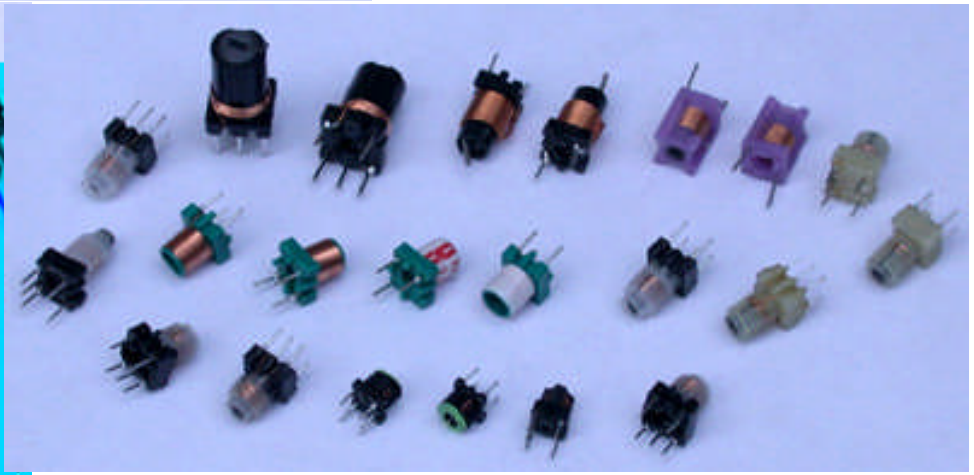
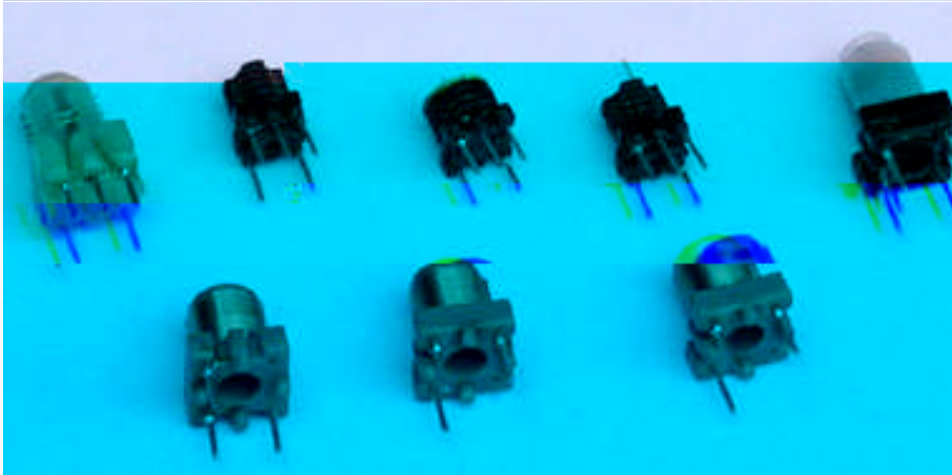
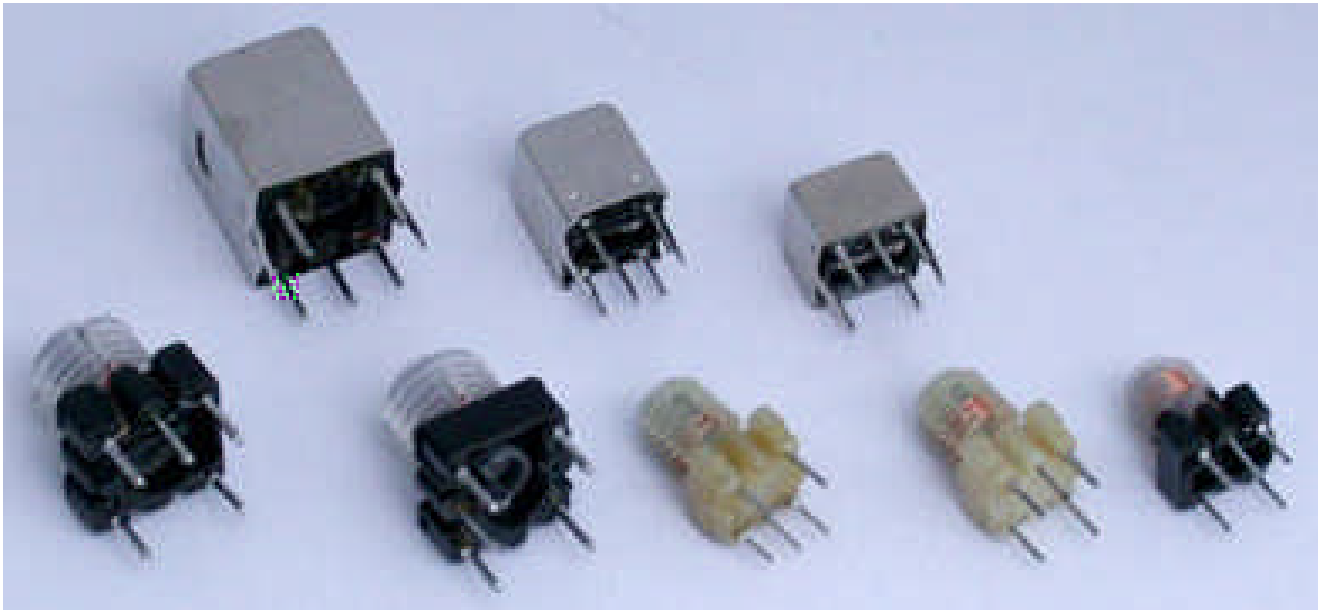
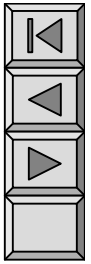
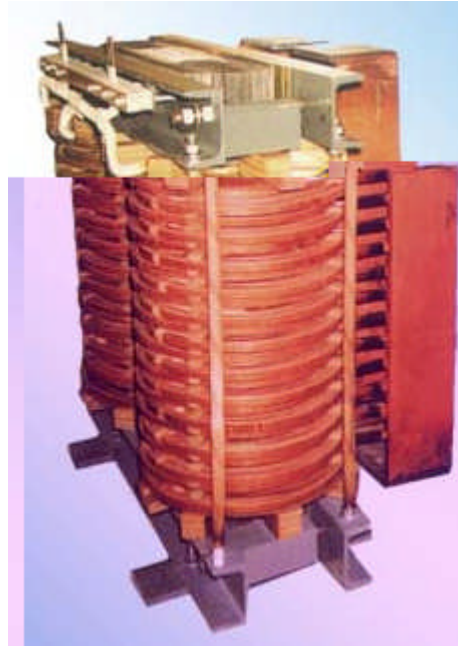


