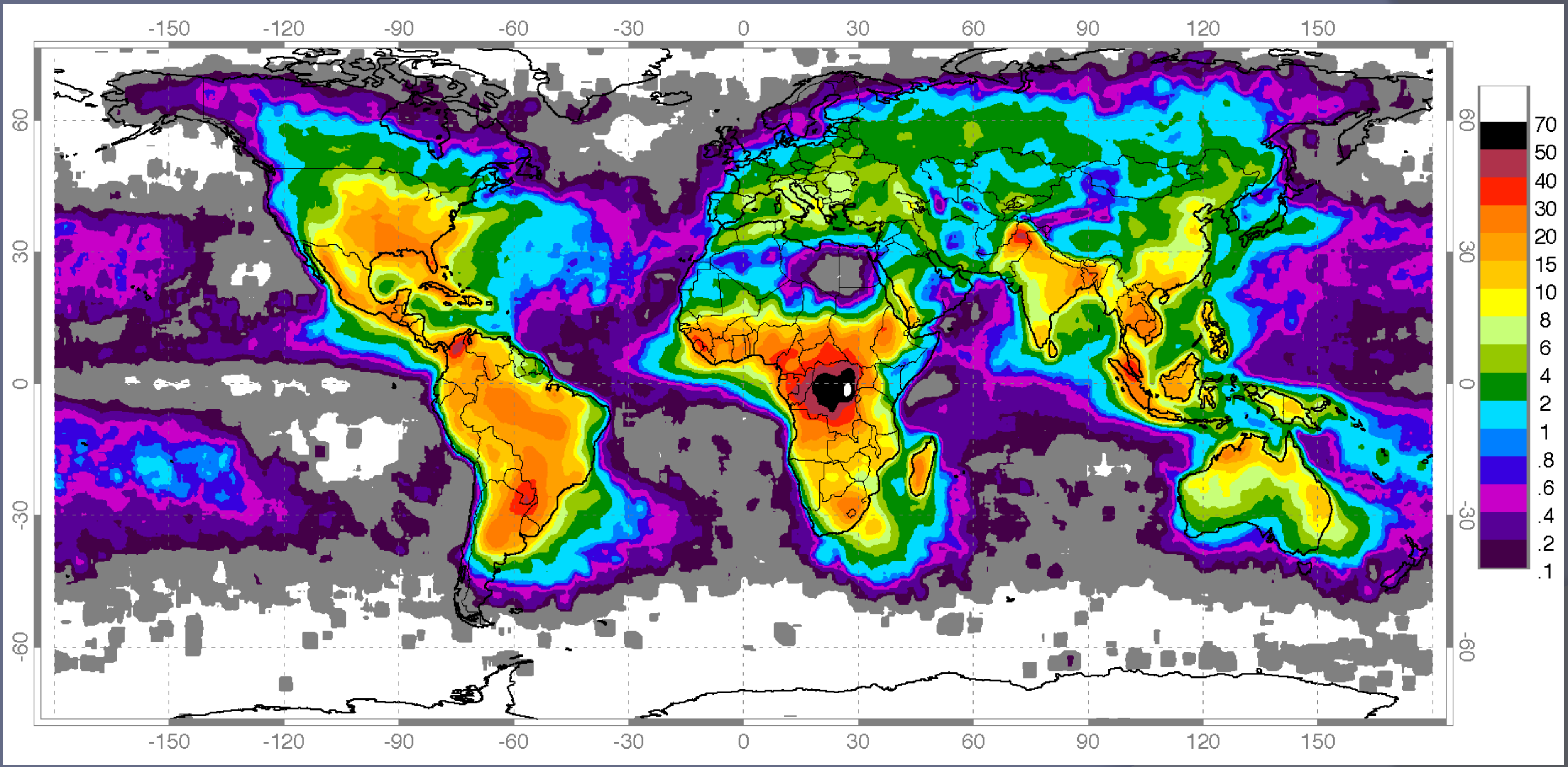


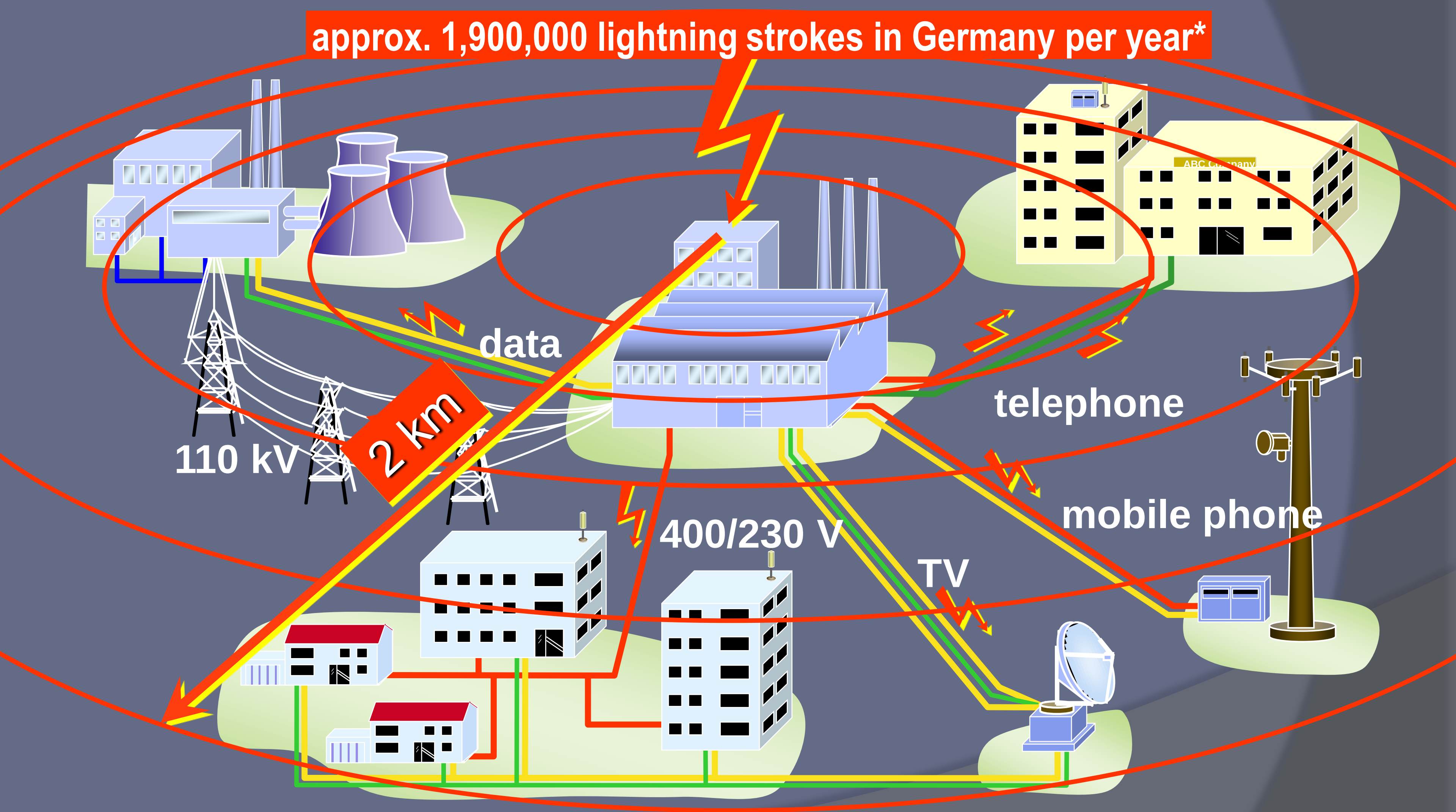
LIGHTING

Dr.-Ing. Getachew Biru

Lightning Prone Regions



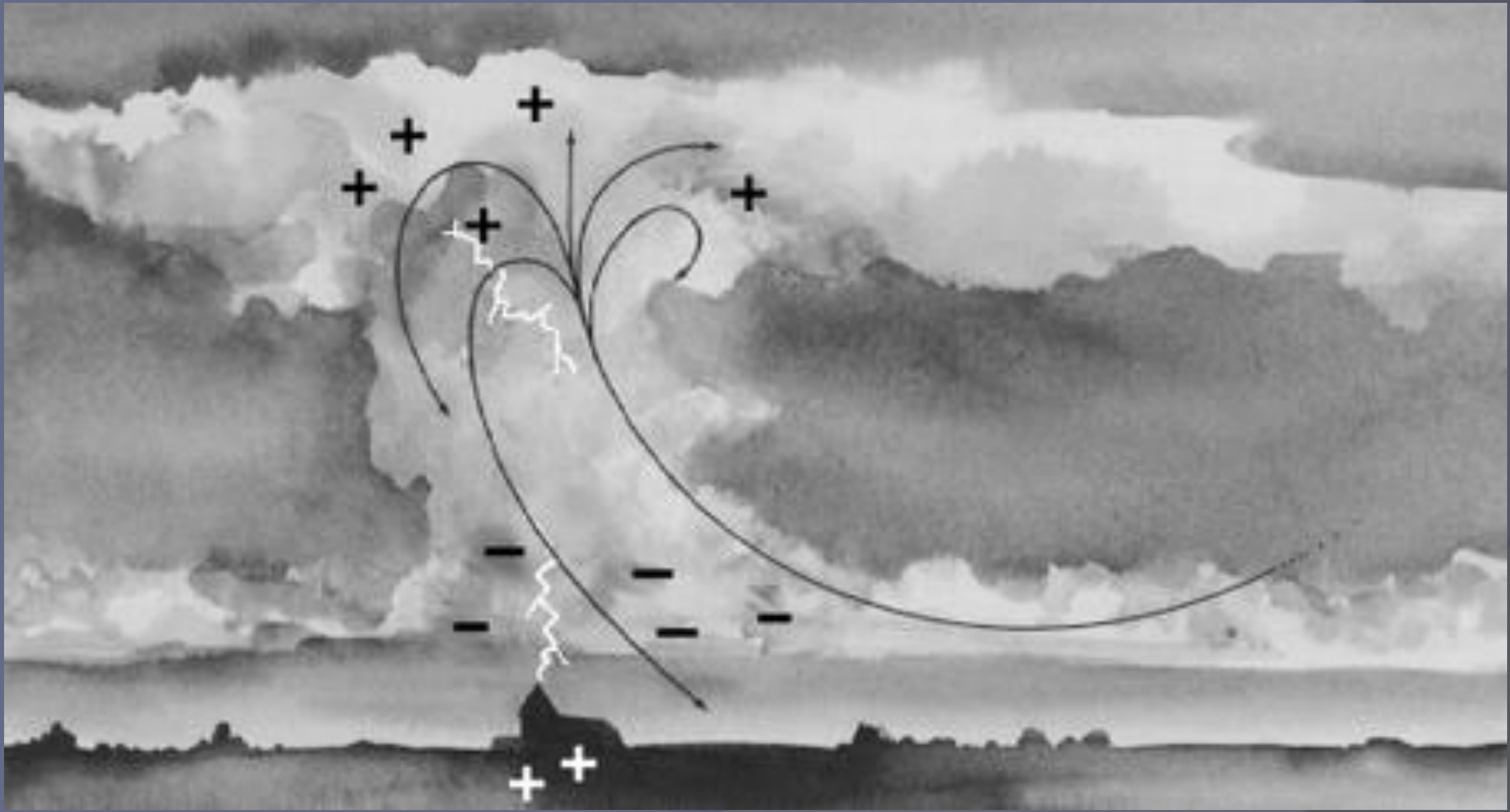
Danger due to Lightning Strokes



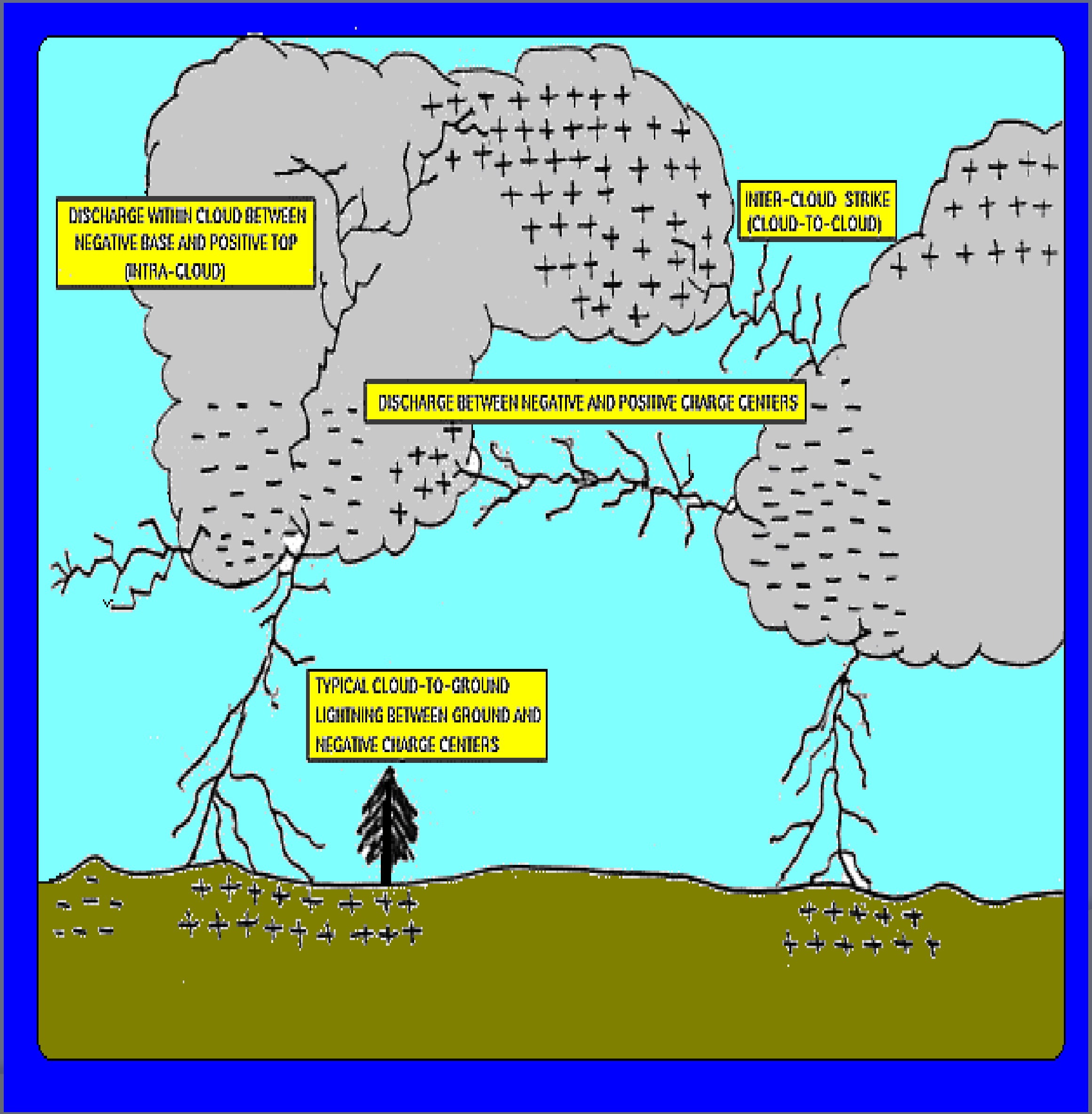
Lightning Production

- Warm, low pressure air moving through cool, high pressure air produces static electricity.
- The friction of moving air particles within the cloud causes ionization and charges.
- As the separation of charge proceeds in the cloud, the potential difference between the centers of charges‘ increases and the vertical electric field along the cloud also increases.

