$i = \frac{dq}{dt} \Rightarrow q = \int i(t)\,dt$

$\boxed{V_{ab} = \frac{dw}{dq}}$

$\boxed{P = \frac{dw}{dt} = Vi}$

$R = \frac{\rho l}{A}$

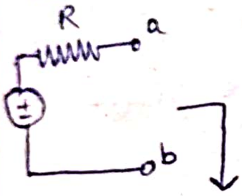
$KCL \Rightarrow \Sigma i_n = 0$

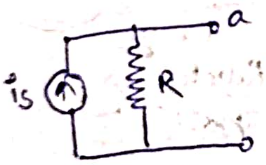
$KVL = \Sigma V_m = 0$

Superposition principle

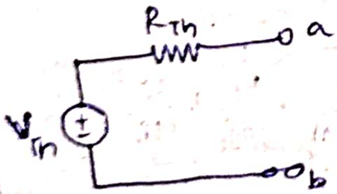
Volt/current across an edge element is sum of voltages/currents due to each independent source acting alone

Source Transformation



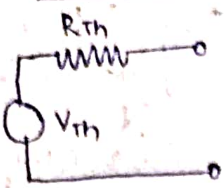


Thevenin Theorem

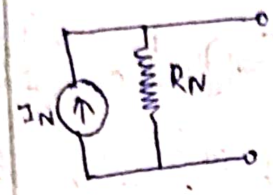


To find R_{Th} short circuit all independent voltage sources and open all independent current sources

Norton Theorem

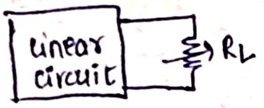


$\updownarrow$



$I_N = \frac{V_{Th}}{R_{Th}}$ $R_N = R_{Th}$

maximum power Transfer principle



max power with-drawn by R_L when $R_L = R_{Th}$ from linear circuit

$$\boxed{P_{max} = \frac{V_{Th}^2}{4R_{Th}}}$$

Thevenin eq

phasors

$z = x + iy = re^{i\phi}$

$r = \sqrt{x^2+y^2}$

$\phi = \tan^{-1}(y/x)$

$v(t) = V_m \cos(\omega t + \phi)$

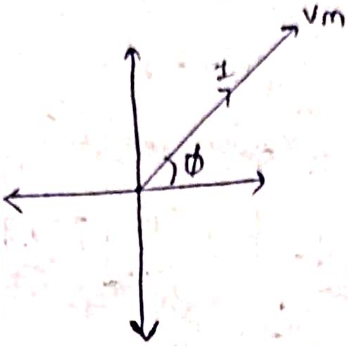
$\updownarrow$

$V = V_m e^{j\phi} \rightarrow$ phasor

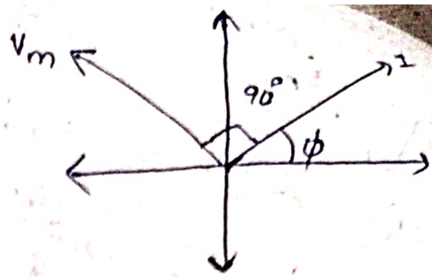
$R \Rightarrow V = IR$

$L \Rightarrow V = j\omega L I$

$C \Rightarrow V = \frac{1}{j\omega C} I$



pure Resistive circuit

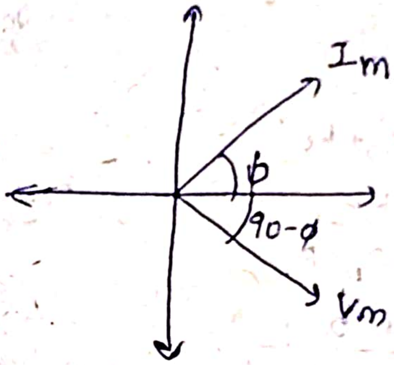


Inductive

ELI

$\downarrow$

Inductor potential leads



capacitor

ICE

$\downarrow$

capacitor current leads

$i(t) = I_m \cos(\omega t + \theta_i)$

$V(t) = V_m \cos(\omega t + \theta_v)$

average power $= \frac{1}{2} I_m V_m \cos(\theta_v - \theta_i)$

$$\boxed{P_{max} = \frac{|V_{Th}|^2}{8R_{Th}}} = \left(\frac{1}{\sqrt{2}} I_m\right)\left(\frac{1}{\sqrt{2}} V_m\right)\cos(\theta_v - \theta_i)$$

$= I_{rms} V_{rms} \cos(\theta_v - \theta_i)$

$\downarrow$

phasors eqn

$P = S\cos(\theta_v - \theta_i)$

$S \Rightarrow$ apparent power

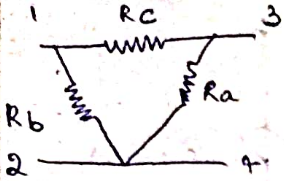
$\cos(\theta_v - \theta_i) \rightarrow$ power factor

