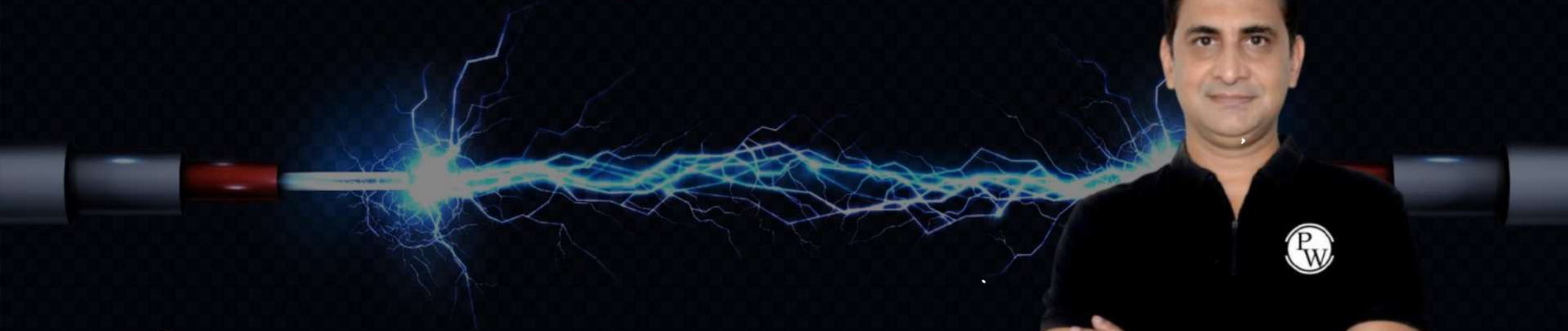


Electrical Engineering

Power System



Lecture No.-1
Transient in Power System

By- Ajay Gupta Sir



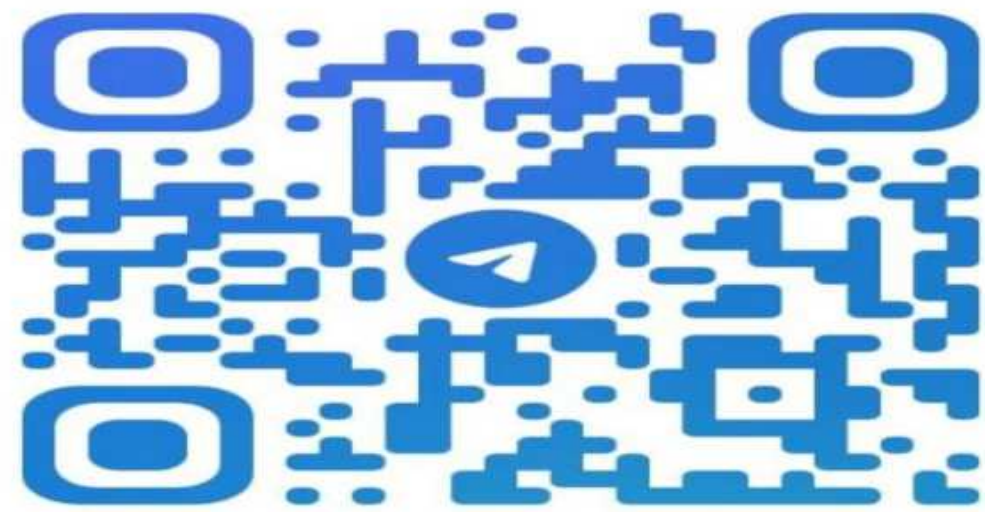
Recap Of previous class

- ✓ 1. Method to improve string efficiency
- ✓ 2. Capacitance grading
- ✓ 3. Static shielding



Topics to be Covered

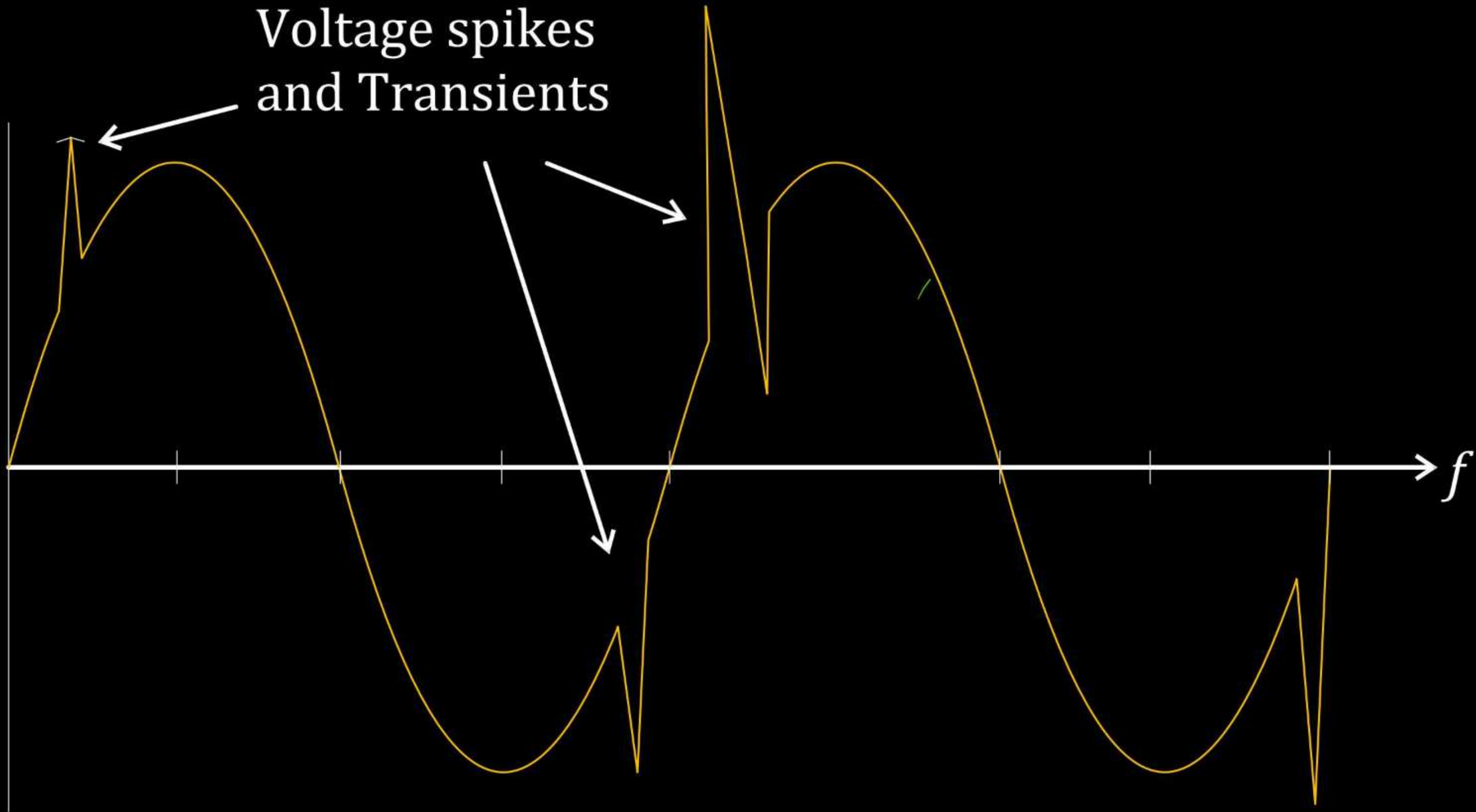
- ✓ 1. Transient
- ✓ 2. Reflection of surges
- ✓ 3. Refraction of surge



@AJAYGUPTASIRPW

Transient - I

Voltage spikes
and Transients



Introduction:

- Transient phenomena is aperiodic function of time, which does not last longer.
- The duration of transient is very less, but it is important because depending upon severity of these transient. The system may result into black out.
- Transient may occur due to change in circuit condition. (e.g. opening & closing of switch, fault, lightning discharge etc.). Which may result into change in voltage & current magnitude. Some time these voltage & current may be higher than those in steady state condition.

During transient, there are two component of voltage

(i) fundamental frequency Voltage

(ii) Natural frequency voltage. It is usually short duration, which are superimposed on power frequency Component



Cause of Transient

$$V = L \frac{di}{dt}$$

The diagram shows the equation $V = L \frac{di}{dt}$ with an upward arrow next to the voltage 'V' and a downward arrow next to the time 't'. To the right of the equation is a hand-drawn symbol for an inductor, represented by a series of loops.

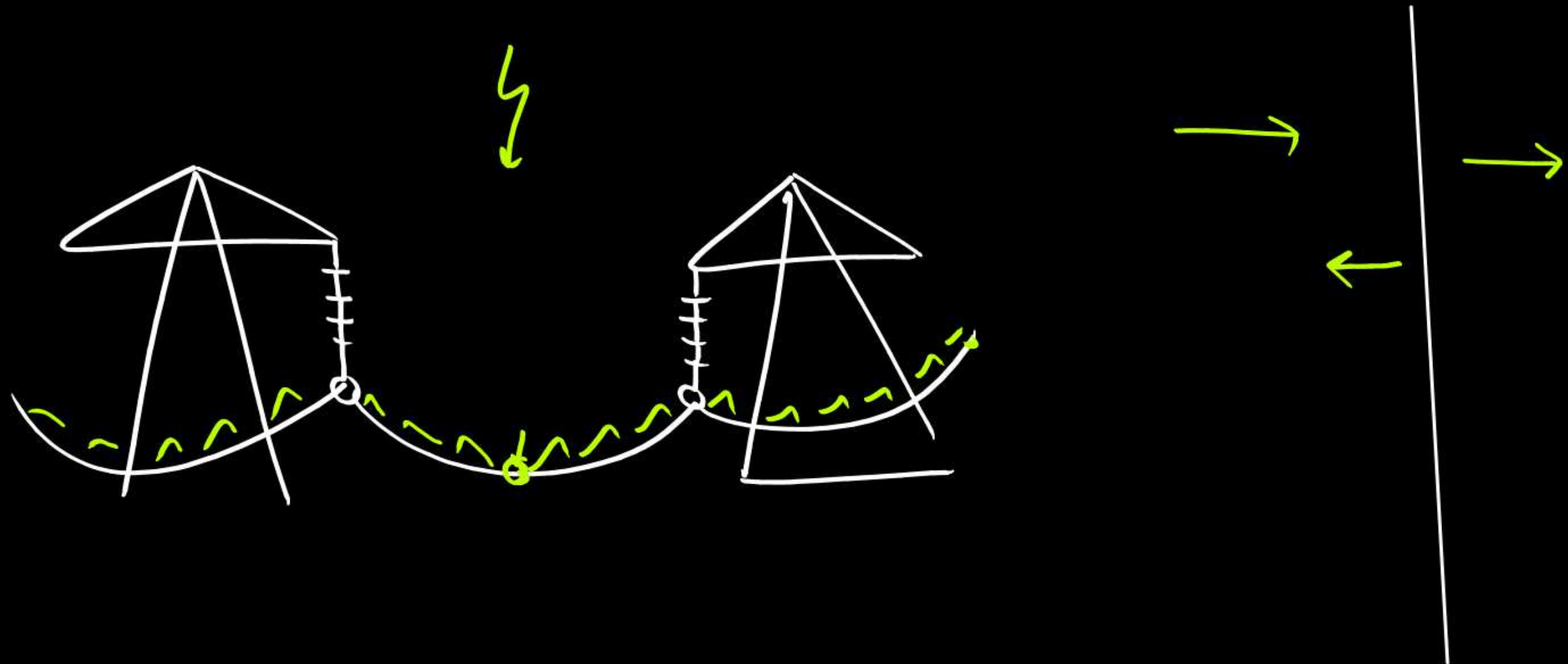
Internal Cause

- (i) Switching surge ✓
- (ii) Insulator failure
- (iii) Arching ground
- (iv) Resonance

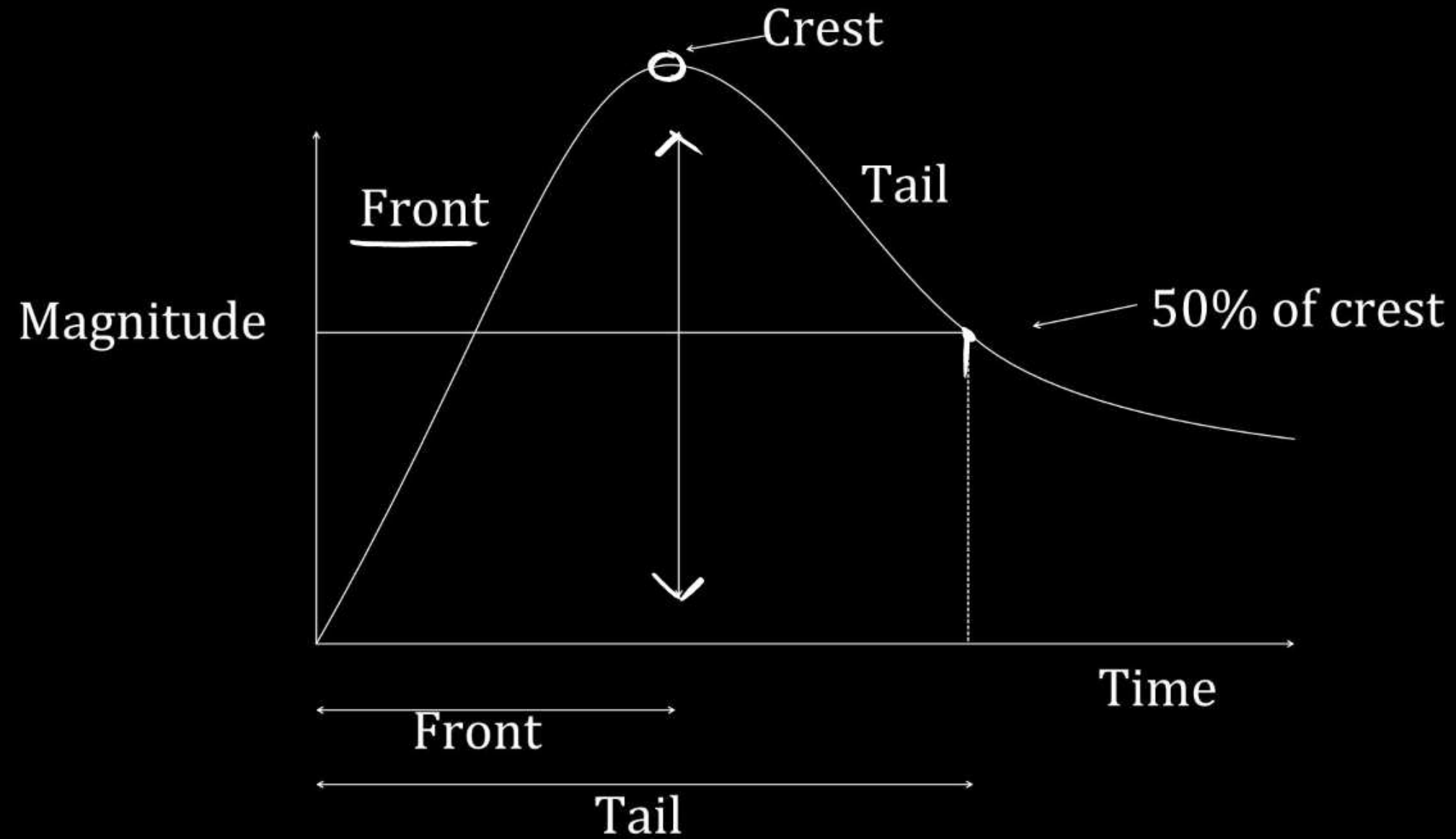
External Cause

- (i) Lighting Strike ✓

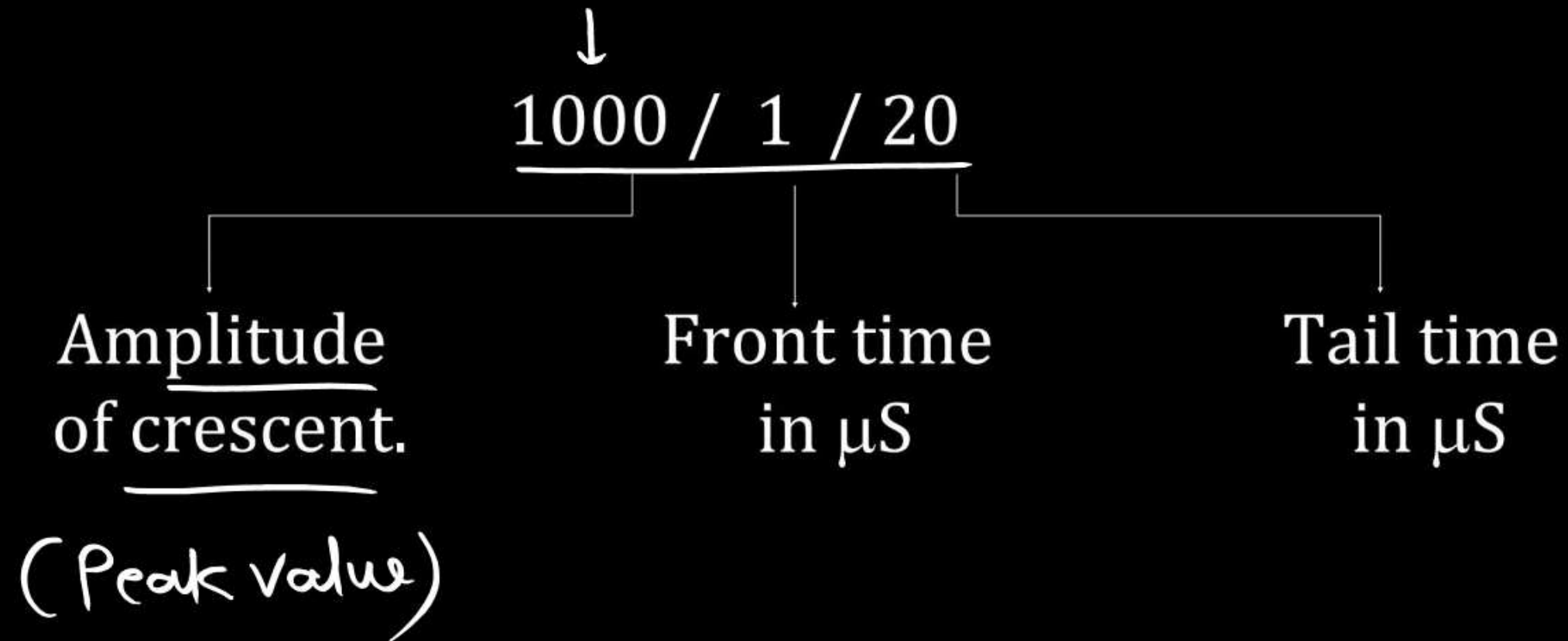
- Power line support the travelling wave of voltage & current. In such circuit, the change in voltage & current due to switching & lightning do not occur simultaneously in all part of circuit but spread out in form of travelling wave & surges.
- At junction and termination surges undergo reflection & refraction.



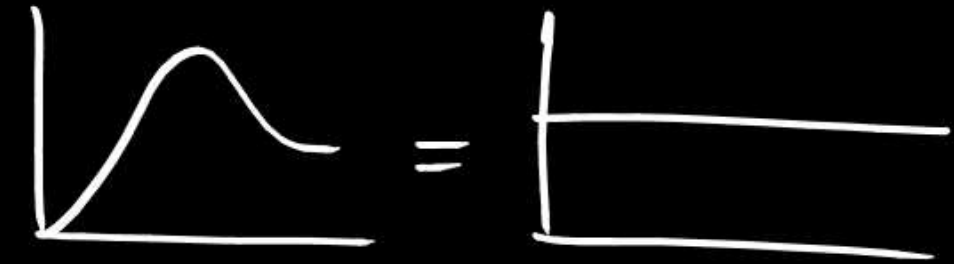
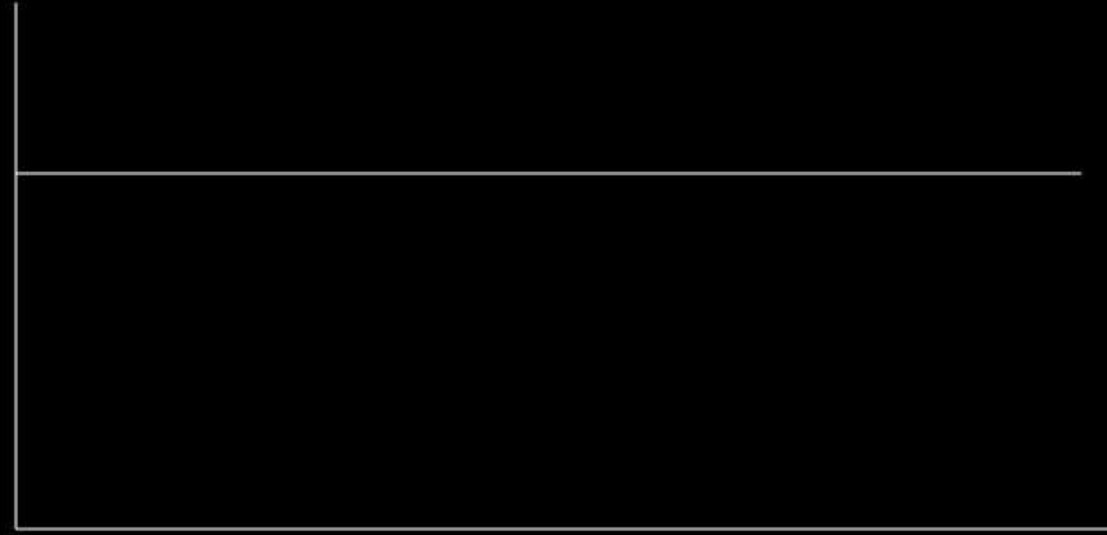
Specification of Travelling wave of Surge:



- Crest is the maximum amplitude in kV and kA.
- Front is a portion before crest. Generally front and tail are measure in time.



- Travelling wave can be represented by number of ways but mostly, we take it as a step wave for Infinite time.

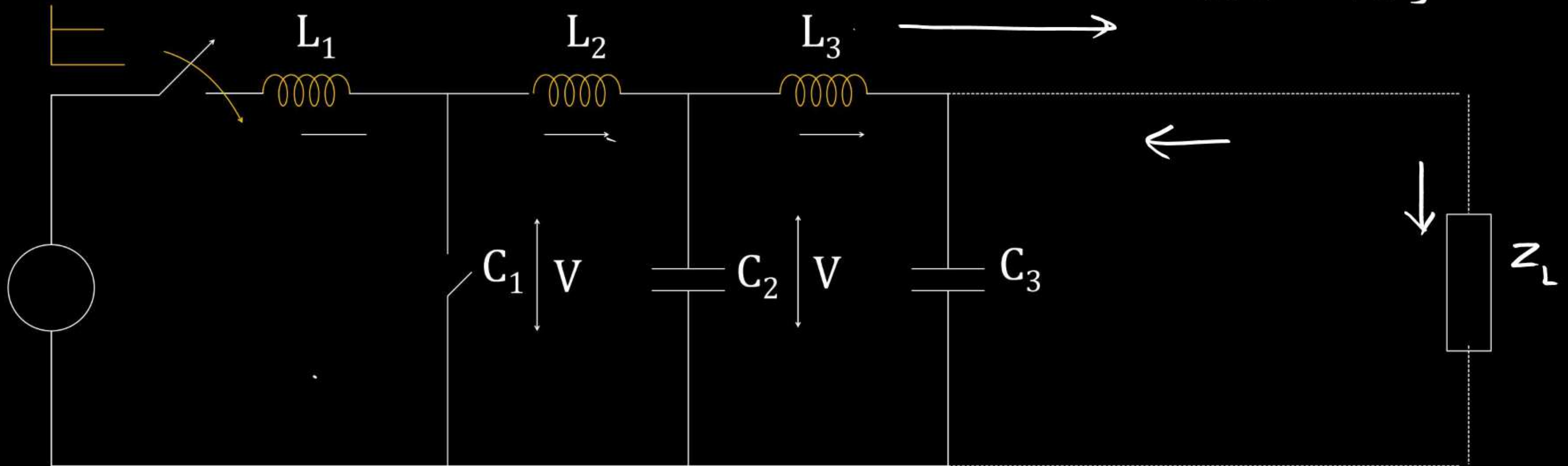


→ ∞

➤ Travelling wave in T.L.

