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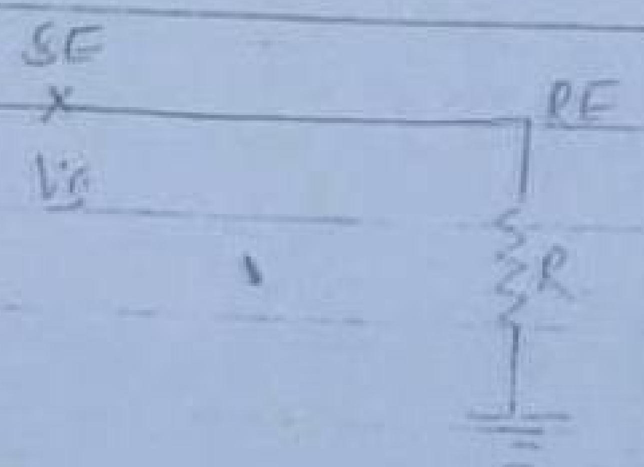
Travelling Waves:

Condition 1: 'R'

Receiving end of T.L terminated by resistance



$$V'' = V + V' \qquad I'' = I + I'$$

$$I = V/Z_c \qquad I' = -V'/Z_c \qquad I'' = V''/R$$

$$V'' \longrightarrow V, \quad V' \rightarrow V$$

Expressing transmitted voltage V'' in terms of incident voltage 'V' and transmitted current I'' in terms of in terms of incident current I

$$\Rightarrow \quad V''/R = \frac{+V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

replacing V' by $(V''-V)$

$$V''/R = \left(\frac{+V'}{Z_c}\right) - \left(\frac{V''-V}{Z_c}\right)$$

$$V''\left[\frac{1}{R} + \frac{1}{Z_c}\right] = \frac{2V}{Z_c}$$

$$\boxed{V'' = V \cdot \left[\frac{2R}{R+Z_c}\right]} \quad \text{- - - - (1)}$$

- transmitted voltage co-efficient $\boxed{\tau_v = \frac{V''}{V} = \frac{2R}{R+Z_c}}$.

Similarly from eqn (I)

$$I''\cancel{R} = IZ_c\left(\frac{2\cancel{R}}{R+Z_c}\right)$$

$$\boxed{I'' = I\left(\frac{2Z_c}{R+Z_c}\right)}.$$

- transmitted current co-efficient

$$\boxed{\tau_i = \frac{I''}{I} = \frac{2Z_c}{R+Z_c}}.$$

Expressing reflected voltage (V') in terms of incident voltage (V) and reflected current (I') in terms of incident current (I).

$$\frac{V''}{R} = \frac{+V}{Z_c} + \frac{(-V')}{Z_c}$$

$$\frac{V+V'}{R} = \frac{+V}{Z_c} + \frac{(-V')}{Z_c}$$

$$V\left[\frac{1}{R} - \frac{1}{Z_c}\right] = -V\left[\frac{1}{R} + \frac{1}{Z_c}\right]$$

$$Z_c+R \quad V\left[\frac{Z_c-R}{R\cancel{Z_c}}\right] = -V'\left[\frac{R+Z_c}{R\cancel{Z_c}}\right] \quad ---(2)$$

- reflection coefficient of voltage $\boxed{\rho_V = \frac{V'}{V} = \frac{R-Z_c}{R+Z_c}}$

similarly using eqn (2)

$$V' = V\left(\frac{R-Z_c}{R+Z_c}\right)$$

$$-I'\cancel{Z_c} = I\cancel{Z_c}\left(\frac{R-Z_c}{R+Z_c}\right)$$

- reflection coefficient of current $\boxed{\rho_i = \frac{I'}{I} = \frac{Z_c-R}{Z_c+R}}$

$$\boxed{\begin{aligned} \tau_V &= \frac{2R}{Z_c+R} \\ \tau_I &= \frac{2Z_c}{Z_c+R} \\ \rho_V &= \frac{R-Z_c}{Z_c+R} \\ \rho_{I\,(i)} &= \frac{Z_c-R}{Z_c+R} \end{aligned}}$$

Condition 2: Receiving end of T.L terminated by underground cable with impedance (Z_1).

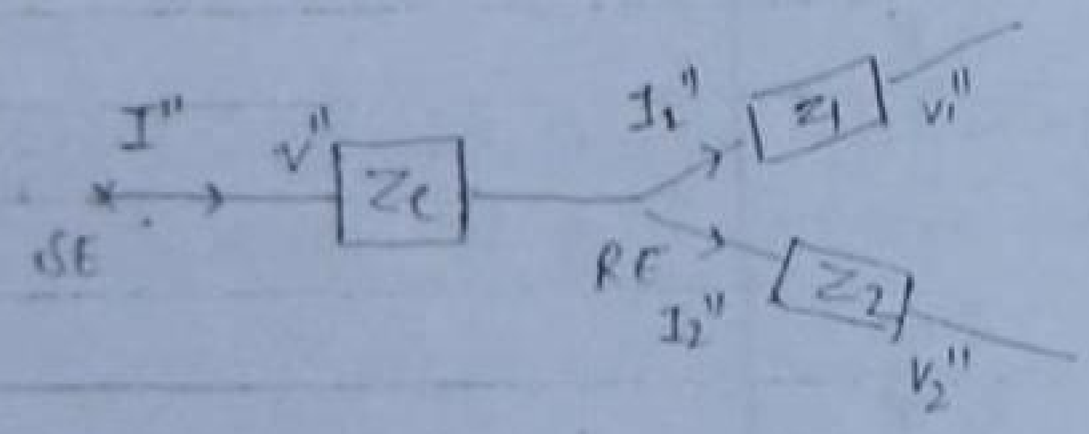
- $\tau_V = \frac{2Z_1}{Z_c + Z_1}$ → replace R by Z_1.