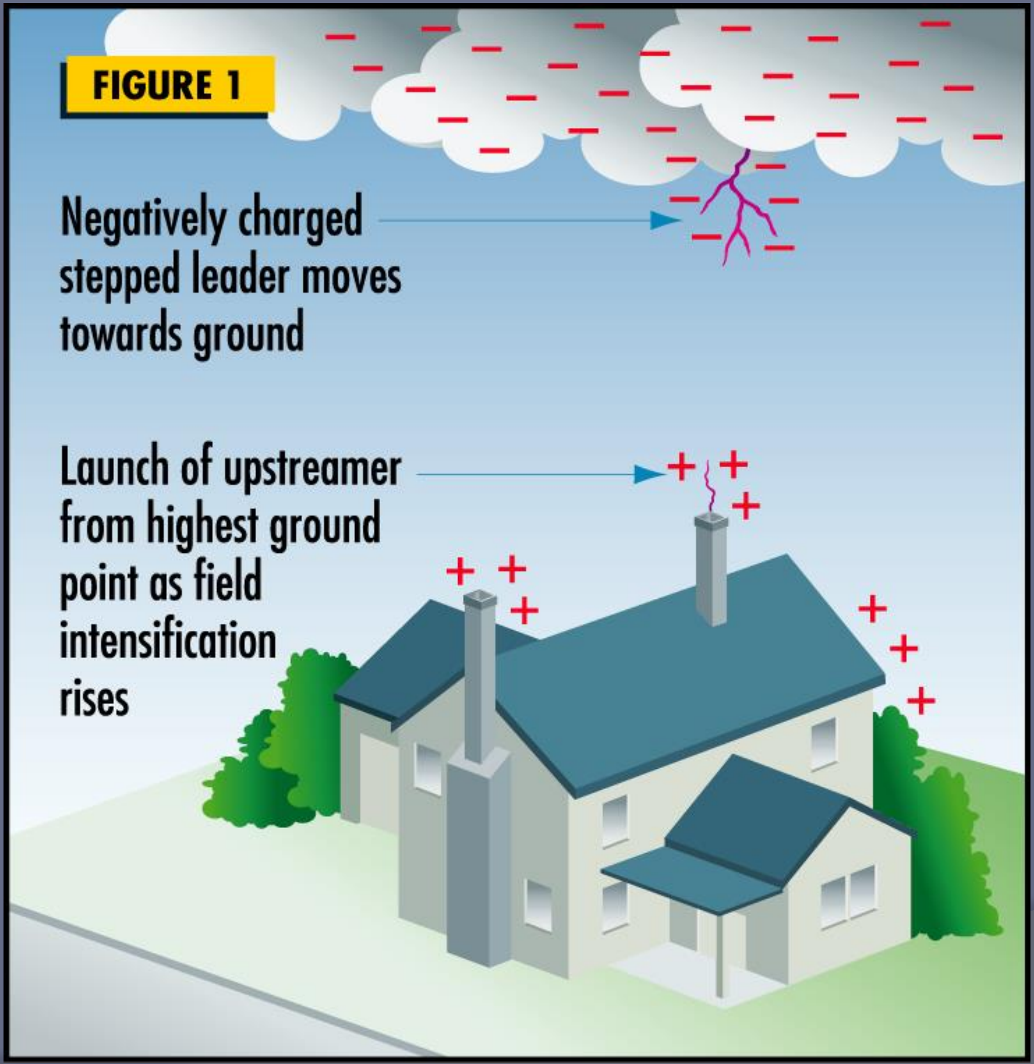
Lightning Production



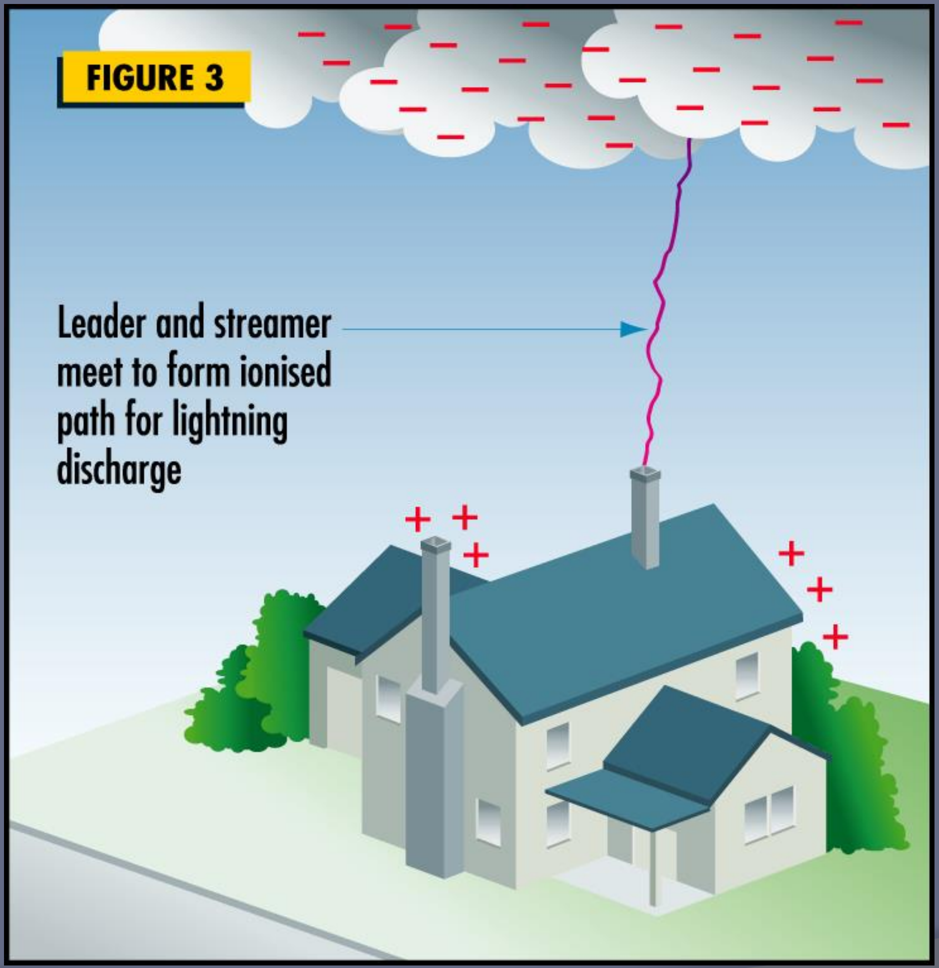
Lightning Production



Lightning Production



Lightning Production



- Positive upward streamer meets the downward step leader
- Conducting path forms
- Potential is equalised by the "return stroke"
- Visible lightning flash

Facts about Lightning

- A strike can produce on average of **100 Mega volts** of Electricity.
- Current of up to 100, kilo amperes
- Can generate 54,000 ^{o}F
- The height of the thundercloud dipole above earth may reach 5 km in tropical regions.
- Lightning strikes somewhere on the Earth every second.
- Kills hundreds of people every year and causes a huge damage to properties and equipments.

Lightning Production

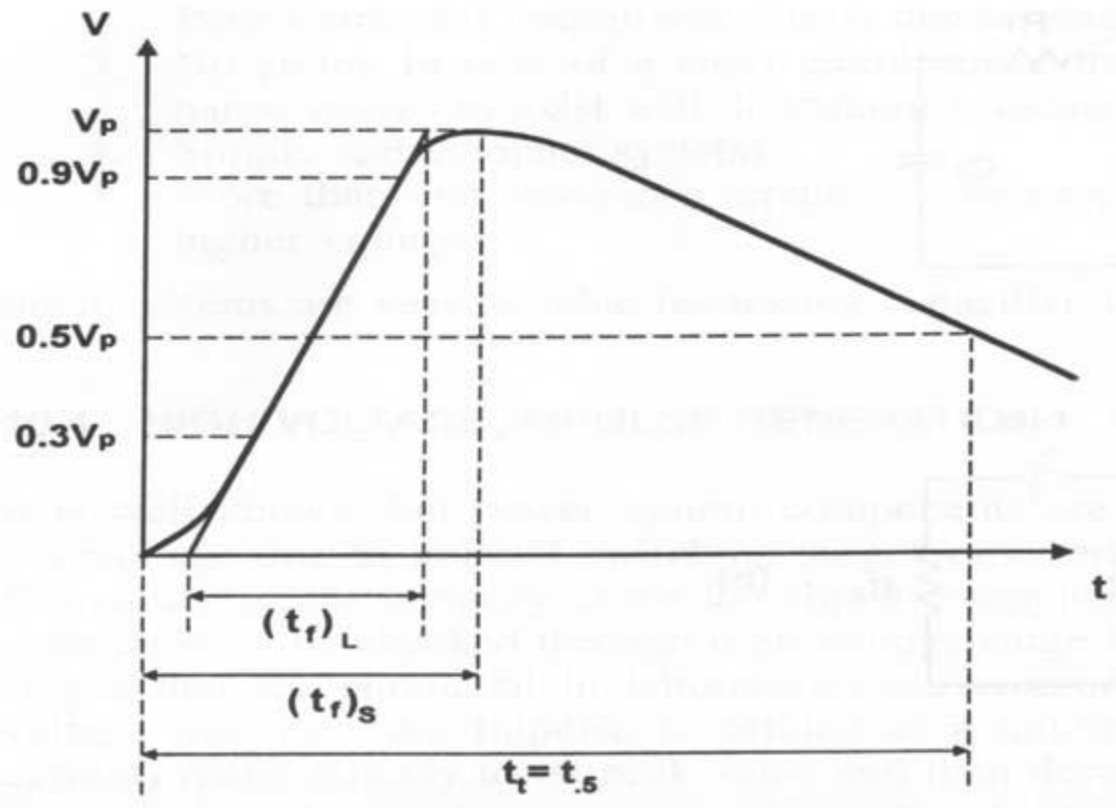
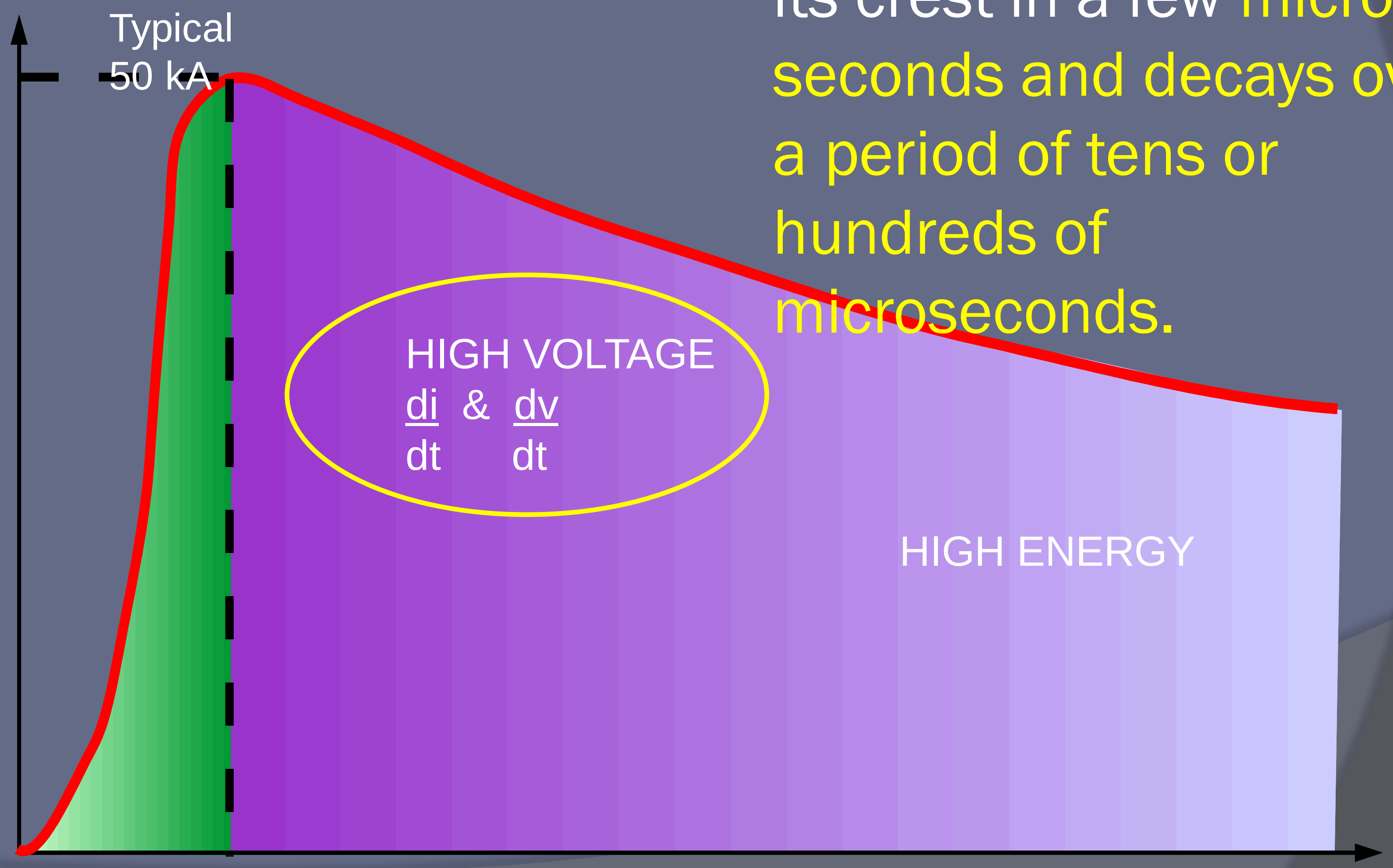