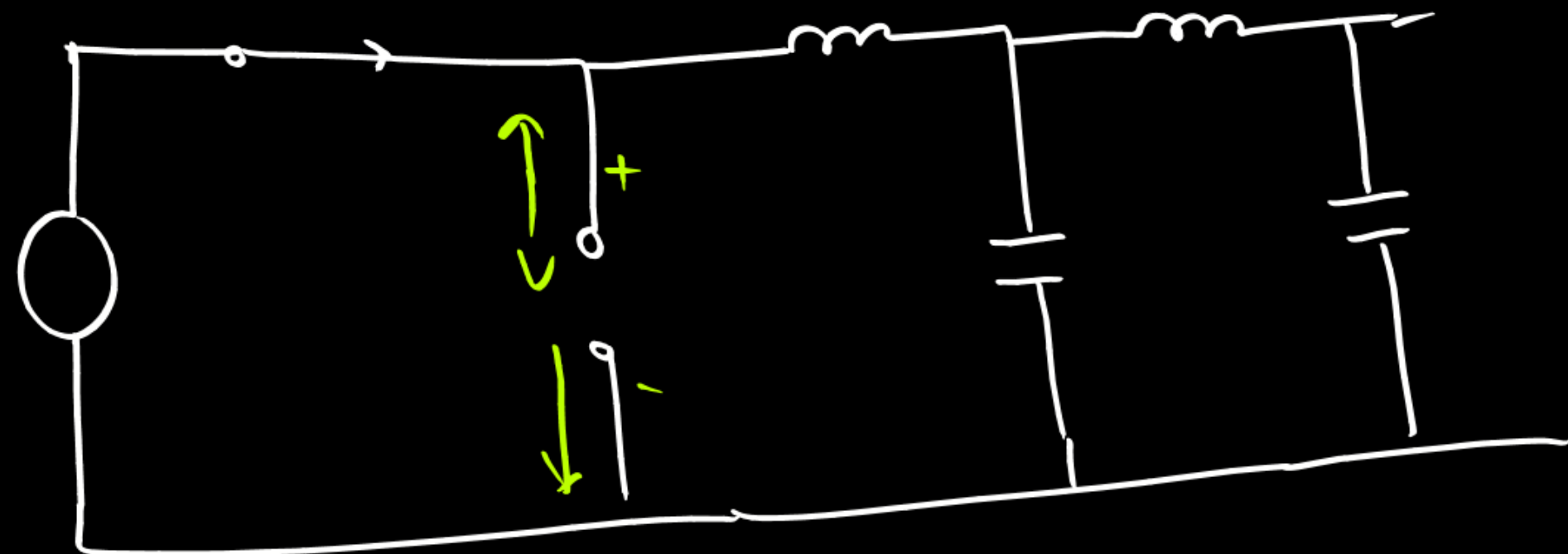
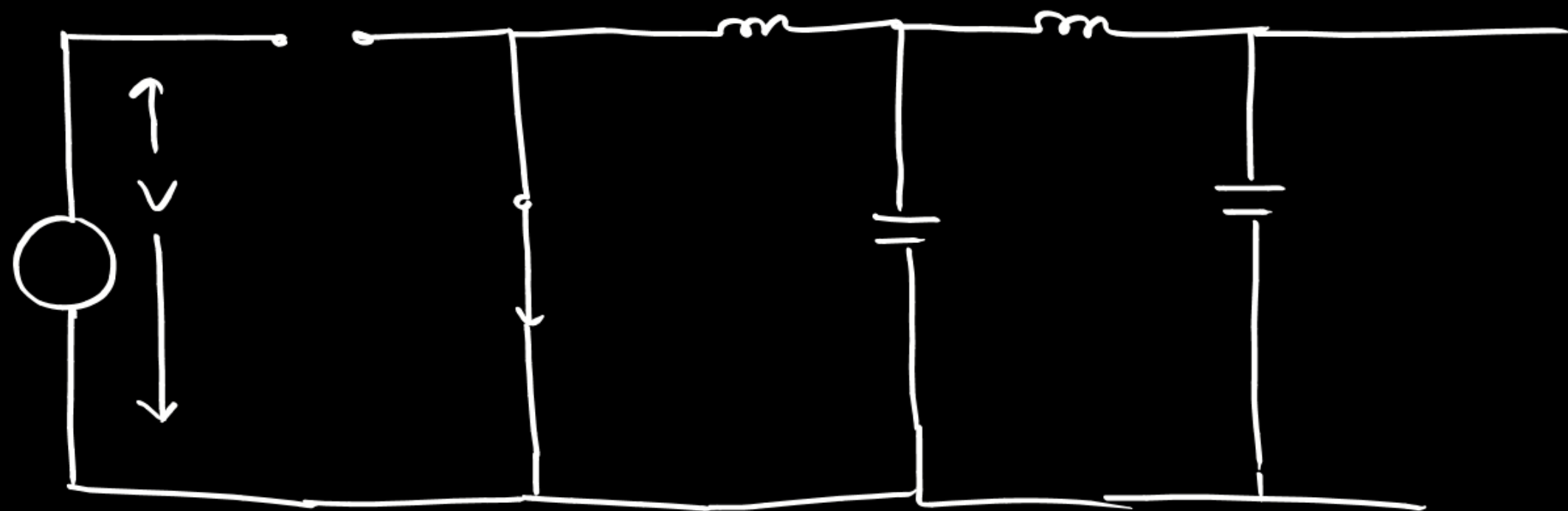
at $t=0$ $\begin{bmatrix} L=0/c \\ C=\infty/c \end{bmatrix}$

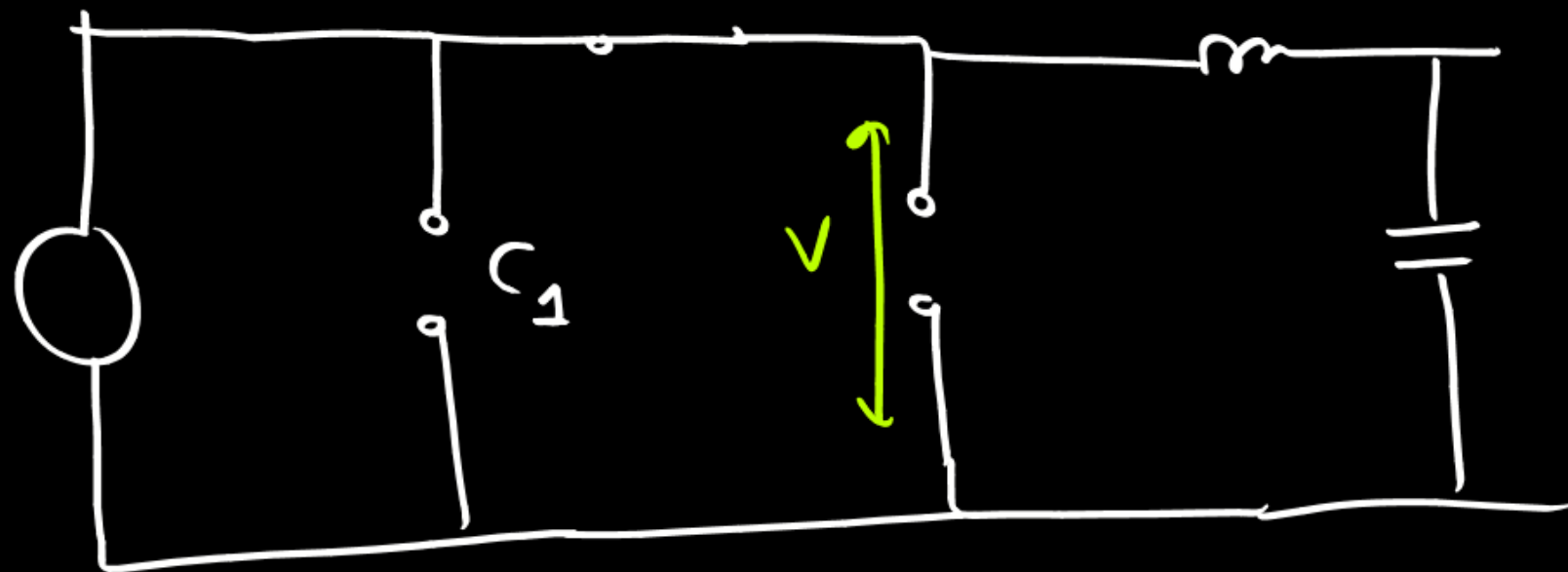
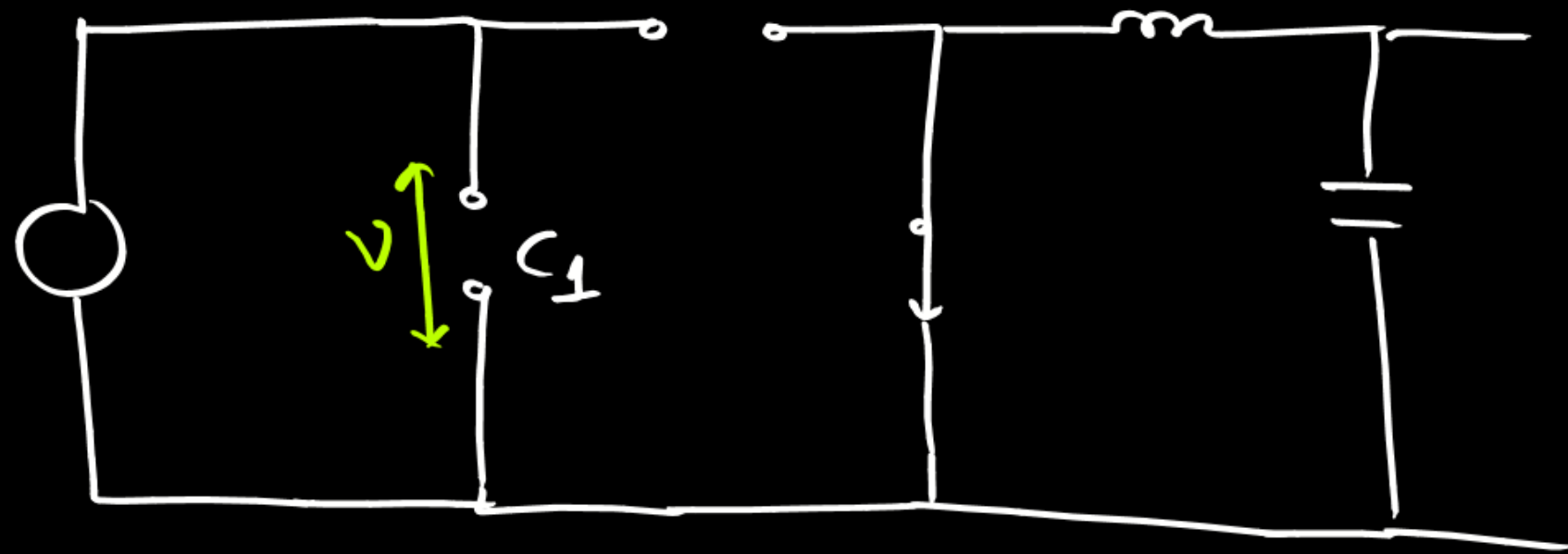
$t=\infty$ $\begin{bmatrix} L=\infty/c \\ C=0/c \end{bmatrix}$



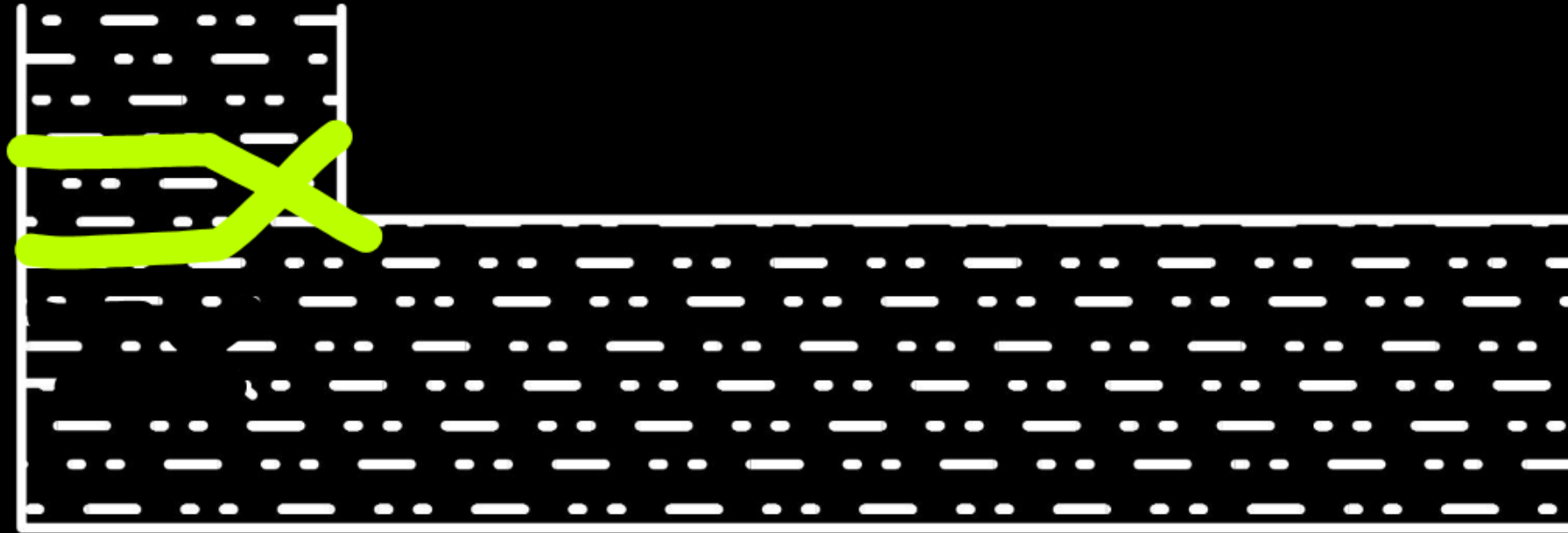
$$Z = R + j\omega L \leftrightarrow \omega L$$

$$Y = G + j\omega C \leftrightarrow \omega C$$





$$\omega = 2\pi f$$



- The closing of switch is similar to opening of a valve of a channel

When switch is closed

L_1 = open circuit

C_1 = short circuit

Now C_1 start charging through L_1

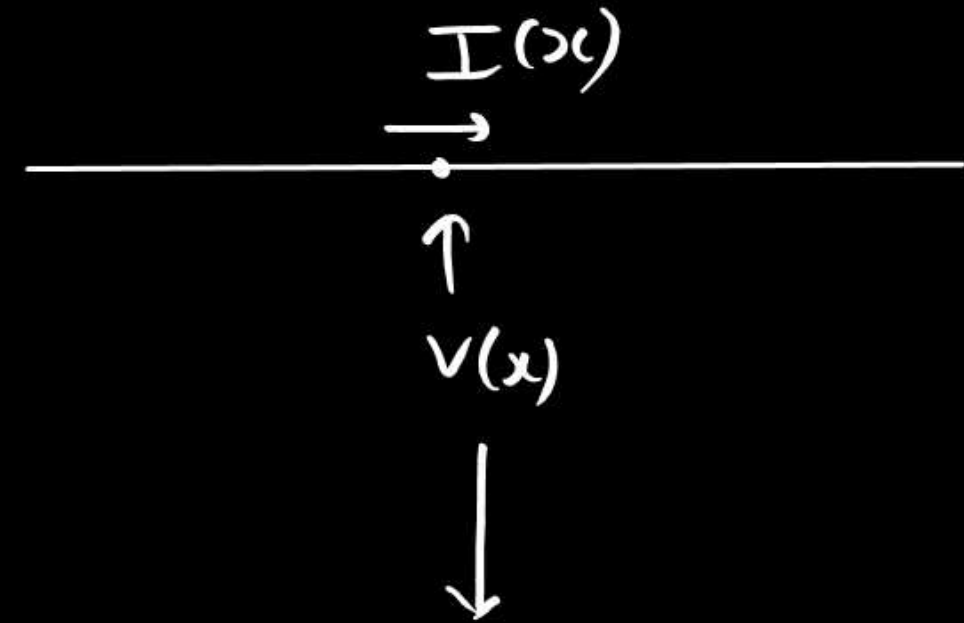
- When C_1 is charged, then only C_2 may be charge through L_2
- So we may say that current & voltage is gradually travelling from sending end to receiving end.
- As we already discussed in long line that at any point voltage & current have two wave
 - (i) Forward moving wave (Incident wave)
 - (ii) Backward moving wave (Reflected wave)

$$V(x) = C_1 e^{\gamma x} + C_2 e^{-\gamma x}$$

$$I(x) = \frac{C_1}{Z_c} e^{\gamma x} - \frac{C_2}{Z_c} e^{-\gamma x}$$

$$\frac{\text{Incident voltage wave}}{\text{Incident current wave}} = +Z_c$$

$$\frac{\text{Reflected voltage wave}}{\text{reflected current wave}} = -Z_c$$



- When surge is travelling. The frequency is very high so

$$R + j\omega L \simeq j\omega L$$

$$\omega L \gg \gg \gg R$$

$$G + j\omega C \simeq j\omega C$$

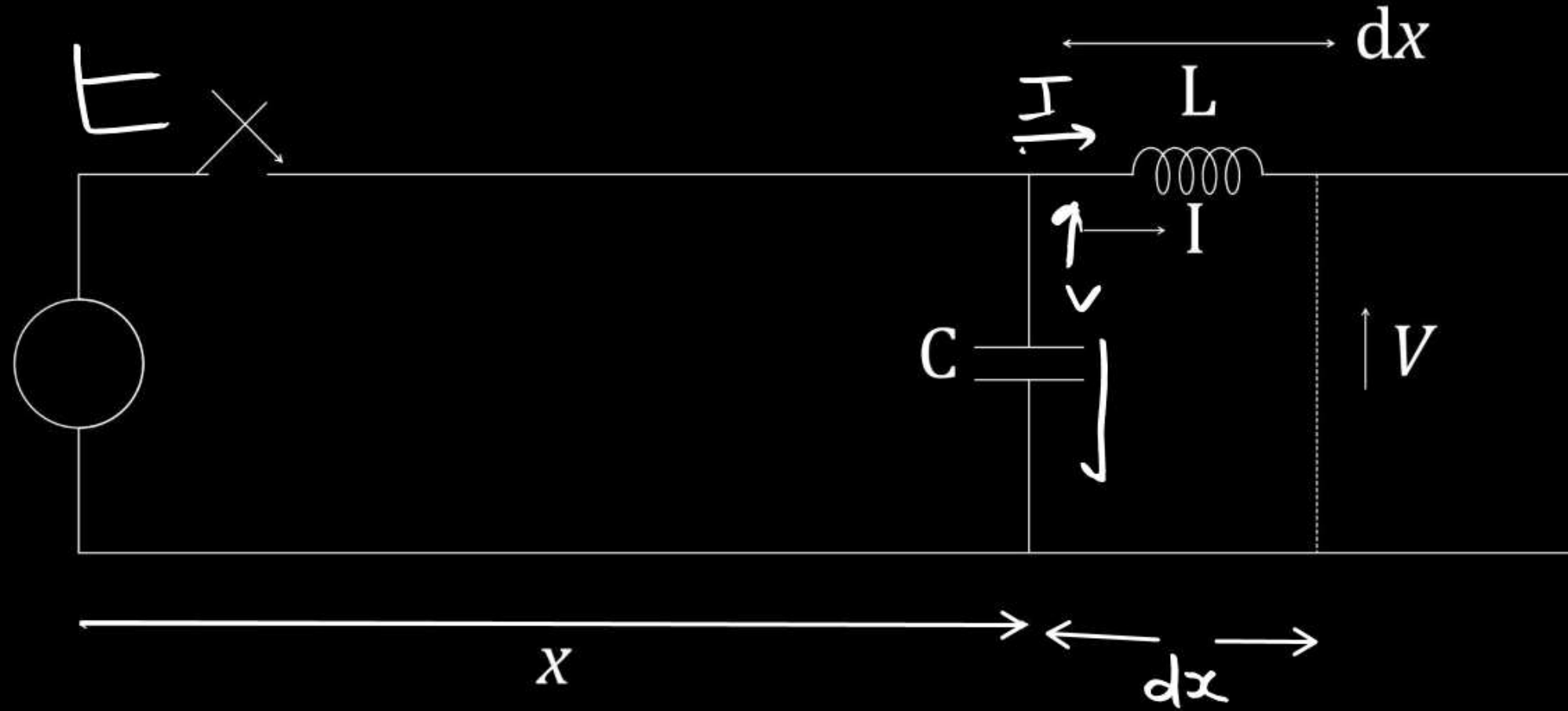
$$\omega C \gg \gg \gg G$$

$$\downarrow$$

$$Z_C = \sqrt{\frac{R + j\omega L}{G + j\omega C}} = \sqrt{\frac{j\omega L}{j\omega C}} = \sqrt{\frac{L}{C}} = \downarrow Z_S$$

- So surge impedance is the impedance offered by TL to surge wave.

II Method:



- Suppose at distance x from source. We took dx differential element.
- Since, it is a lossless line so V and I will be same.

➤ The electrostatic flux (charge) up to x distance

$$q = \lambda = (C x) V$$

$C = \text{p.u length Capacitance}$

$$\text{So current } I = \frac{dq}{dt} = C V \frac{dx}{dt} = C V v \quad \dots (1)$$

$$\frac{dx}{dt} = v = \text{velocity}$$

$$\text{The electromagnetic flux, } \Psi = (L x) I$$

$L = \text{p.u length Inductance}$

$$\text{So } V = \frac{d\Psi}{dt} = L I \frac{dx}{dt} = L I v \quad \dots (2)$$

Divide equation (1) by equation (2)

$$\frac{V}{I} = \frac{L I \cancel{v}}{C V \cancel{v}} \Rightarrow \left(\frac{V}{I} \right)^2 = \frac{L}{C} \Rightarrow Z_s = \sqrt{\frac{L}{C}}$$

Multiplying (1) and (2)



$$\cancel{V}I = (L\cancel{I}U)(C\cancel{V}U)$$

$$U^2 = \frac{1}{LC}$$

$$U = \frac{1}{\sqrt{LC}}$$

$$U = \frac{1}{\sqrt{\frac{\mu}{2\pi} \ln \frac{GMD}{GMR} \times \frac{2\pi\epsilon}{\ln \frac{GMD}{GMR}}}}$$

$$U = \frac{1}{\sqrt{\mu\epsilon}}$$

$$U = \frac{1}{\sqrt{\mu_0\epsilon_0}}$$

$$= \frac{1}{\sqrt{4\pi \times 10^{-7} \times 8.854 \times 10^{-12}}}$$
$$= 3 \times 10^8 \text{ m/s.}$$

- Here, we assume loss-less line, so In real T.L. the speed is less than speed of light (2.5×10^8)
- In cable (ϵ_r) exist, so velocity of wave travel in cable will be less.

$$v = \frac{1}{\sqrt{\mu_0 \epsilon_0 \epsilon_r}} = \frac{3 \times 10^8}{\sqrt{\epsilon_r}} \rightarrow \text{For Cable}$$

The reflection and refraction coefficient of a line terminated by a

Impedance:

(V, I)

(V'', I'')

Incident wave

Refracted wave
(transmitted wave)



(V', I')