- $\tau_I = \frac{2Z_c}{Z_c + Z_1}$

- $\rho_V = \frac{Z_1 - Z_c}{Z_c + Z_1}$

- $\rho_I = \frac{Z_c - Z_1}{Z_c + Z_1}$.

Condition 3: Receiving end of T.L line forming a T junc^n.



* Z_1, Z_2 connected in parallel.

$$V_1'' = V_2'' = V''$$

$$I'' = I_1'' + I_2''$$

$$\Rightarrow \quad I'' = I + I'$$

$$\Rightarrow \quad I_1'' + I_2'' = I + I'$$

Expressing Transmitted voltage (V'') in terms of incident voltage (V), and transmitted current (I'') in-terms of incident current (I):-

$$I_1'' + I_2'' = I + I'$$

$$\Rightarrow \frac{V_1''}{Z_1} + \frac{V_2''}{Z_2} = \frac{V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

$$\Rightarrow \frac{V''}{Z_1} + \frac{V''}{Z_c} = \frac{V}{Z_c} - \frac{V'}{Z_c}$$

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

$$\Rightarrow V''\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right] = \frac{2V}{Z_c}$$

$$V'' = \frac{V(2/Z_c)}{\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right]} \quad \text{-----} \; (1).$$

- Transmitted ~~reflection~~ coefficient of voltage $\boxed{\tau_V = \frac{V''}{V} = \frac{2/Z_c}{\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}}}$

now using equatn (1)

$$I'' Z_1 = \frac{I \cancel{Z_c} (2/\cancel{Z_c})}{\left[\frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_c}\right]}$$

- Transmitted coefficient of current $\boxed{\tau_I = \frac{I_1''}{I} = \frac{2/Z_1}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}}}$.

$$\therefore \quad \boxed{\tau_{I_2''} = \frac{I_2''}{I} = \frac{2/Z_2}{\frac{1}{Z_1}+\frac{1}{Z_2}+\frac{1}{Z_c}}}$$

- Expressing reflected voltage in terms of incident voltage and reflected current in terms of incident current

$$I_1'' + I_2'' = I + I'$$

$$\Rightarrow \frac{V_1''}{Z_1} + \frac{V_2''}{Z_2} = \frac{V}{Z_c} + \left(\frac{-V'}{Z_c}\right)$$

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

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

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

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

$$\Rightarrow V' = V \frac{\left(\frac{1}{Z_c} - \frac{1}{Z_1} - \frac{1}{Z_2}\right)}{\left(\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_c}\right)} \quad \text{-----} \; 2(a)$$

reflected coefficient of voltage $\boxed{\rho_v = \frac{V'}{V} = \left[\frac{1/Z_c - 1/Z_1 - 1/Z_2}{1/Z_c + 1/Z_1 + 1/Z_2}\right]}$

Similarly: from eqn (a)

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

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

- reflected coefficient of current $\boxed{\rho_i = \frac{I'}{I} = \left[\frac{1/Z_1 + 1/Z_2 - 1/Z_c}{\frac{1}{Z_c} + \frac{1}{Z_1} + \frac{1}{Z_2}}\right]}$

$C_r = \left(2/Z_1\right) / \left(1/Z_c + \frac{1}{Z_1} + 1/Z_2\right)$

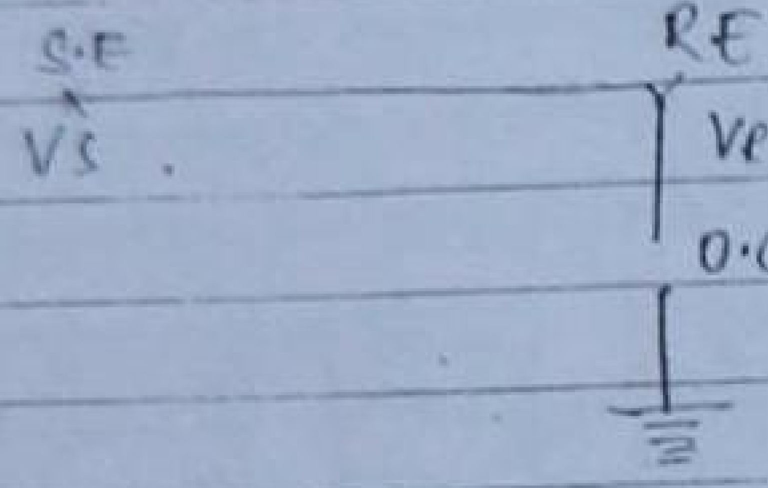
$C_i = \left(2/Z_1 \text{ or } 2/Z_2\right) / \left(1/Z_c + 1/Z_1 + \frac{1}{Z_2}\right)$