$S = P + jQ$

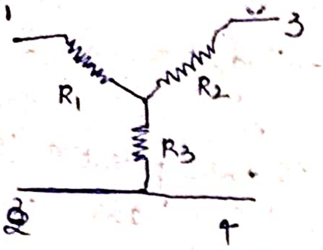
$P = I_{rms} V_{rms} \cos\theta \rightarrow$ real power

$Q = I_{rms} V_{rms} \sin\theta \rightarrow$ Reactive power

$$\boxed{\begin{aligned} P &= I_{rms}^2 R \\ Q &= I_{rms}^2 X \end{aligned}}$$



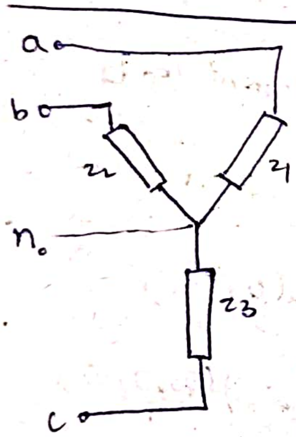
⇓



$$R_1 = \frac{R_b R_c}{R_a + R_b + R_c}$$

$$R_2 = \frac{R_a R_c}{R_a + R_b + R_c}$$

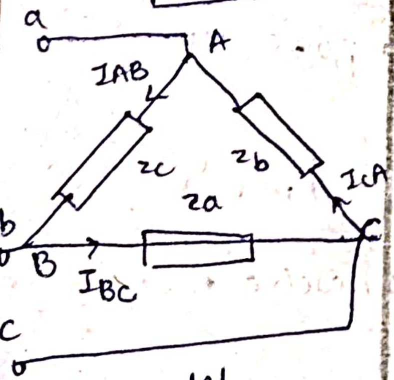
$$R_3 = \frac{R_a R_b}{R_a + R_b + R_c}$$



Y-conneced load

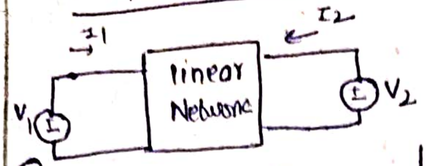
$\boxed{Z_\Delta = 3Z_Y}$

$\boxed{\Delta = 3Y}$



Δ-connected load

Two-port Networks



(z)

$$V_1 = z_{11} I_1 + z_{12} I_2$$

$$V_2 = z_{21} I_1 + z_{22} I_2$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} z_{11} & z_{12} \\ z_{21} & z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

↓ open-circuit admittance parameters

(y)

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}$$

↓ Short circuit admittance parameters

Transmission parameters

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ -I_2 \end{bmatrix}$$

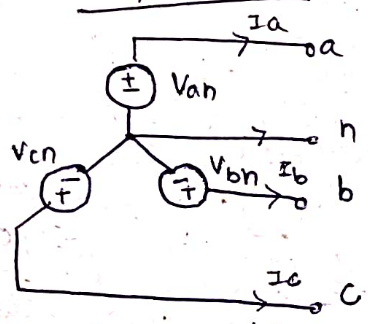
Hybrid

$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

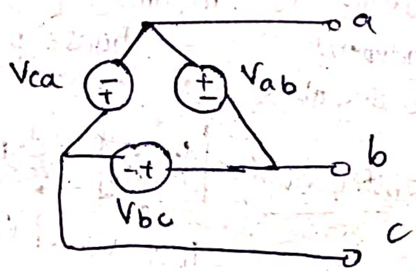
g-parameters

$$\begin{bmatrix} I_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \begin{bmatrix} V_1 \\ I_2 \end{bmatrix}$$

Three phase circuits



Y-connected Sources



Δ-connected source

power in 3-phase systems

$S_p = P_p + jQ_p$

P → average
Q → Reactive
S → apparent

per phase	Total	
$P = V_p I_p \cos\theta$	$P = 3V_p I_p \cos\theta$	$P = \sqrt{3} V_L I_L \cos\theta$
$Q = V_p I_p \sin\theta$	$Q = 3V_p I_p \sin\theta$	$Q = \sqrt{3} V_L I_L \sin\theta$
$S_p = V_p I_p$	$S = 3V_p I_p$	$S = \sqrt{3} V_L I_L$

units P → kW
S → kVA
Q → kVAR

$$X(s) = \frac{a_0}{(s+\lambda)^r} + \frac{a_1}{(s+\lambda)^{r-1}} + \cdots + \frac{a_{r-1}}{(s+\lambda)} + \frac{k_1}{s+P_1} + \frac{k_2}{s+P_2} + \cdots + \frac{k_n}{s+P_n}$$

