SUBSTATION GROUNDING

By
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Guidelines

IEEE Std. 80 , Guide for Safety in AC Substation Grounding.

IEEE std 81 – Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System.

BS 7430 – Code of practice for Earthing.

Safe grounding design has the following objectives

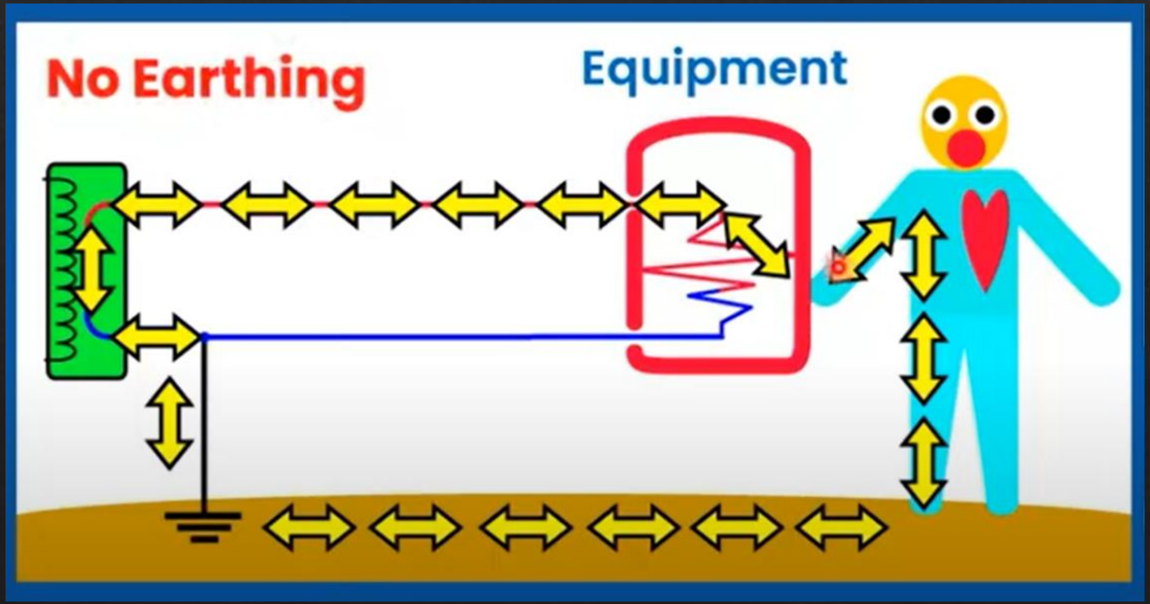
- To assure that a person in the vicinity of grounded facilities is not exposed to the danger of critical electric shock.
- To provide grounding for impulses and the surges occurring from the switching of substation equipment, which reduces damage to equipment and cable.
- To provide a low-resistance path that allows protective relays to detect and clear ground faults more effectively, thereby improving overall protective system performance.

In common usage, “Earthing" and "grounding" are often considered to be the same thing.

British Standards

"Earthing" Non-Current-Carrying parts to the ground

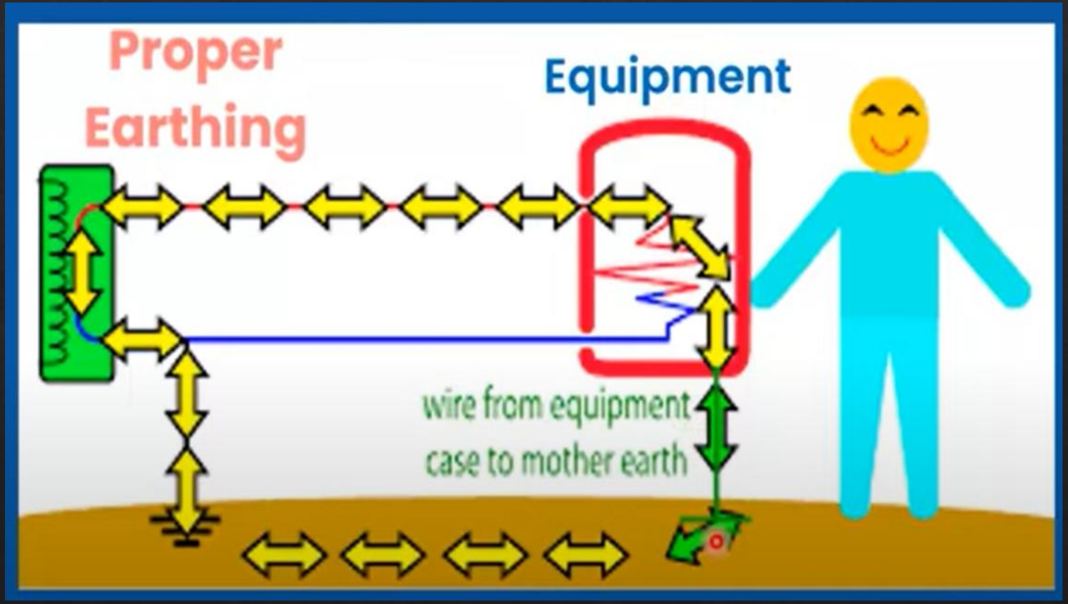
In this case the equipment is not connected to the earth in case a fault in which phase entering the equipment accidentally touches the body of equipment the potential of the Non-Current part of the equipment raises and if anyone touches the body of equipment then may get electrical shocked.



British Standards

"Earthing" Non-Current-Carrying parts to the ground

In this case the equipment is connected to the earth If the same fault This Earthing discharges the leakage of the current to the earth.