Reflected wave

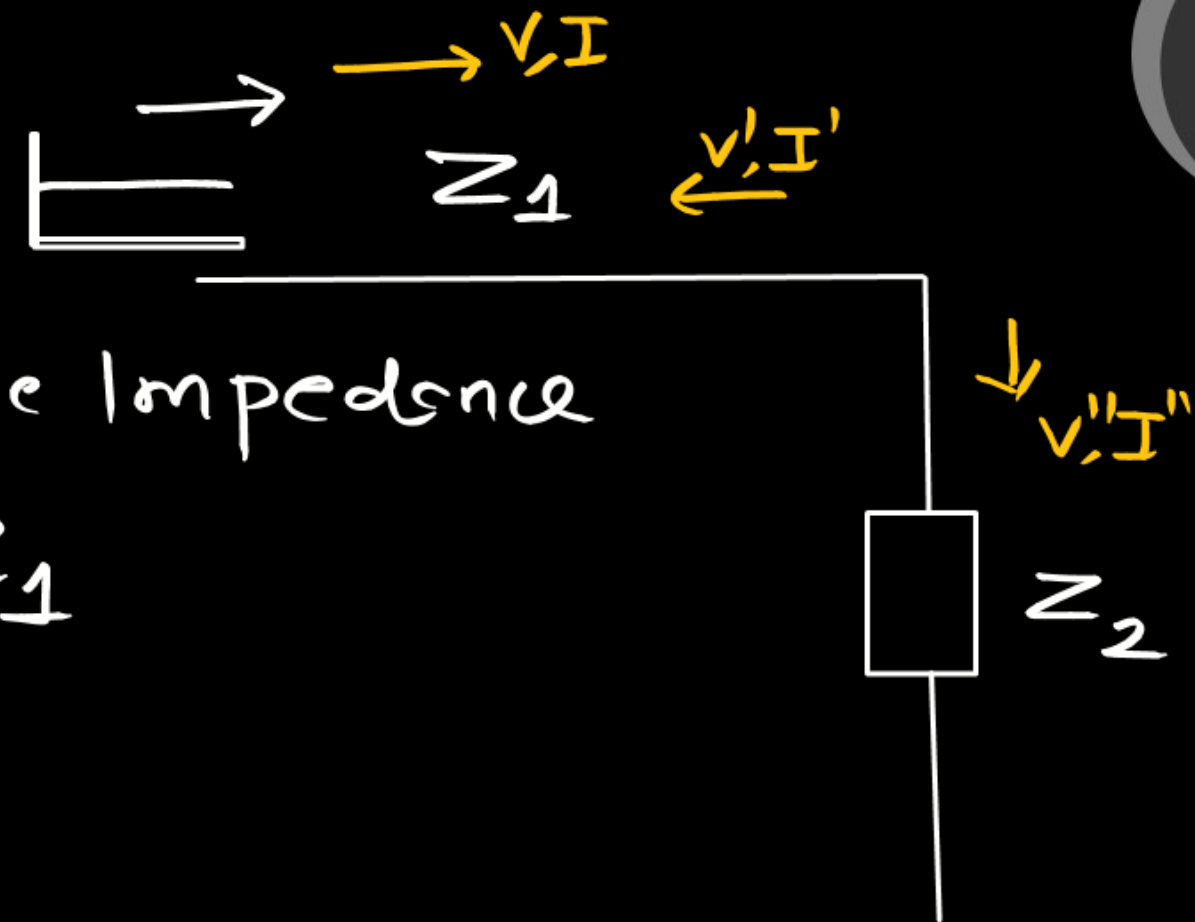


As per boundary condition, incident wave + reflected wave = Refracted wave

incident wave + Reflected wave = Transmitted wave

$$1 + \frac{\text{Reflected wave}}{\text{incident wave}} = \frac{\text{Transmitted wave}}{\text{incident wave}}$$

$$\boxed{1 + \rho_r = \rho_T} \leftarrow \text{Valid for all wave}$$



Characteristic Impedance of T.L $\approx$ Surge Impedance
 $= Z_1$

Load Impedance $= Z_2$

$$V + V' = V'' \quad (I)$$

$$I + I' = I'' \quad (II)$$

$$\frac{V}{I} = Z_1 \quad \Rightarrow \quad I = \frac{V}{Z_1}$$

$$\frac{V''}{I''} = Z_2 \quad \Rightarrow \quad I'' = \frac{V''}{Z_2}$$

$$\frac{V'}{I'} = -Z_1 \quad \Rightarrow \quad I' = -\frac{V'}{Z_1}$$

Voltage reflection coefficient:

$$\frac{V'}{V}$$



$$I + I' = I''$$

$$\frac{V}{Z_1} - \frac{V'}{Z_1} = \frac{V''}{Z_2}$$

$$V + V' = V''$$

$$\frac{V}{Z_1} - \frac{V'}{Z_1} = \frac{V + V'}{Z_2}$$

$$\frac{V}{Z_1} - \frac{V}{Z_2} = \frac{V'}{Z_2} + \frac{V'}{Z_1}$$

$$v \left(\frac{1}{z_1} - \frac{1}{z_2} \right) = v' \left(\frac{1}{z_1} + \frac{1}{z_2} \right)$$

$$v \left(\frac{z_2 - z_1}{\cancel{z_1 z_2}} \right) = v' \left(\frac{z_1 + z_2}{\cancel{z_1 z_2}} \right)$$

$$\rho_{rv} = \frac{v'}{v} = \frac{z_2 - z_1}{z_1 + z_2}$$

$$v' = \frac{z_2 - z_1}{z_2 + z_1} \cdot v$$

Voltage refraction(transmission) coefficient: $\frac{V''}{V}$



$$V + V' = V''$$

$$V + \frac{Z_2 - Z_1}{Z_2 + Z_1} V = V''$$

$$V \left[1 + \frac{Z_2 - Z_1}{Z_2 + Z_1} \right] = V''$$

$$V \left[\frac{2Z_2}{Z_2 + Z_1} \right] = V''$$

$$\rho_{TV} = \frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2}$$

$$V'' = \frac{2Z_2}{Z_1 + Z_2} \cdot V$$

Current reflection coefficient:

$$\frac{I'}{I}$$



$$\frac{V'}{V} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$-\frac{I' \cancel{Z_1}}{\cancel{I} Z_1} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$\rho_{VI} = \frac{I'}{I} = - \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right) = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

$$\frac{V}{I} = Z_1$$

$$V = I Z_1$$

$$\frac{V'}{I'} = -Z_1$$

$$V' = -I' Z_1$$

Current refraction(transmission) coefficient: $\frac{I''}{I}$



$$\frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2}$$

$$\frac{V}{Z_1} = I$$

$$V = IZ_1$$

$$\frac{V''}{Z_2} = I''$$

$$V'' = I''Z_2$$

$$\frac{I'' \cancel{Z_2}}{IZ_1} = \frac{2 \cancel{Z_2}}{Z_1 + Z_2}$$

$$\rho_{II} = \frac{I''}{I} = \frac{2Z_1}{Z_1 + Z_2}$$

- If line is terminated by a ~~Impcdance~~ equal to surge Impedance

$$Z_2 = Z_1$$

$$V' = 0 \quad I' = 0$$

- So no reflection will occur, such line is said to be infinite line and load corresponding to this is called surge Impedance loading.

Surge travel to denser medium:

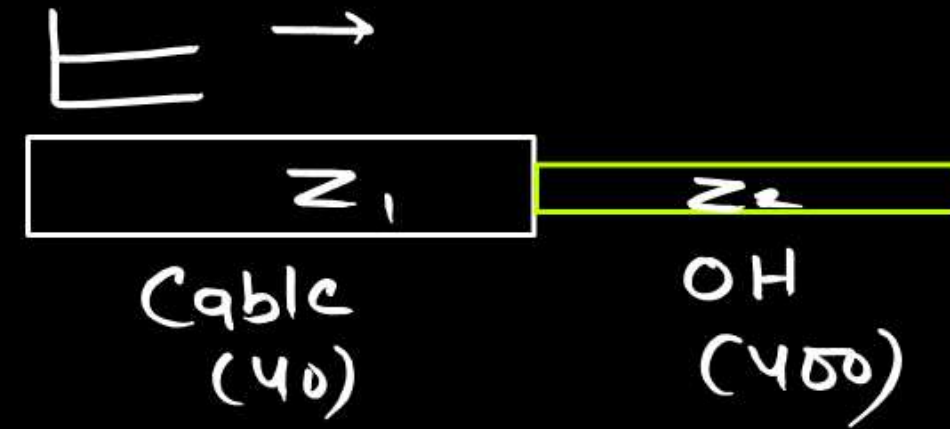


$$Z_2 > Z_1$$

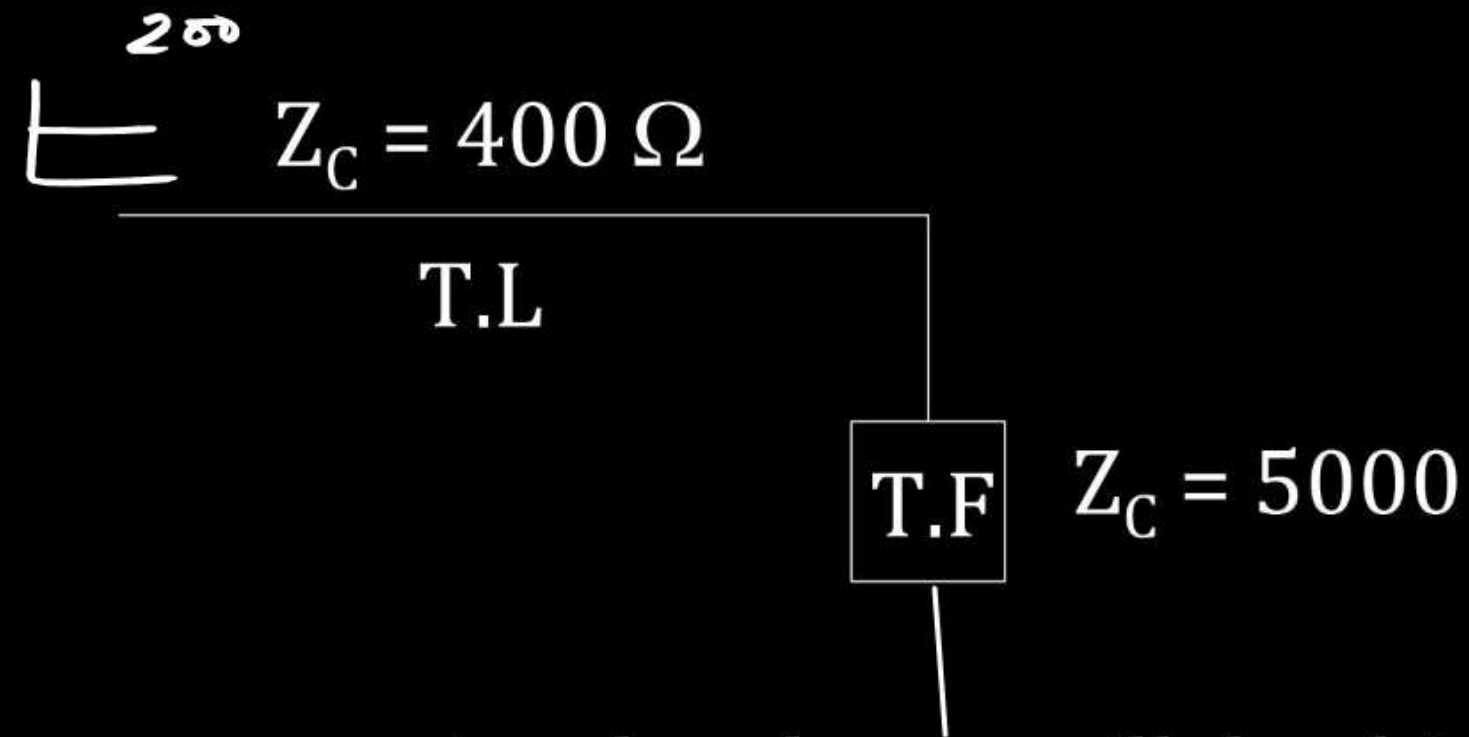
$$\frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2}$$

$$\frac{V''}{V} = \frac{Z_2 + Z_2}{Z_1 + Z_2} > 1$$

$$V'' > V$$



- So, when surge travel to denser medium then transmitted wave > Incident wave



- So in transformer transmitted voltage will be higher than incident wave, so it is not allowed to enter at transformer, otherwise

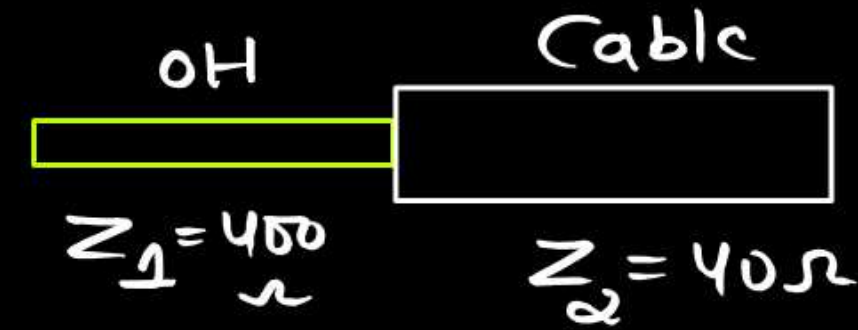
transformer insulation will be damage. $Z_c = Z_s = \sqrt{\frac{L}{C}}$

Surge travel to lighter medium:

$$Z_2 < Z_1$$

$$\frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2} = \frac{Z_2 + Z_2}{Z_1 + Z_2} < 1$$

$$V'' < V$$



Line connected with cable :

- Impedance of overhead line $\approx 400 \Omega$, impedance of cable = 40Ω

$$\frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2}$$

$$\frac{V''}{V} = \frac{2 \times 40}{400 + 40} \approx 0.2$$

$$\underline{V''} \approx 0.2 \underline{V}$$



- In addition to reduction of magnitude, the steepness of voltage is also reduced (Due to capacitance of cable)
- So station equipment should be connected by overhead line by a short underground cable.



2 Minutes Summary

→ Surge & Transient

$$\rightarrow Z_0 = \sqrt{\frac{L}{C}}$$

→ Reflection and Refraction coefficient

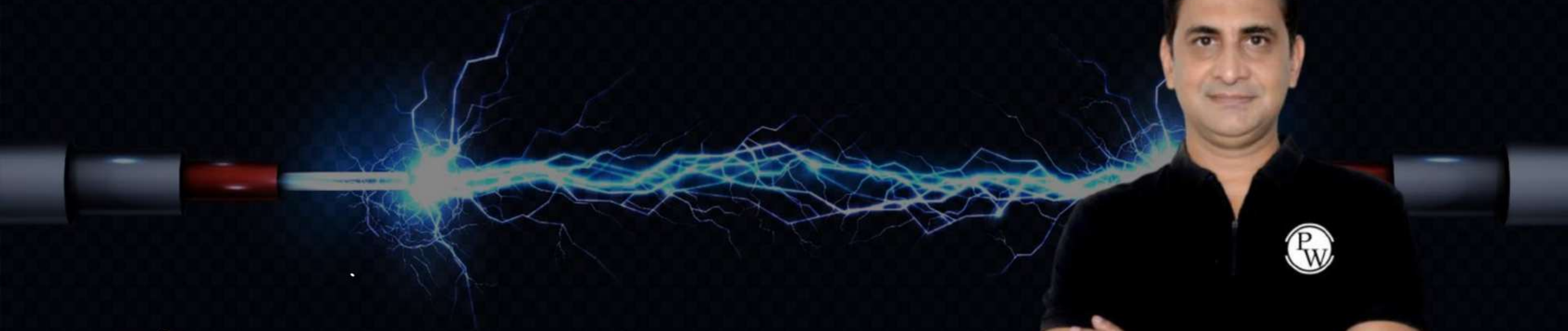
Thank you

GW
Soldiers !



Electrical Engineering

Power System



Lecture No.-2
Transient in Power System

By- Ajay Gupta Sir



Recap Of previous class

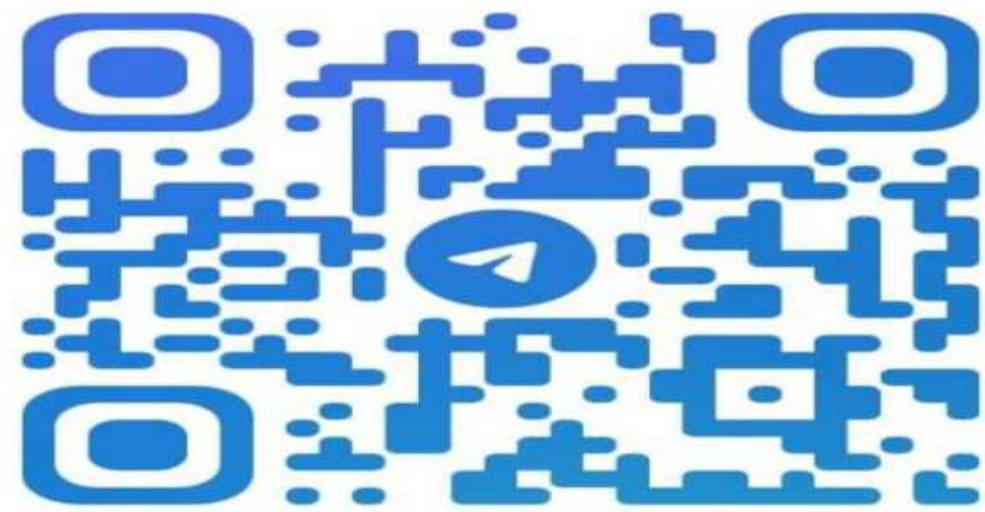
- ✓ 1. Transient
- ✓ 2. Reflection of surges
- ✓ 3. Refraction of surge



Topics to be Covered

- ✓ 1. Line connected with cable
- ✓ 2. Open circuit line

3 Questions



@AJAYGUPTASIRPW

Q.

A surge of 15 kV magnitude travel along a cable toward into junction with an OH line. The inductance & capacitance of cable is 0.3 mH, 0.4 μF and for OH line is 15 mH & 0.012 μF. Find voltage rise at junction due to surge.



A

22.2 kV

B

27.87 kV

C

32.13 kV

D

35.83 kV

$$Z_1 \text{ Surge Impedance of cable} = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.3 \times 10^{-3}}{0.4 \times 10^{-6}}} = 27.38$$

$$Z_2 \text{ Surge Impedance of OH line} = \sqrt{\frac{15 \times 10^{-3}}{0.012 \times 10^{-6}}} = 353.55$$

(e) None.

$$\frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2}$$

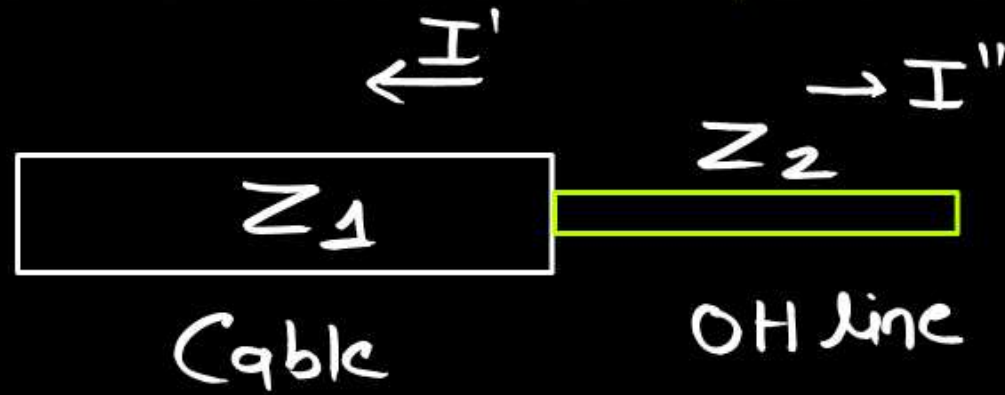
$$\frac{V''}{15} = \frac{2(353.55)}{27.38 + 353.55}$$

$$V'' = 27.84 \text{ kV.}$$

Q.



A surge of 15 kV magnitude travel along a cable toward into junction with an OH line. The inductance & capacitance of cable is 0.2 mH, 0.4 μ F and for OH line is 1.2 mH & 0.012 μ F. Find reflected voltage in the cable.



$$Z_1 = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.2 \times 10^{-3}}{0.4 \times 10^{-6}}} = 22.36$$

$$Z_2 = \sqrt{\frac{L}{C}} = \sqrt{\frac{1.2 \times 10^{-3}}{0.012 \times 10^{-6}}} = 316.22.$$

$$\frac{V'}{V} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$\frac{V'}{V} = \frac{316.22 - 22.36}{316.22 + 22.36} = 0.868$$

$$V' = 15 \times 0.868 = 13.01$$

$$\rightarrow V + V' = V''$$

$$15 + 13.01 = 28.01$$

II Method

$$V'' = \frac{2Z_2}{Z_1 + Z_2} \cdot V$$

$$= \frac{2(316.22)}{316.22 + 22.36} \times 15$$

$$V'' = 28.01$$

$$\rightarrow V + V' = 28.01$$

$$15 + V' = 28.01$$

$$V' = 13.01$$

Q.



A surge of 15 kV magnitude travel along a cable toward into junction with an OH line. The inductance & capacitance of cable is $0.2 \mu\text{H}$, $0.4 \mu\text{F}$ and for OH line is $12 \mu\text{H}$ & $0.012 \mu\text{F}$. Find current in OH line.

$$I'' = \frac{V''}{Z_2} = \frac{28.01 \times 10^3}{316.22} \\ = 88.577 \text{ Amp.}$$

IMM

$$\frac{I''}{I} = \frac{2Z_1}{Z_1 + Z_2}$$

$$I = \frac{V}{Z_1} = \frac{15 \times 10^3}{22.36} = 670.84$$

$$I' = \frac{2(22.36)}{22.36 + 316.22} \times 670.84 = 88.6$$

Q.



A surge of 15 kV magnitude travel along a cable toward into junction with an OH line. The inductance & capacitance of cable is $0.2 \mu\text{H}$, $0.4 \mu\text{F}$ and for OH line is $12 \mu\text{H}$ & $0.012 \mu\text{F}$. Find reflected current in the cable.

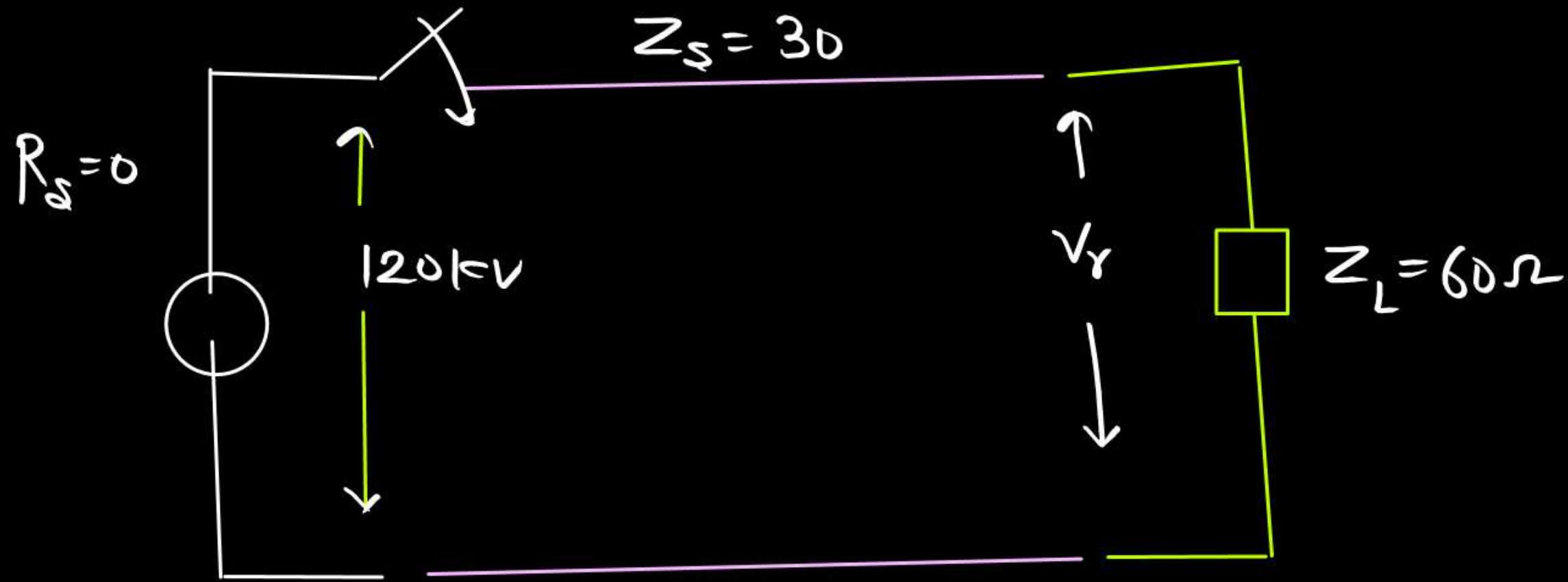
$$\frac{V'}{I'} = -Z_1$$

$$I' = -\frac{V'}{Z_1} = -\frac{13.01 \times 10^3}{22.36} = -581.84$$

Q.



A D.C. Source of 120 V with negligible resistance is connected through switch to a lossless line having $Z_s = 30 \text{ ohm}$. The line is terminated with resistance of 60 ohm . If switch is close at $t=0$. Plot V_r with time until $t=5T$, where T is the time taken by wave to travel one length of line. Draw Bewley lattice diagram too?