laplace $X(S) = \int_{-\infty}^{+\infty} x(t) e^{-st} dt$

$$X(S) = \frac{k(s+z_1)(s+z_2) \cdots (s+z_m)}{(s+P_1)(s+P_2) \cdots (s+P_n)}$$

$$= \frac{k_1}{(s+P_1)} + \frac{k_2}{s+P_2} + \cdots + \frac{k_n}{s+P_n}$$

$$k_i = \left[(s+P_i) X(s)\right]\Big|_{s=-P_i}$$

for repeated roots

$$a_j = \left[\frac{1}{j!} \frac{d^j}{ds^j} (s+\lambda)^r X(s)\right]_{s=-\lambda}$$

Initial Value Theorem

$$x(0^+) = \lim_{s\to\infty} sX(s)$$

Final value Theorem

$$\lim_{t\to\infty} x(t) = \lim_{s\to 0} sX(s)$$

$x(t) = 0$ for $t < 0$

Y-Y

phase Voltage	line voltage	phase current	line current
$V_{an} = V_p\angle 0^\circ$	$V_{ab} = \sqrt{3}V_p\angle 30^\circ$	Same as line currents	$I_a = V_{an}/Z_y$
$V_{bn} = V_p\angle -120^\circ$	$V_{bc} = V_{ab}\angle -120^\circ$		$I_b = I_a\angle -120^\circ$
$V_{cn} = V_p\angle +120^\circ$	$V_{ca} = V_{ab}\angle +120^\circ$		$I_c = I_a\angle +120^\circ$

Y-Δ

phase Voltage	line voltage	phase current	line current
$V_{an} = V_p\angle 0^\circ$	$V_{AB} = \sqrt{3}V_p\angle 30^\circ$	$I_{AB} = \frac{V_{AB}}{Z_\Delta}$	$I_a = \sqrt{3}I_{AB}\angle -30^\circ$
$V_{bn} = V_{an}\angle -120^\circ$	$V_{BC} = V_{AB}\angle -120^\circ$	$I_{BC} = \frac{V_{BC}}{Z_\Delta}$	$I_b = I_a\angle -120^\circ$
$V_{cn} = V_{an}\angle +120^\circ$	$V_{CA} = V_{AB}\angle 120^\circ$	$I_{CA} = \frac{V_{CA}}{Z_\Delta}$	$I_c = I_a\angle +120^\circ$

Δ-Δ

phase Voltage	line voltage	phase current	line current
$V_{ab} = V_p\angle 0^\circ$	Same as line voltages	$I_{AB} = \frac{V_{ab}}{Z_\Delta}$	$I_a = I_{AB}\sqrt{3}\angle -30^\circ$
$V_{bc} = V_p\angle -120^\circ$		$I_{BC} = \frac{V_{bc}}{Z_\Delta}$	$I_b = I_a\angle -120^\circ$
$V_{ca} = V_p\angle +120^\circ$		$I_{CA} = \frac{V_{ca}}{Z_\Delta}$	$I_c = I_a\angle +120^\circ$

Δ-Y

phase Voltage	line voltage	phase current	line current
$V_{ab} = V_p\angle 0^\circ$	Same as phase voltages	Same as line currents	$I_a = \frac{V_p\angle -30^\circ}{\sqrt{3}Z_y}$
$V_{bc} = V_p\angle -120^\circ$			$I_b = I_a\angle -120^\circ$
$V_{ca} = V_p\angle +120^\circ$			$I_c = I_a\angle +120^\circ$

signal	laplace Transform	ROC
$ax(t)+by(t)$	$aX(s)+bY(s)$	$R_1 \cap R_2$
$x(t-t_0)$	$e^{-st_0}X(s)$	R
$e^{s_0t}x(t)$	$X(s-s_0)$	$R+Re(s_0)$
$x^*(t)$	$X^*(s^*)$	R
$\frac{dx(t)}{dt}$	$sX(s)$	atleast R
$-tx(t)$	$\frac{dX(s)}{ds}$	R
$\int_{-\infty}^{t} x(\tau)d\tau$	$\frac{1}{s}X(s)$	

unilateral laplace Transform

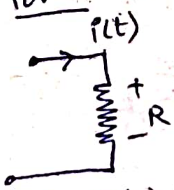
$$\mathcal{L}\left(\frac{dx}{dt}\right) = SX(s) - x(0^-)$$

$$\mathcal{L}\left(\frac{d^2x}{dt^2}\right) = s^2X(s) - s(x(0^-)) - \left.\frac{dx(t)}{dt}\right|_{t=0^-}$$