$\rho_v = \left(\frac{1}{Z_c} - \frac{1}{Z_1} - \frac{1}{Z_2}\right) / \left(1/Z_c + 1/Z_1 + 1/Z_2\right)$

$= \left(\frac{1}{Z_1} + \frac{1}{Z_2} - \frac{1}{Z_c}\right) / \left(1/Z_c + 1/Z_1 + \frac{1}{Z_2}\right)$

Imp

* Condition 4: Receiving end of T.L is open circuited.



$\frac{1}{2}LI^2$ $\frac{1}{2}CV^2$.

$I=0$

$\frac{1}{2}LI^2=0$

When the receiving end of T.L is open circuited $\boxed{(I=0)}$.
, Electromagnetic energy stored by inductor in magnetic field is equal. $\boxed{\frac{1}{2}LI^2 = 0}$.
According to law of conservation of energy, energy cannot be destroyed but only can be converted from one form to another form. i.e the entire electromagnetic energy is converted into electrostatic energy stored by capacitor in the electric field

The e increase in electrostatic energy increases the voltage. Let the voltage be increased by 'e' volts.

$V\uparrow \rightarrow$ 'e' volts.

so $\frac{1}{2}LI^2 = \frac{1}{2}Ce^2$

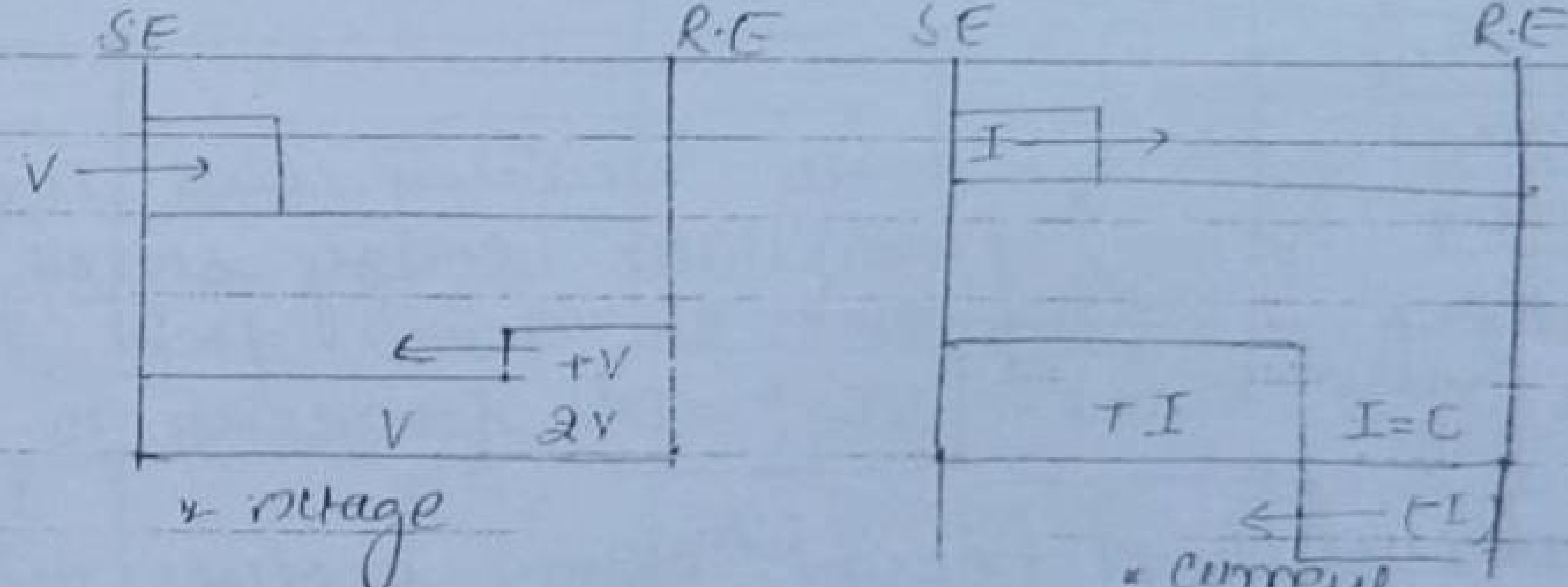
$I^2 = e^2/L/C$

incident current

$$= \underbrace{e^2 = I^2}_{\text{incident current}} Z_c^2$$

$$\boxed{e = I.Z_c = V.}$$

when the receiving end is open circuit the voltage is increased by 'V' when V is incident or voltage at sending end.