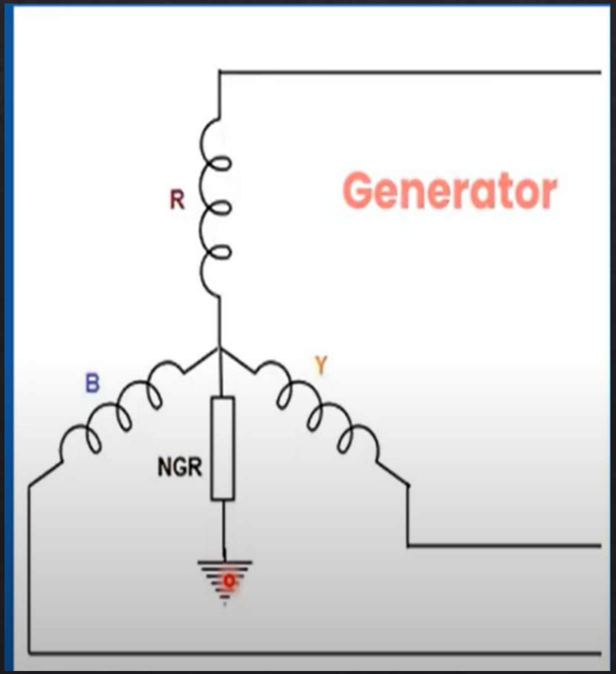


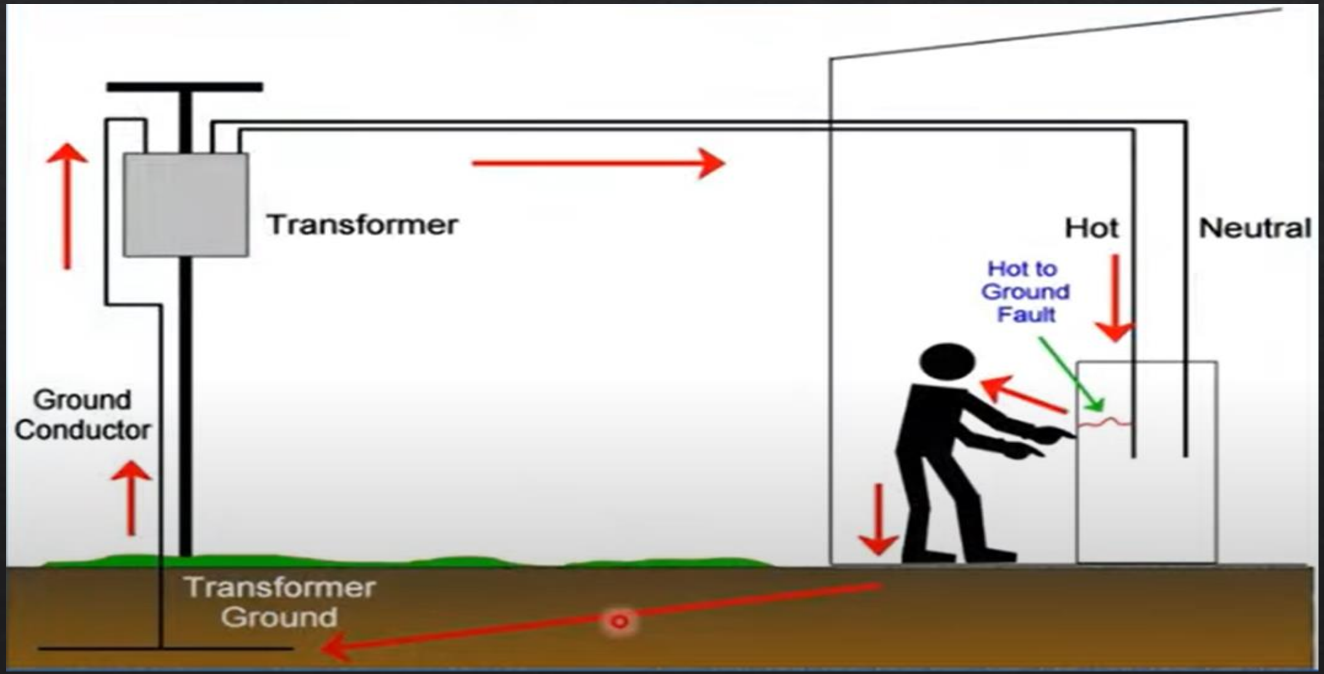
"Grounding" Current-Carrying Conductors

Such as

The neutral wire

Ex: Transformer star point
Generator star point



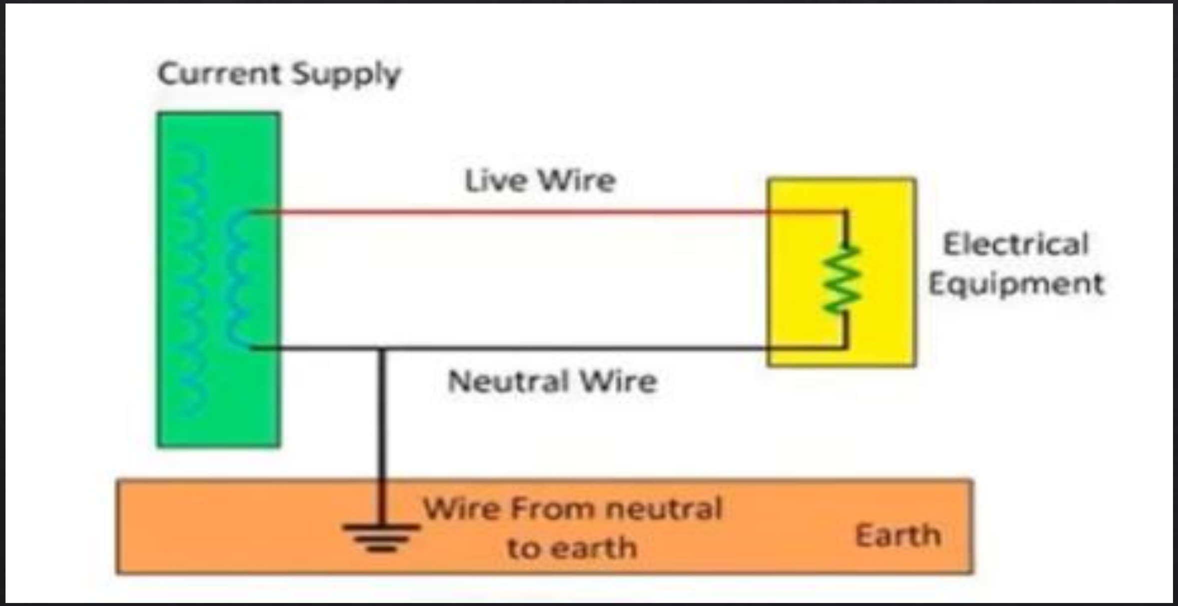


British Standards

“Grounding”

Functional grounding

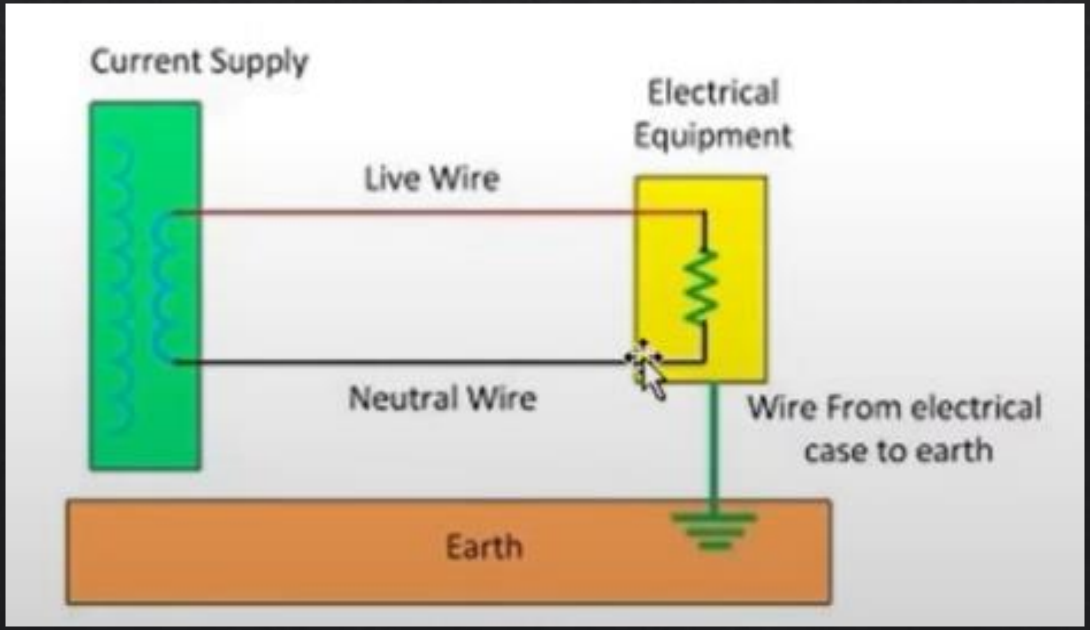
Current-Carrying Conductors
Such as
The neutral wire



"Earthing”

Safety grounding

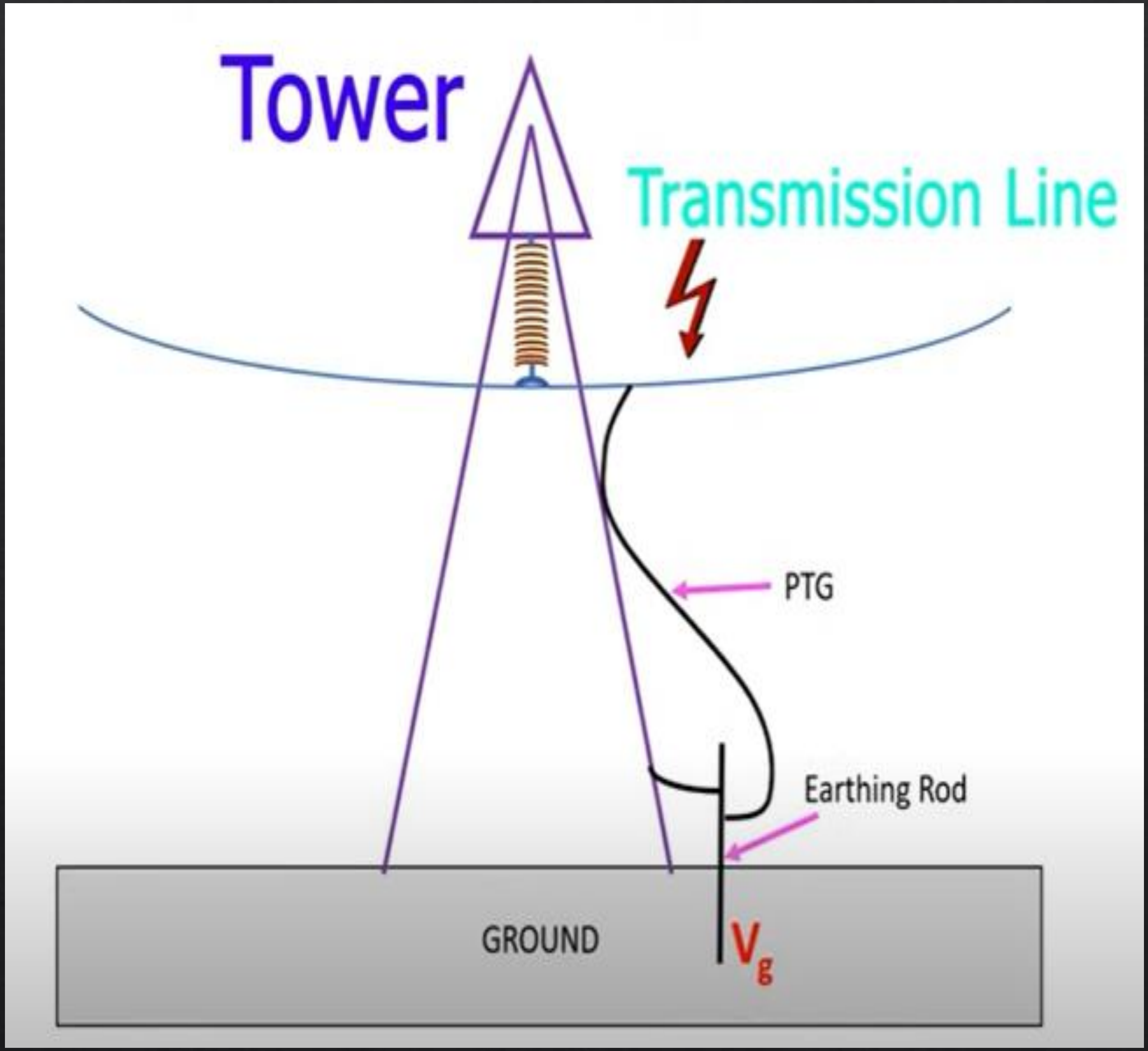
Non-Current-Carrying parts to the ground