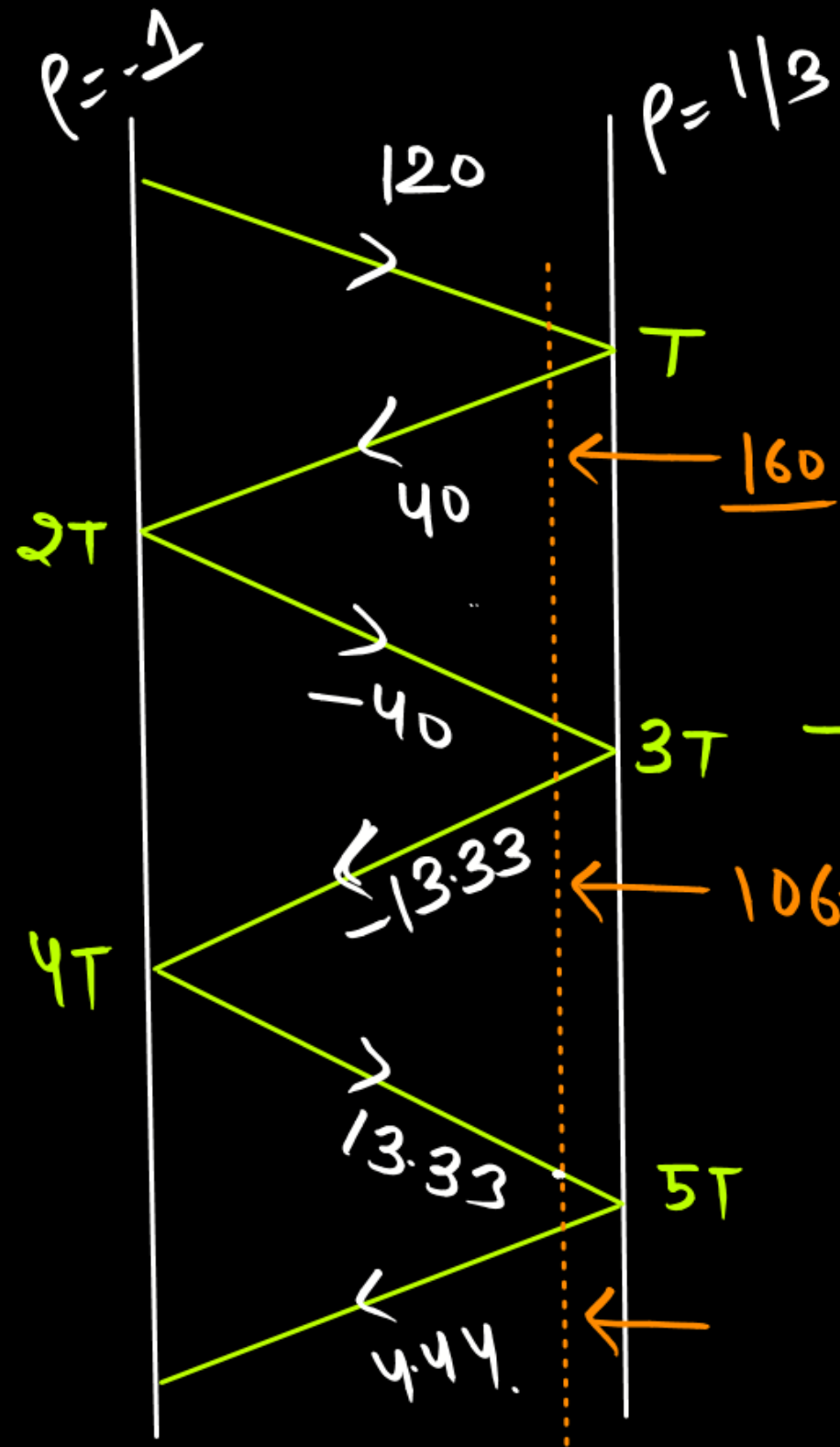


Voltage Reflection Coefficient at the receiving end

$$= \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{Z_L - Z_s}{Z_L + Z_s} = \frac{60 - 30}{60 + 30} = \frac{1}{3}$$

Voltage Reflection coefficient at the sending end

$$= \frac{Z_2 - Z_1}{Z_2 + Z_1} = \frac{R_s - Z_s}{R_s + Z_s} = \frac{0 - 30}{0 + 30} = -1$$



→ First Reflected wave at the receiving end

$$= 120 \times \frac{1}{3} = 40V$$

→ First reflected wave at the sending end

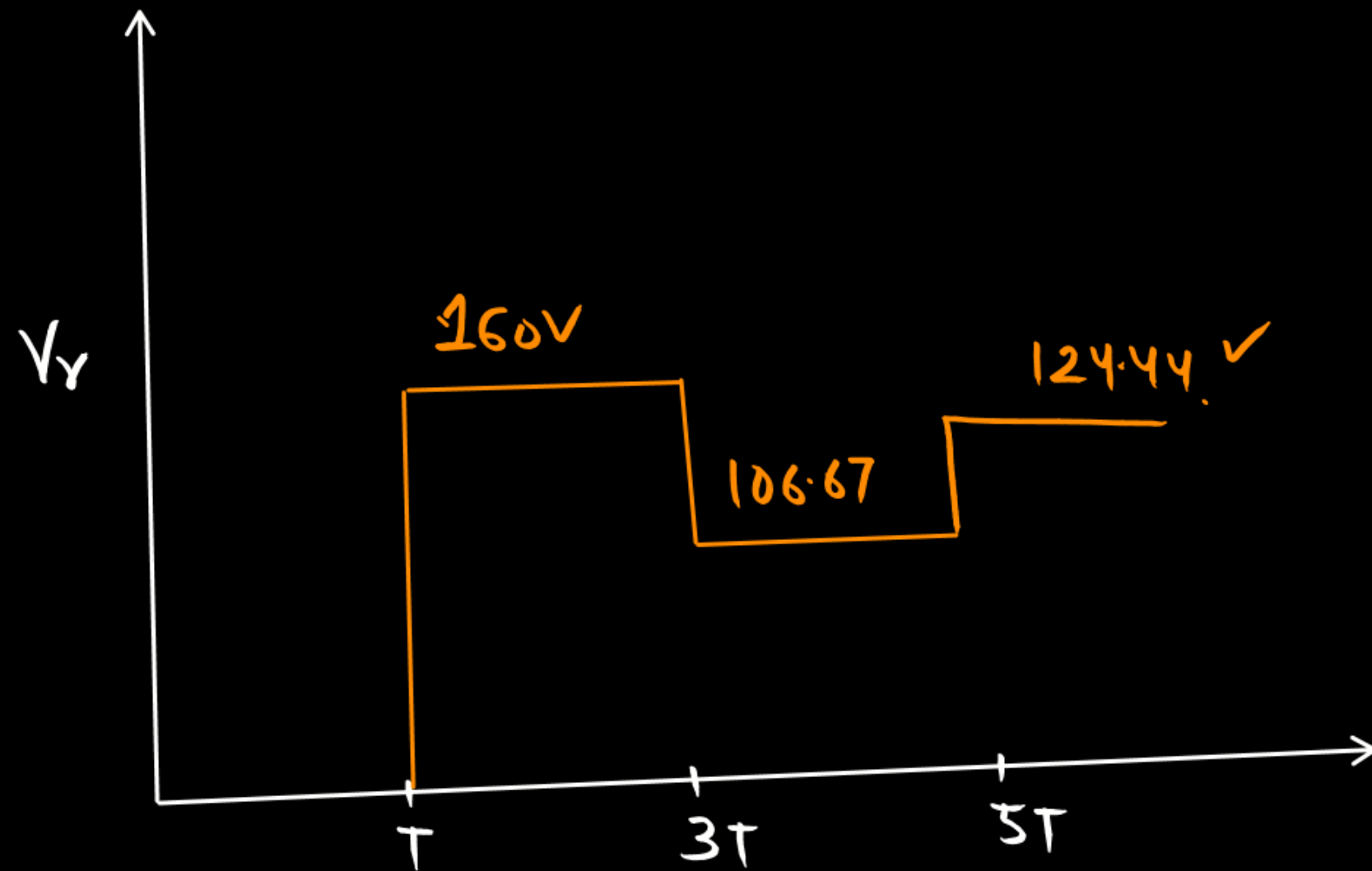
$$= 40 \times -1 = -40$$

→ Second reflected wave at the receiving end

$$= -40 \times \frac{1}{3}$$

Send Reflected wave at the sending end $= (-13.33)(-1)$
 $= 13.33$

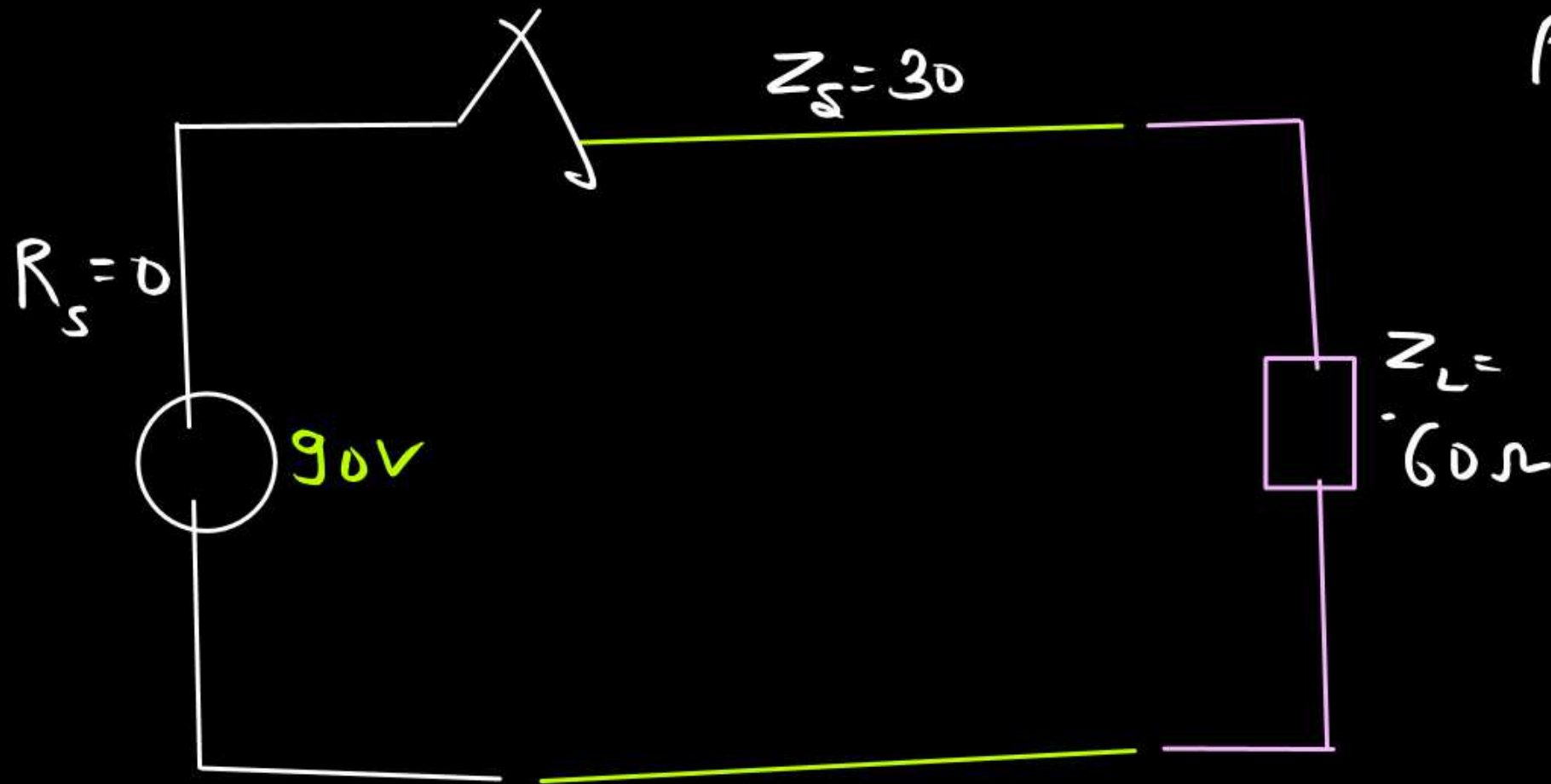
Third Reflected wave at the receiving end $= 13.33 \times \frac{1}{3}$
 $= 4.44$



Q.



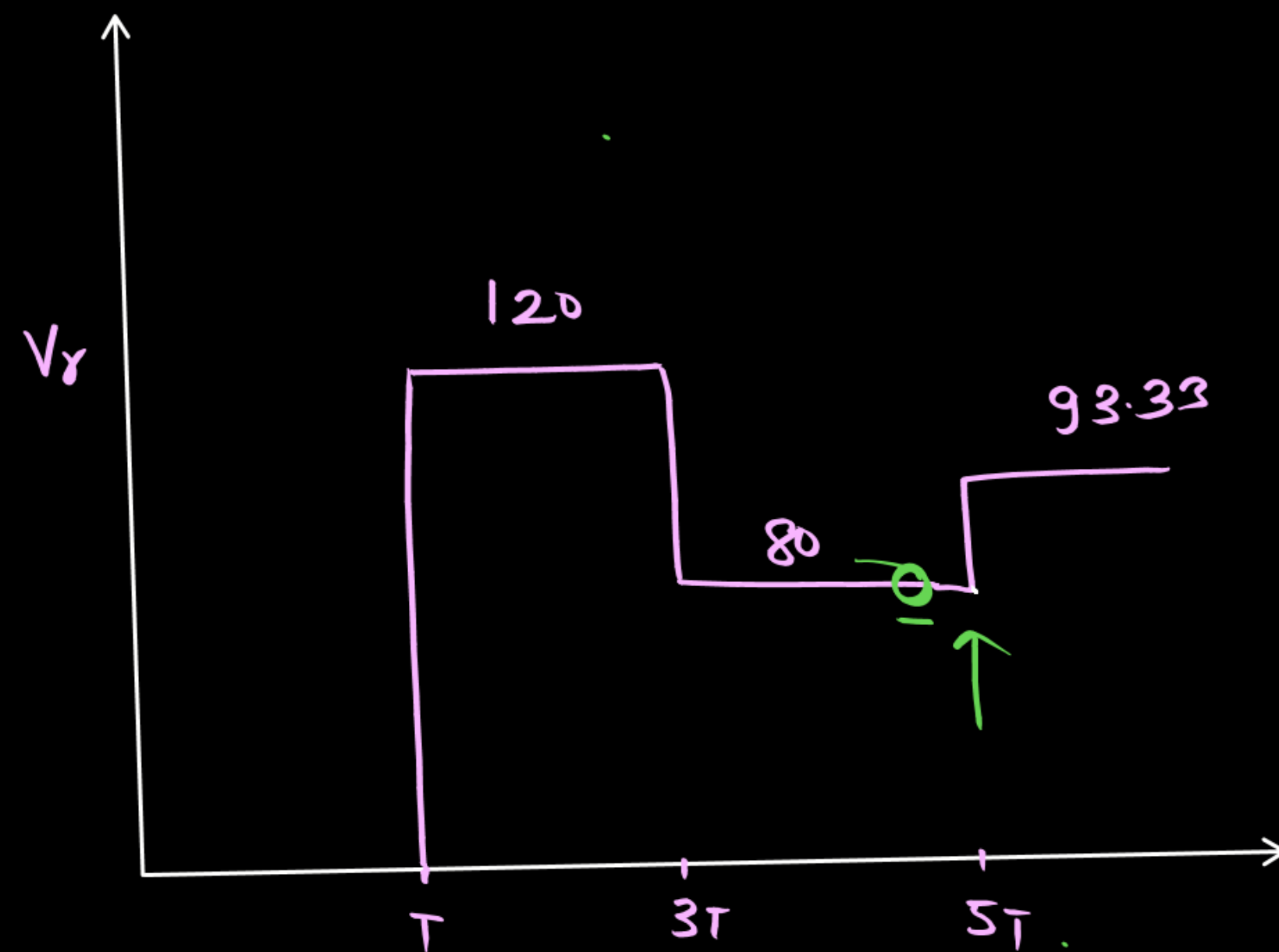
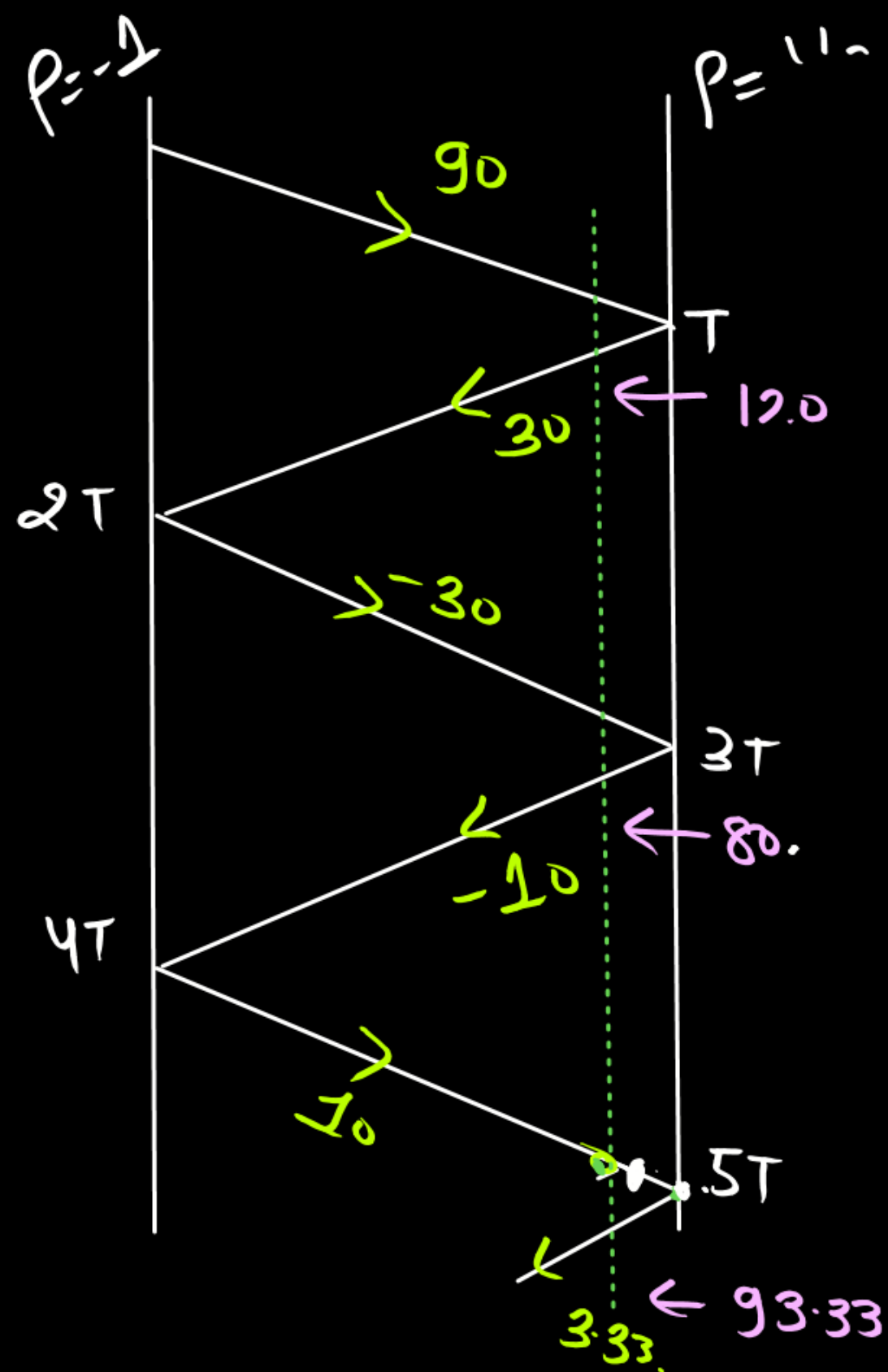
A D.C. Source of 90 V with negligible resistance is connected through switch to a lossless line having $Z_s = 30 \text{ ohm}$. The line is terminated with resistance of 60 ohm. Find the voltage at the receiving end just before the $t = 5T$, where T is the time taken by wave to travel one length of line. Draw Bewley lattice diagram too?



$$\rho(\text{receiving end}) = \frac{Z_L - Z_s}{Z_L + Z_s}$$

$$= \frac{60 - 30}{60 + 30} = \frac{1}{3}$$

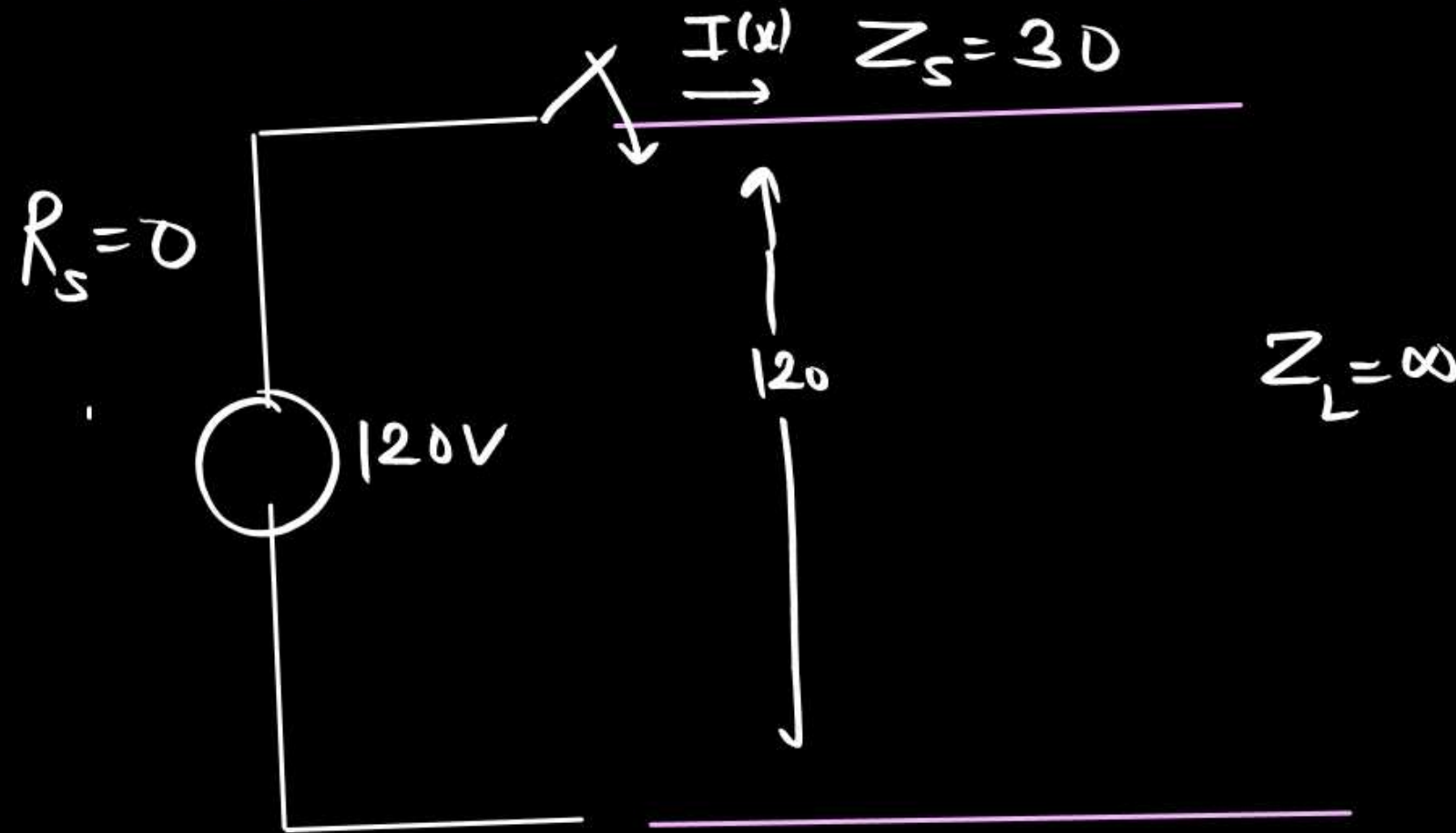
$$\rho(\text{sending}) = \frac{R_s - Z_s}{R_s + Z_s} = \frac{0 - 30}{0 + 30} = -1$$



Q.



A D.C. Source of 120 V with negligible resistance is connected through switch to a lossless line having $Z_s = 30 \text{ ohm}$. The line is open circuited. If switch is close at $t=0$. Plot I_s with time until $t=5T$, where T is the time taken by wave to travel one length of line. Draw Bewley lattice diagram too?