* voltage

* current

$$\boxed{\text{reflection coefficient } \rho_v = +V/V = 1}$$

← when receiving end is O.C

$$\boxed{\text{reflection coefficient } \rho_I = \frac{-I}{+I} = -1}$$

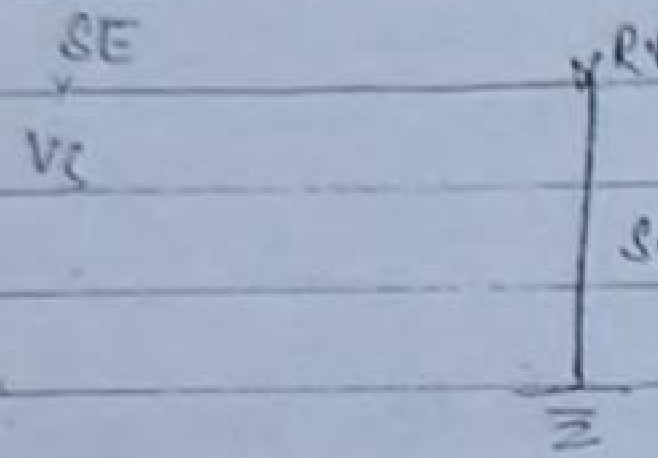
$$\tau_v = \frac{V''}{V} = \frac{V'+V}{V} = \frac{V+V}{V} = 2$$

$$\boxed{\tau_v = 2}$$

$$\tau_I = 0/I = 0$$

$$\boxed{\tau_I = 0}$$

Condition 5: Receiving end to T.L Short-circuited.



$V = 0$

$\frac{1}{2}LI^2 , \ \underbrace{\frac{1}{2}CV^2}_{0} \to 0$

$\frac{1}{2}LI^2$.

EMF ↑
I ↑
i Amp.

When receiving end is S.C $\boxed{V=0}$, electrostatic energy stored by capacitor in electric field is equal to $\boxed{\frac{1}{2}CV^2 = 0}$. According to law of conservation of energy, energy is never destroy but only is converted from one form to another form i.e entire electro-static energy is converted into electromagnetic energy. As a result electromagnetic energy increases and current increase.

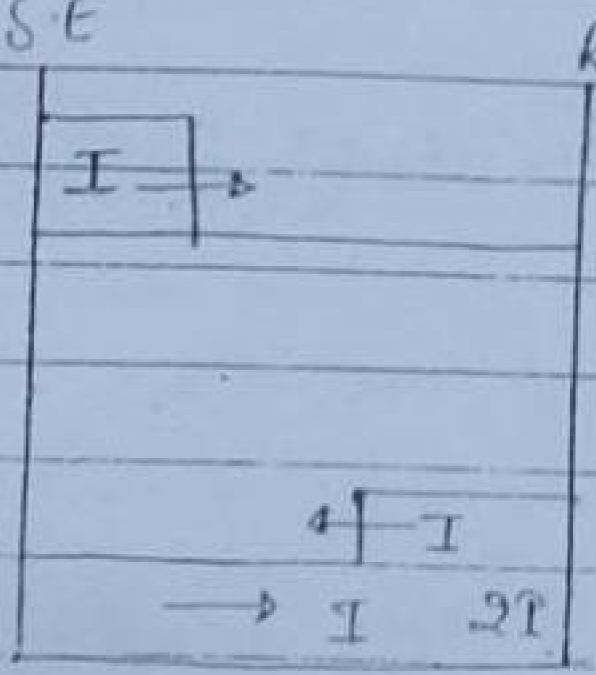
Let the current be increased by (i Amp)

$$\frac{1}{2}Li^2 = \frac{1}{2}CV^2$$

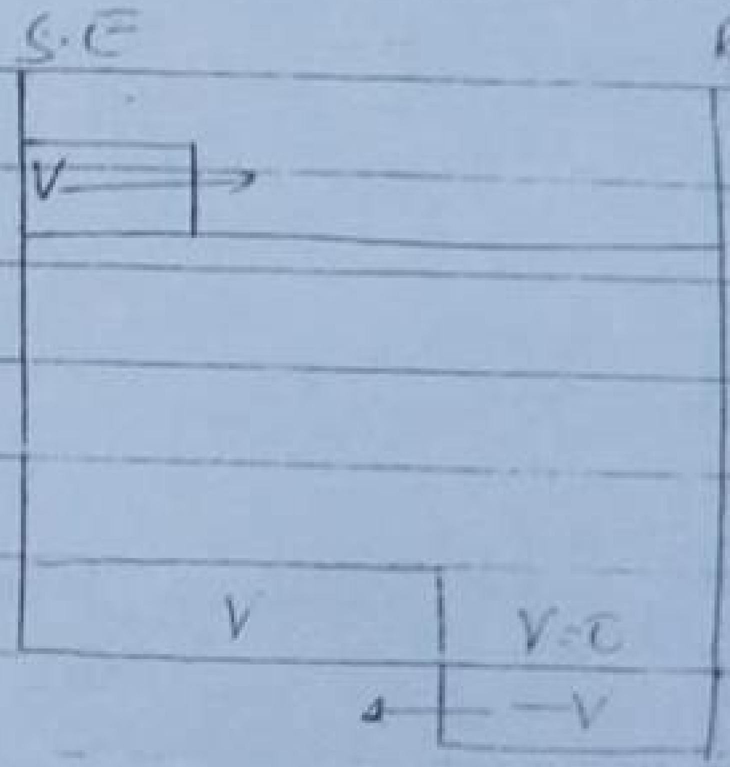
$$\Rightarrow i^2 = \frac{V^2}{L/C} = \frac{V^2}{Z_c^2}$$

$$\boxed{i = \frac{V}{Z_c} = I}$$

The current i increases by I Amp, where I is incident current or current flowing from sending end to the receiving end of the T.L.