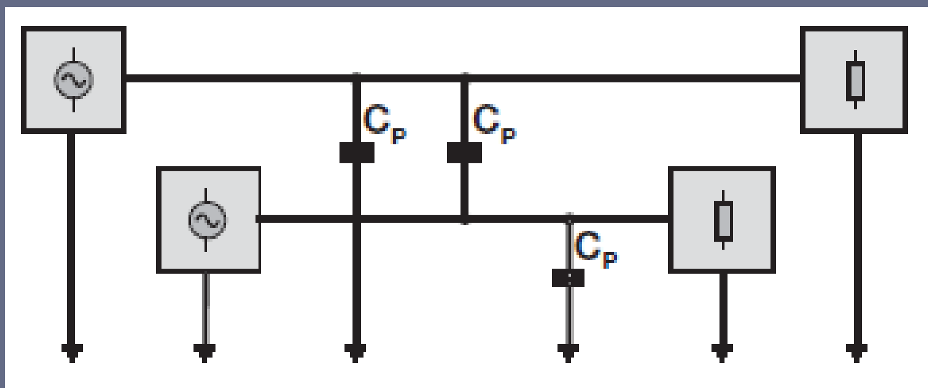
Figure 10.6 Impulse waveshape parameters. $(t_f)_L$ = front time for lightning impulses, $(t_f)_S$ = front time for switching impulses and t_t = time to half value.

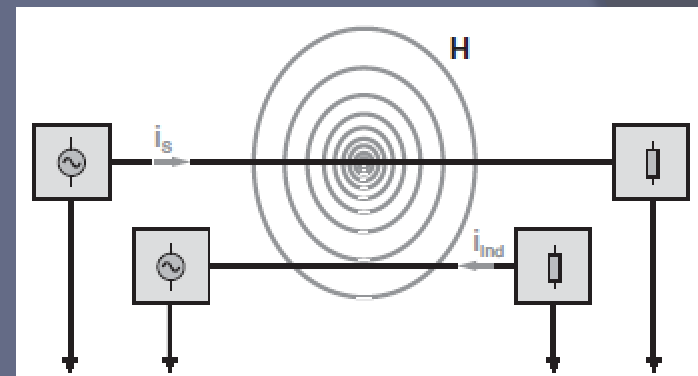
Lightning Production

- The current pulse rises to its crest in a few micro seconds and decays over a period of tens or hundreds of microseconds.