ρ_I (Receiving end)

$$= - \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right)$$

$$= - \left(\frac{Z_L - Z_s}{Z_L + Z_s} \right)$$

$$= - \left(\frac{1 - Z_s/Z_L}{1 + Z_s/Z_L} \right) = -1$$

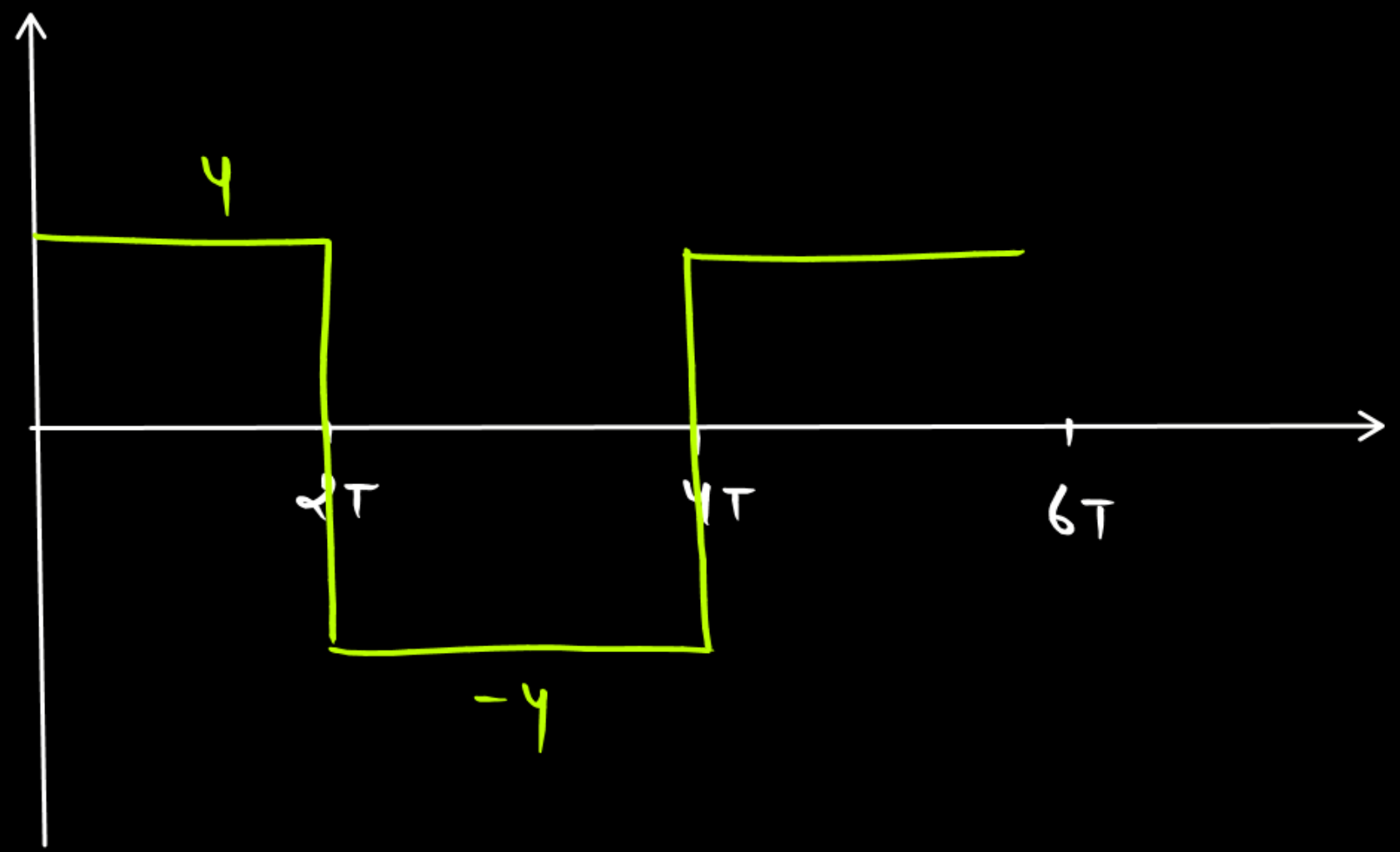
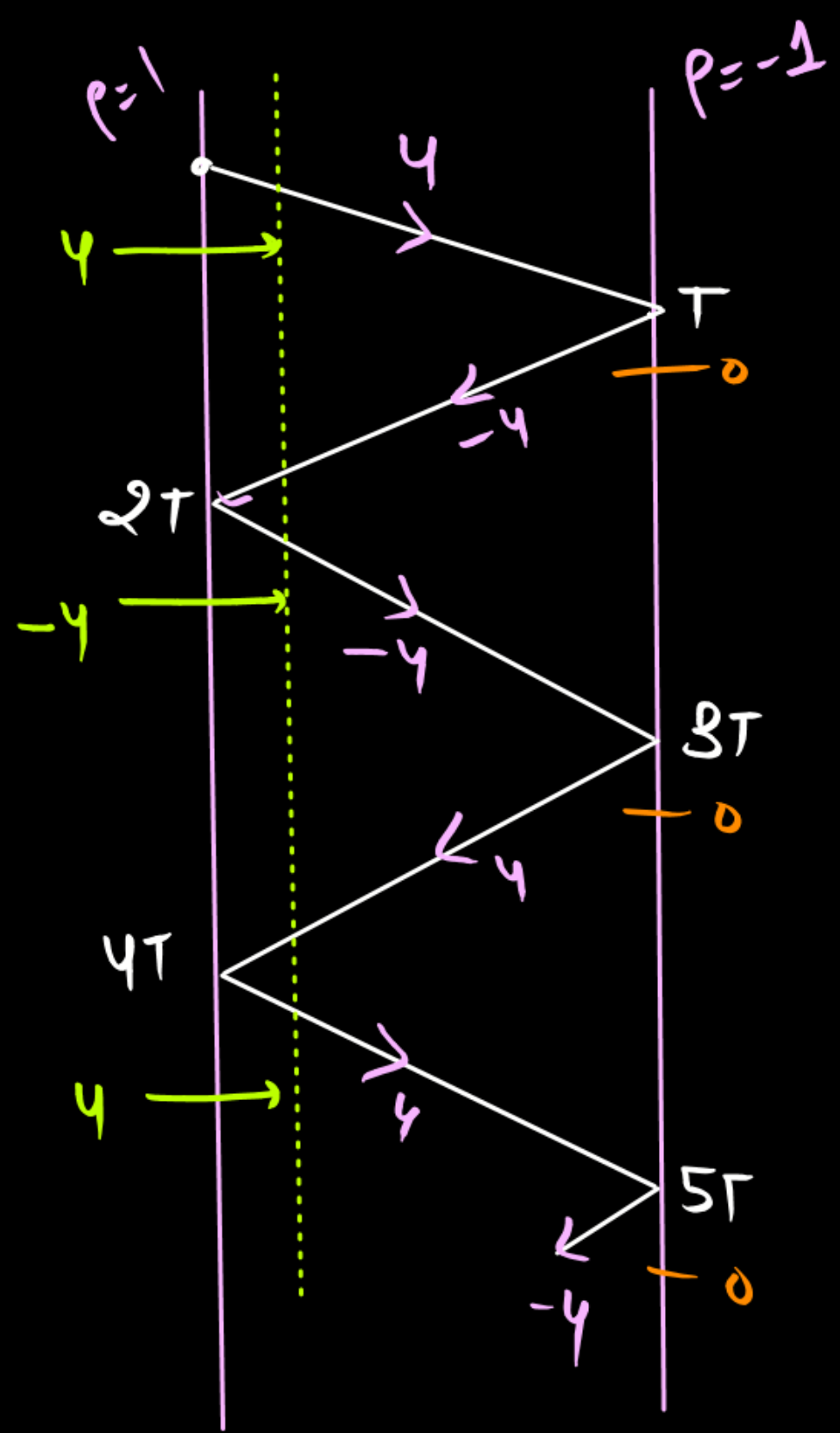
$$\begin{aligned}\rho_I(\text{Sending end}) &= -\left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right) \\ &= -\left(\frac{R_s - Z_s}{R_s + Z_s}\right) = -\left(\frac{0 - Z_s}{0 + Z_s}\right) = 1\end{aligned}$$

$$Z_s = \frac{V(x)}{I(x)}$$

$$I = \frac{V}{Z_s}$$

$$V = \frac{120}{30} = 4$$

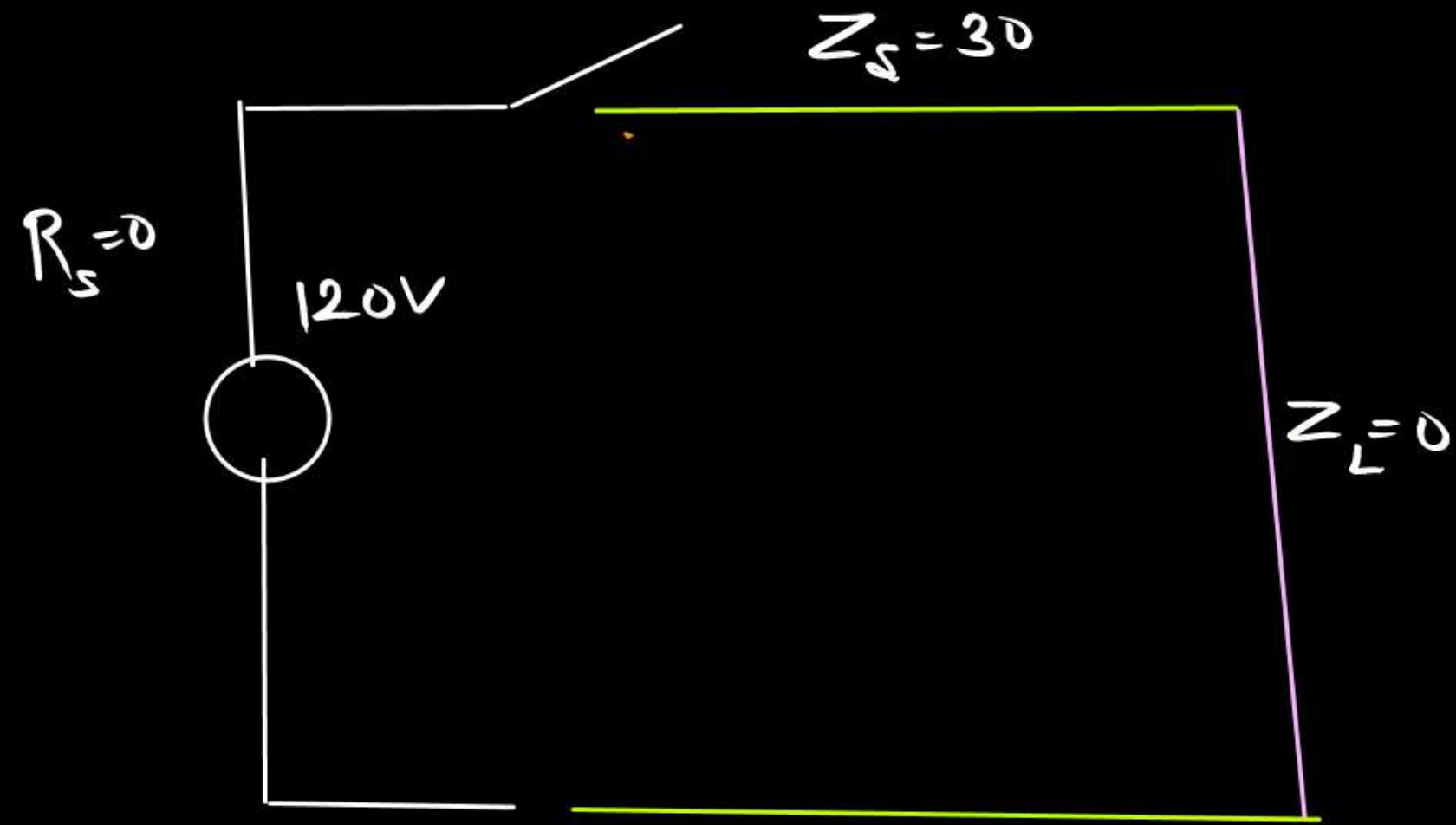
(Incident current wave)



Q.

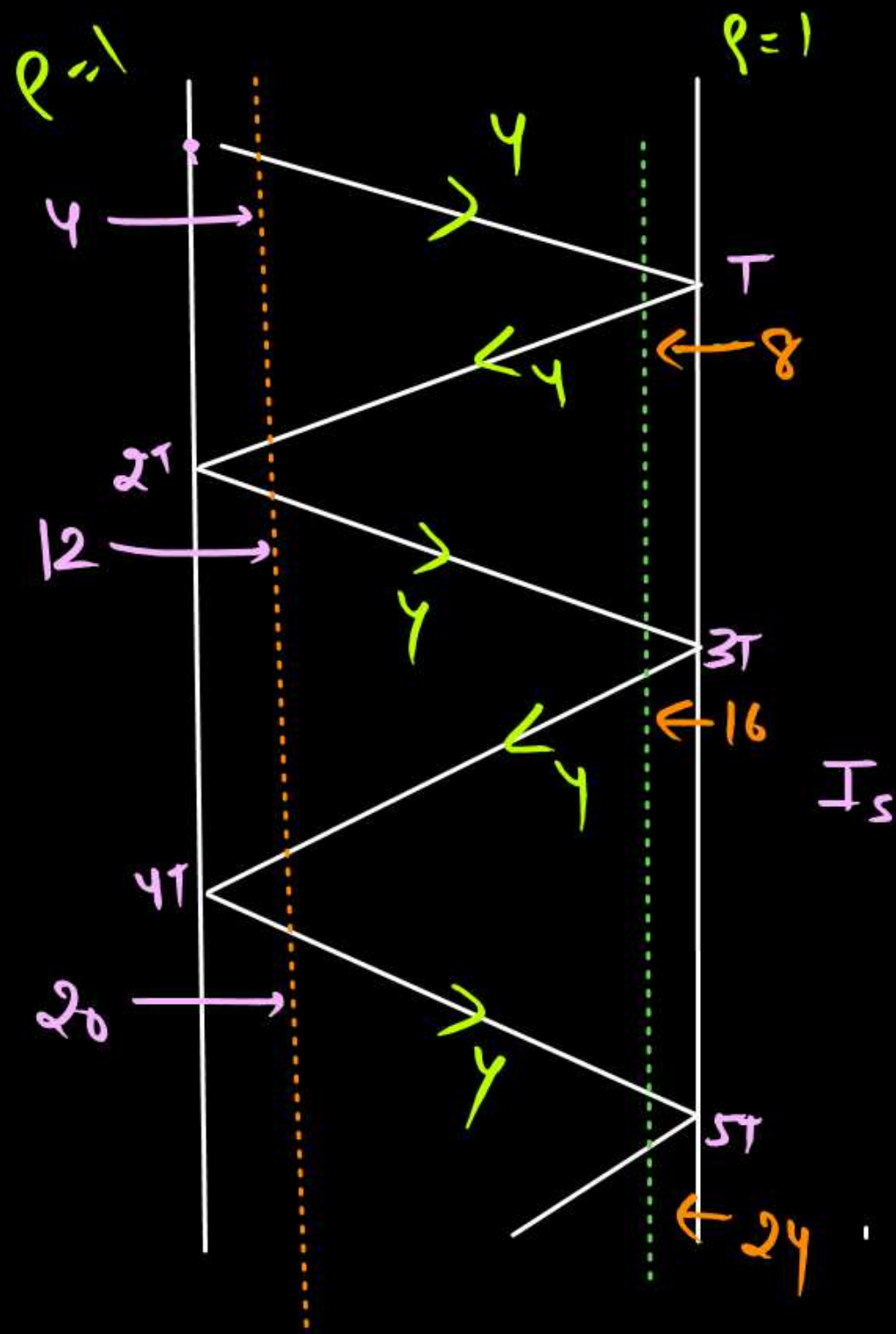


A D.C. Source of 120 V with negligible resistance is connected through switch to a lossless line having $Z_s = 30 \text{ ohm}$. The line is short circuited. If switch is close at $t=0$. Plot I_s with time until $t=5T$, where T is the time taken by wave to travel one length of line. Draw Bewley lattice diagram too?

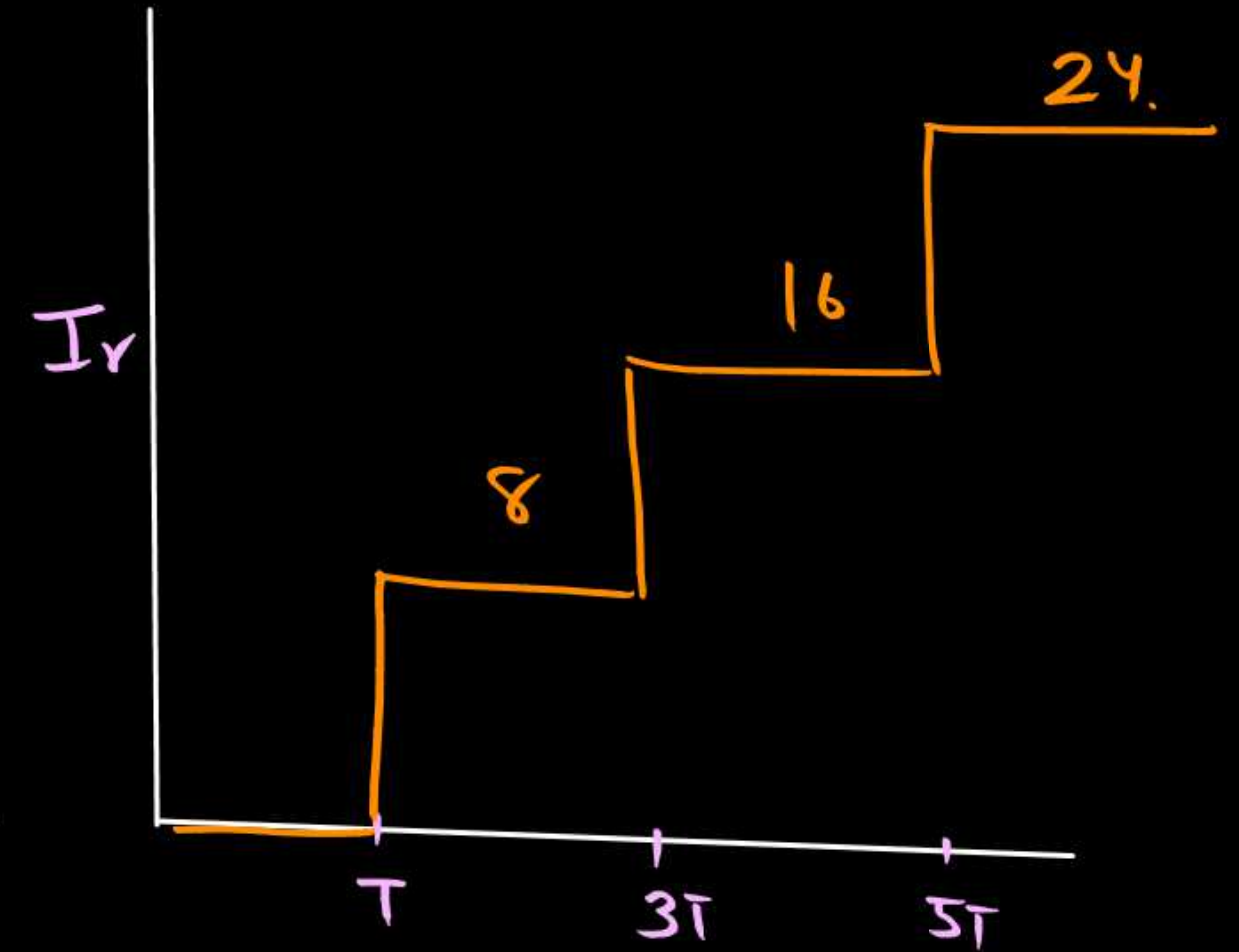
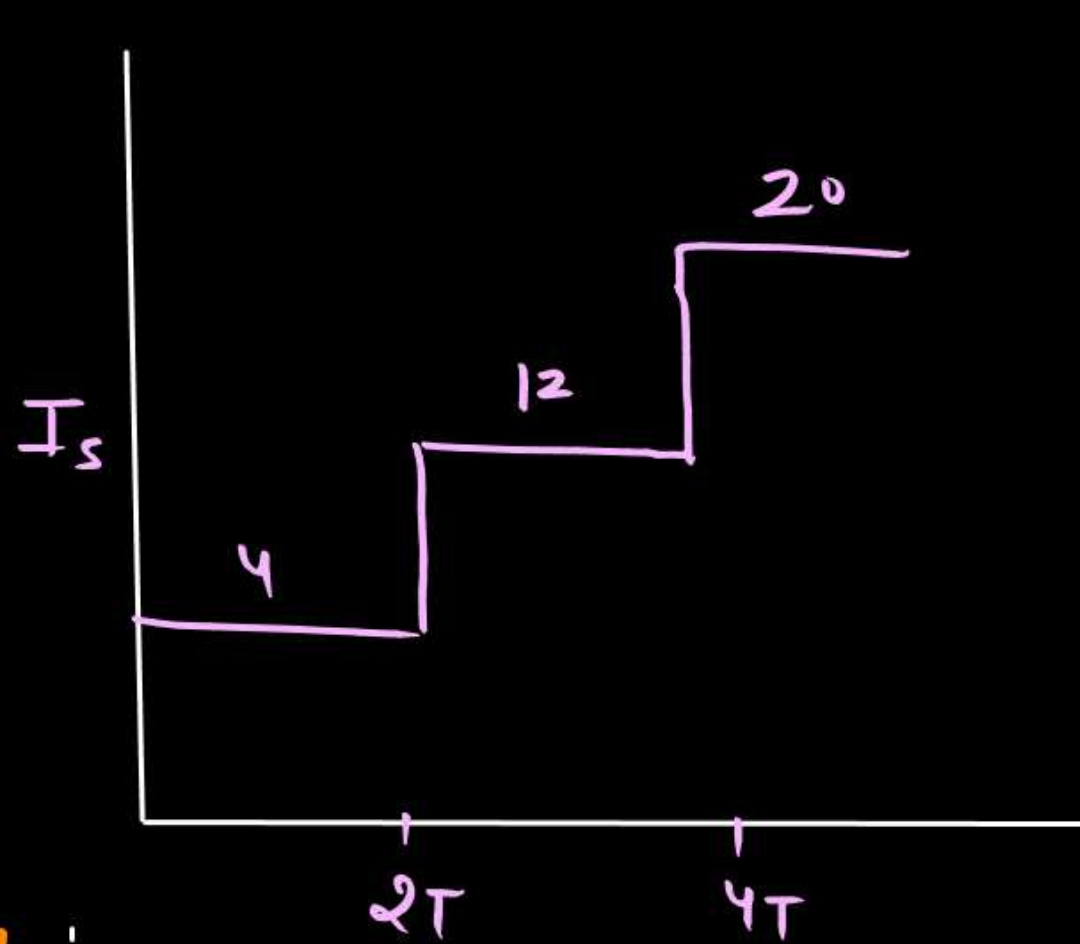


$$\rho(\text{Sending}) = -\left(\frac{0-30}{0+30}\right) = 1$$

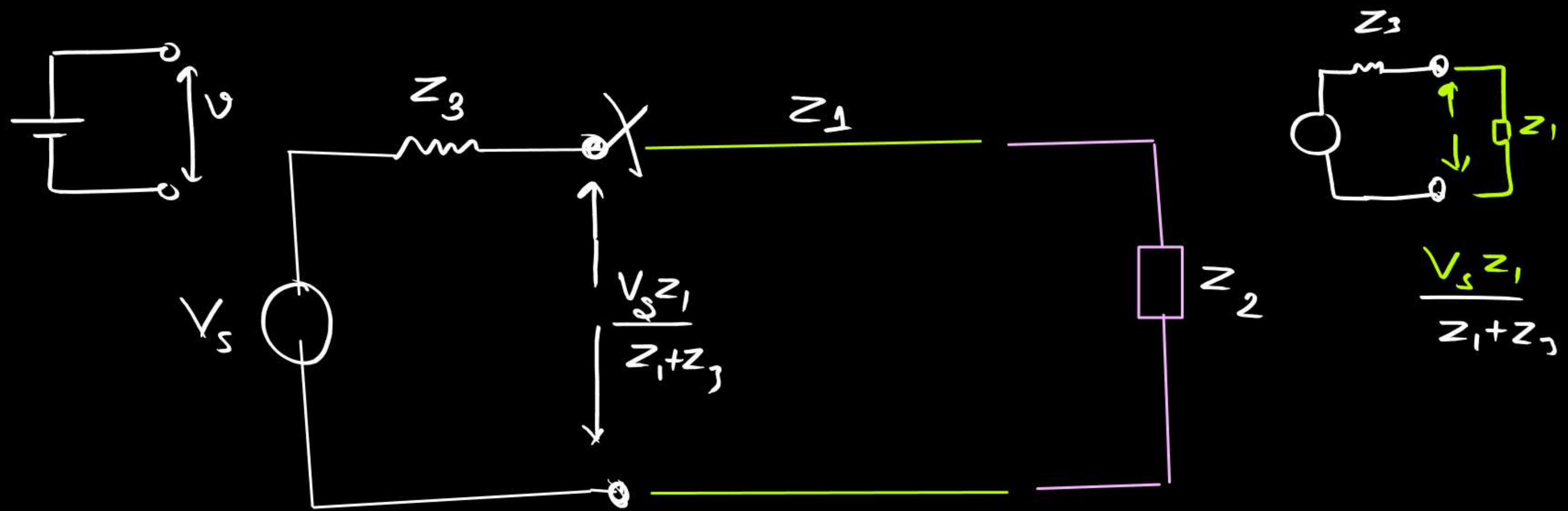
$$\rho(\text{receiving}) = -\left(\frac{0-30}{0+30}\right) = 1$$



incident current wave = $\frac{120}{30} = 4$



Bewley lattice diagram if source impedance is given:



Z_3 = Internal Impedance of Source

Z_2 = load Impedance

Z_1 = Surge Impedance of T.L

$$\text{incident voltage wave} = \frac{V_s Z_1}{Z_1 + Z_3}$$

$$\text{incident current wave} = \frac{\frac{V_s Z_1}{Z_1 + Z_3}}{Z_1} = \frac{V_s}{Z_1 + Z_3}$$

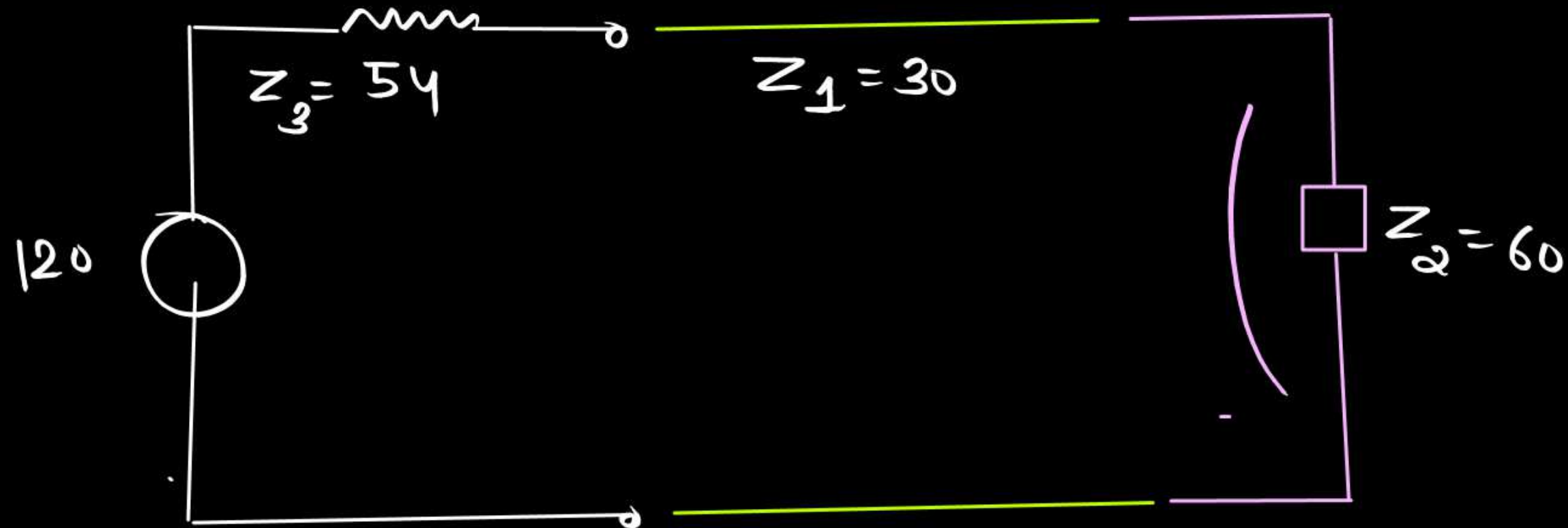
$$\rho_v(\text{receiving}) = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$\rho_v(\text{sending}) = \frac{Z_3 - Z_1}{Z_3 + Z_1}$$

Q.