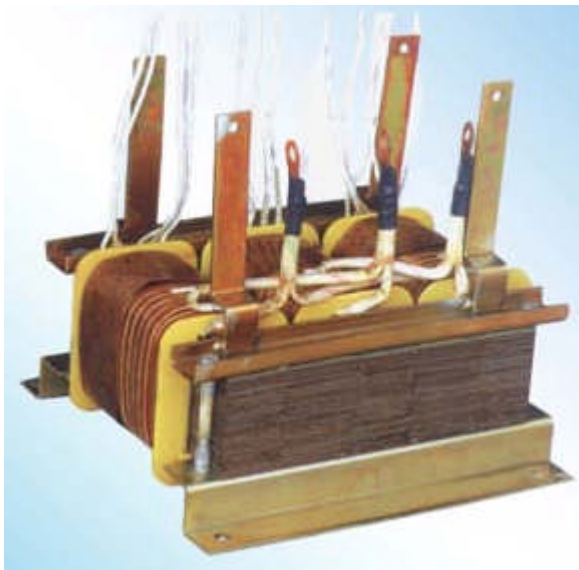
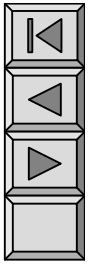
()

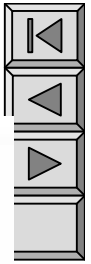
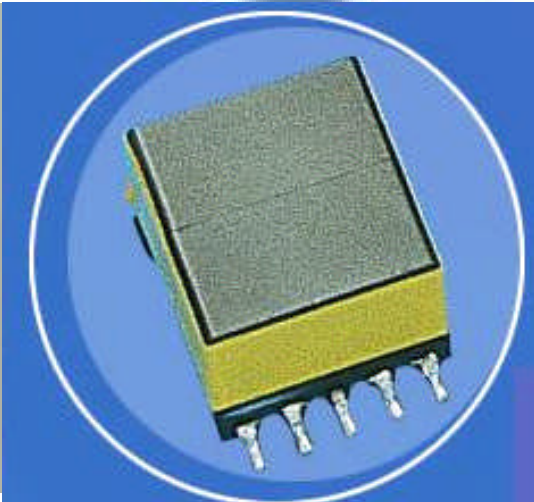


()

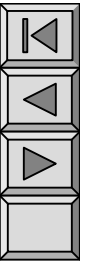


10kVA~300kVA

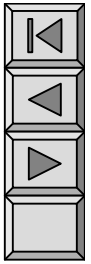




Power Transformer Telecom Transformer Audio Transformer



§ 10-1



1.