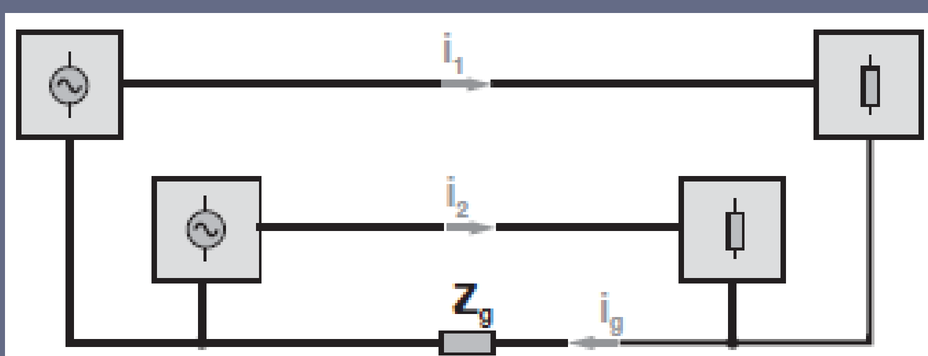
How Transients Enter your Equipment

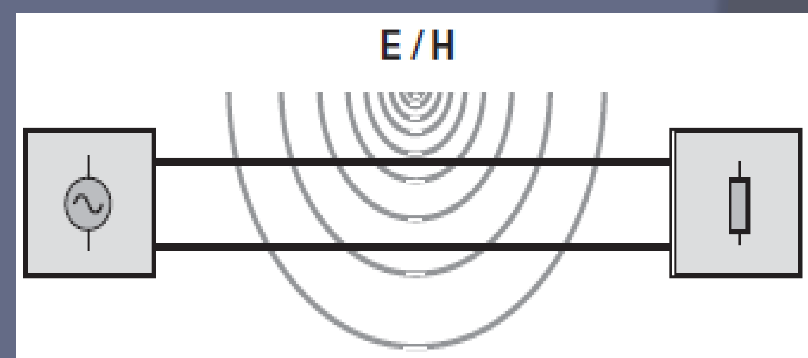




Capacitive coupling

Magnetic coupling

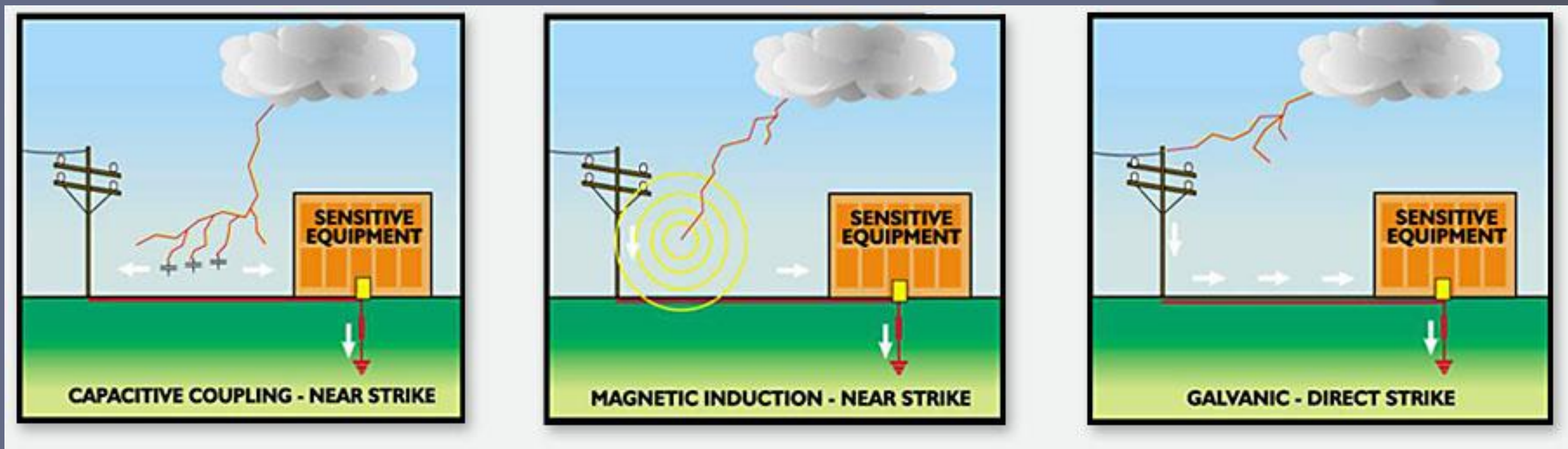




Conductive coupling

Electromagnetic Coupling

How Transients Enter your Equipment



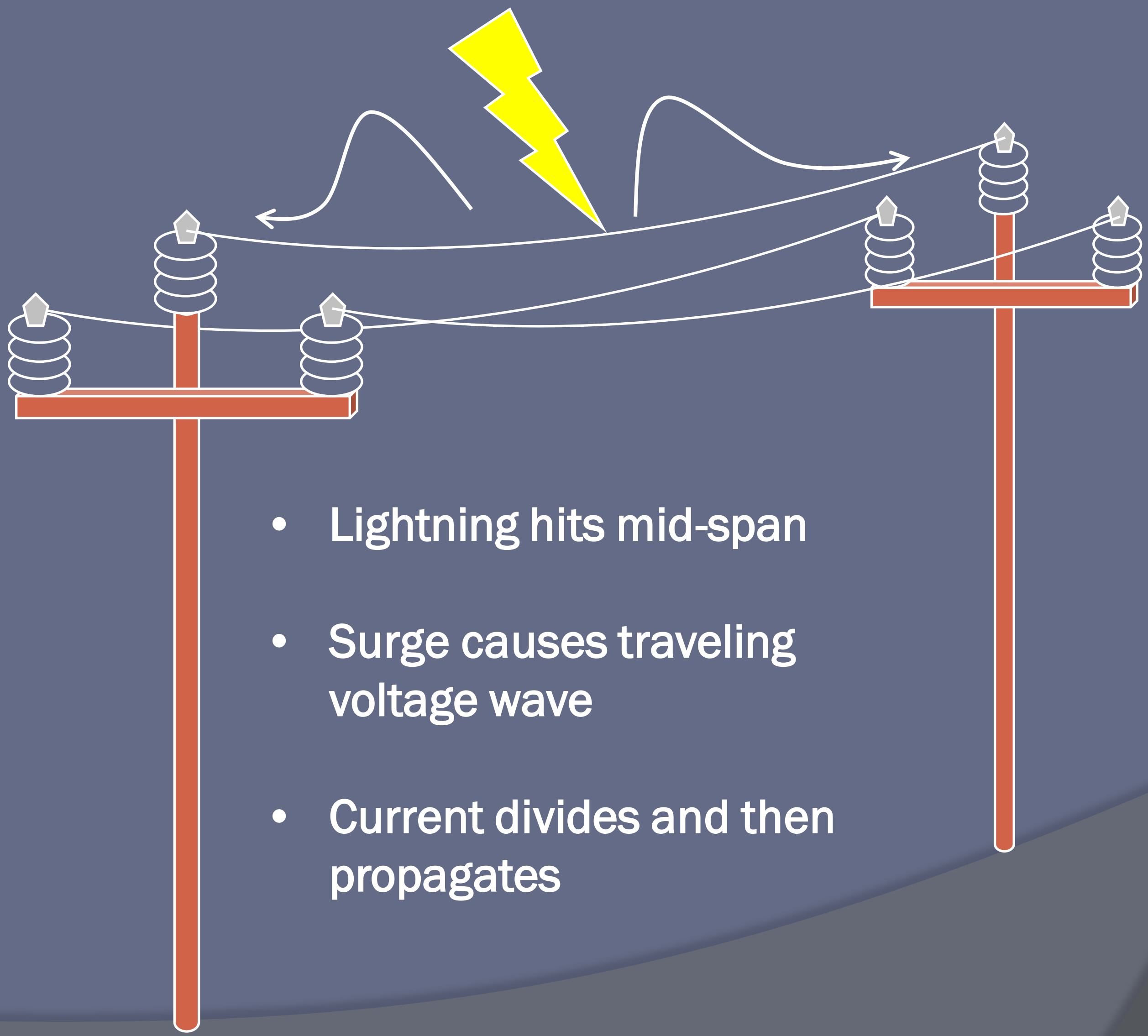
Capacitive coupling is where the transient voltage is coupled due to the inherent capacitance between two circuits

Magnetic coupling occurs when magnetic field of a current carrying conductor induces lightning current on to an adjacent conductor

Galvanic coupling is a direct electrical connection

Lightning Surges

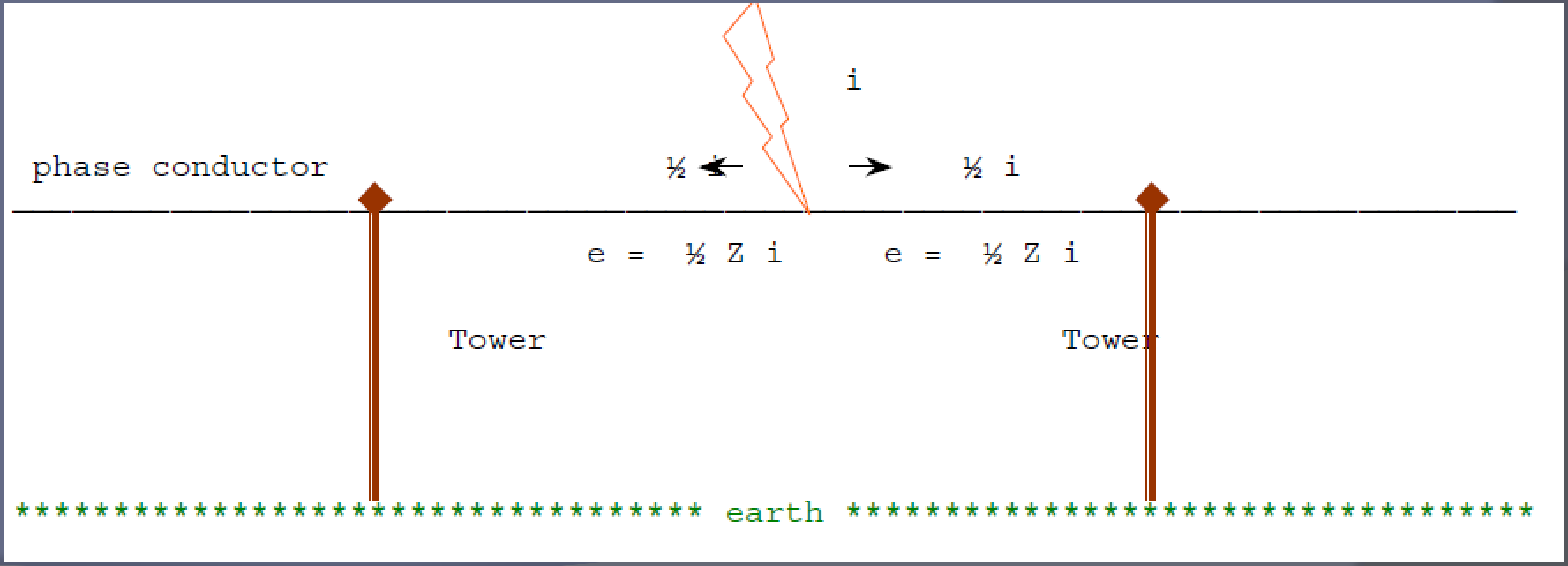
Traveling Wave/ Overvoltage Protection



- Lightning hits mid-span
- Surge causes traveling voltage wave
- Current divides and then propagates

Strokes to a Phase-conductor

- The charged cloud could discharge directly onto the line.
- If the line is struck a long distance from a station or substation, the surge will flow along the line in both directions, shattering insulators and sometimes even wrecking poles until all the energy of the surge is spent.



Lightning Strokes

Lightning current magnitude

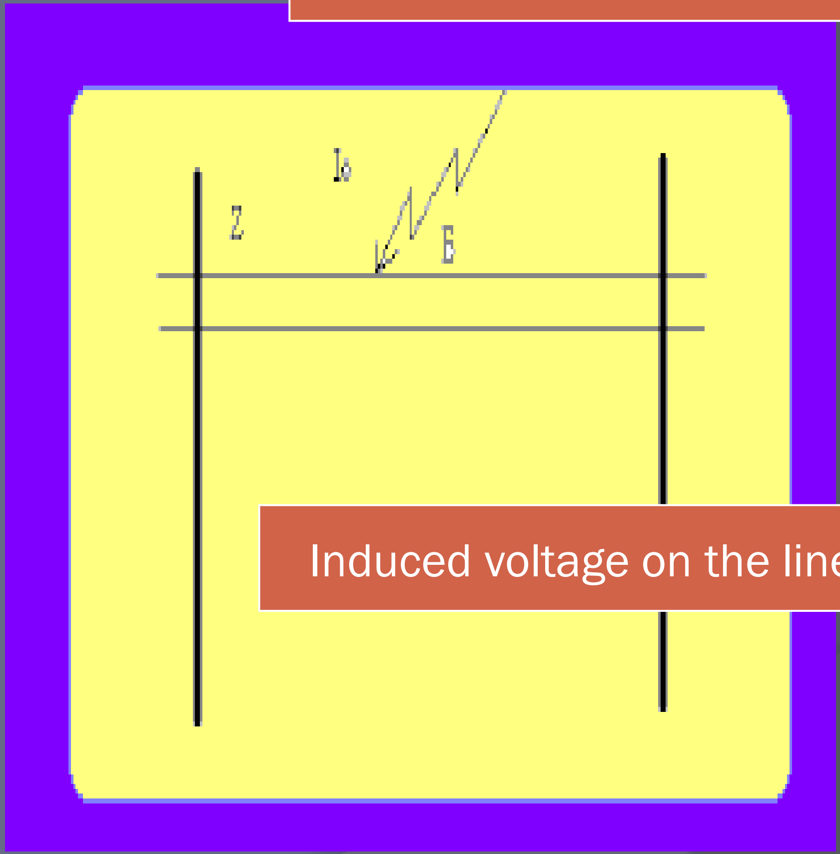
- Direct Stroke
- $V = I\, Z_c / 2$
- $Z_0 = \sqrt{(L/C)}$

  L henry/m

  C farad/m

  Typically:

  $Z_c = 350$ ohm



Induced voltage on the line

Z_o- Surge impedance of the line

Strokes to a Phase-conductor

- The discharge current splits itself equally on contact with the phase conductor, giving travelling waves of magnitude e.

$$e = \frac{1}{2} Z i \left(e^{-\alpha t} - e^{-\beta t} \right)$$

where Z is the surge impedance of the phase conductor.