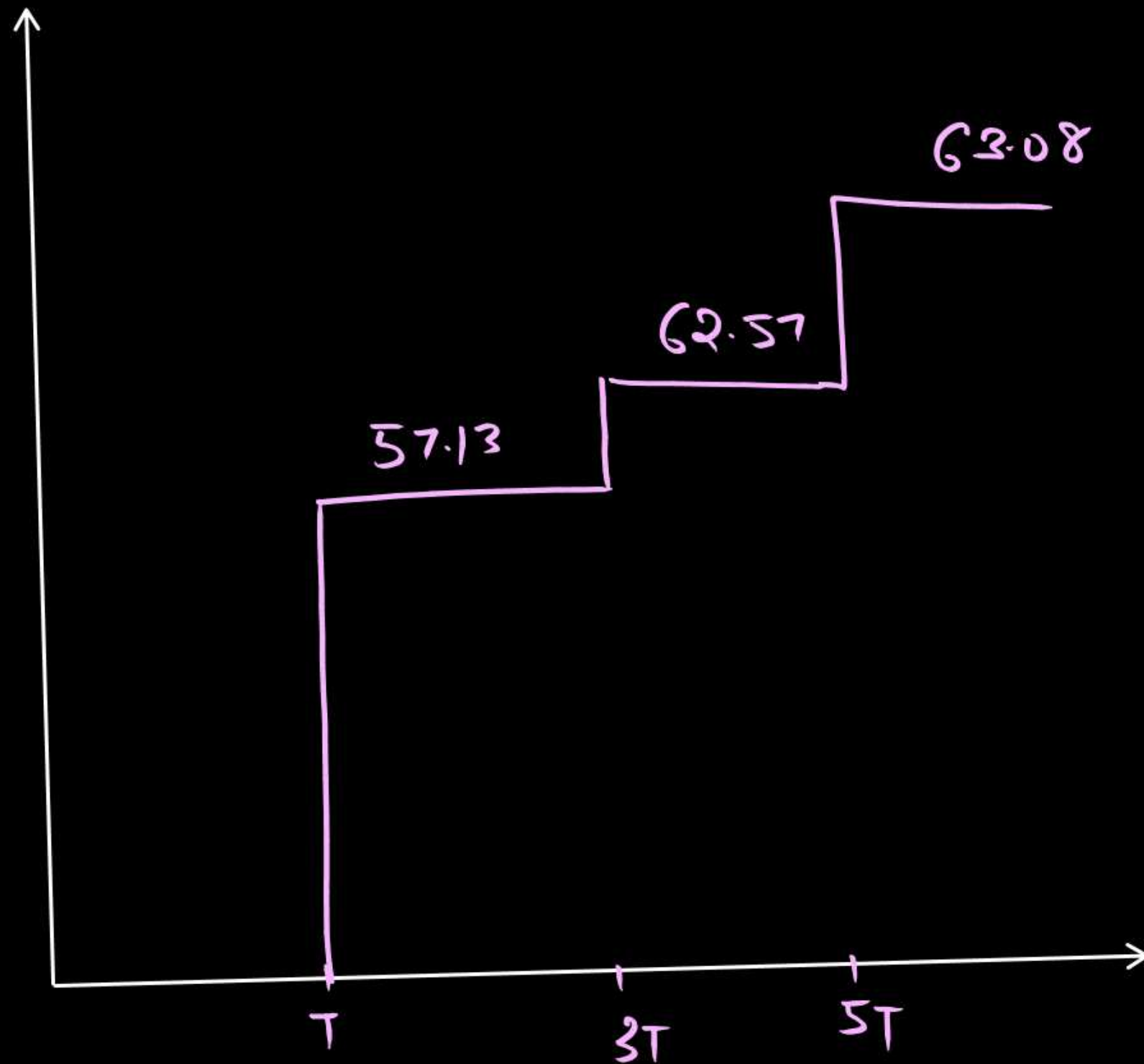
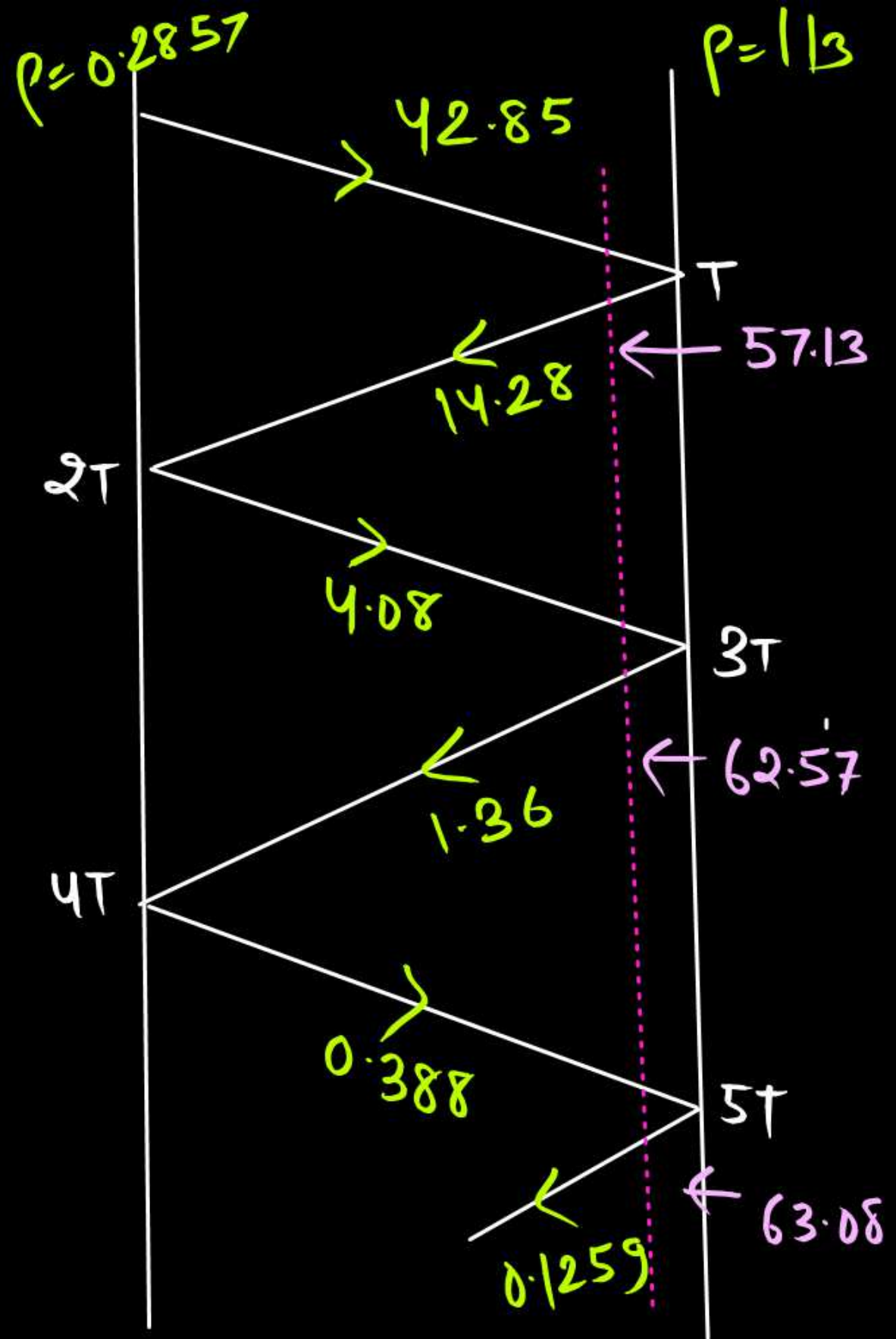
A D.C. Source of 120 V with internal impedance of 54 ohm is connected through switch to a lossless line having $Z_s = 30$ ohm. The line is terminated with resistance of 60 ohm. If switch is close at $t=0$. Plot V_r with time until $t=5T$, where T is the time taken by wave to travel one length of line. Draw Bewley lattice diagram too?




$$\rho_{V(Rcv)} = \frac{60-30}{60+30} = \frac{1}{3}$$

$$\rho_{V(Snd)} = \frac{54-30}{54+30} = 0.2857$$

$$\text{Incident voltage wave} = \frac{120 \times 30}{30+54} = 42.857$$





2 Minutes Summary

→ Bewley lattice diagram

→ Question

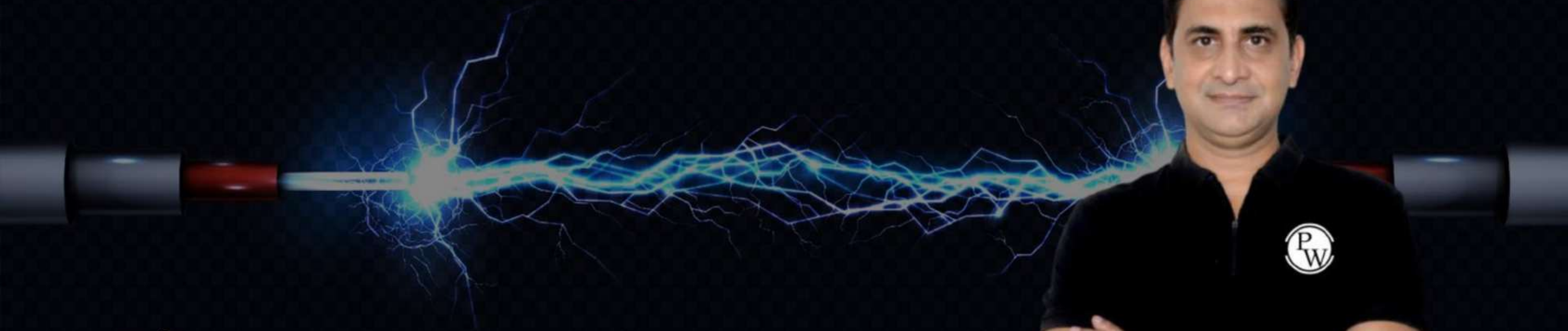
Thank you

GW
Soldiers !



Electrical Engineering

Power System



Lecture No.-3
Transient in Power System

By- Ajay Gupta Sir



1. Bewley lattice diagram,

2. Questions

3.

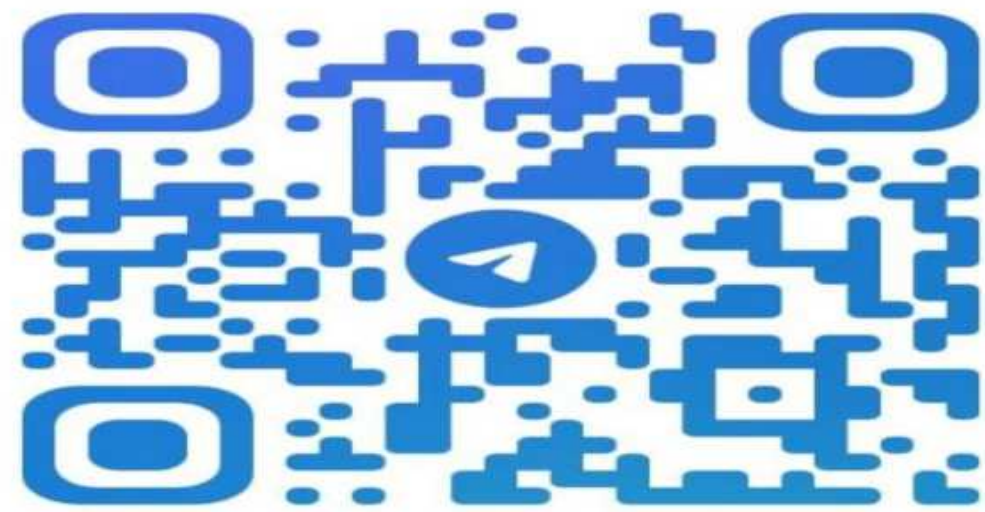
4

5.



Topics to be Covered

1. Bifurcated line
2. Thevenin equivalent model
3. Line terminated by capacitor
4. Line terminated by inductor
5. Questions



@AJAYGUPTASIRPW

Thevenin equivalent circuit for travelling wave:

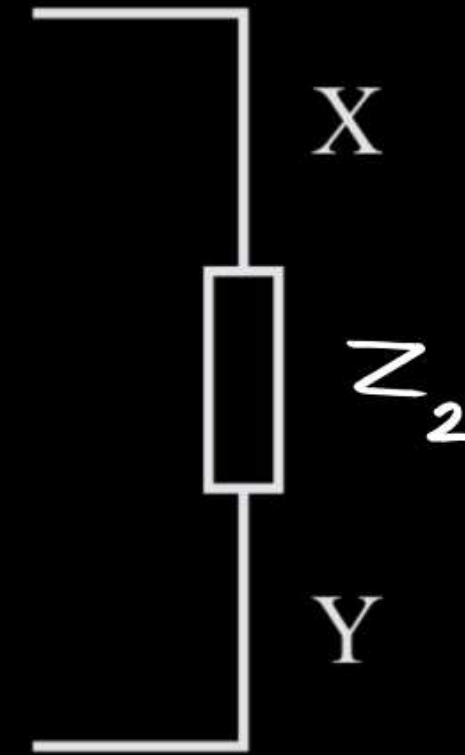
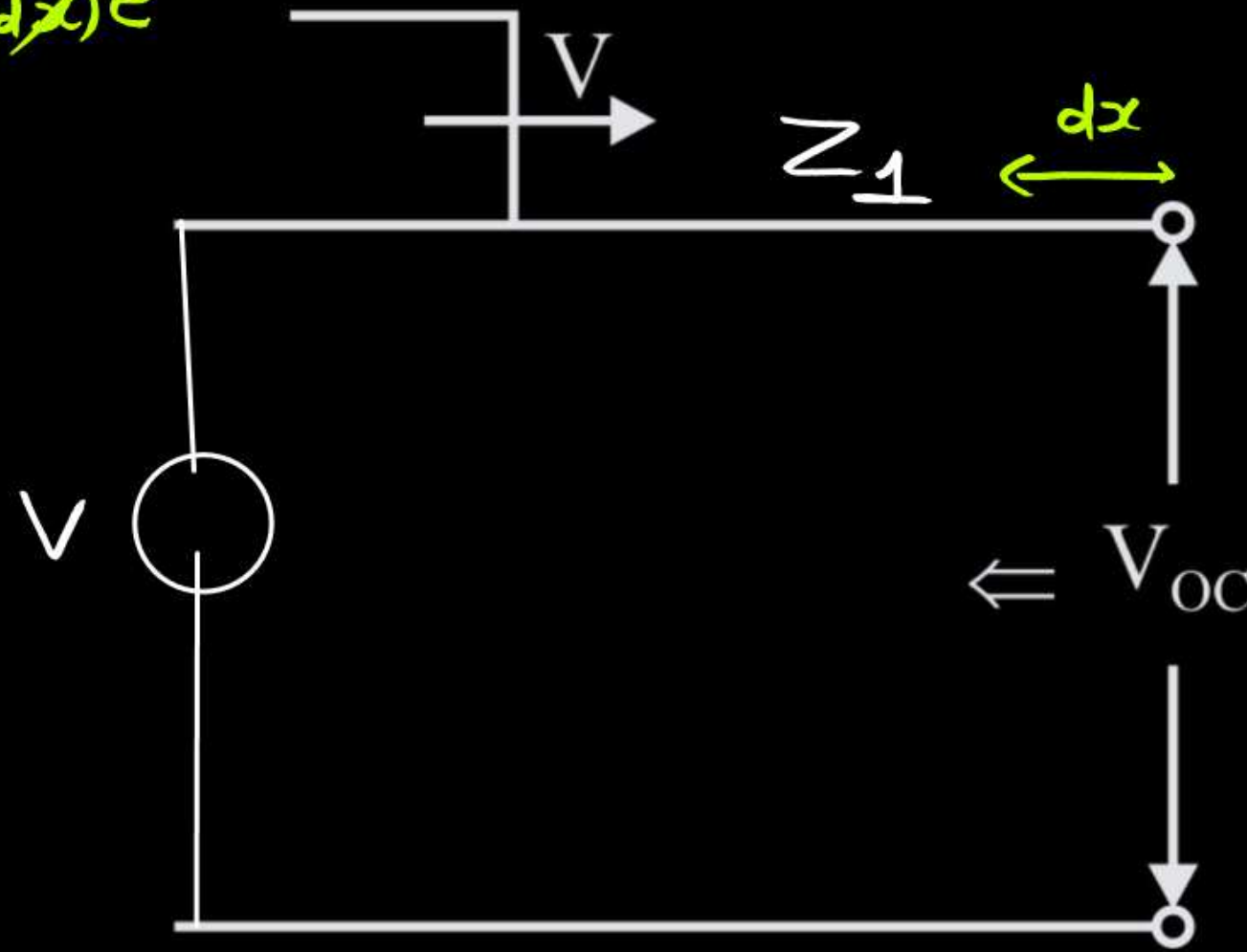


$$\frac{1}{2}(L \frac{dx}{dt})^2 = \frac{1}{2}(C \frac{dx}{dt})^2$$

$$e = j\sqrt{L/C}$$

$$e = jZ_1$$

$$\underline{e = V}$$



In o/c $Z_2 = \infty$

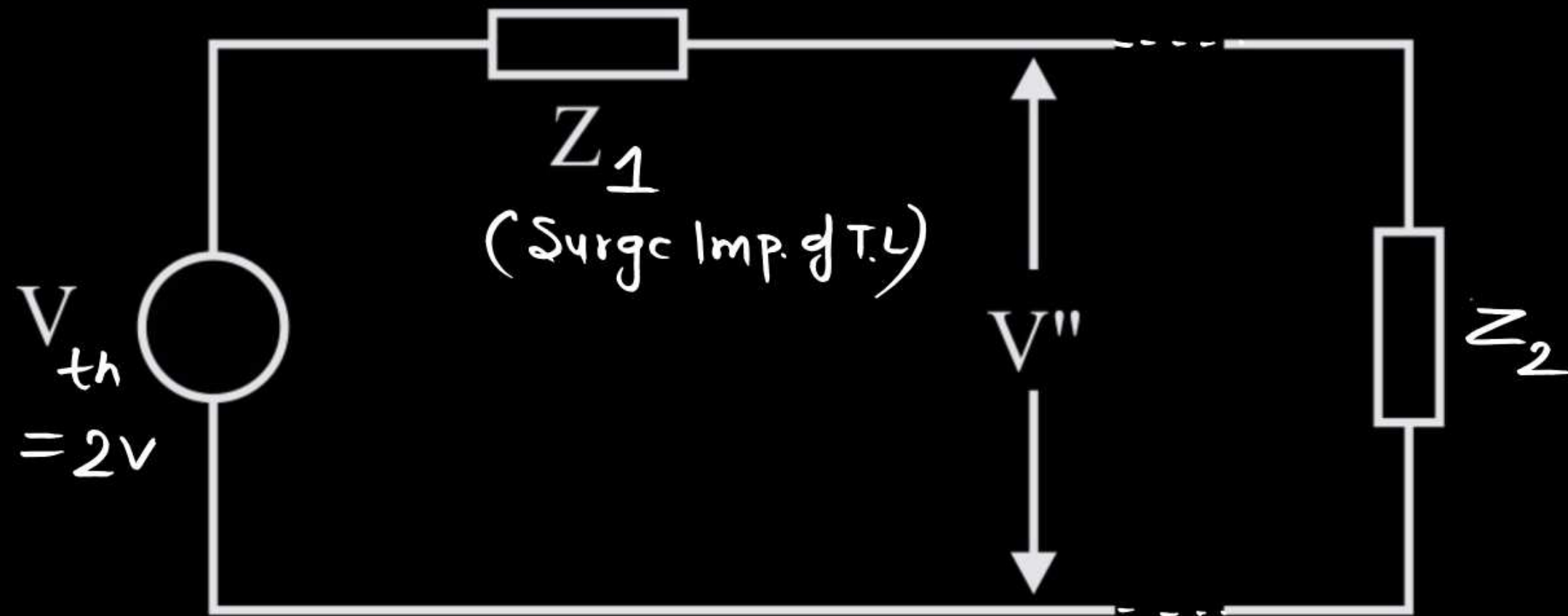
$$\frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2}$$

$$\frac{V''}{V} = \frac{2}{\frac{Z_1}{Z_2} + 1}$$

$$\underline{V'' = 2V}$$

✓ $V_{Th} = \text{open circuit voltage} = 2V$

$$Z_{tn} = Z_1$$



Thevenin eqⁿ ckt

Now from Voltage division Rule

$$V'' = \frac{Z_2}{Z_1 + Z_2} \cdot 2V$$

$$\rho_{tv} = \frac{V''}{V} = \frac{2Z_2}{Z_1 + Z_2}$$

$$V + V' = V''$$

$$V + V' = \frac{2Z_2}{Z_1 + Z_2} V$$

$$V' = \frac{Z_2 - Z_1}{Z_2 + Z_1} V$$

$$\rho_{rv} = \frac{V'}{V} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$V' = -I' Z_1$$

$$V = I Z_1$$

$$\frac{-I' Z_1}{I Z_1} = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$\rho_{rI} = \frac{I'}{I} = -\left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)$$

$$V'' = I'' Z_2$$

$$V = I Z_1$$

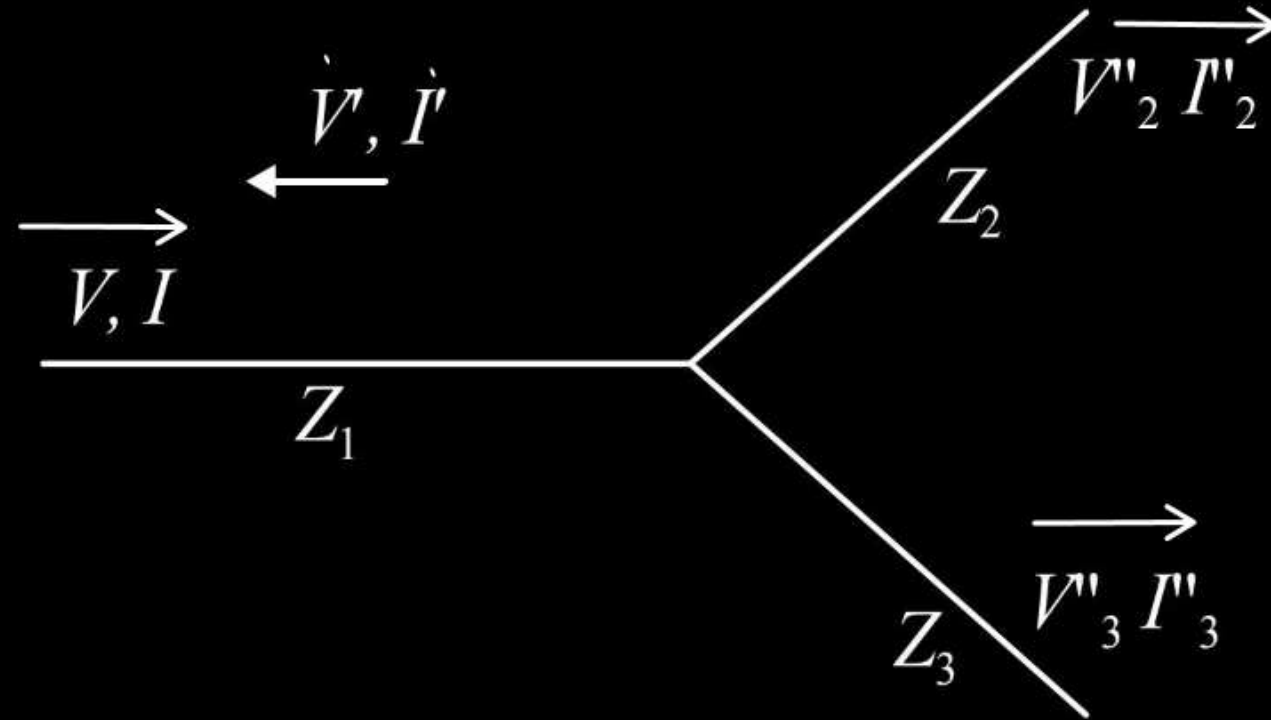
$$\frac{I'' \cancel{Z_2}}{I Z_1} = \frac{\cancel{2Z_2}}{Z_1 + Z_2}$$

$$\rho_{tI} = \frac{I''}{I} = \frac{2Z_1}{Z_1 + Z_2}$$

Reflection and Refraction at T junction



(Bifurcated line/Parallel line)