i_1

i_1

11

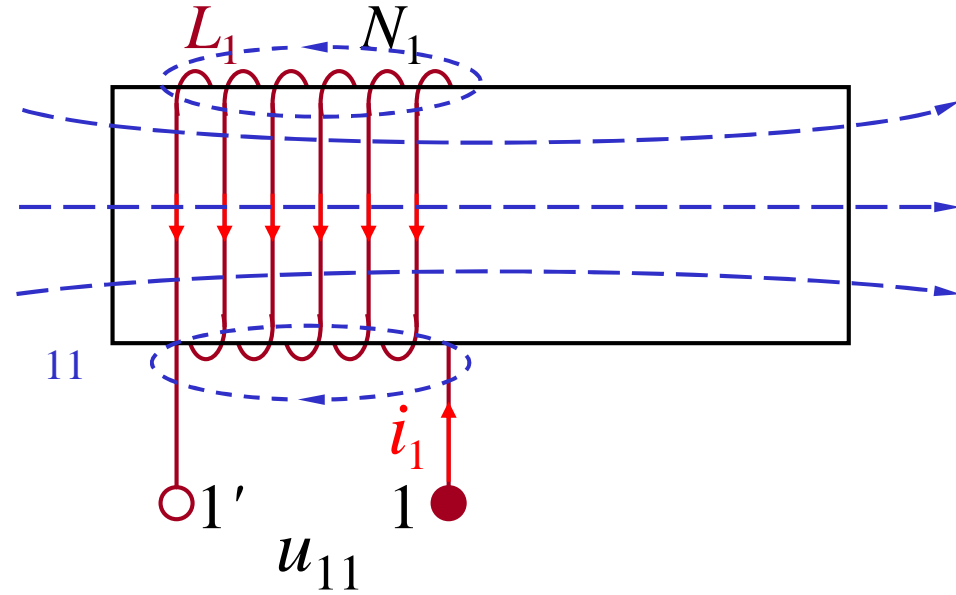
11

11

i_1

u_{11}

11



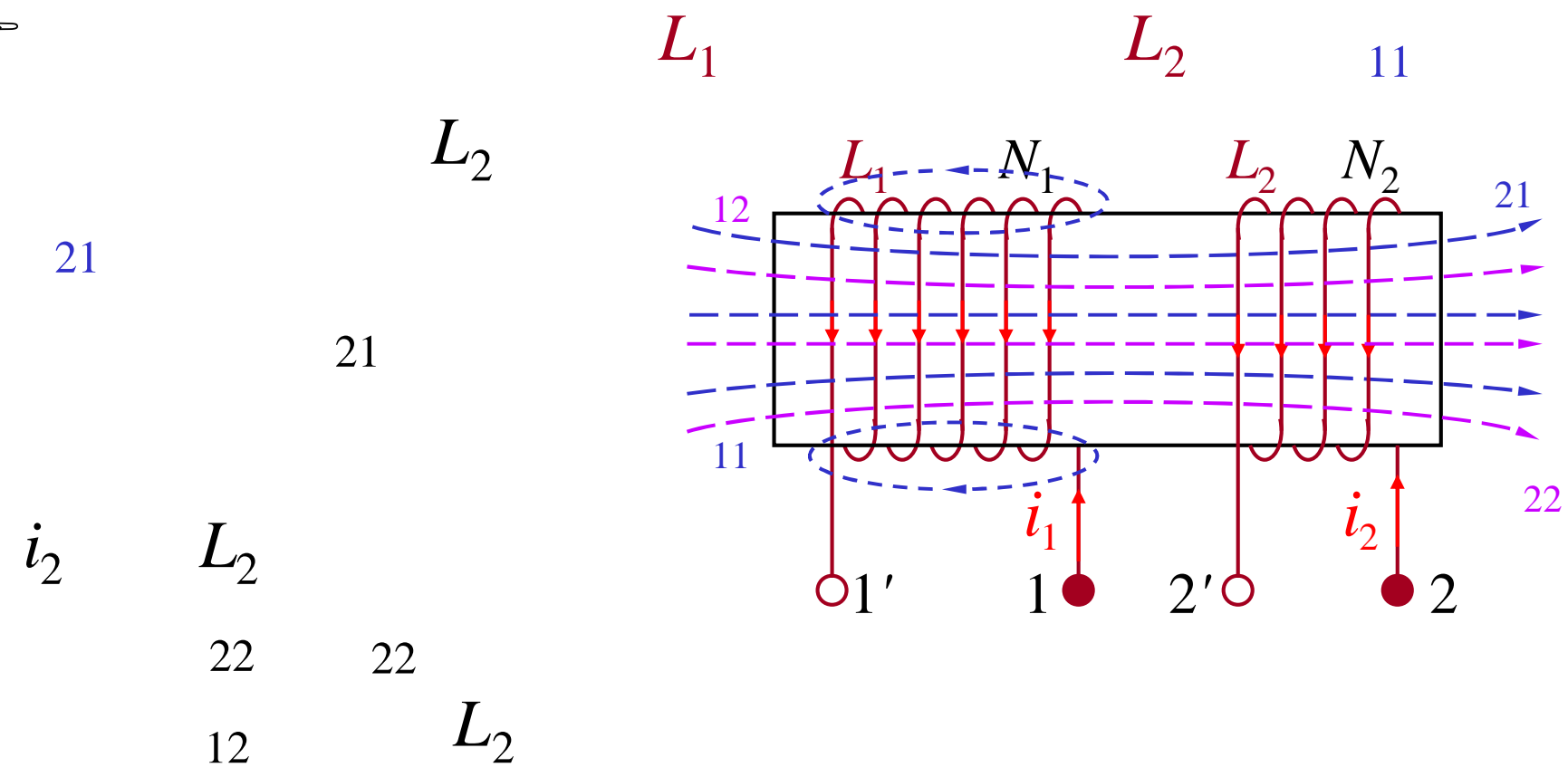
u_{11} i_1

$$u_{11} = \frac{d}{dt} \lambda_{11}$$

$$L_1 \frac{di_1}{dt}$$

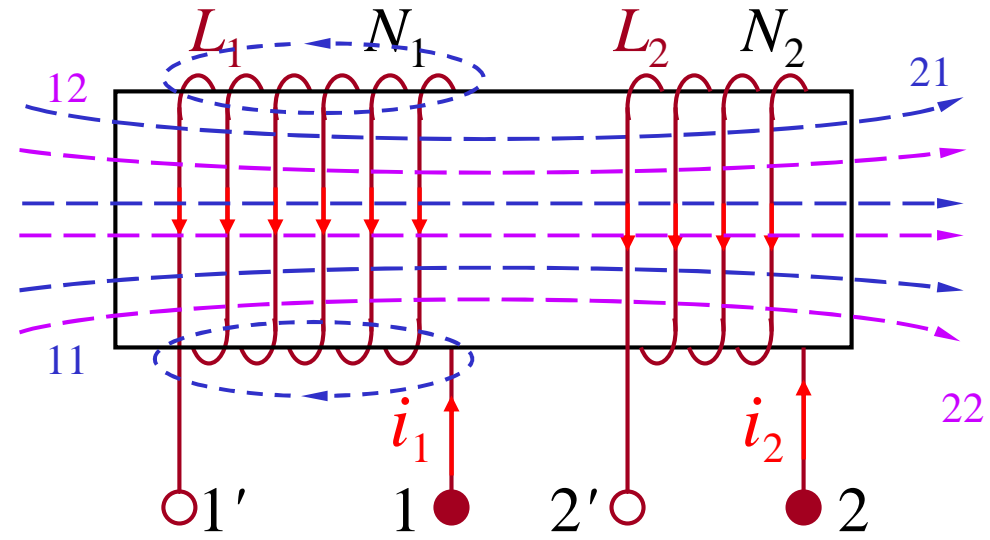