- Using a typical value for the line surge impedance (say 300 Ω **average lightning current** (20 kA), the voltage waves on the line would have a crest value of

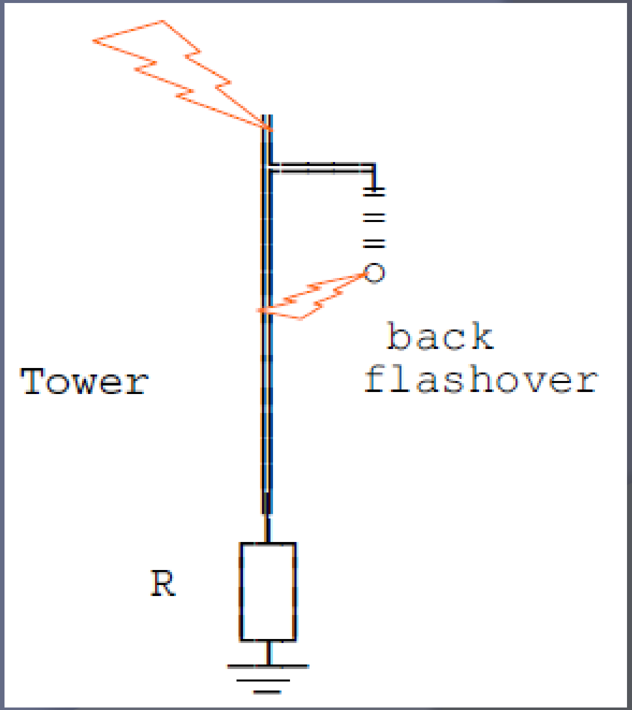
$$E = \frac{1}{2} Z i = (300/2) \times 20 \times 10^{3} = 3 \text{ MV}$$

Strokes to a tower with no earth wire

- The Figure shows a steel tower (inductance **L**) of a transmission line with no earth wire. If the earthling resistance of the tower is **R** (=5-100Ω) and it is struck by lightning then the potential on the tower top will be:

$$R\,i + L\,\frac{d\,i}{d\,t}$$

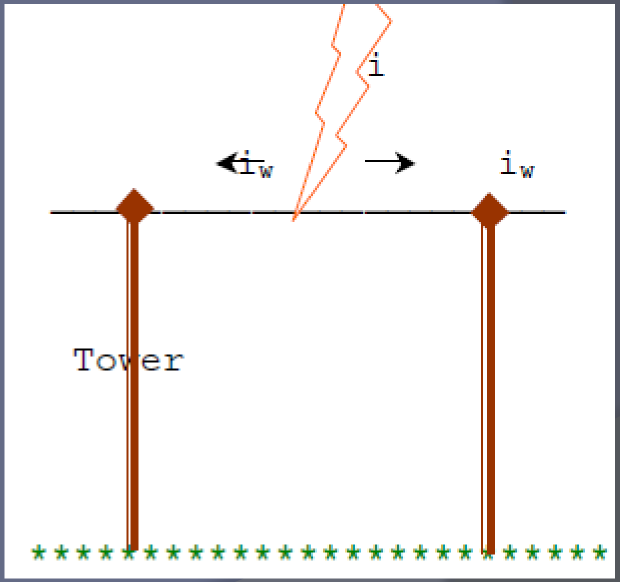
- If the value of **e** exceeds the line insulation strength, then a flashover occurs from the tower to the line and this is termed a **back flashover.**



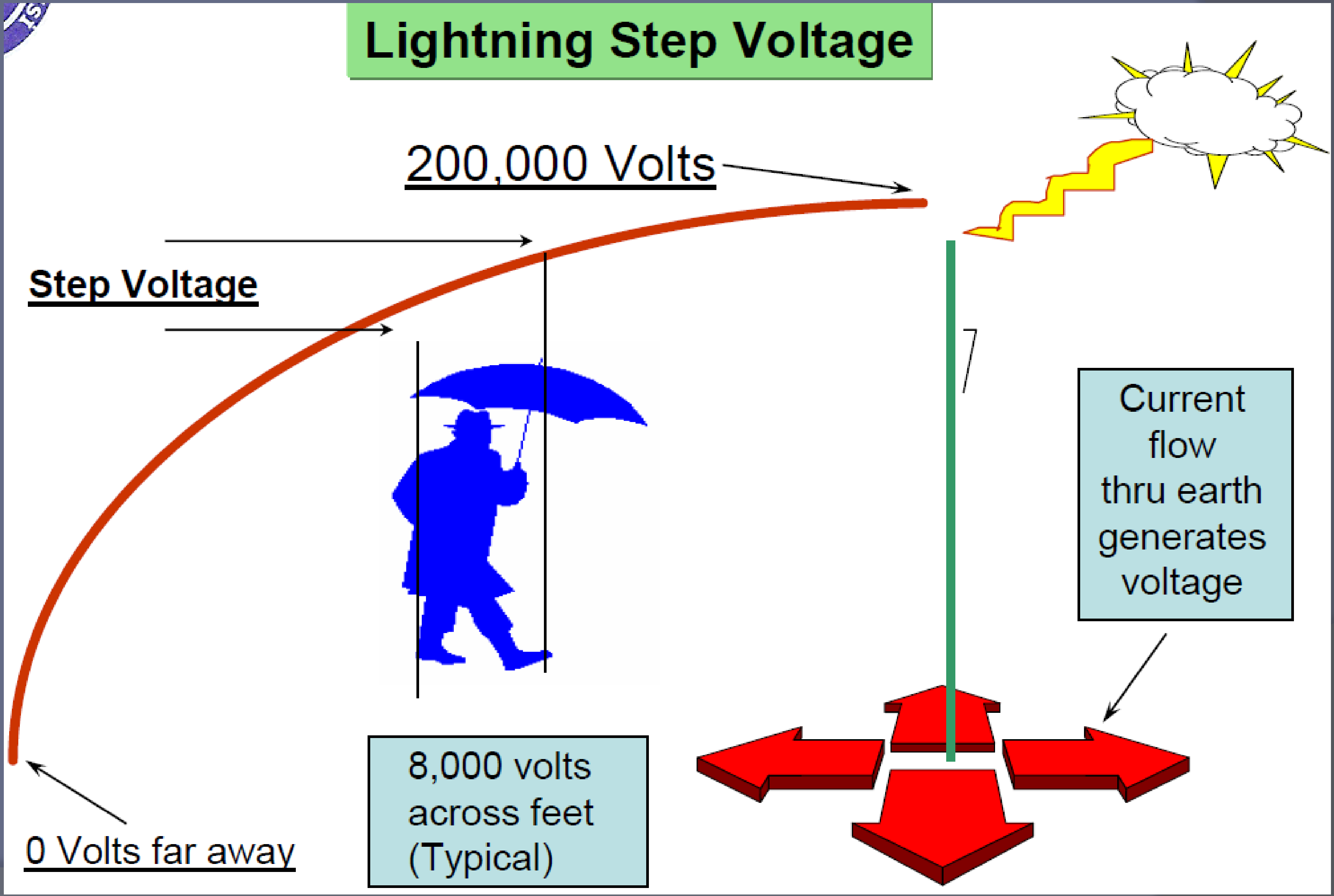
Strokes to Earth Wire

- When a lightning stroke terminates on the tower of a transmission line having an overrunning earth wire, or terminates on the earth wire of the transmission line, then the resulting current flow would be as shown in figure:

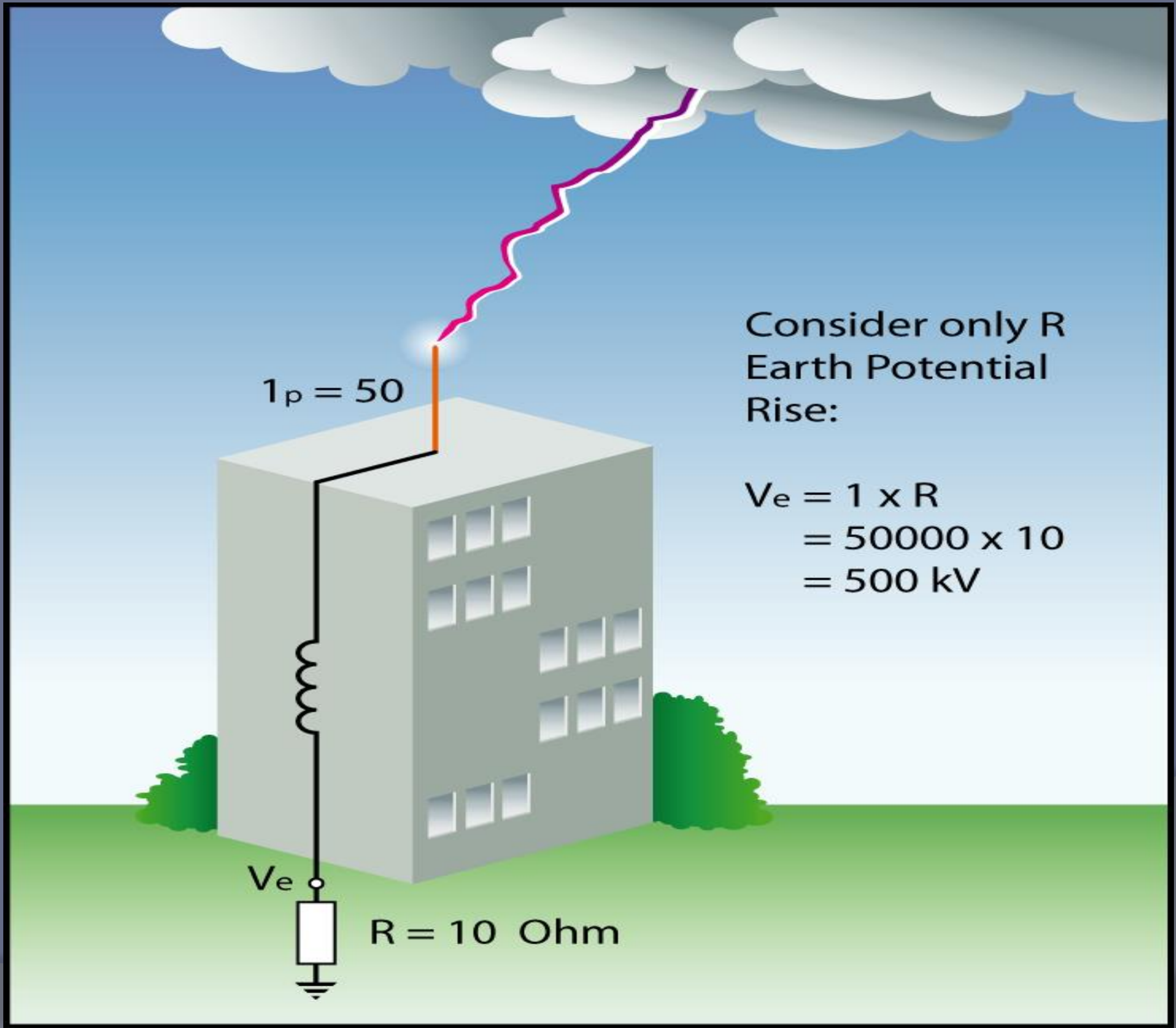
- The voltage waves produced by the current i_w flowing along the earth wire will travel along the earth wire in both directions from the tower struck