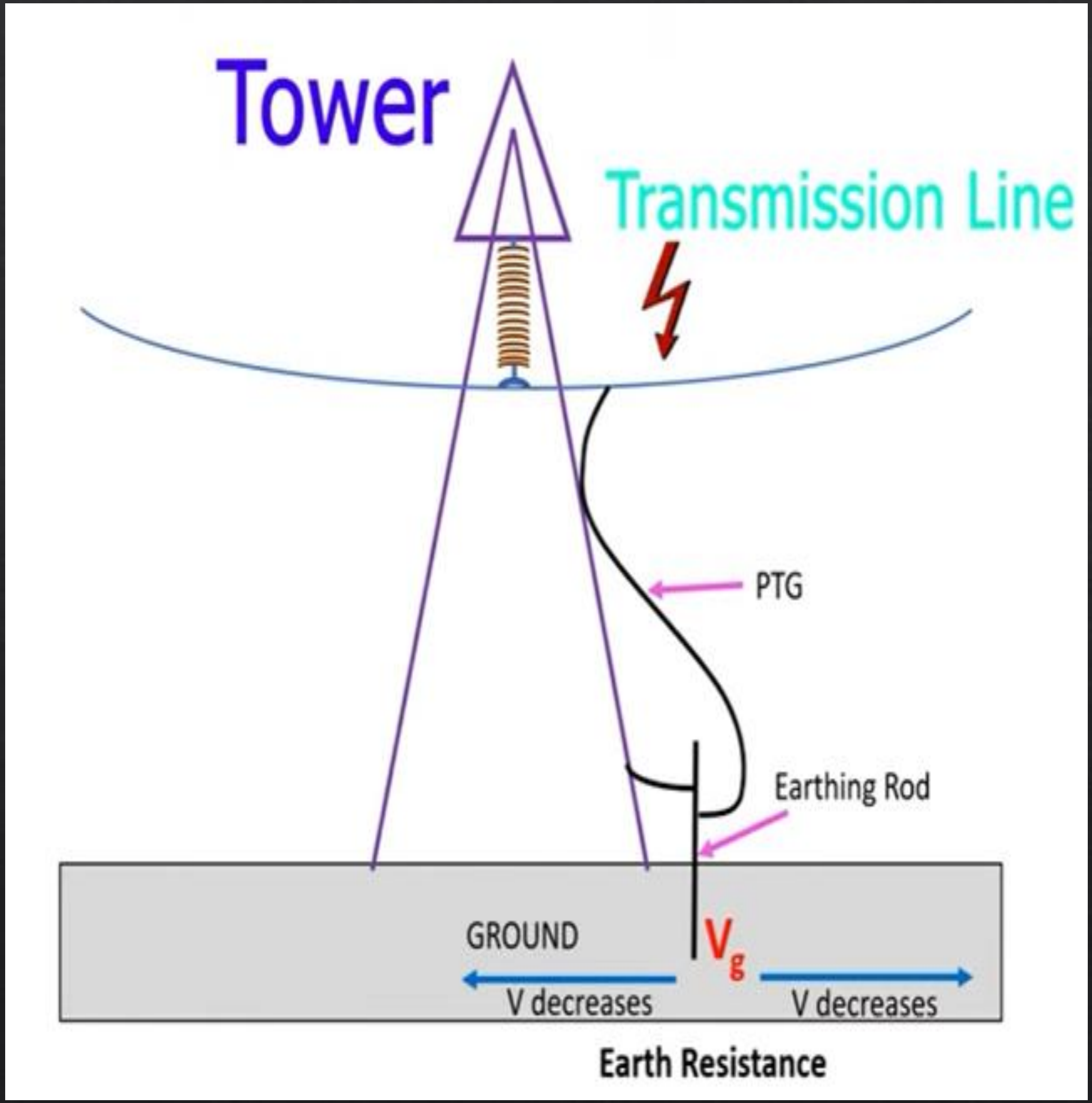
North American Standards

“Grounding” is the prevalent term used for both safety and functional connections to the ground.

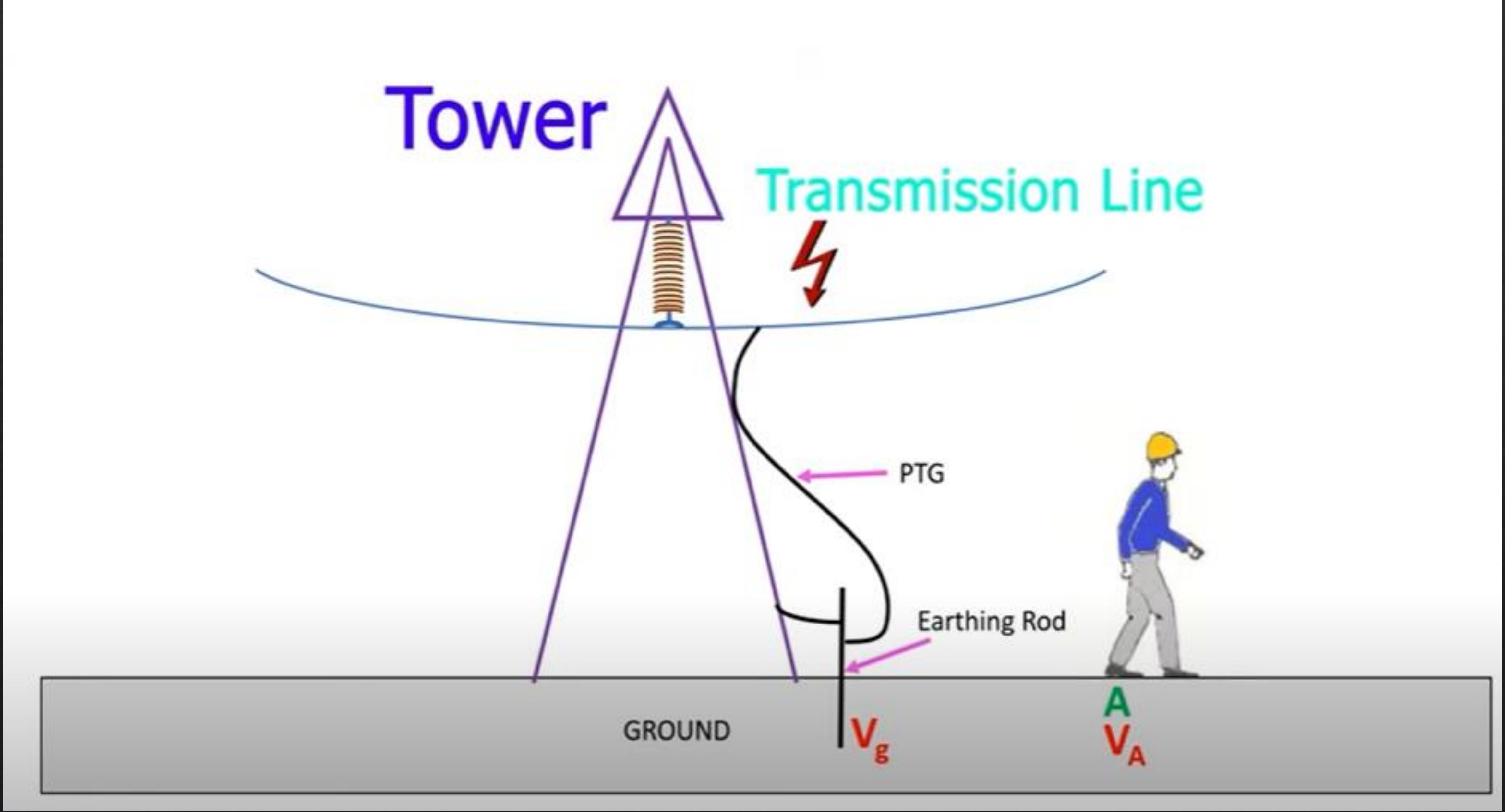
“Earthing” is not commonly used, and the concept is encompassed within the broader notion of grounding.



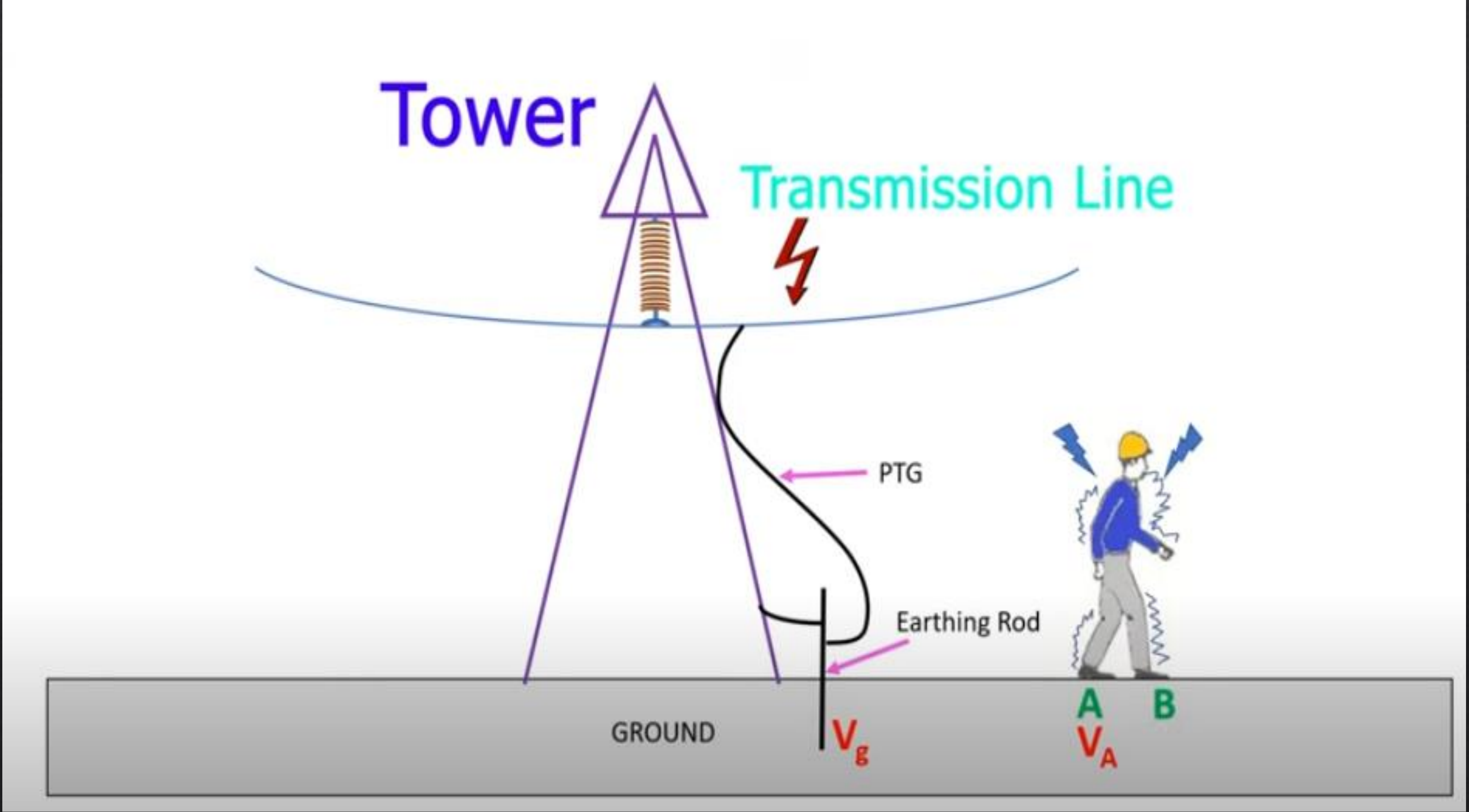
Tower
Transmission Line
PTG
Earthing Rod
GROUND
V_g