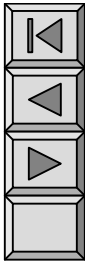
$$L_1 i_1$$

11



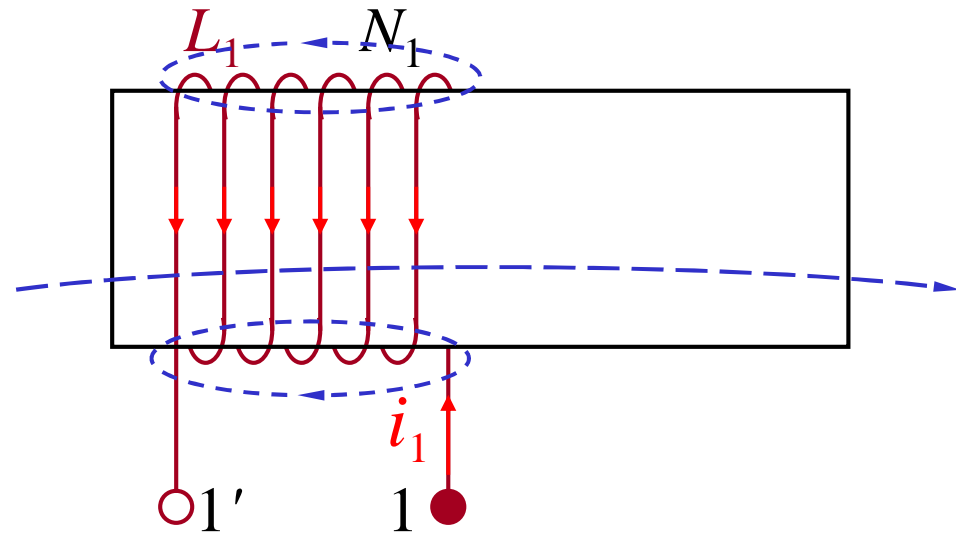
i_2 L_2
 22 22
 12 L_2

$$\begin{aligned} 1 &= 11 \pm 12 \\ 2 &= 22 \pm 21 \end{aligned}$$



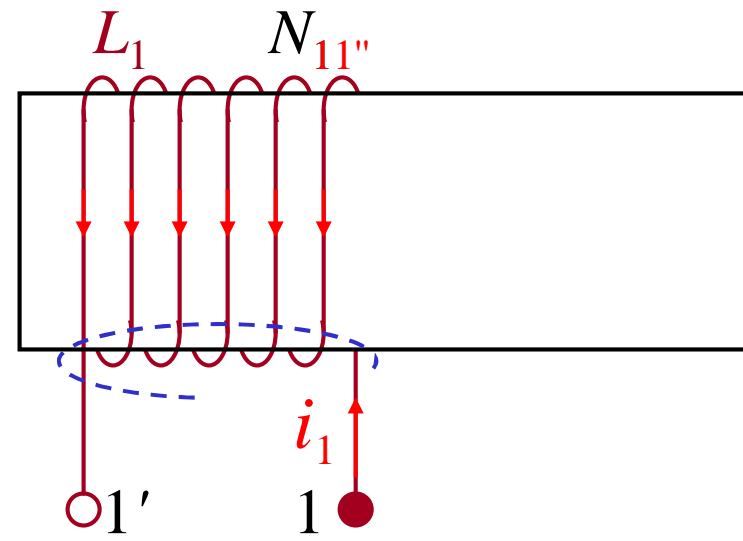
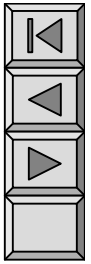
2.