Lighting Strokes

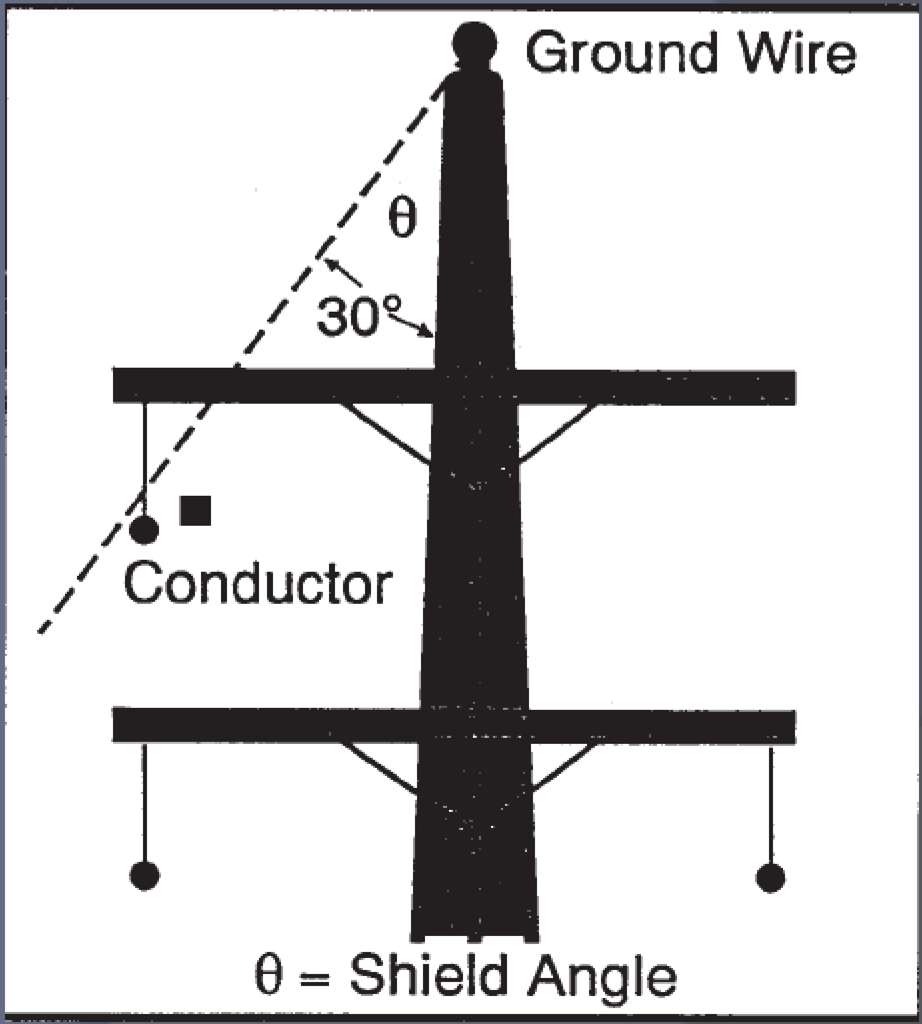


Lighting Strokes



Lightning Protection Using Shield Wires or Ground Wires

- Ground wire is a conductor run parallel to the main conductor of the transmission line supported on the same tower and earthed at every equally and regularly spaced towers.



Lightning Protection Using Shield Wires or Ground Wires

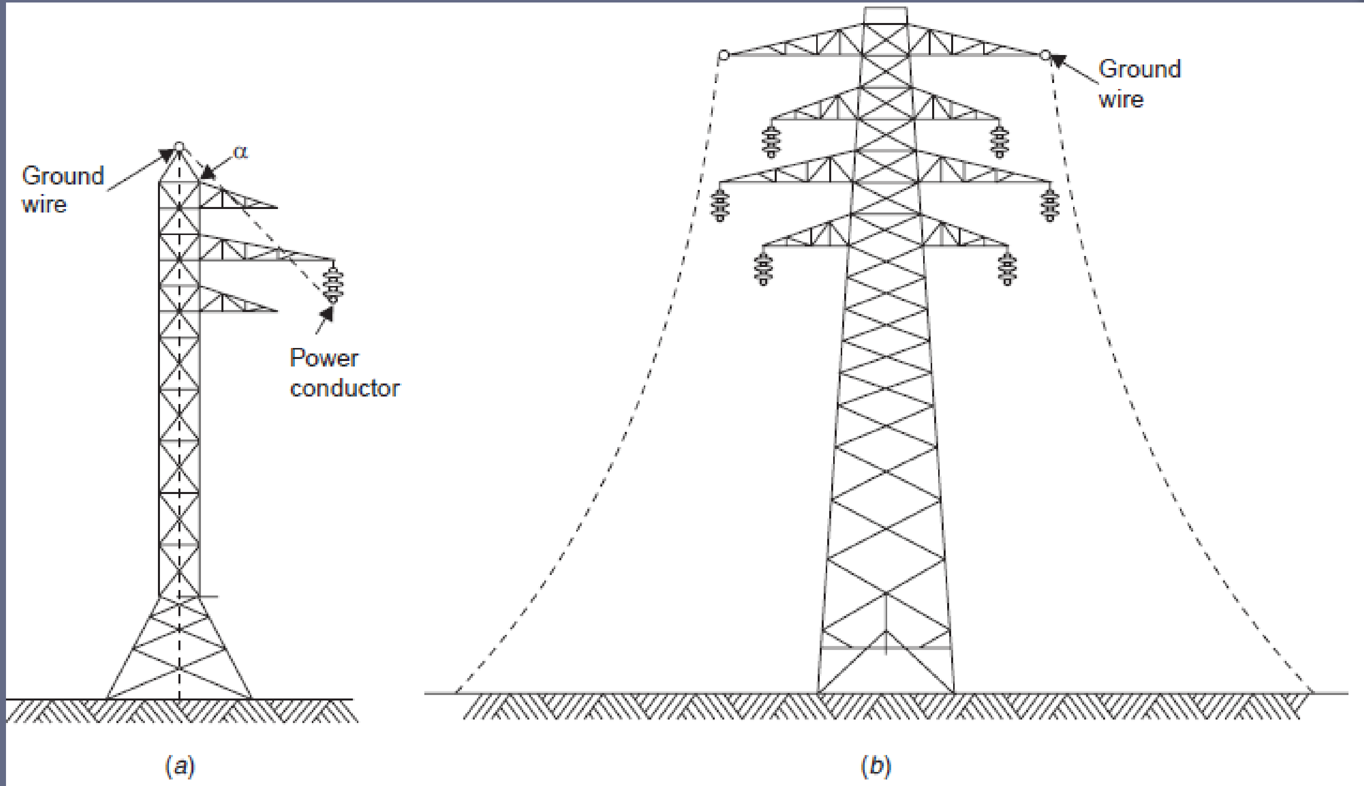
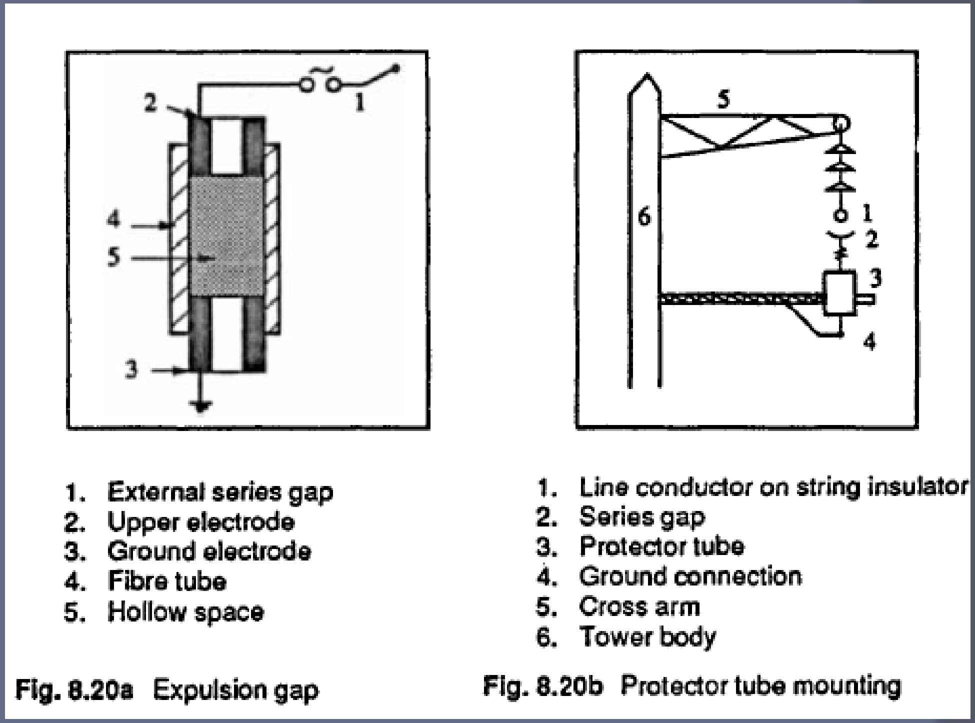


Fig. 7.44 (*a*) Protective angle; (*b*) Protection afforded by two ground wires

Surge Arrestor

Surge arrestor with expulsion gap is a device which consists of a spark gap together with an arc quenching device which extinguishes the current arc when the gaps break over due to over voltages.