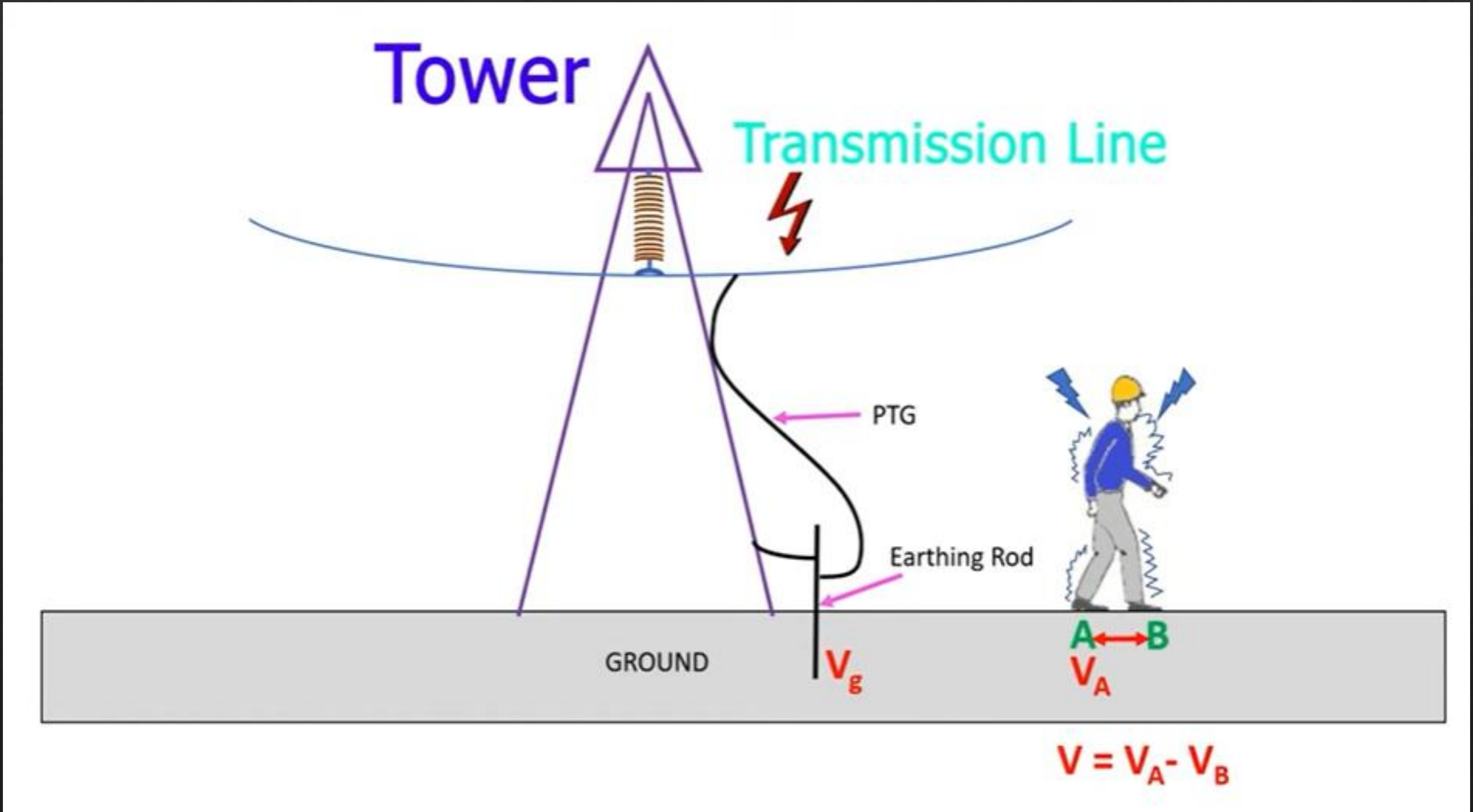
Tower
Transmission Line
PTG
Earthing Rod
GROUND
V_g
V decreases
V decreases
Earth Resistance



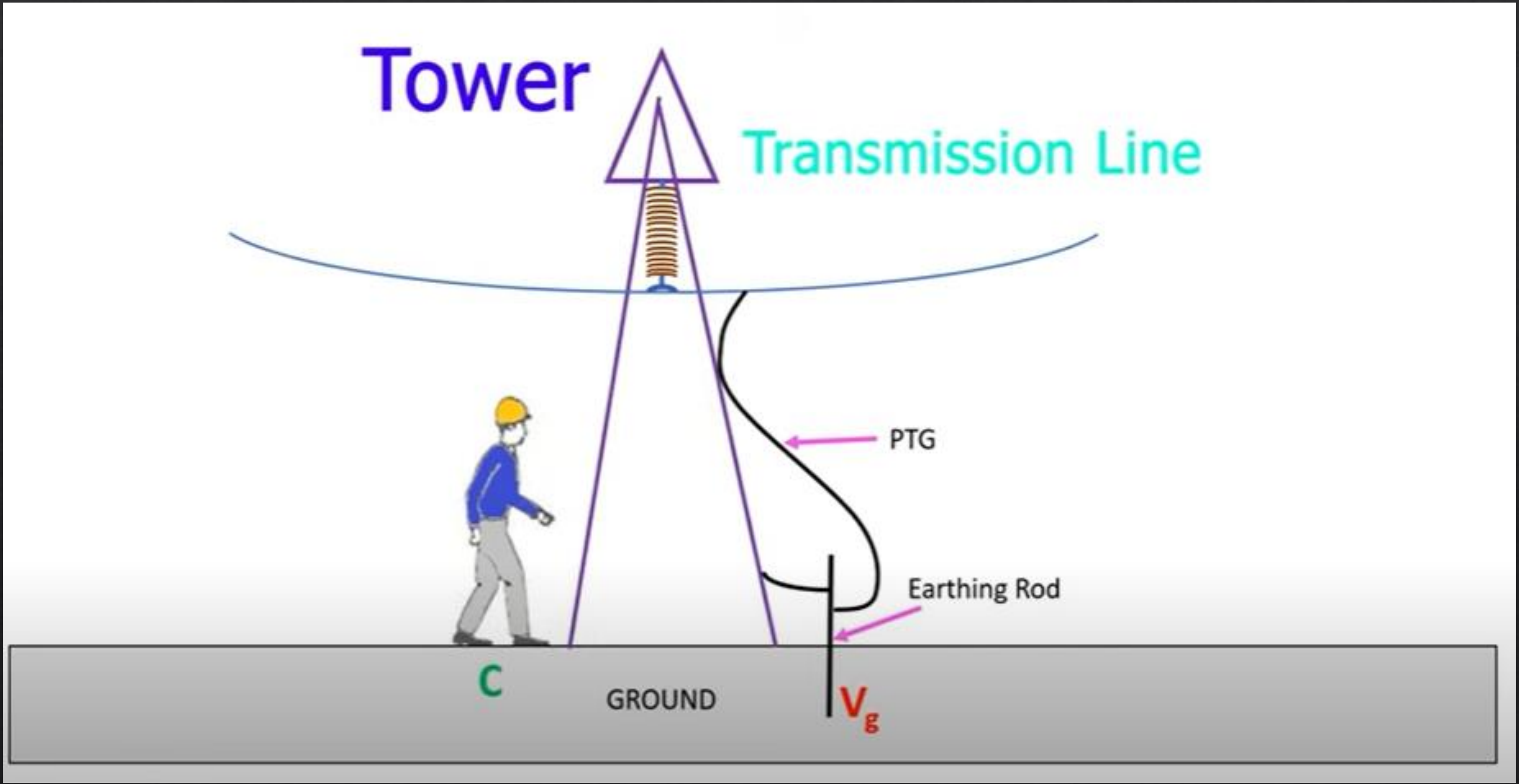
Tower
Transmission Line
PTG
Earthing Rod
GROUND
V_g
A
V_A