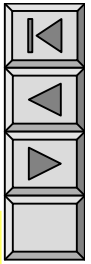
- $_{11} L_1 i_1$ $_{22} L_2 i_2$
- $_{12} M_{12} i_2$ $_{21} M_{21} i_1$
- M_{12} M_{21}
- H_0



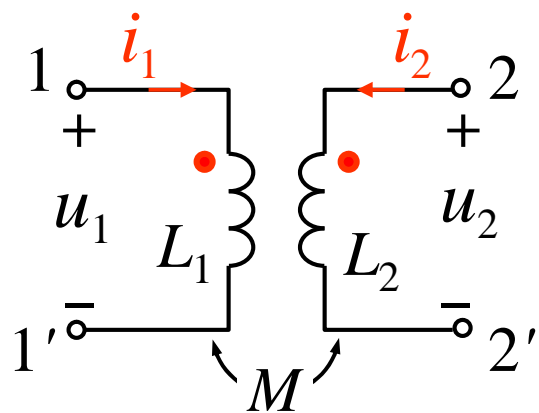
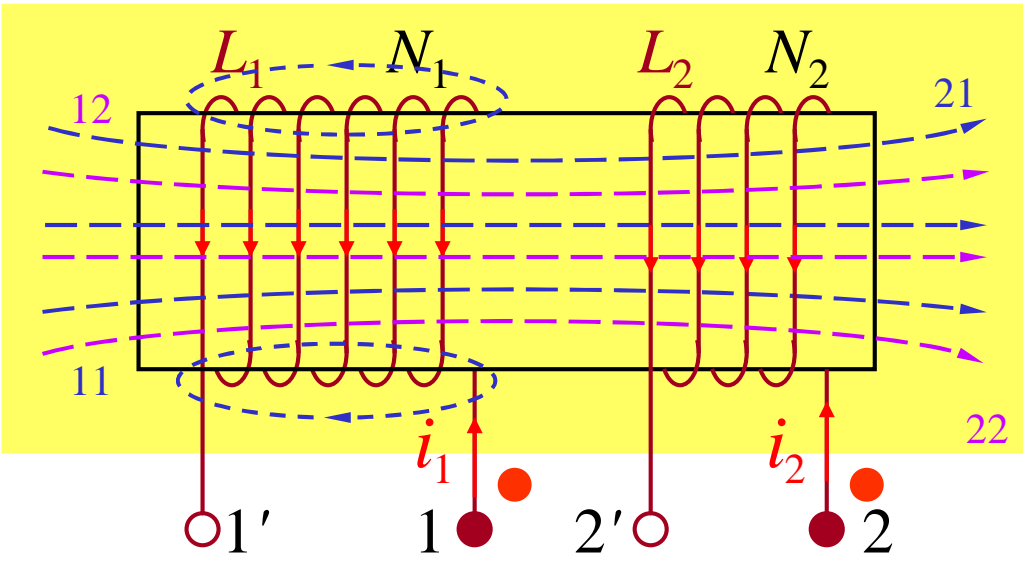
L

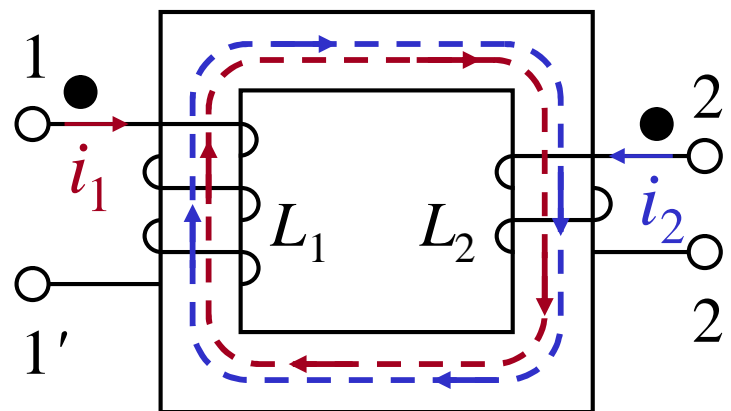
M





“●” “*”
“ ”