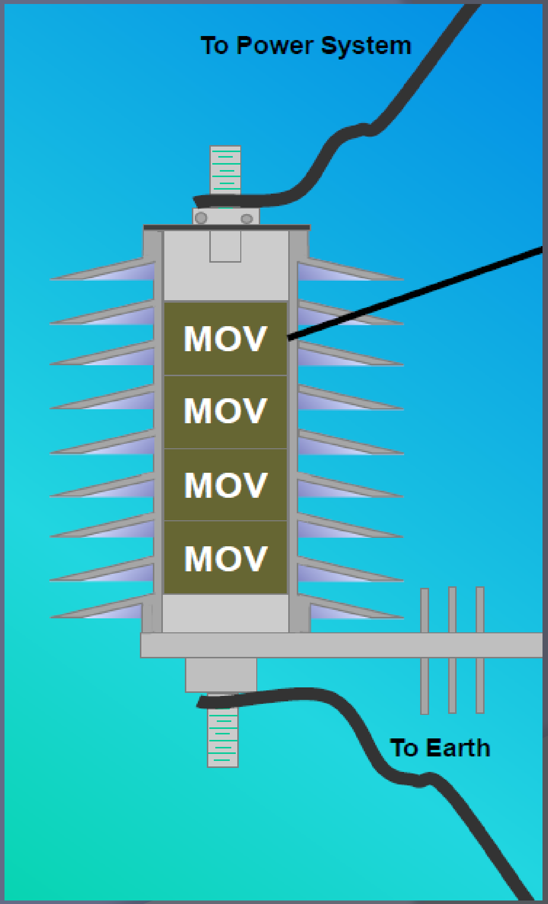
- It **Divert** the Lightning to Ground or

Surge Arrestor

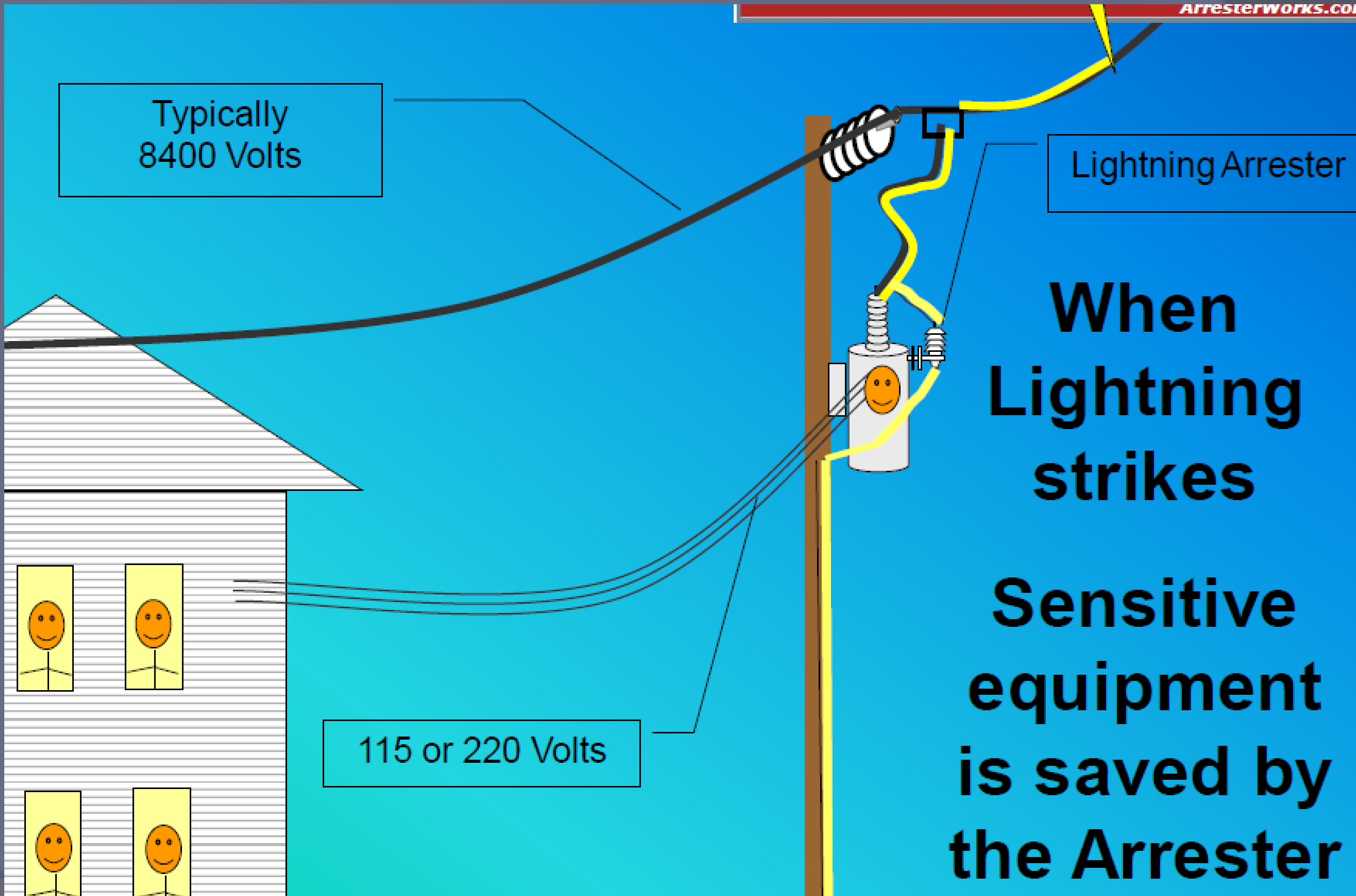
In the second type, the air gap is replaced by a nonlinear element which offers a very high impedance at low currents but has low impedance for high or lightning currents.

Lighting Arrestor

The Metal Oxide Varistor (MOV) Disk is a Semiconductor that is sensitive to Voltage. At normal Voltages the MOV disk is an insulator and will not conduct current; but at higher voltages it becomes a conductor .



Lighting Arrestor



Lighting Arrestor Ratings

The highest phase to earth voltage: the power frequency highest voltage applied to the arrestor.

$$U_{pm} = \frac{\sqrt{2}U_s}{\sqrt{3}}$$

U_s-system voltage

- Continuous operating voltage (Maximum continuous operating voltage MCOV) Uc: the power frequency phase voltage which the arrestor can be operated at without any type of restriction. It is greater than the highest continuously occurring voltage by at least 5%.

Lighting Arrestor Ratings

- Rated voltage of an arrestor U_r: characterizes the capability of the arrestor to deal with temporary overvoltages in the system. It can be only applied for a very short period of time (10-100 seconds). The leakage current is around 1 mA. Ur=1.25 Uc.
- The maximum current the arrestor can conduct during breakdown.

Lighting Arrestor Ratings

Description	230 kV	132 kV	15 kV
Installation	Outdoor	Outdoor	Outdoor
Rated voltage of arrestor, (kV)	198	120	18
Highest system voltage (kV)	245	145	17.5
Lightning impulse withstand voltage (1.2/50μ sec) kV	1050	650	120
Power frequency withstand voltage 1min, (kV)	$\geq$460	$\geq$300	55
Rated discharged current (KA)	10	10	10
Standard Applied	***IEC 60099-4***		

Lighting Arrestor Ratings

Example – Find a suitable lightning arrester for a 240 kV transformer.

For the transformer, MCOV = 264 kV (=240×110%) and BIL = 850 kV (as per AESO FS)
Therefore, the arrester's voltage rating (V_r) and continuous operating voltage (V_c) is ≥153 kV ($= 264 \div \sqrt{3}$)

The following arresters can be chosen:

Voltage Rating (kV rms)		TOV (kV rms) (10 sec)	Max Residual Voltage (kV peak)			
V_r	V_c		SPL (1 kA) 30/60 μs	SPL (2 kA) 30/60 μs	LPL (5 kA) 8/20 μs	LPL (10 kA) 8/20 μs
210	156	231	417	433	469	494
240	191	264	476	495	536	564
276	221	303	547	569	617	648

Insulation strength (BIL) = 850 kV
Therefore, protective margin = (850/564 – 1) = 0.51 or 51% (which is >25%)

Assuming an effectively grounded system, and the power frequency over-voltage is limited to no more than 40% at the arrester,

so MCOV × 140% = 153 × 140% = 214 kV (which is less than 264 kV)

Lightning Protective Level (*LPL*) Switching Protective Level (*SPL*)