The Z_2 and Z_3 are in parallel, so their voltage will be same

$$V_2'' = V_3'' = \underline{V''}$$

$$V'' = I_2'' Z_2 = I_3'' Z_3$$

Incident wave + Reflected wave = Refracted wave.



$$V + V' = V'' \quad - (1)$$

$$I + I' = I_2'' + I_3''$$

$$\frac{V}{Z_1} - \frac{V'}{Z_1} = \frac{V''}{Z_2} + \frac{V''}{Z_3} \quad - (11)$$

$$I = \frac{V}{Z_1}$$

$$I' = -\frac{V'}{Z_1}$$

$$I_2'' = \frac{V_2''}{Z_2} = \frac{V''}{Z_2}$$

$$I_3'' = \frac{V_3''}{Z_3} = \frac{V''}{Z_3}$$

Voltage Reflection coefficient $\frac{V'}{V}$



Put the value of V'' from eqn (1) to eqn (2)

$$\frac{V}{Z_1} - \frac{V'}{Z_1} = (V + V') \left(\frac{1}{Z_2} + \frac{1}{Z_3} \right)$$

$$V \left(\frac{1}{Z_1} - \frac{1}{Z_2} - \frac{1}{Z_3} \right) = V' \left(\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} \right)$$

$$\rho_{VV} = \frac{V'}{V} = \frac{\frac{1}{Z_1} - \frac{1}{Z_2} - \frac{1}{Z_3}}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}} \quad - (3)$$

Voltage transmission coefficient $\frac{V''}{V}$



Put the value of V' from eqn (1) to eqn (2)

$$\frac{V}{Z_1} - \frac{(V'' - V)}{Z_1} = \frac{V''}{Z_2} + \frac{V''}{Z_3}$$

$$\frac{2V}{Z_1} = V'' \left(\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} \right)$$

$$P_{tv} \frac{V''}{V} = \frac{2/Z_1}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}} \quad - (4)$$

Current Reflection coefficient

$$I'/I = ?$$



Put the value of V and V' in eqn (3)

$$\frac{-I'Z_1}{IZ_1} = \frac{\frac{1}{Z_1} - \frac{1}{Z_2} - \frac{1}{Z_3}}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}}$$

$$\rho_{ZI} = \frac{I'}{I} = - \left(\frac{\frac{1}{Z_1} - \frac{1}{Z_2} - \frac{1}{Z_3}}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3}} \right)$$

current transmission coefficient $\frac{I_2''}{I} = ?$ $\frac{I_3''}{I}$



Put the value of V'' and V in eqn (4)

$$\frac{I_2'' z_2}{I \cancel{z_1}} = \frac{2 \cancel{z_1}}{\frac{1}{z_1} + \frac{1}{z_2} + \frac{1}{z_3}}$$

$$\frac{I_2''}{I} = \frac{2 z_2}{1/z_1 + 1/z_2 + 1/z_3}$$

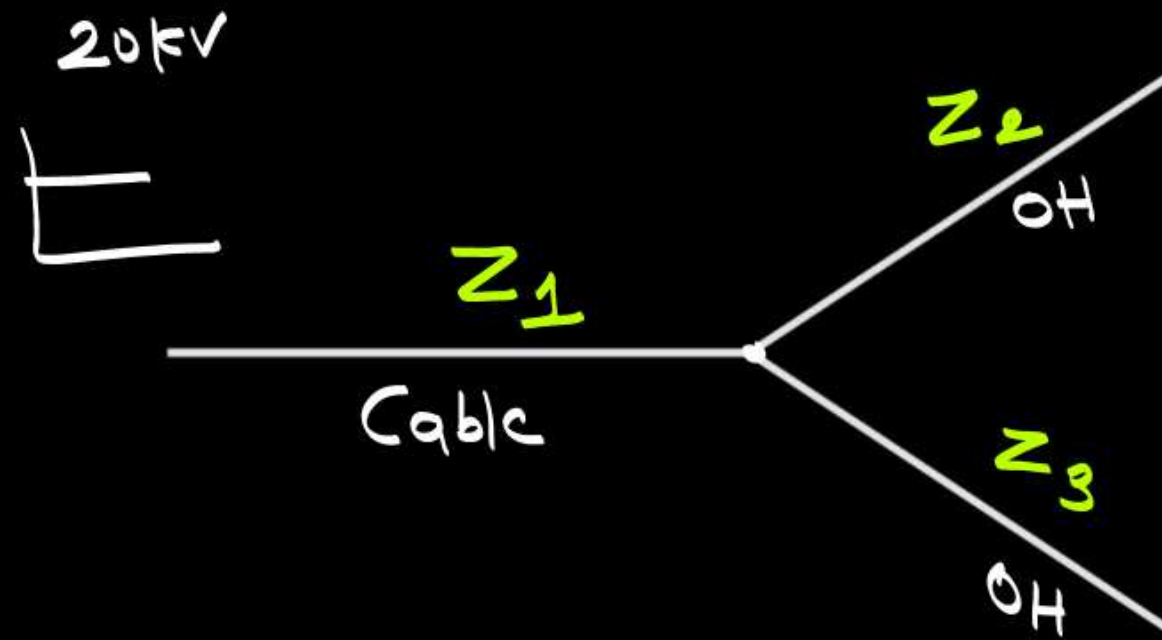
$$\frac{I_3'' z_3}{I \cancel{z_1}} = \frac{2 \cancel{z_1}}{1/z_1 + 1/z_2 + 1/z_3}$$

$$\frac{I_3''}{I} = \frac{2 z_3}{1/z_1 + 1/z_2 + 1/z_3}$$

Q.

A surge of 20 kV magnitude travels along a lossless cable towards its junction with two identical lossless over head transmission line. The inductance and the capacitance of the cable are 0.4 mH and 0.5 μ F km. The inductance and capacitance of the overhead lines are 1.5 mH and 0.015 μ F per km. The magnitude of the voltage at the junction due to surge is

- A 36.72 kV
- B 18.36 kV
- C 6.07 kV
- D ~~33.93 kV~~



$$Z_1(\text{Cable}) = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.4 \times 10^{-3}}{0.5 \times 10^{-6}}} = 28.28 \Omega$$

$$Z_2 = Z_3(\text{OH}) = \sqrt{\frac{L}{C}} = \sqrt{\frac{1.5 \times 10^{-3}}{0.015 \times 10^{-6}}} = 316.22$$

$$\frac{V''}{V} = \frac{2/Z_1}{1/Z_1 + 1/Z_2 + 1/Z_3} = \frac{2/Z_1}{1/Z_1 + 2/Z_2} = \frac{2}{\frac{1}{28.28} + \frac{2}{316.22}} = 1.6965$$

$$V'' = 20(1.6965) = 33.93$$

$$I'' = \frac{V}{Z_2}$$

$$I'' = \frac{33.93 \times 10^3}{316.22}$$

$$I'' = 107.29$$

Q.

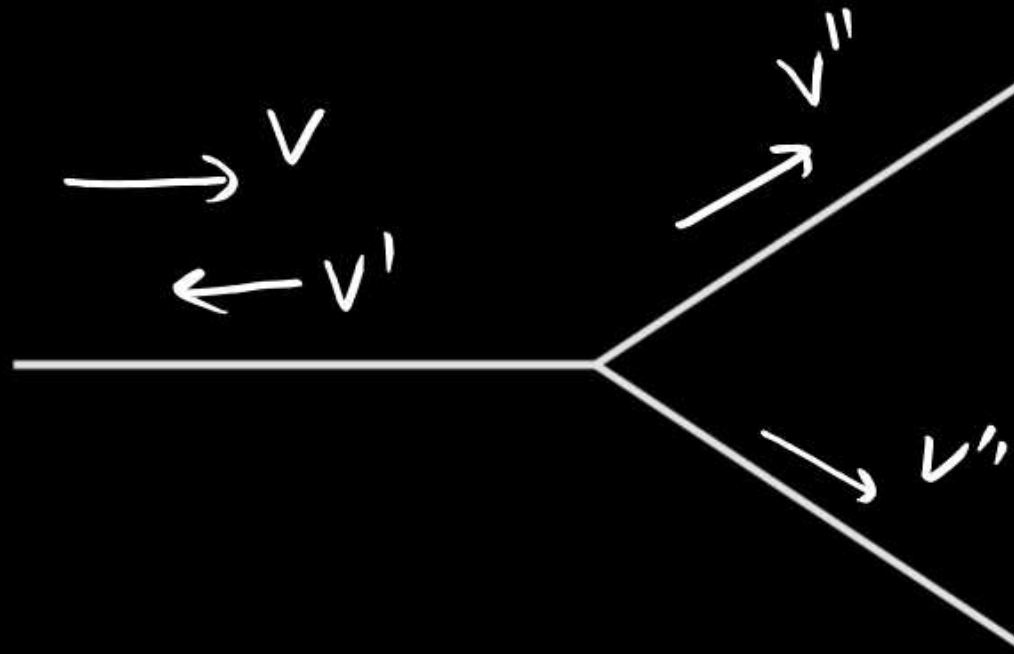
A surge of 20 kV magnitude travels along a lossless cable towards its junction with two identical lossless over head transmission line. The inductance and the capacitance of the cable are 0.4 mH and 0.5 μF km. The inductance and capacitance of the overhead lines are 1.5 mH and 0.015 μF per km. The magnitude of the reflected voltage

A 36.72 kV

B 18.36 kV

C 6.07 kV

D none



$$V + V' = V''$$

$$20 + V' = 33.93$$

$$V' = 33.93 - 20$$

$$V' = 13.93 \text{ kv}$$

Q.

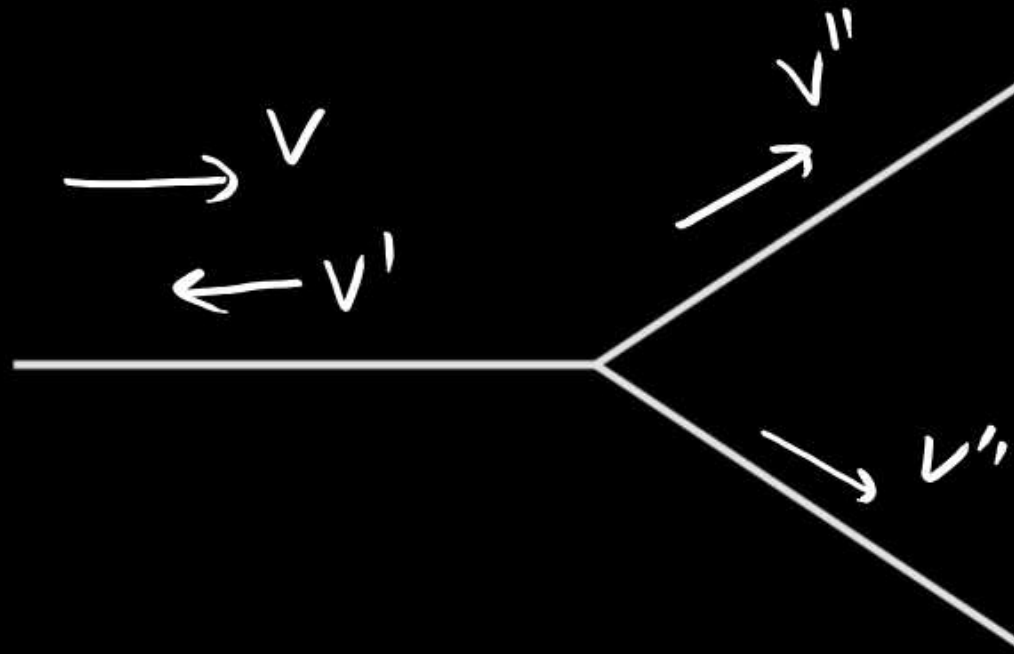
A surge of 20 kV magnitude travels along a lossless cable towards its junction with two identical lossless over head transmission line. The inductance and the capacitance of the cable are 0.4 mH and 0.5 μ F km. The inductance and capacitance of the overhead lines are 1.5 mH and 0.015 μ F per km. The magnitude of the reflected current



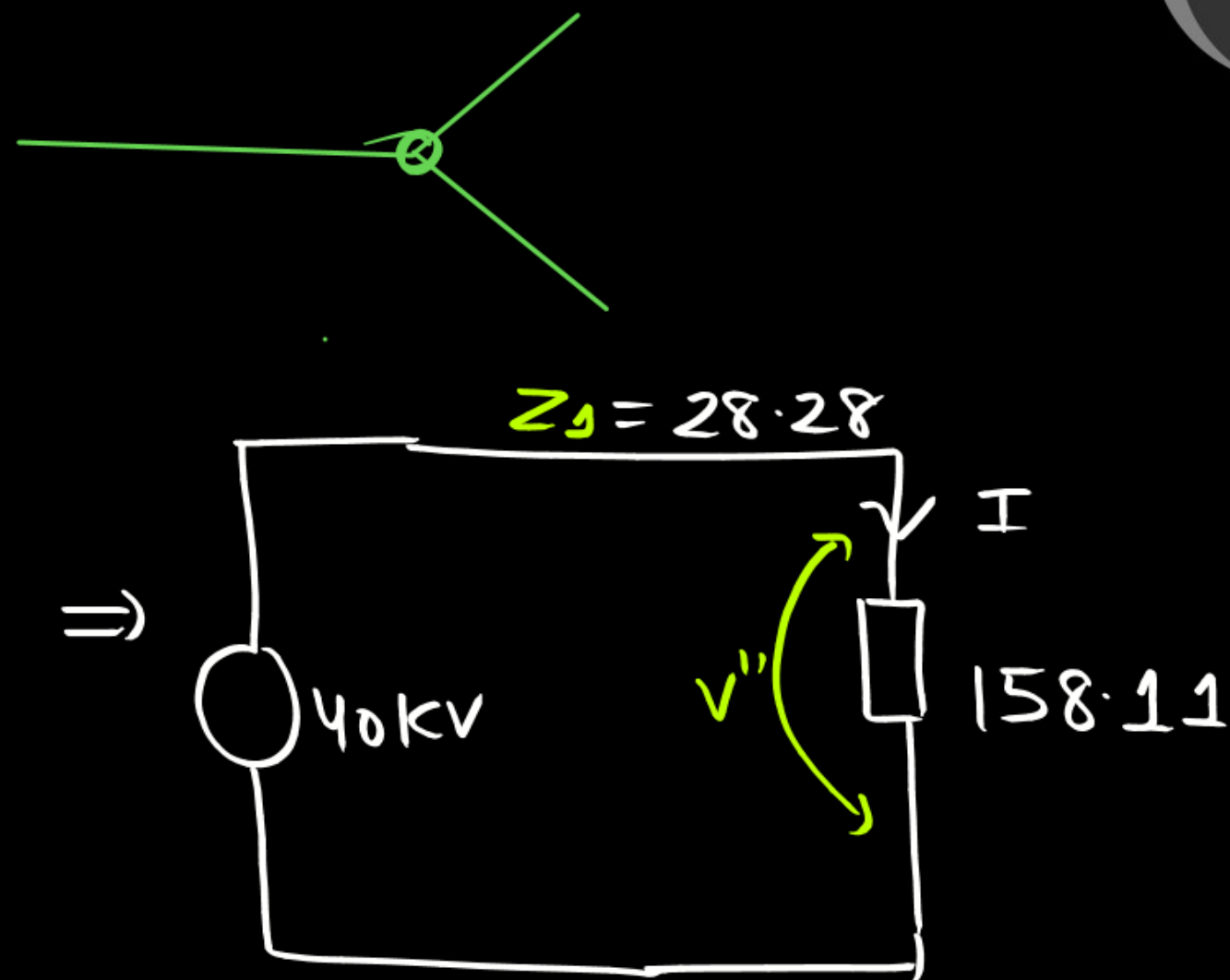
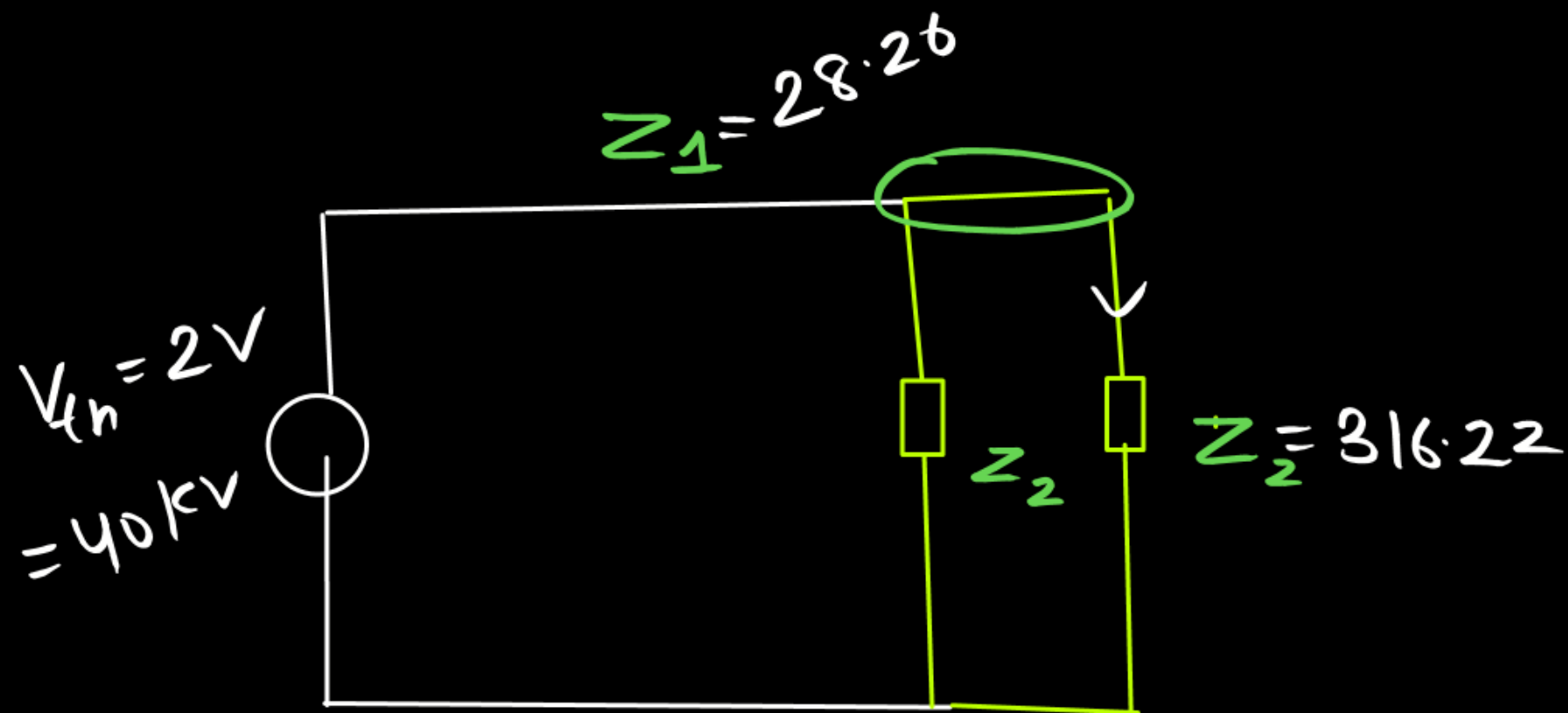
$$I' = -\frac{V'}{Z_1}$$

$$= -\frac{13.93 \times 10^3}{28.28}$$

$$= 492.57$$



Thevenin Method



$$V'' = \frac{158.11}{28.28 + 158.11} \times 40 = 33.93 kV$$

Points to Remember

Incident wave + Reflected wave = refracted wave

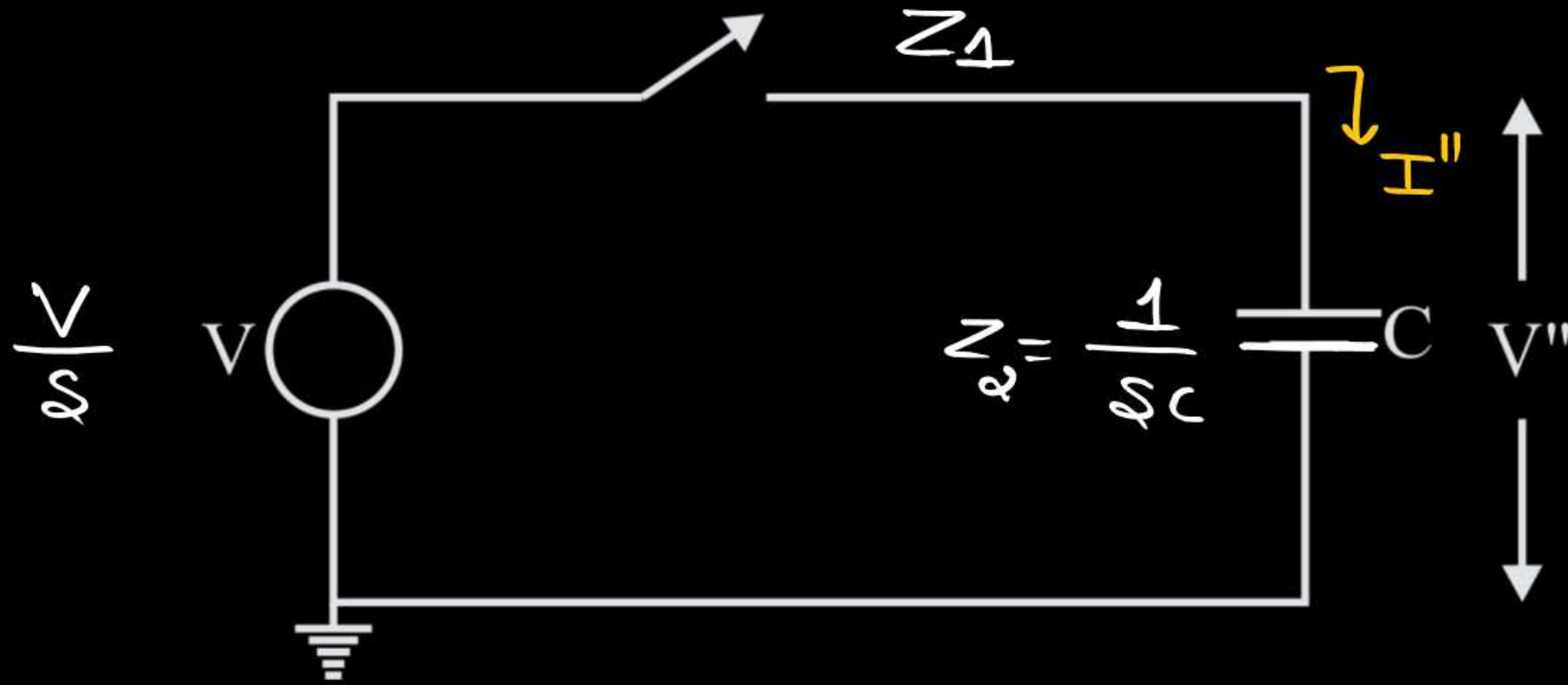
$$V + V' = V''$$

$$1 + \frac{V'}{V} = V''/V$$

1 + Reflection coefficient = Refraction coefficient

$$1 + \rho_r = \rho_t$$

Line Terminating through capacitor



So capacitance reduce steepness of voltage

$$\frac{V''(s)}{V(s)} = \frac{2Z_2}{Z_1 + Z_2} = \frac{2 \cdot \frac{1}{sC}}{Z_1 + \frac{1}{sC}} = \frac{\cancel{2}}{\cancel{sC} Z_1 C s + 1}$$