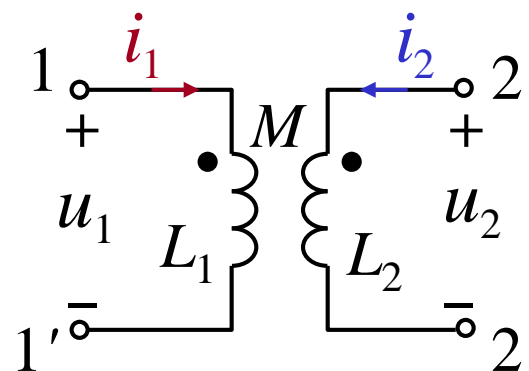




$$i_1 \quad i_2 (>0)$$

$$i_1 \quad i_2$$

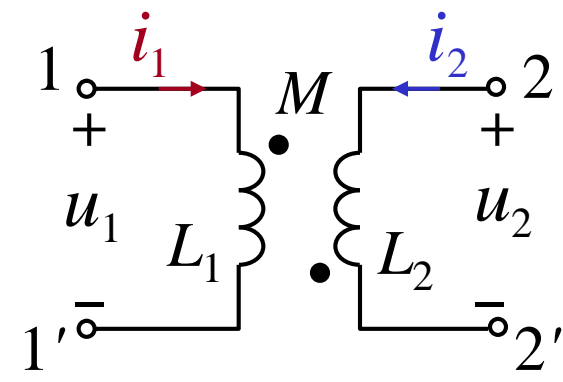
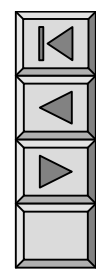
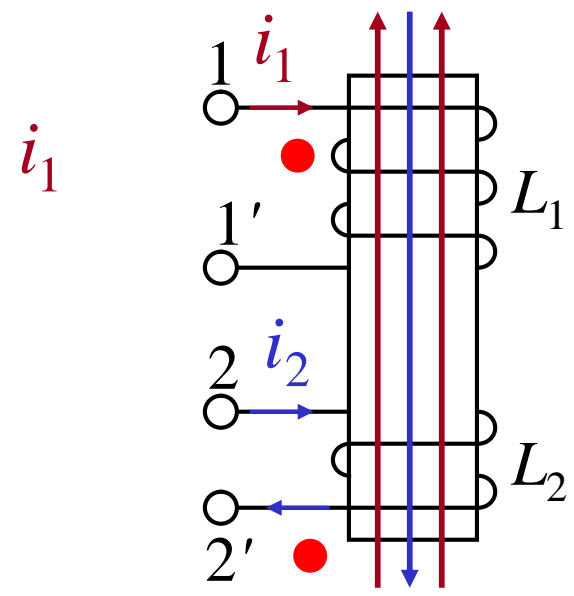
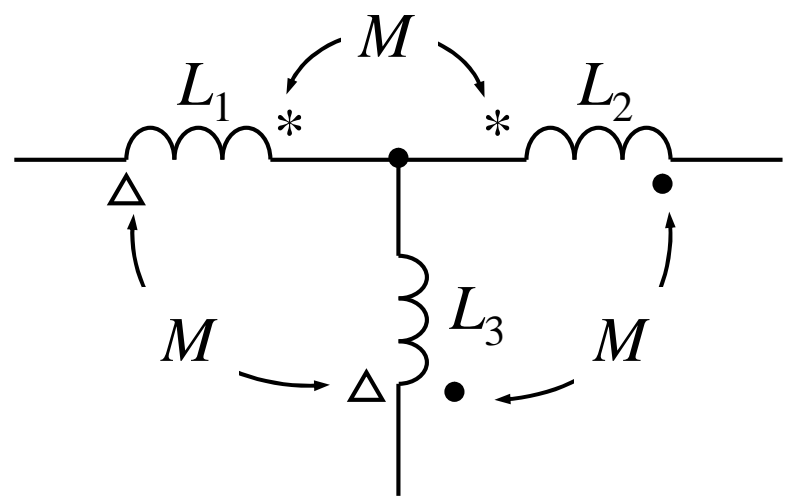
1 2
1' 2'



$>0)$

i_2

i_1 i_2



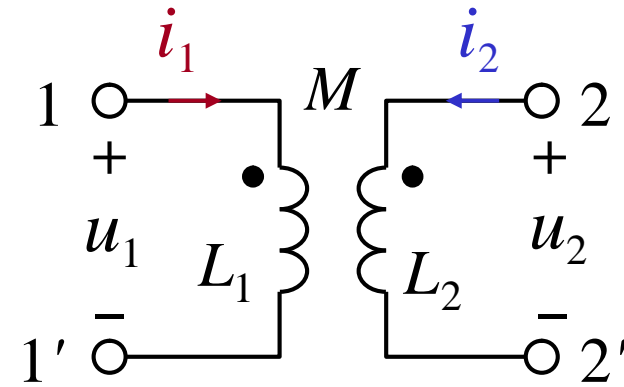
VCR



4.



$$\begin{aligned}
 u_1 &= \frac{d}{dt} L_1 i_1 + M \frac{di_2}{dt} \\
 u_2 &= \frac{d}{dt} L_2 i_2 + M \frac{di_1}{dt}
 \end{aligned}$$



i_1 L_1

“+”

L_2

i_1 L_2

i_2 L_2

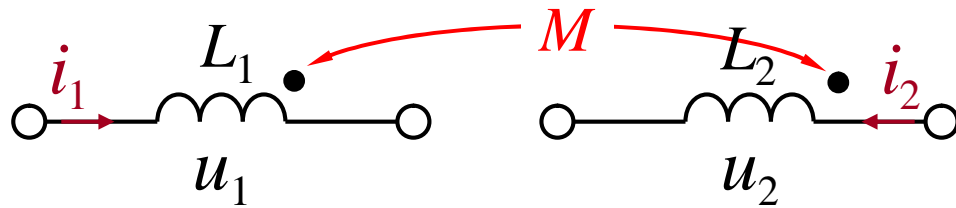
“+”

L_1

i_2 L_1

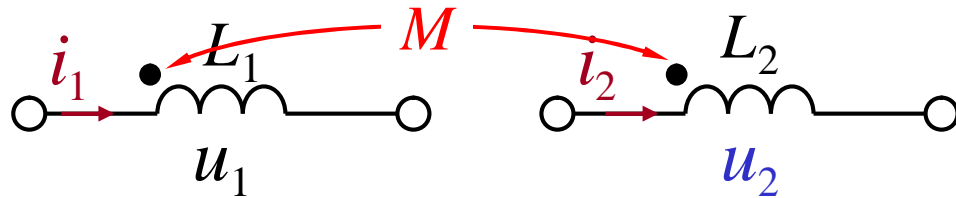


VCR



$$u_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$u_2 = L_2 \frac{di_2}{dt} + M \frac{di_1}{dt}$$



$$u_1 = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$

$$u_2 = L_2 \frac{di_2}{dt} - M \frac{di_1}{dt}$$

VCR

$$\dot{U}_1 = j L_1 \dot{I}_1 + j M \dot{I}_2$$

$$\dot{U}_2 = j L_2 \dot{I}_2 + j M \dot{I}_1$$

$$\dot{U}_1 = j L_1 \dot{I}_1 + j M \dot{I}_2$$

$$\dot{U}_2 = j M \dot{I}_1 + j L_2 \dot{I}_2$$



“ ”