$$\left.\frac{dx(t)}{dt}\right|_{t=0^-} = x'(0^-)$$

Transfer Impedance

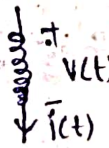
for R



$V(s) = RI(s)$

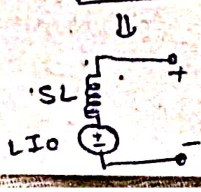
$v(t) = Ri(t)$

for L

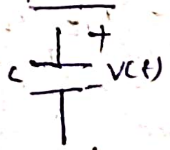


$I_0 \to$ initial

$$\boxed{sLI(s) = V(s) + LI_0}$$

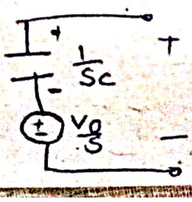


for C



$V_0 \to$ Initial

$$\boxed{\frac{I(s)}{Cs} = V(s) - \frac{V_0}{s}}$$



First-order circuit

(1) Natural response | Source-free $\boxed{V(0)=V_0}$

$v(t)=V_0e^{-t/RC}$

$v(t)=V_0e^{-t/\tau}$ $\boxed{RC}$

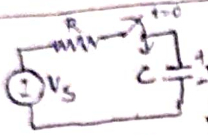
$i_R(t)=\frac{V_0}{R}e^{-t/\tau}$

$\boxed{RL}$ $i(0)=I_0$

$i(t)=I_0e^{-Rt/L}$

$\tau=L/R$

$\boxed{i(t)=I_0e^{-t/\tau}}$



$v(0^-)=v(0^+)=V_0$

$v(t)=\begin{cases} V_0 & t<0 \\ V_s+(V_0-V_s)e^{-t/\tau} & t>0 \end{cases}$

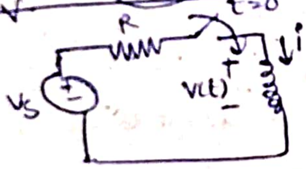
Voltage of capacitance cannot change instantaneously

$\boxed{i(t)=\frac{V_s}{R}e^{-t/\tau}u(t)}$

complete response = Natural + forced response

RC

$\boxed{RL}$



$\boxed{i(t)=\frac{V_s}{R}+\left(I_0-\frac{V_s}{R}\right)e^{-t/\tau}}$ $\boxed{\tau=\frac{L}{R}}$

$\boxed{v(t)=V_se^{-t/\tau}u(t)}$

Transfer function for two port

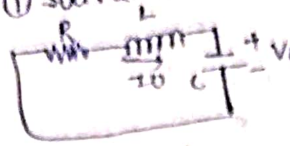
Numerator

	$V_2(s)$	$I_2(s)$
$V_1(s)$	$G_{12}(s)$	$Y_{12}(s)$
$I_1(s)$	$Z_{12}(s)$	$\alpha_{12}(s)$

denominator

Second order

(1) Source free



$\frac{d^2i}{dt^2}+\frac{R}{L}\frac{di}{dt}+\frac{i}{LC}=0$

$i=Ae^{st}$

$s^2+\frac{R}{L}s+\frac{1}{LC}=0$

$s_1=-\frac{R}{2L}+\sqrt{\left(\frac{R}{2L}\right)^2-\frac{1}{LC}}$

$s_2=-\frac{R}{2L}-\sqrt{\left(\frac{R}{2L}\right)^2-\frac{1}{LC}}$

$s_1=-\alpha+\sqrt{\alpha^2-\omega_0^2}$

$s_2=-\alpha-\sqrt{\alpha^2-\omega_0^2}$

$\alpha=\frac{R}{2L}$ $\omega_0=\frac{1}{\sqrt{LC}}$

$\boxed{\alpha>\omega_0}$

$\boxed{i(t)=A_1e^{s_1t}+A_2e^{s_2t}}$

$\boxed{\alpha=\omega_0}$

$i(t)=(A_2+A_1t)e^{-\alpha t}$

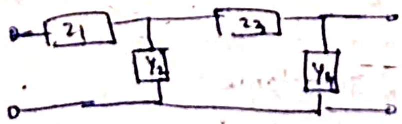
$\boxed{\alpha<\omega_d}$

$s_1=-\alpha+j\omega_d$

$s_2=-\alpha-j\omega_d$

$i(t)=e^{-\alpha t}(B_1\cos\omega_dt+B_2\sin\omega_dt)$

Ladder Network



$Z=Z_1+\cfrac{1}{Y_2+\cfrac{1}{Z_3+\cfrac{1}{Y_4+\cfrac{1}{Z_5+\cfrac{1}{Y_6+\cdots}}}}}$

Poles and zeroes

$F(s)=H\frac{(s-z_1)(s-z_2)(s-z_3)\cdots(s-z_n)}{(s-p_1)(s-p_2)\cdots(s-p_m)}$ → zeroes (numerator), → poles (denominator)