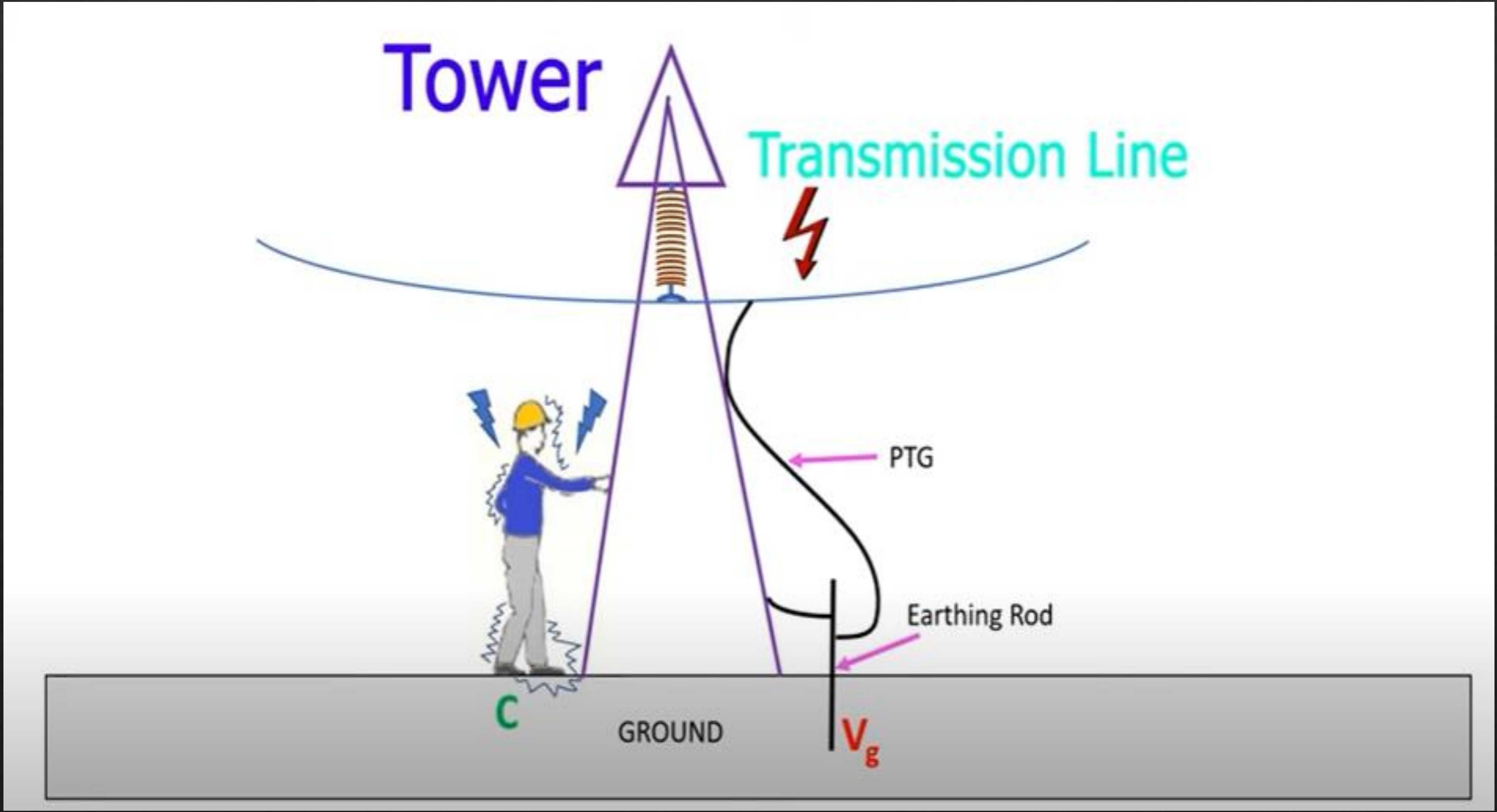


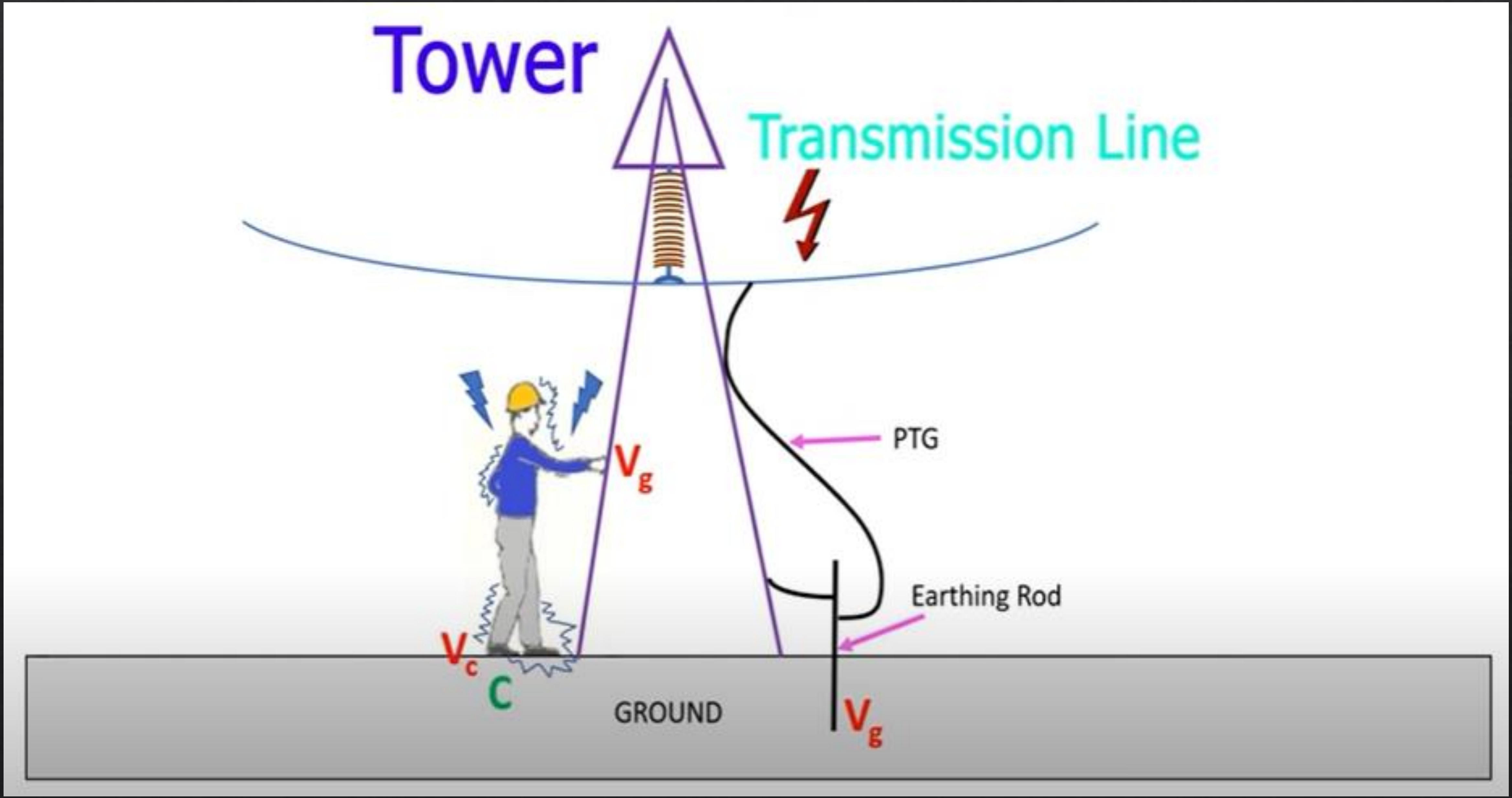
Tower
Transmission Line
PTG
Earthing Rod
GROUND
V_g
A
B
V_A


Tower
Transmission Line
PTG
Earthing Rod
GROUND
V_g
A
B
V_A
$V = V_A - V_B$

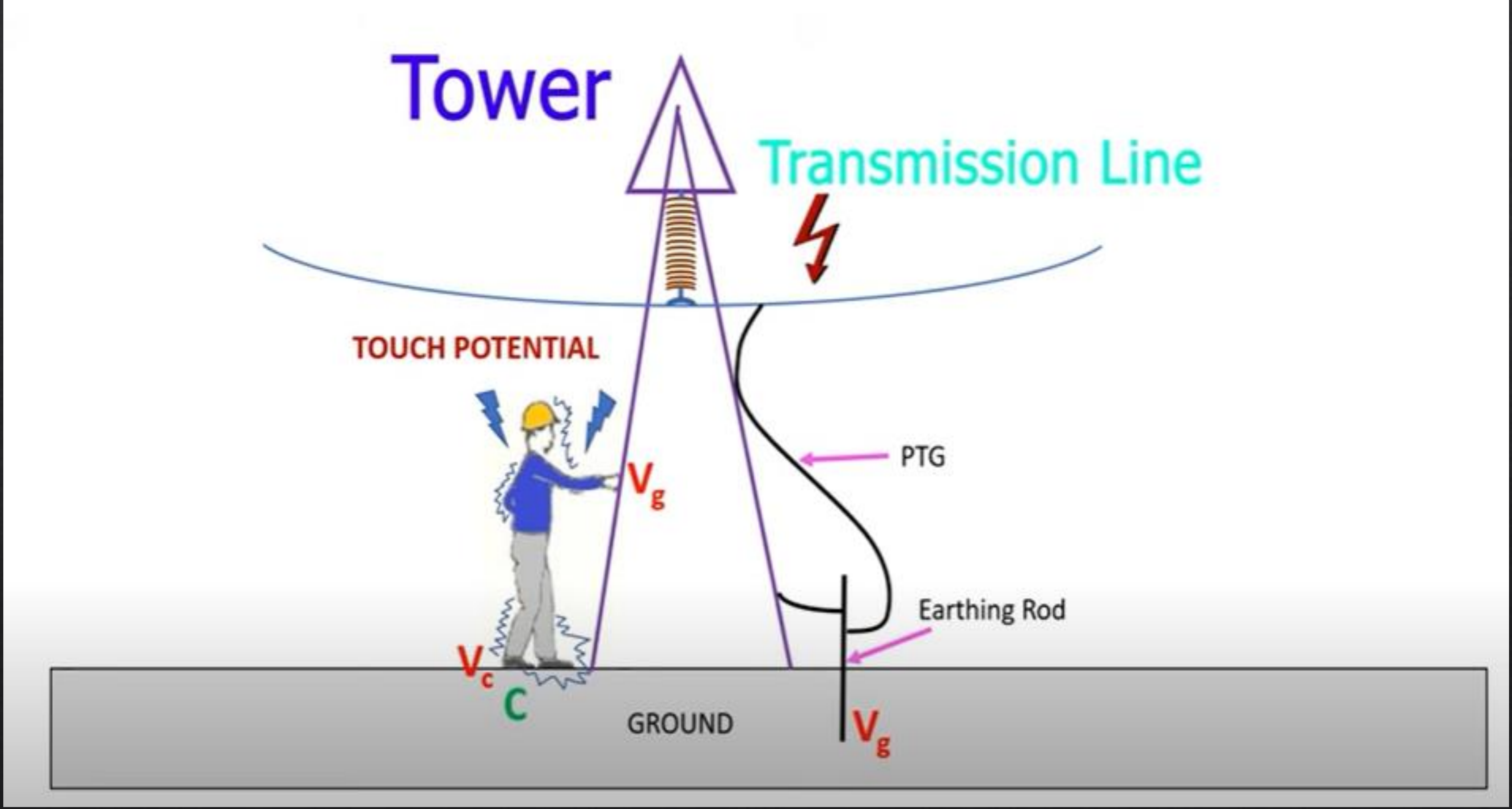
Step Potential is the difference in surface potential experienced by a person’s feet bridging a distance of 1m without contacting any other grounded surface.