Current



voltage

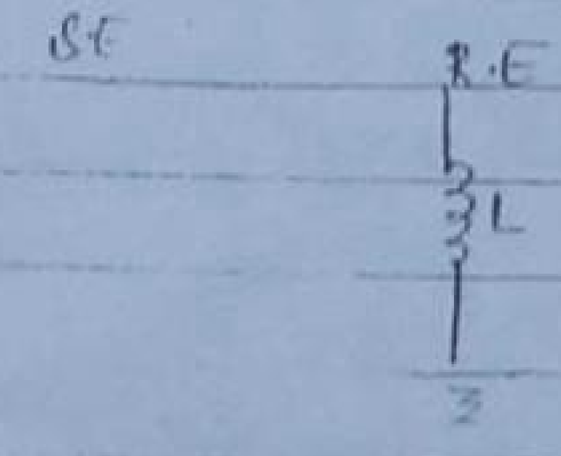
$$\rho_I = \frac{I}{I} = 1$$

$$\tau_I = \frac{2I}{I} = 2.$$

$$\rho_V = -V/V = -1$$

$$\tau_V = 0/V = 0$$

Condition 6: Receiving end of T.L is terminated by inductor 'L'



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

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

$$I = V/Z_c \quad ; \quad I' = -V'/Z_c$$

$$I'' = \frac{1}{L}\int V''(t)\, dt$$

Expressing transmitted voltage in terms of incident voltage V

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

$$\Rightarrow \frac{1}{L}\int V''(t)\, dt = \frac{V}{Z_c} + \frac{(-V')}{Z_c}$$

$$\Rightarrow \frac{1}{L}\int V''(t)\, dt = \frac{V}{Z_c} - \left(\frac{V''-V}{Z_c}\right)$$

$$\Rightarrow \frac{1}{L}\int V''(t)\, dt = \frac{2V}{Z_c} - \frac{V''}{Z_c}$$

$$\Rightarrow \frac{1}{L}\int V''(t)\, dt + \frac{V''}{Z_c} = \frac{2V}{Z_c}$$

Applying Laplace Transform.

$$\frac{1}{L}\left\{\frac{V''(s)}{s}\right\} + \frac{V''(s)}{Z_c} = \frac{2V}{sZ_c}.$$

$$V''(s)\left[\frac{1}{sL} + \frac{1}{Z_c}\right] = \frac{2V}{sZ_c}.$$

$$\Rightarrow V''(S) \cdot \left\{ \frac{SL + Z_c}{\cancel{S} L \cancel{Z_c}} \right\} = \frac{2V}{\cancel{S} \cancel{Z_c}}.$$

$$V''(S) = \frac{2VL}{SL + Z_c}.$$

dividing by L.

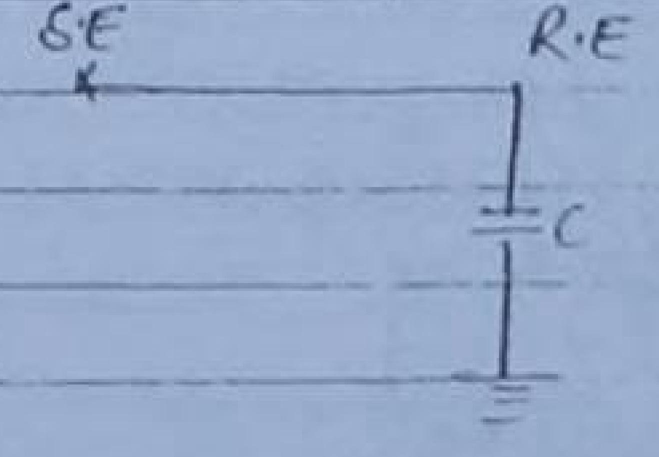
$$V''(S) = \frac{2V}{S + \frac{Z_c}{L}}.$$

Applying inverse laplace transform.

$$\Rightarrow \boxed{V''(t) = 2V \cdot e^{-Z_c/L \cdot t}}$$

when T.L is terminated by inductor the ~~incident~~ transmitted voltage. decreases exponentially due to presence of inductor.