2 3 ()
220V

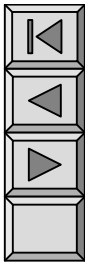
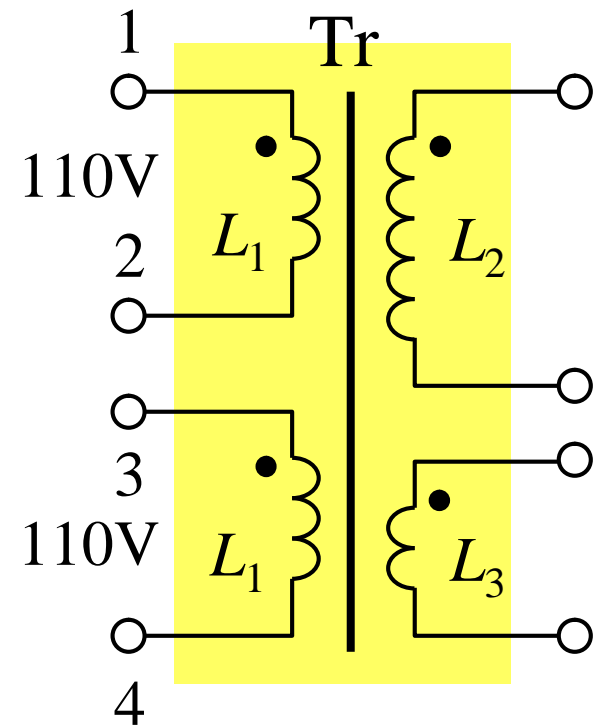
1 4

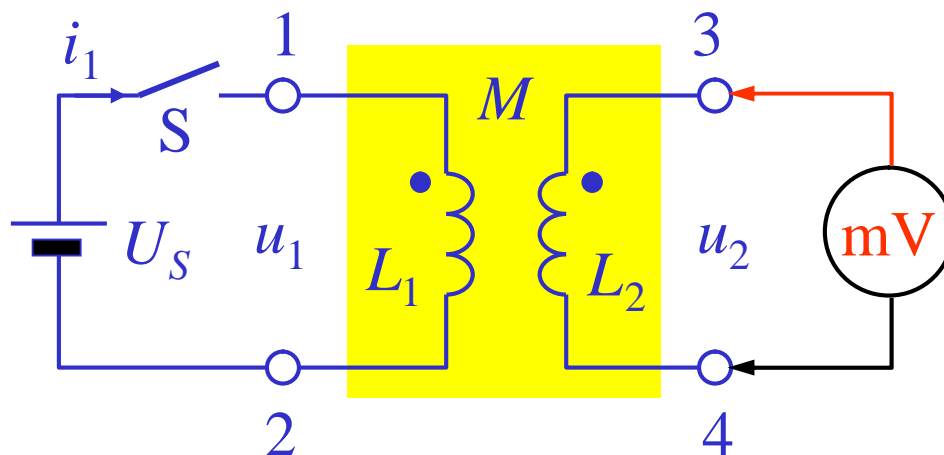
1 3 2 4 ()

110V



()





$$u_2 = M \frac{di_1}{dt}$$

S $\frac{di_1}{dt} > 0$ S

$u_2 > 0$ $1 \quad 4$

5.

k

•

•

$$k = \frac{\text{del}}{\sqrt{\frac{L_{11} L_{22}}{L_{12} L_{21}}}}$$

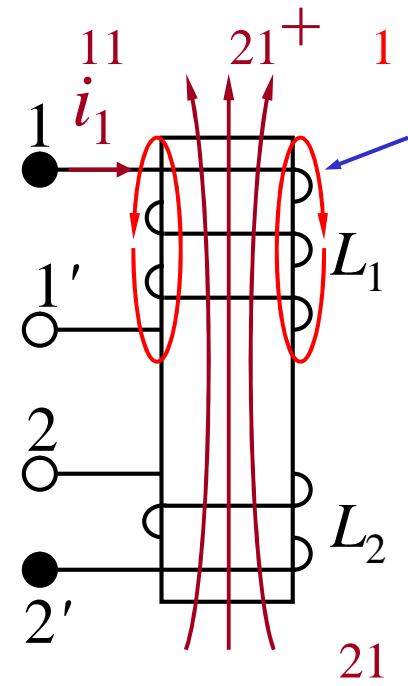
$$L_{11} i_1 \quad L_{22} i_2$$

$$M i_2 \quad M i_1$$

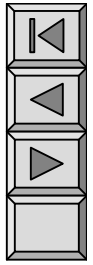
$$0 \quad k \quad \frac{M}{\sqrt{L_1 L_2}} \quad 1$$

k

$k \quad 1$



1



§ 10-2



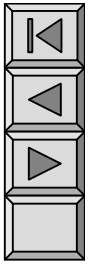
1



2

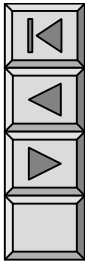
()

VCR





3



1.