Tower
Transmission Line
PTG
Earthing Rod
C
GROUND
V_g


Tower
Transmission Line
PTG
Earthing Rod
C
GROUND
V_g

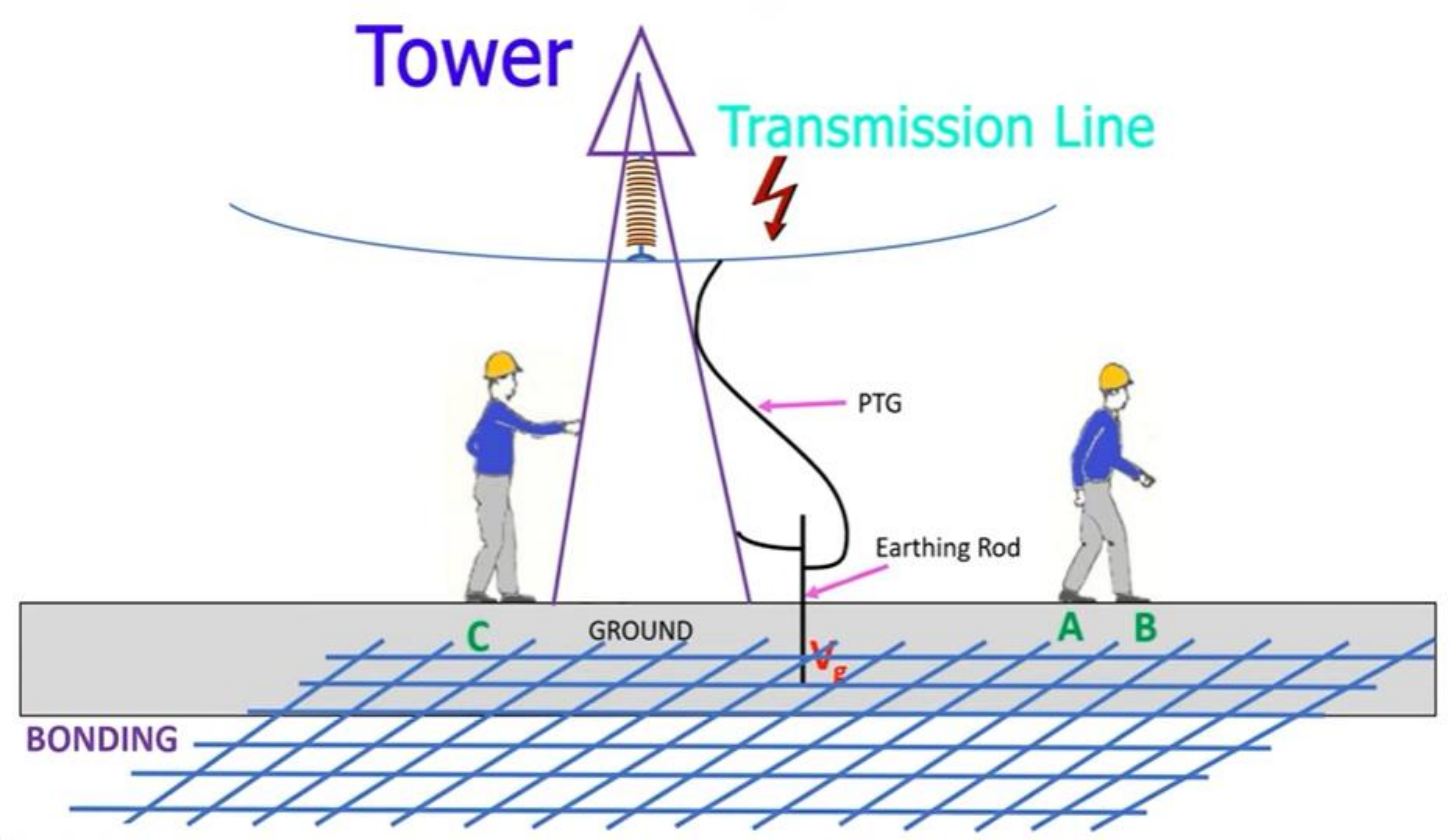


Tower
Transmission Line
PTG
V_g
Earthing Rod
V_c
C
GROUND
V_g



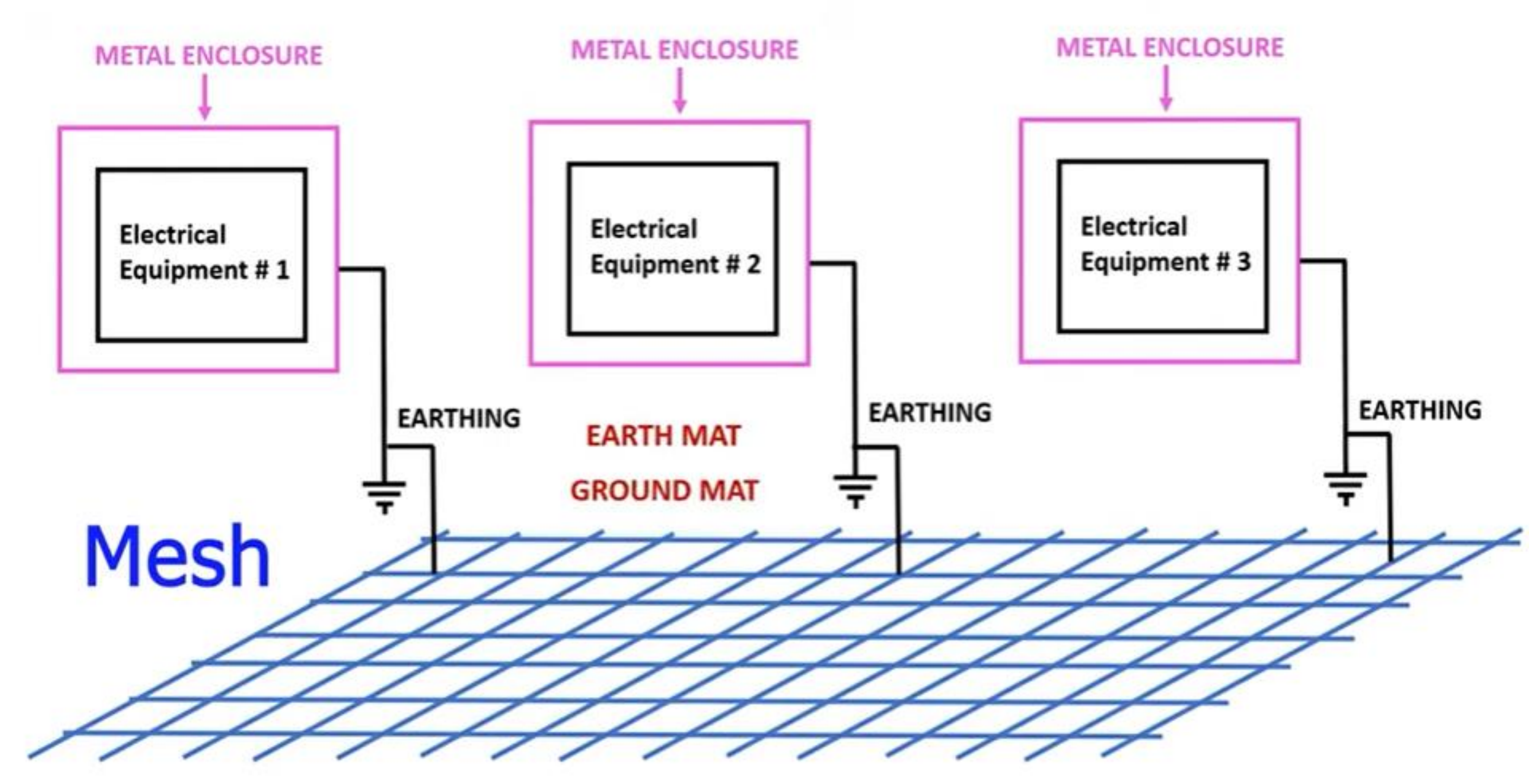
Tower
Transmission Line
TOUCH POTENTIAL
V_g
PTG
Earthing Rod
V_c
C
GROUND
V_g

Touch Potential is the potential difference between the surface potential at the point where a person is standing, while at the same time having hands in contact with a grounded structure.


Tower
Transmission Line
PTG
Earthing Rod
C
GROUND
A
B
BONDING

Bonding

- Connecting all the metallic parts together to maintain them at same potential. Ground potential
- Connecting earthing rods of all equipment together


METAL ENCLOSURE
Electrical Equipment # 1
METAL ENCLOSURE
Electrical Equipment # 2
METAL ENCLOSURE
Electrical Equipment # 3
EARTHING
EARTH MAT
GROUND MAT
EARTHING
EARTHING
Mesh

- The concept of the equipotential environment is quite simple: Connect all conductive parts of the environment together to eliminate voltage differences.
- This connection creates an equipotential environment or zone where a person can touch multiple conductive surfaces without experiencing a dangerous voltage difference between them.