condition 7: Receiving end of T.L terminated by capacitance



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

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

$$I = V/Z_c \; ; \; I' = -V'/Z_c.$$

$$I'' = \frac{C\,dV''(t)}{dt}$$

$$I + I' = \frac{C\,dV''(t)}{dt}$$

$$\frac{V}{Z_c} - \frac{V'}{Z_c} = C\frac{dV'(t)}{dt} \Rightarrow C\frac{dV''(t)}{dt} + \frac{V''(t)}{Z_c} = \frac{2V}{Z_c}.$$

applying Laplace transform

$$\frac{V(s)}{Z_c} - \frac{V'(s)}{Z_c} = \frac{C}{s}$$

$$\Rightarrow C\left\{sV''(s)\right\} + \frac{V''(s)}{Z_c} = \frac{2V}{sZ_c}$$

$$\Rightarrow V''(s)\left\{Cs + \frac{1}{Z_c}\right\} = \frac{2V}{sZ_c}.$$

$$\Rightarrow V''(s)\left\{\frac{sCZ_c+1}{Z_c}\right\} = \frac{2V}{sZ_c}$$

$$\Rightarrow V''(s) = \frac{2V}{s(sCZ_c+1)}$$

dividing by CZ_c

$$V''(s) = \frac{2V/CZ_c}{s\left(s+\frac{1}{CZ_c}\right)}$$

using partial fraction

$$A \cdot \frac{1}{CZ_c} = \frac{2V}{CZ_c}$$

's' : $A + B = 0$

$B = -A = -2V$

$$V''(s) = \frac{2V}{S} - \frac{2V}{S+\frac{1}{CZ}}$$

Applying inverse laplace Transform:-

$$V''(t) = 2V - 2V \cdot e^{-1/CZ \cdot t}$$

$$\boxed{V''(t) = 2V\left\{1 - e^{-1/CZ \cdot t}\right\} \text{ volt}}$$

due to discharging effect.

when T.L terminated by capacitor is decrease exponenti

Questn:

An inductance of 800mH connect two sectn of T.L each having surge impedence of 350Ω. & 500

A 500kV, 2μsec rectangular surge travels along the line towards the inductance. The maxm value of transmitted wave is. $V'' = 2Ve^{-Z_C/L \cdot t}$

$$V'' = 2 \times 500 \times e^{-\left(\frac{350}{800\times10^{-6}}\right)\left(2\times10^{-6}\right)}$$

$$V'' = 416.86 \text{ kV}$$

4) A 500kV, 2μsec rectangular wave surge on T.L having surge impedence of 350Ω approaches a generating statn at which the concentrated earth capacitance is 3000pF the max^m value of the transmitted wave is

V

$$V'' = 2V\left(1 - e^{-\tau/ZC}\right).$$

$$V'' = 2\times 500\left[1 - e^{-(2\times10^{-6}/350\times3000\times10^{-12})}\right]$$

$$V'' = 850\,kV.$$

5) A voltage surge of 60kV travelling in a line of natural impedence 500Ω, arrives at a junc^n with two T.L of impedence, 650Ω, 250Ω. the surge voltages and current transmitted into each branch of line or are:

$Z_c = 500\Omega$

$Z_1 = 650, \quad Z_2 = 250.$

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

$$I_1'' = \frac{V_1''}{Z_1} = \frac{31.84\times10^3}{650} = 48.97 \text{ Amp.}$$

$$I_2'' = V_2''/Z_2 \quad \frac{31.84\times10^3}{250} = 127.4 \text{ Amp}$$

4) A voltage surge of 15KV travels along a cable. towards a junctn with an over-head T.L. The inductance and capacitance of overhead T.L cable are 0.3mH, 0.4μf. The inductance and capacitance of over head T.L are 1.5mH, and 0.12 μF. The increase in voltage at the junctn due to surge is?

$$Z_{c\,cable} = \sqrt{\frac{L}{C}} = \sqrt{\frac{0.3\times10^{-3}}{0.4\times10^{-6}}} = 27.38\,\Omega$$

$$Z_{c\,T.L} = \sqrt{\frac{1.5\times10^{-3}}{0.12\times10^{-6}}} = 353\,\Omega$$

$$V'' = \frac{2R}{Z_c+R} \Rightarrow \frac{2Z_{cable}}{Z_c+Z_{c\,cab}}$$ as surge travels through cable

$$\frac{2\times27.38}{353+27.38}\cdot 15\times10^3 = \cancel{2.148kV}$$

$\cancel{2159.4V}$

$27.84\,kV$

A- 3ϕ overhead conductors in equilateral configuration the corr characteristic impedance is 500Ω. What should be load impedance so that reflections do not occur in T.L.

• TELEGRAPHER | WAVE EQUATION :

$$\frac{\partial^2 e}{\partial x^2} = RGe + (RC + LG)\frac{\partial e}{\partial t} + LC\frac{\partial^2 e}{\partial t^2}$$

$$\frac{\partial^2 i}{\partial x^2} = RGi + (RC + LG)\frac{\partial i}{\partial t} + LC\frac{\partial^2 i}{\partial t^2}$$

SURGE IMPEDENCE :-

the impedence of lossless Transmission line is known as surge impedence.

for a lossless T.L $\boxed{Z_C = Z_S}$

$$Z_C = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{R+j\omega L}{G+jB_C}} \rightarrow \text{characteristic impedence}$$