$$V''(s) = \frac{2V}{s} \cdot \frac{1}{Z_1 C s + 1} = \frac{2V}{s} \cdot \frac{1}{Z_1 C \left(s + \frac{1}{Z_1 C} \right)}$$

$$V''(s) = \frac{2V}{Z_1 C} \cdot \frac{1}{s \left(s + \frac{1}{Z_1 C} \right)}$$

$$\frac{1}{s \left(s + \frac{1}{Z_1 C} \right)} = \frac{A}{s} + \frac{B}{s + \frac{1}{Z_1 C}}$$

$$A = Z_1 C$$

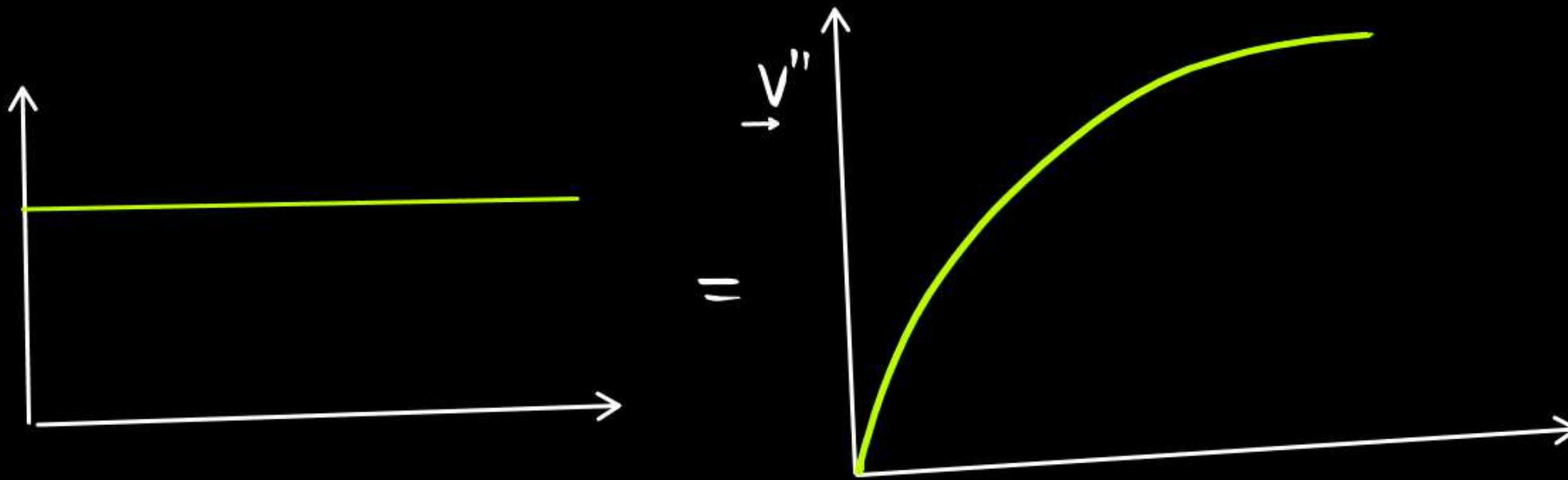
$$B = -Z_1 C$$

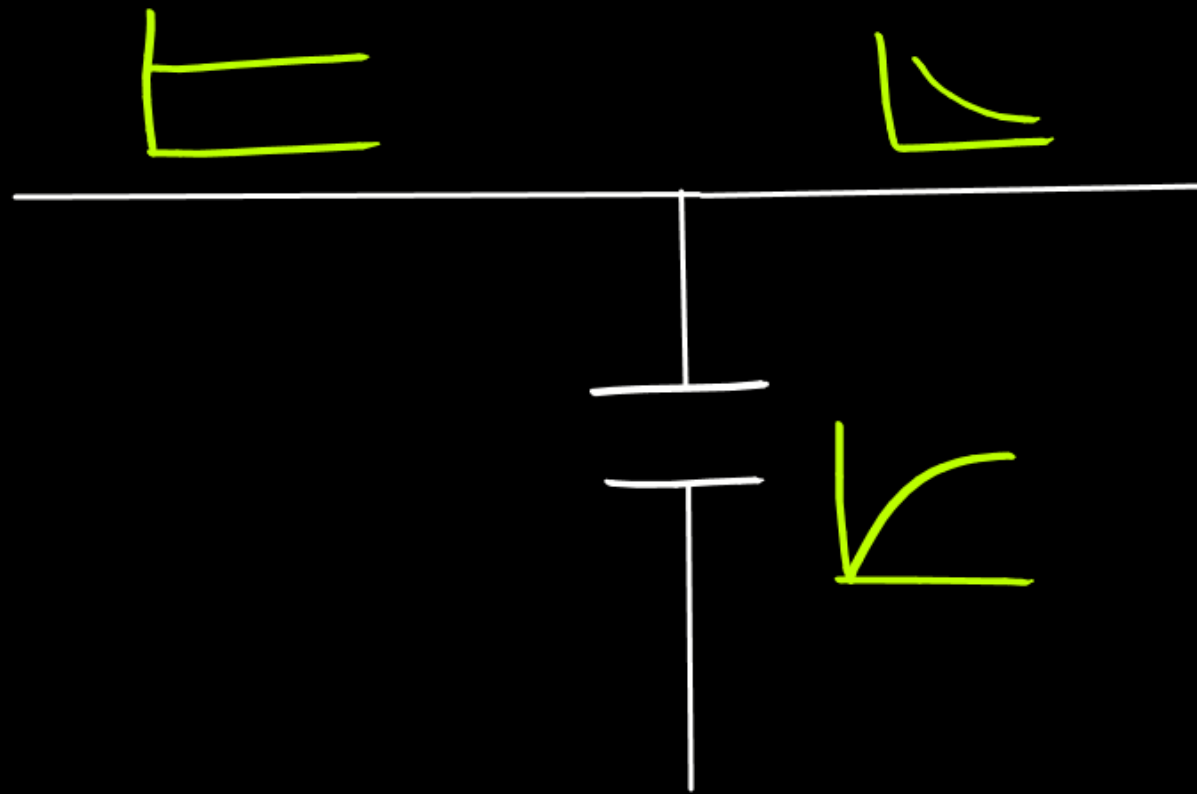
$$= Z_1 C \left(\frac{1}{s} - \frac{1}{s + \frac{1}{Z_1 C}} \right)$$

$$V''(s) = \frac{2V}{Z_{1C}} \left[\frac{Z_{1C}}{s} - \left(\frac{1}{s} - \frac{1}{s + \frac{1}{Z_{1C}}} \right) \right]$$

Inverse Laplace

$$V''(t) = 2V \left[1 - e^{-\frac{t}{Z_{1C}}} \right]$$





$$V + V' = V''$$

$$V' = V'' - V$$

$$V' = 2V \left[1 - e^{-\frac{t}{2\tau_c}} \right] - V$$

$$V' = V - 2V e^{-\frac{t}{2\tau_c}}$$

$$V' = V \left[1 - 2e^{-\frac{t}{2\tau_c}} \right]$$

$$I'' = C \frac{dv''}{dt}$$

$$I'' = C \frac{d}{dt} \left[2V \left(1 - e^{-\frac{t}{Z_1 C}} \right) \right]$$

$$I'' = C \cdot \frac{2V}{Z_1 C} e^{-\frac{t}{Z_1 C}}$$

$$I'' = \frac{2V}{Z_1} e^{-t/Z_1 C}$$

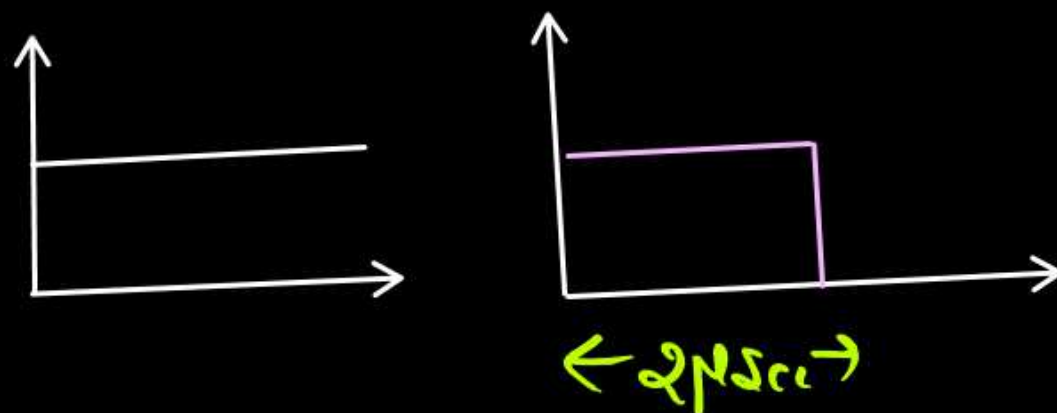
$$I + I' = I''$$

$$\frac{V}{Z_1} + I' = \frac{2V}{Z_1} e^{-\frac{t}{Z_1 C}}$$

$$I' = \frac{V}{Z_1} \left[2e^{-\frac{t}{Z_1 C}} - 1 \right]$$

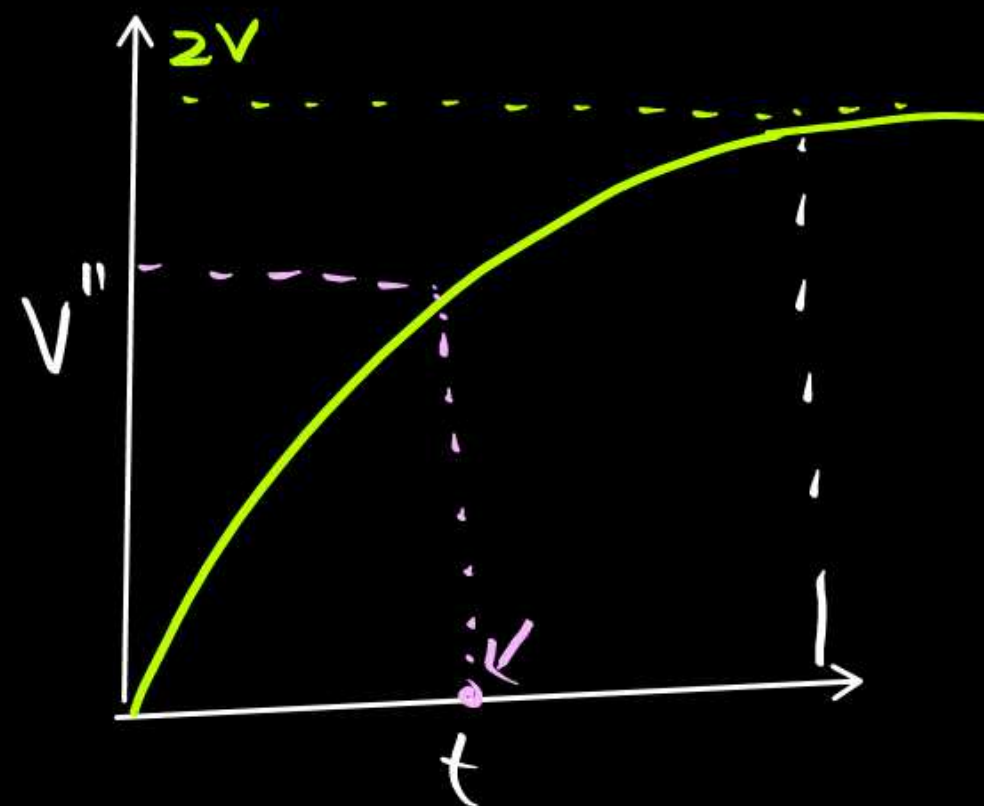
Q.

A 400 Kv , 2 microsec rectangular surge on a line having a surge impedance of 350ohm approach at a station at which an earth capacitance of 300 pF is connected. Determine the maximum value of transmitted wave?



$$Z_1 = 350 \Omega$$

$$C = 300 \times 10^{-12}$$



A 760 kV

B 850 kV

C 418 kV

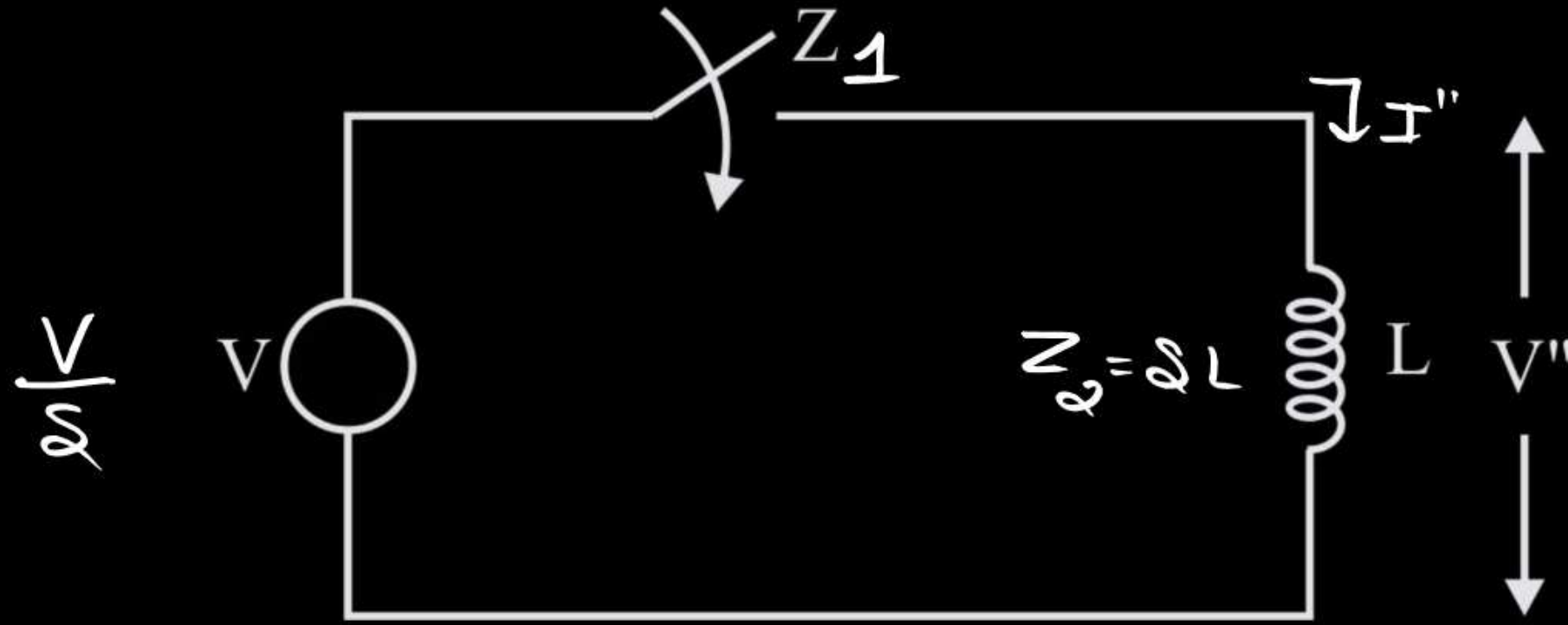
D None

$$V'' = 2v \left[1 - e^{-\frac{t}{\tau_c}} \right]$$

$$V' = 2 \times 450 \left[1 - e^{-\frac{2 \times 10^{-6}}{350 \times 30 \times 10^{-12}}} \right]$$

$$V' = 799.99$$

Line Terminating by Inductor



$$\frac{V''(s)}{V(s)} = \frac{2Z_2}{Z_1 + Z_2} = \frac{2sL}{Z_1 + sL}$$

$$V''(s) = \frac{V}{s} \cdot \frac{2sL}{Z_1 + sL}$$

$$V''(s) = \frac{2V}{s + \frac{Z_1}{L}}$$

Inverse Laplace

$$V''(t) = 2V e^{-\frac{Z_1}{L}t}$$

$$V + V' = V''$$

$$V' = V'' - V$$

$$V' = 2V e^{-\frac{Z_1}{L}t} - V$$

$$V'' = V [2e^{-\frac{Z_1}{L}t} - 1]$$

$$v'' = L \frac{dI''}{dt}$$

$$I'' = \frac{1}{L} \int_0^t v'' dt$$

$$I'' = \frac{1}{L} \int 2V e^{-\frac{Z_1}{L}t} dt$$

$$I'' = \left[\frac{2V}{L} \left(-\frac{L}{Z_1} \right) e^{-\frac{Z_1}{L}t} \right]_0^t$$

$$I'' = -\frac{2V}{Z_1} e^{-\frac{Z_1}{L}t} + \frac{2V}{Z_1}$$

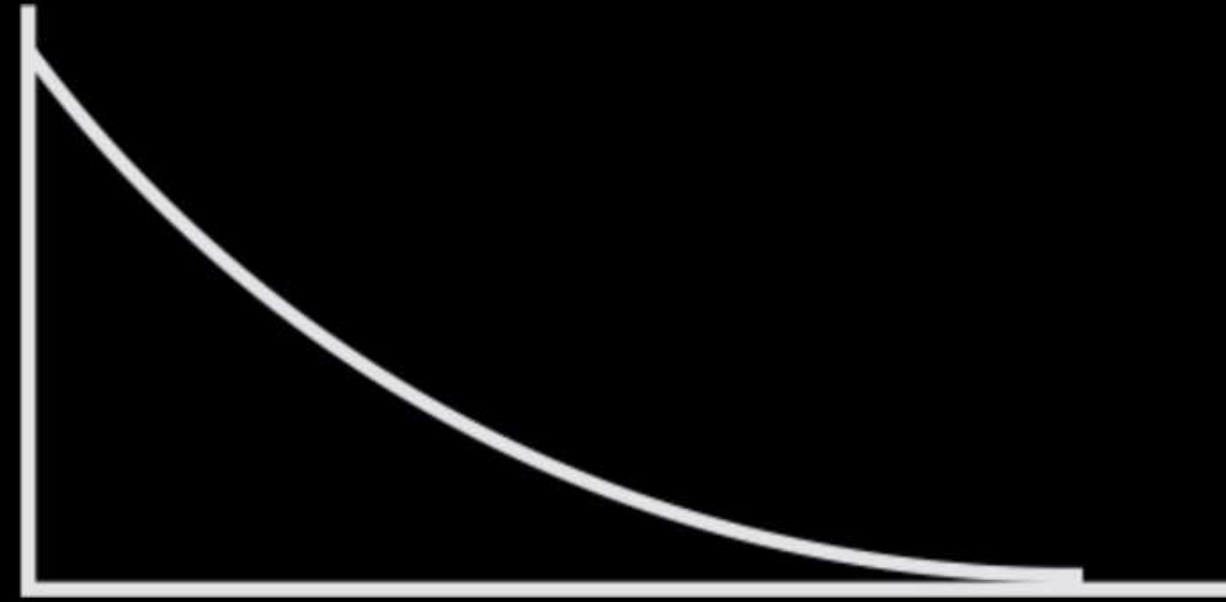
$$I'' = \frac{2V}{Z_1} \left[1 - e^{-\frac{Z_1}{L}t} \right]$$

$$I + I' = I''$$

$$\frac{V}{Z_1} + I' = \frac{2V}{Z_1} - \frac{2V}{Z_1} e^{-\frac{Z_1}{L}t}$$

$$I' = \frac{V}{Z_1} - \frac{2V}{Z_1} e^{-\frac{Z_1}{L}t}$$

$$I' = \frac{V}{Z_1} \left[1 - 2e^{-\frac{Z_1}{L}t} \right]$$



The Inductor and capacitor are dual to each other.

So capacitor in parallel will give same effect as inductor in series.

Parallel capacitor / Series inductor.

→ To reduce steepness.

#Q. A rectangular voltage wave is impressed on a loss-free overhead line, with the far end of the line being short-circuited. On reaching the end of this line

[ESE-2003]

$$\boxed{Z_2 = 0}$$

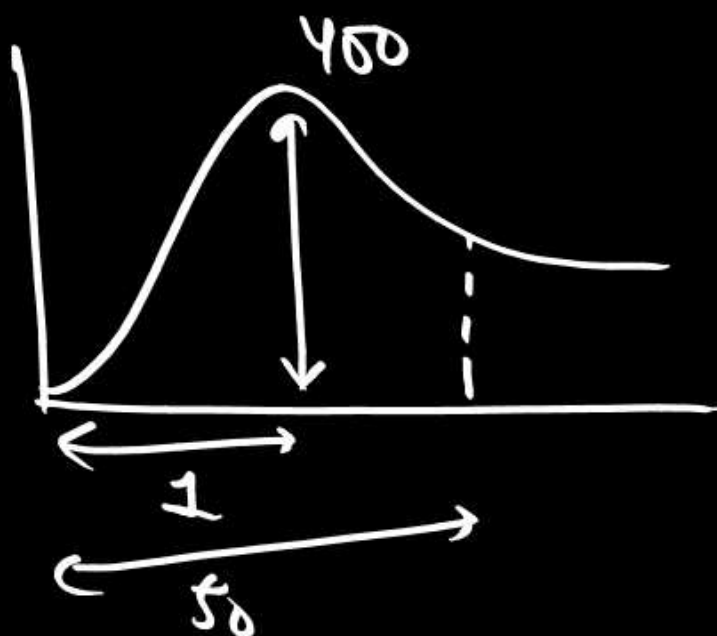
- A** ✓ The current wave is reflected back with positive sign, but the voltage wave with negative sign.
- B** The current wave is reflected back with negative sign, but the voltage wave with positive sign.
- C** Both the current and the voltage waves are reflected with positive sign.
- D** Both the current and the voltage waves are reflected with negative sign.

$$\frac{V'}{V} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right) = \frac{0 - Z_1}{0 + Z_1} = -1$$

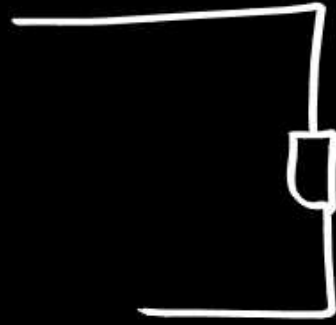
$$\frac{I'}{I} = - \left(\frac{Z_2 - Z_1}{Z_2 + Z_1} \right) = +1$$

#Q. A travelling wave 400/1/50 means crest value of

- A** 400 V with rise time of 1/50 s
- B** 400 kV with rise time 1 s and fall time 50 s
- C** 400 kV with rise time 1 μ s with fall time 50 μ s
- D** 400 MV with rise time 1 μ s and fall time 50 μ s



#Q. If a travelling-wave travelling along a loss-free overhead line does not result in any reflection after it has reached the far end, then the far end of the line is
[ESE-2001]



- A** Open circuited
- B** Short circuited
- C** Terminated into a resistance equal to surge impedance of the line
- D** Terminated into a capacitor



2 Minutes Summary

- Reflection and refraction of T line
- line terminated with C, L
- Questions.

Thank you

GW
Soldiers !