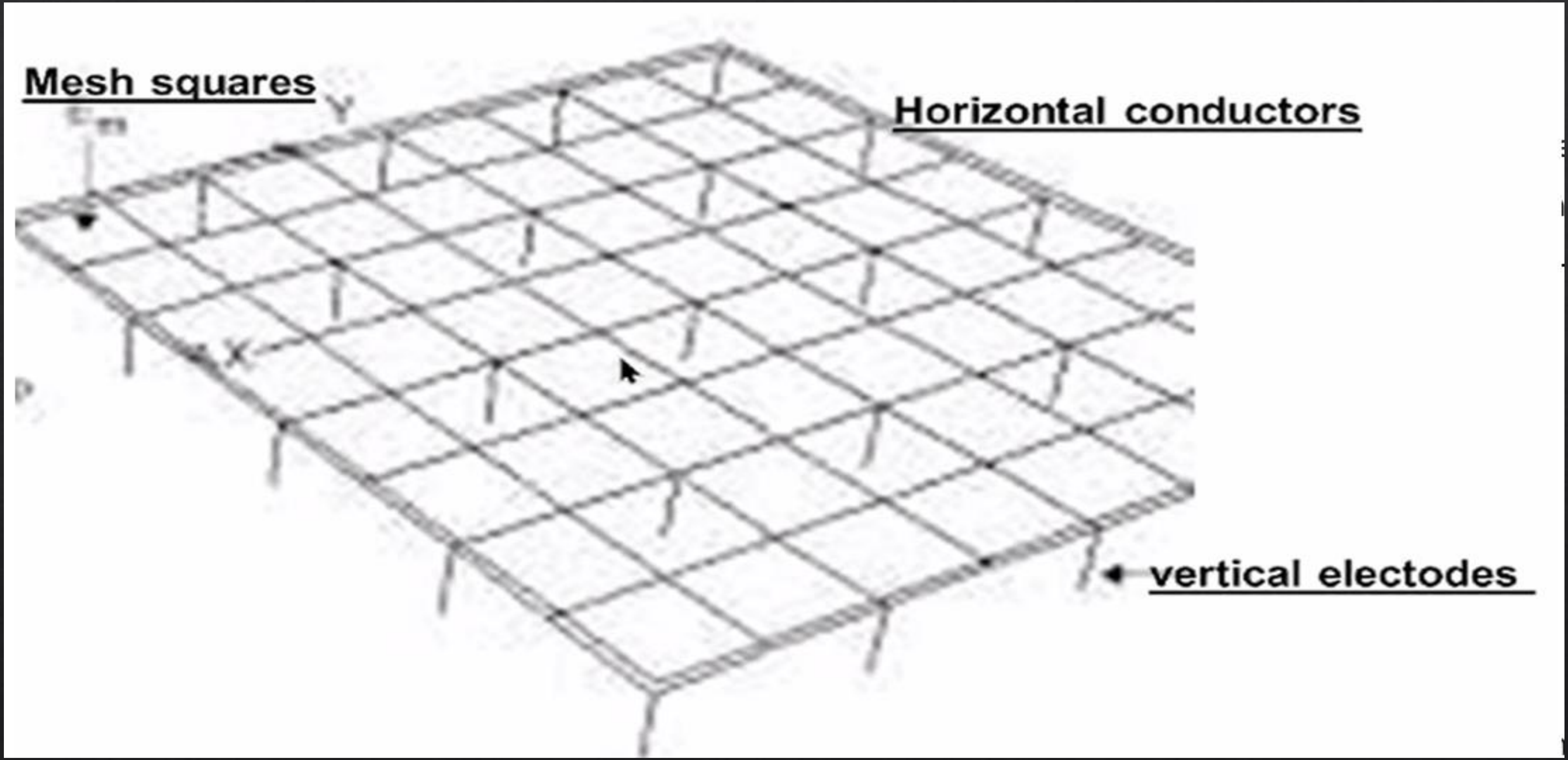
An important aspect of substation grounding system design is the calculation of the ground resistance offered by the grounding grid, and the values of the step and touch voltages on the surface.

• The values of these parameters have to be kept within certain established limits, keeping in view the safety of the personnel present within and without, the substation area

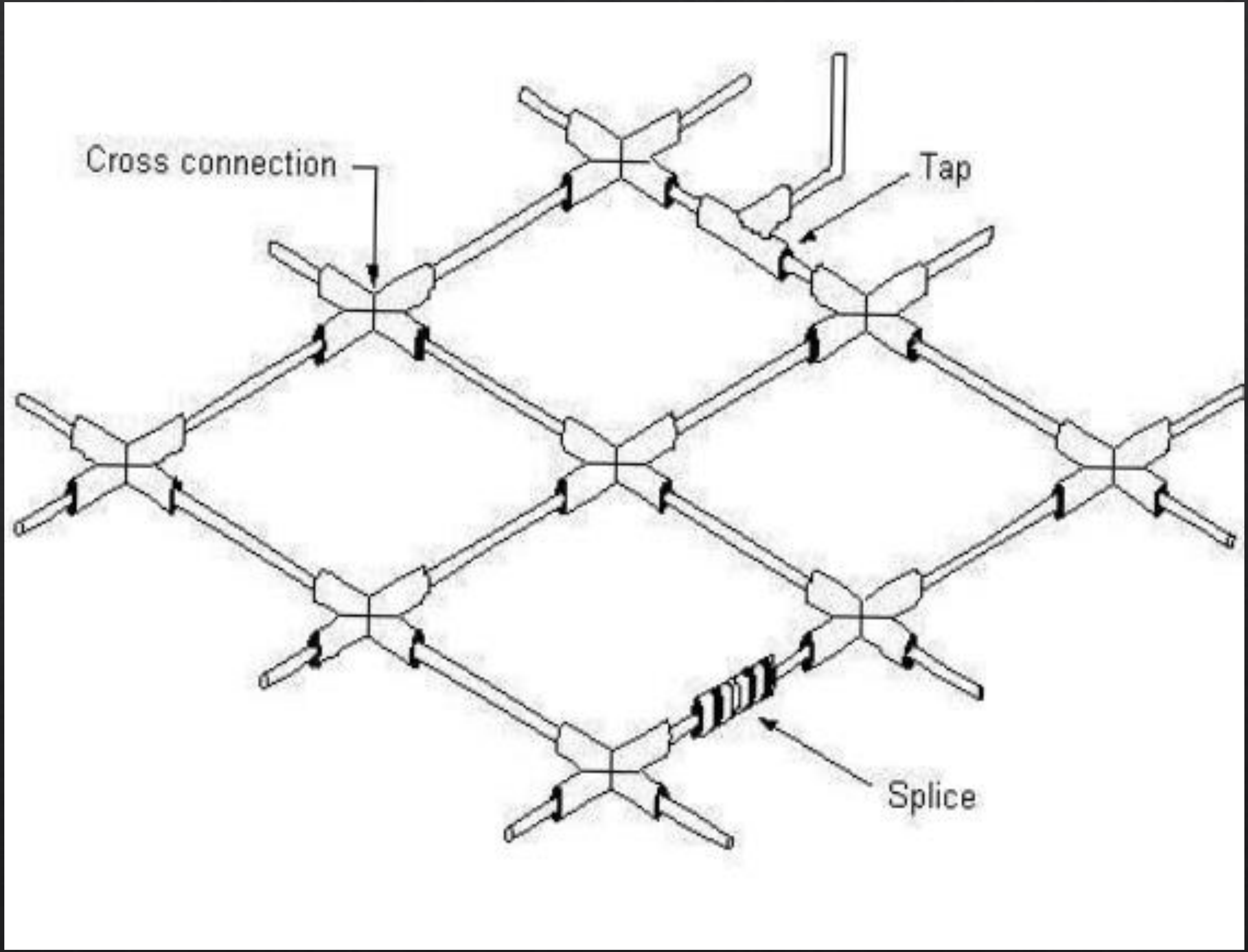
In principle, a safe grounding design for substations has the following objective Provide means to carry electrical currents into the ground under normal and fault conditions without exceeding operating and equipment limits or impairing continuity of service

Construction of ground mat

- The ground mat consists of a grid of horizontally arranged copper conductors, embedded a little below grade, and connected to the substation equipment and metallic structures; grounding rods can be added to reach layers of lower resistivity at a greater depth. This system is the most effective but also the most expensive.
- The grounding rods shall be driven into the ground and their tops shall be welded to clamp and the grounding clamps are used to connect the grounding electrode conductor to the ground grid.
- An electrical grounding conductor is a metal wire, metal bar, or similar item that performs as a conductor that connects equipment to the earth via grounding.


Mesh squares
Horizontal conductors
vertical electodes


4


Cross connection
Tap
Splice

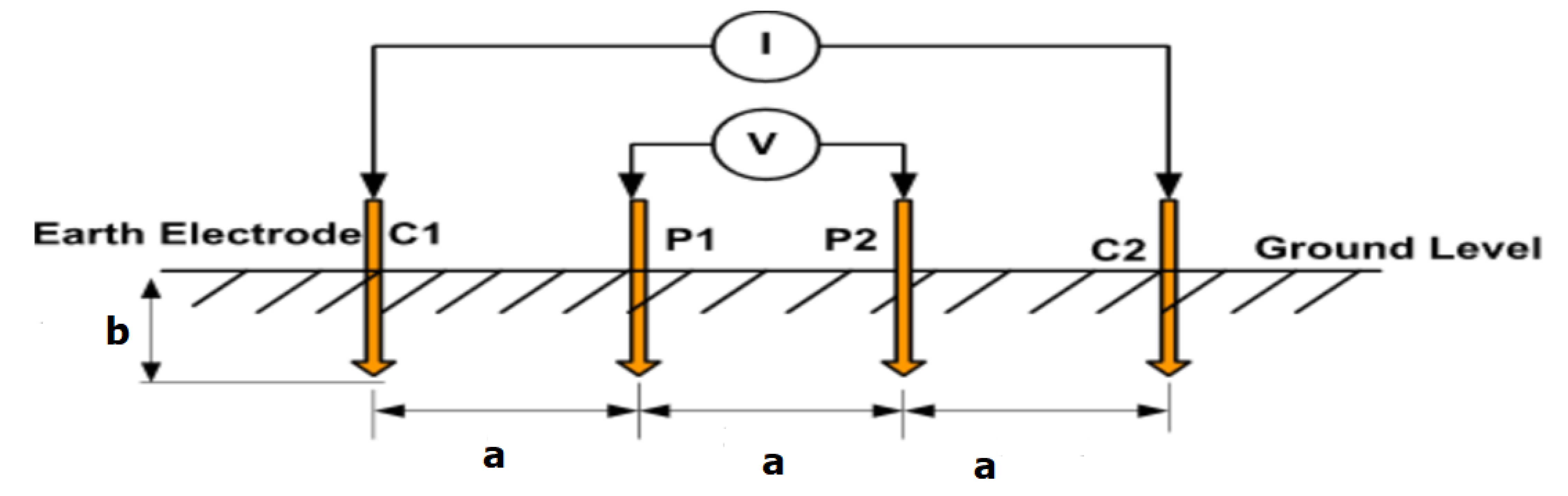
Rod contents of earth

Steps to design ground mat

Step 1.Ground resistivity test This is the first and most important factor in substation grounding. It measures the quality and nature of the ground soil to conduct electrical currents. The four-point method is the most commonly used technique To find the earth resistivity value, it will be described later.