$R=0;\ G=0$

$$Z_S = \sqrt{\frac{j\omega L}{jB_C}} = \sqrt{\frac{j\omega L}{j\omega C}}$$

$$\boxed{Z_S = \sqrt{\frac{L}{C}}}$$

characteristic impedence of over overhead line is $400\,\Omega$

• underground cable is $40\,\Omega$

FLAT LINE OR INFINITE LINE

A lossless transmission line terminated with its characteristic impendence it is known as flat line or infinite line. the phase angle of characteristic impedence of T.L is b/w $0 - (-15^\circ)$

• Surge impedence loading / characteristic impedence loadin

CIL and S.I.L refers to MW, MVA, MVAR of load connected at the receiving end of T.L, when the T.L donot have losses. SIL

$$\boxed{SIL = \frac{V_S V_R}{Z_s}}$$

If the T.L have losses

$$\boxed{CIL = \frac{V_S V_R}{Z_C}}$$

in terms of ABCD constant

$$\boxed{SIL/CIL = \frac{V_S V_R}{B}}$$

Relation b/w characteristic impedence, open-circuit impedence, short circuit impedence :

$V_S = AV_R + BI_R$

$I_S = CV_R + DI_R$

$I_S = AV_R + BI_R$

$CV_R + DI_R$

Receiving end is O.C

$I_R = 0$

$\Rightarrow V_S = A \cdot V_{RO} \Rightarrow A = V_S / V_{RO}$

$I_S = C \cdot V_{RO} \Rightarrow C = I_S / V_{RO}$

$$\boxed{A/C = V_S/I_S} \quad \text{— (1)}$$

Receiving end is S.C. $V_R = 0$.

$V_S = B I_R \Rightarrow B = V_S / I_R$

and $D = I_S / I_R$.

$$\boxed{B/D = \frac{V_S}{I_S}} \quad \text{——— (2)}$$

multiplying eq^n (1) and (2)

$$\frac{V_S}{I_S} = \sqrt{\frac{\cancel{A} \cdot B}{C \cdot \cancel{D}}} \qquad A = D$$

$$\boxed{\frac{V_S}{I_S} = \sqrt{\frac{B}{C}}}$$

S.E $\xrightarrow{Z_c}$ R.E

$\frac{V_s}{I_s} = Z_C$ $\qquad$ $\frac{V_R}{I_R} = Z_C$

$$Z_C = \sqrt{\frac{B}{C}} = \sqrt{\frac{Z_{sc}}{Y_{oc}}}$$

$$\boxed{Z_C = \sqrt{Z_{sc} Z_{oc}}}$$

<u>Question:</u>

1) the surge impedence loading of 400KV T.L is

$$\frac{V_s \times V_R}{B} = \frac{V_s \cdot V_r}{Z_c} = \frac{400 \times 400}{400}$$

$$Z_s = 400MW.$$

2) Surge impedence loading of a 220KV of T.L is

$$\frac{\cancel{220} \times \cancel{220}}{\cancel{400}} = 121MW$$

A T.L can be loaded & more than surge impedence loading or less than surge impedence loading

Condition 1:-

Loading > S.I.L

1) Current increases.
2) load impedence (Z_L) < Z_c.
3) As $\frac{1}{2}Li^2 > \frac{1}{2}CV^2$, so the power factor is lagging
4) $V_R < V_S$

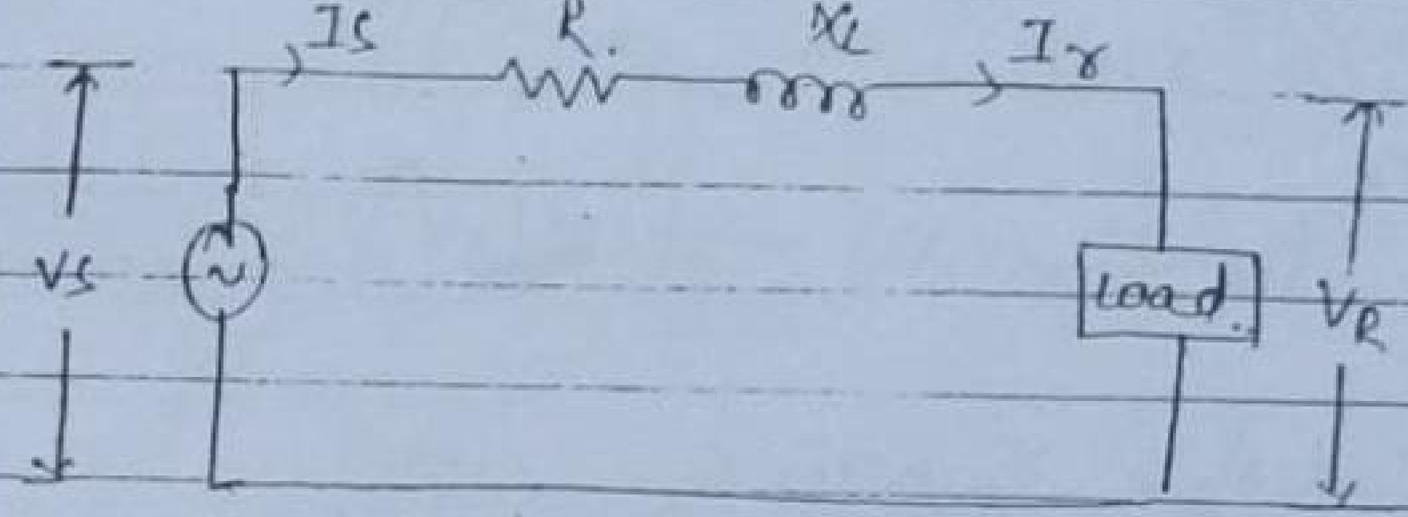
Condition 2:

Loading < S.I.L

1) Current decrease.
2) load impedence (Z_L) > Z_S
5) As $\frac{1}{2}Li^2 < \frac{1}{2}CV^2$, so the power factor is leading
4) $V_R > V_S$.

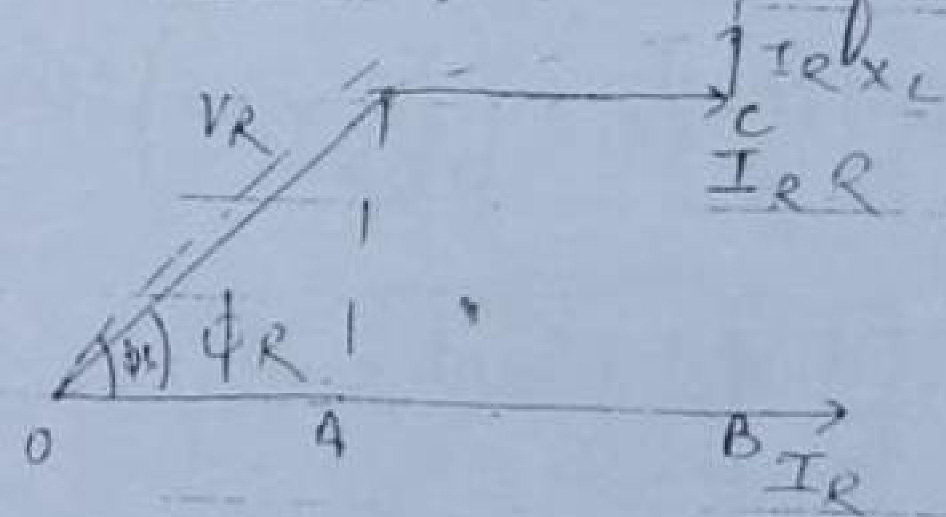
In general T.L is loaded more than surge impedence loading. Surge impedence also called Natural impedence

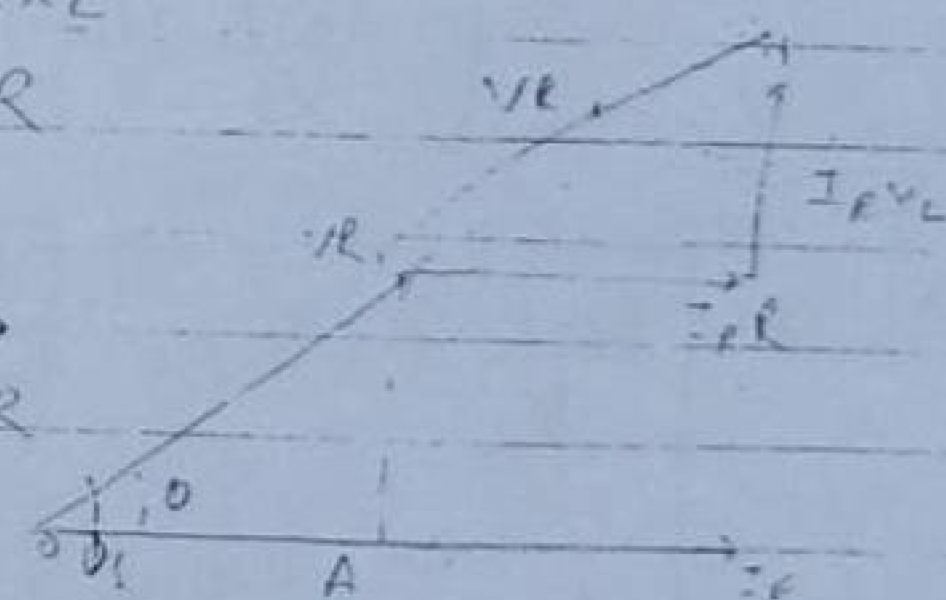
CONDITION FOR ZERO REGULATION OF T.L :-



Vs ≈ 0

consider R.E current I_R as reference vector.





$$V_S^2 = OD^2 = OB^2 + BD^2$$

$$V_S^2 = (OA + AB)^2 + (BC + CD)^2$$

$$OB = V_S \cos\phi_S = OA + AB$$
$$= V_R \cos\phi_R + I_R \cdot R \quad \text{— (1)}$$

$$BD = V_S \sin\phi_S = BC + CD.$$
$$= V_R \sin\phi_R + I_R X_L \quad \text{— (2)}$$

$(1)^2 + (2)^2$

$$V_S^2 = V_R^2 + I_R^2(R^2 + X_L^2)$$