Wenner Four-Pin Method

Four probes are inserted in a straight line, equidistant from one another into the soil area being tested. The distance between the earth ground probes should be at least three times greater than the depth into which the probes are inserted into the soil. The earth ground tester then generates a constant current which flows through the two outer ground probes (C1 and C2) and the develops potential difference which is measured between the two inner ground probes (P1 and P2). The resistance measured by the tester is used to calculate the soil resistivity



$$\rho_a = \frac{4\pi a R}{1 + \frac{2a}{\sqrt{a^2 + 4b^2}} - \frac{a}{\sqrt{a^2 + b^2}}}$$

where

ρ_a	is the apparent resistivity of the soil in Ω·m
R	is the measured resistance in Ω
a	is the distance between adjacent electrodes in m
b	is the depth of the electrodes in m

- Step 2. Getting Fault currents: fault current is the abnormal high magnitude current that flows during faulty conditions like short circuits or lightning strikes. Based on Predetermined data of the substation fault currents, conductor sizing and the design of the entire grounding process can be accomplished.

Step 3 Based on 1 and 2 above, size adequatly the ground mat conductors that will carry the ground currents to ground.

$$A_{mm^2} = I \frac{1}{\sqrt{\left(\frac{TCAP \cdot 10^{-4}}{t_c \alpha_r \rho_r}\right) \ln\left(\frac{K_o + T_m}{K_o + T_a}\right)}}$$

I	is the rms current in Ka
A_{mm^2}	is the conductor cross section in mm²
Tm	is the maximum allowable temperature in °C
Ta	is the ambient temperature in °C
Tr	is the reference temperature for material constants in °C
α_o	is the thermal coefficient of resistivity at 0°C in 1/°C
α_r	is the thermal coefficient of resistivity at reference temperature T_r in 1/°C
ρ_r	is the resistivity of the ground conductor at reference temperature T_r in µΩ-cm
Ko	$1/\alpha_o$ or $(1/\alpha_r) - T_r$ in °C
tc	is the duration of current in s
$TCAP$	is the thermal capacity per unit volume from table 11-1, in J/(cm³·°C)

- Step 4. selection of the quantity and length of ground electrode : Earth electrodes are constructed and buried deep in the ground to direct the ground fault current toward the ground. Based on fault current data and soil resistivity the number and length of ground electrodes are selected.

For a single vertical rod in homogeneous soil the commonly used approximation (Dwight's form) is:

$$R_{rod} \approx \frac{\rho}{2\pi L}\left(\ln\frac{4L}{d} - 1\right)$$

where

- R_{rod} = single rod resistance (Ω)
- ρ = soil resistivity (Ω·m)
- L = rod length (m)
- d = rod diameter (m).

$$R_{group} \approx \frac{R_{rod}}{N} \times K_N$$

where K_N is the correction factor for N rods (depends on spacing). Use the IEEE/AEMC table or earthing software to choose K_N.

Step 5 calculating step and touch potential:

Step and Touch Voltage Allowable

E step = (1000+6Cρ) 0.116/√t

E touch = (1000+1.5Cρ) 0.116/√t

R grid = ρ[(1/L)+1 /√20A{1+1/(1+h /√20/A)}]

Where

H=Depth of the grid

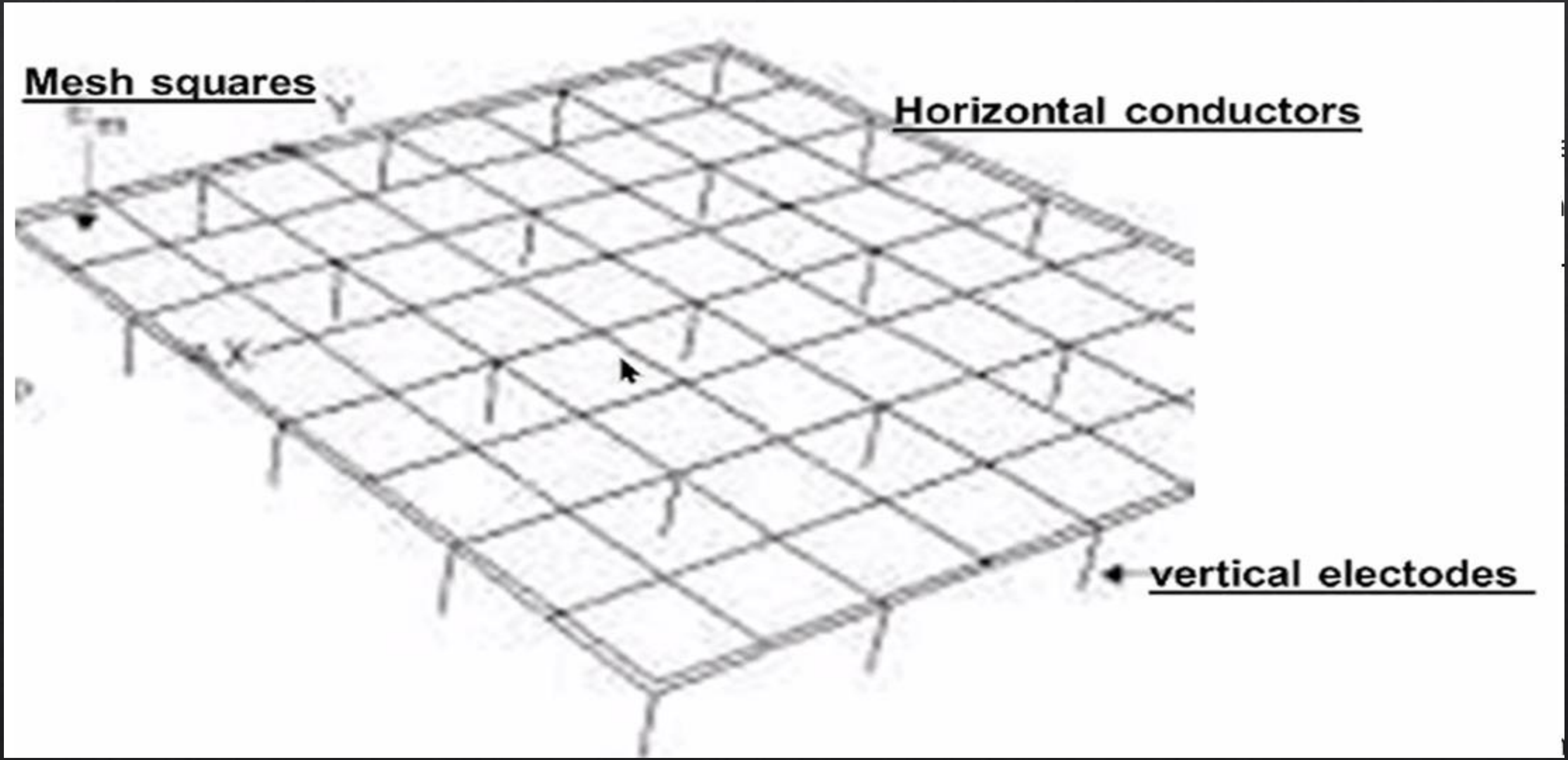
A= Area occupied by the ground grid

L=Conductor buried length

ρ = Soil resistivity

C=Surface layer de-rating factor

Step 6.Selection of the ground grid mesh size: As shown, sizing will include the horizontal grid which is also known as horizontal conductors and ground mat. A system of interconnecting ground electrodes arranged in a pattern in a specified area burred below the ground. Its mesh size is also calculated based on ground resistivity and fault current


Mesh squares
Y
X
Horizontal conductors
vertical electodes

Mesh & Step voltage for the grounding grid

$E_m = \rho K_m K_i I_G / L_m$

$E_s = \rho K_i K_s I_G / L_s$

Where

Em= mesh voltage

Es= step voltage

ρ= soil resistivity

Lm = The effective buried length

Ls = The effective buried conductor length

IG /L= average current density per unit buried conductor

Mesh voltage (Em):

$E_m = \rho K_m K_i I_G / L_m$

$K_m = 1/2\pi \ \ln[\{D^2/16hd\}+\{(D+2h)^2/8Dd\}-\{h/4d\}]+[K_{ii}/K_h]\ln[8/\pi(2n-1)]$

Where

$K_{ii} = 1$ for grids with ground rods along the perimeter, or with ground rods in the grid corners, or both

$K_{ii} = 1/(2n)^{2/n}$ for grids with no ground rods or with few rods non located in the corners or on the perimeter

$K_h = \sqrt{1+(h/h_o)}$ $h_o = 1m$ (reference depth of grid)

Where

D = spacing between parallel conductors in m

h = depth of ground grid in m

n = number of parallel conductors in a given grid

d = diameter of grid conductor in m

And

$K_i = 0.644 + 0.148\, n$

$L_m = L_c + L_R$ For grids with no ground rods , or with few rods located away from the perimeter

$L_m = L_c + [1.55 + 1.22\{L_r / \sqrt{(L_x^2 + L_y^2)}\}]\, L_R$

For grids with ground rods in the corners, as well as along the perimeter and throughout the grid

Where

- L_c = total grid conductor length in m
- L_R = total length of all ground rod in m
- L_r = length of each ground rod in m
- L_x = is the maxi length of the grid in the x direction in m
- L_y = is the maxi length of the grid in the y direction in m
- L_m = The effective buried length

$E_s = \rho K_i K_s I_G / L_s$

For the usual burial depth of 0.25m < h < 2.5m

$K_s = 1/\pi[(1/2h) + (1/(D+h)) + (1/D)(1-0.5n-2)]$

Where

Ls = The effective buried conductor length

Ls = 0.75 Lc + 0.85 LR

Lc = total grid conductor length in m

LR = total length of all ground rod in m

D = spacing between parallel conductors in m

h = depth of ground grid in m

n = number of parallel conductors in a given grid

• Step 7 This is the last step to perform the measurement Off the Grid resistance: Generally the value Of the Grid resistance should be less than one Ohm. The resistance depends primarily on the area occupied by the system which is also known in the early design stage. using the following formula:

$$R_g = \rho\left[\frac{1}{L_T} + \frac{1}{\sqrt{20A}}\left(1 + \frac{1}{1 + h\sqrt{20/A}}\right)\right]$$

Where:

Rg is the resistance to ground of the substation grid in ohms,

ρ is the resistivity of soil in ohm-meters,

A is the area of the grounding grid in square meters.

LT is the total buried length of conductors in m

h is the depth of the grid in m

Thank you for your attention