(1) L_1 L_2 “ ”

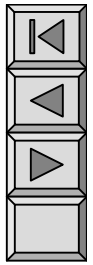
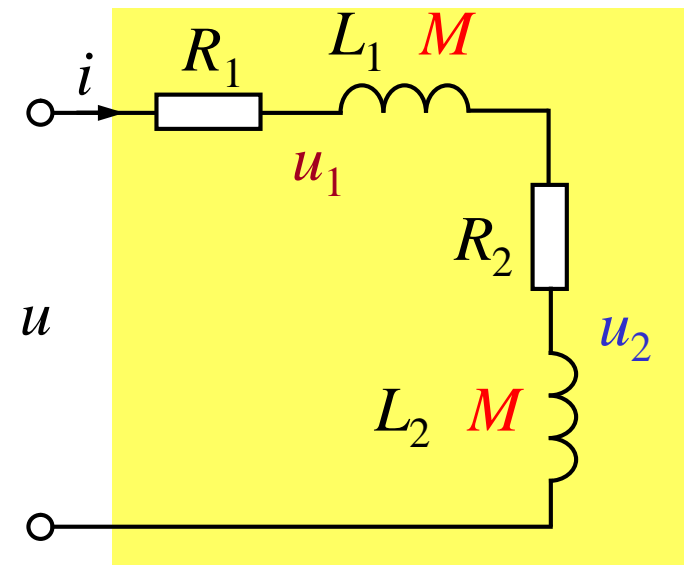
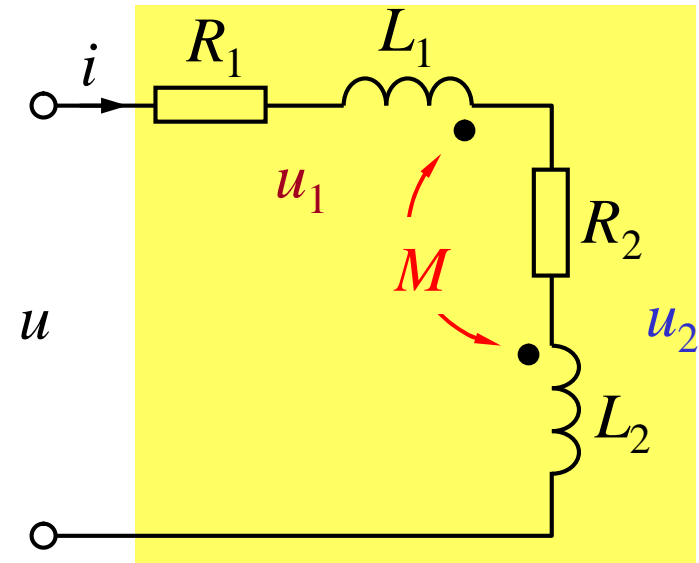
KVL()

$$u_1 = R_1 i + L_1 \frac{di}{dt} + M \frac{di}{dt}$$

$$R_1 i + (L_1 + M) \frac{di}{dt}$$

$$u_2 = R_2 i + L_2 \frac{di}{dt} + M \frac{di}{dt}$$

$$R_2 i + (L_2 + M) \frac{di}{dt}$$





$$u_1 = R_1 i + (L_1 - M) \frac{di}{dt} \quad u_2 = R_2 i + (L_2 + M) \frac{di}{dt}$$

$$\dot{U}_1 = R_1 \dot{I} + j(L_1 - M) \dot{I} + Z_1 \dot{I}$$

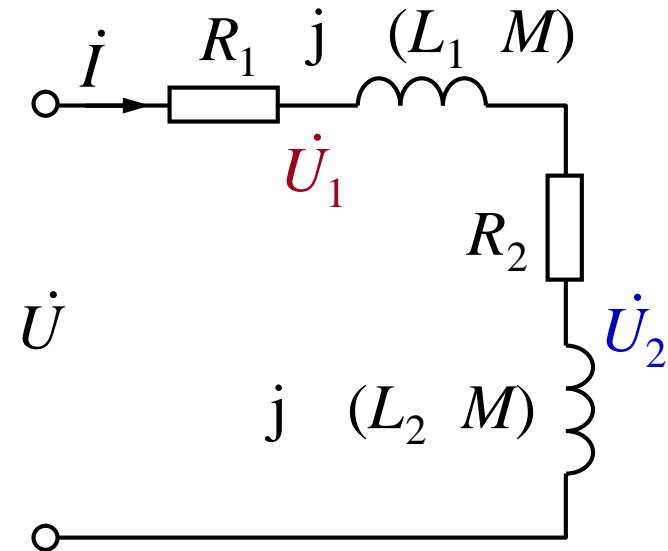
$$Z_1 = R_1 + j(L_1 - M)$$

$$\dot{U}_2 = R_2 \dot{I} + j(L_2 + M) \dot{I} + Z_2 \dot{I}$$

$$Z_2 = R_2 + j(L_2 + M)$$

$$\text{KVL } \dot{U} = \dot{U}_1 + \dot{U}_2 = (Z_1 + Z_2) \dot{I} = Z \dot{I}$$

$$Z = Z_1 + Z_2 = (R_1 + R_2) + j(L_1 + L_2 + 2M)$$

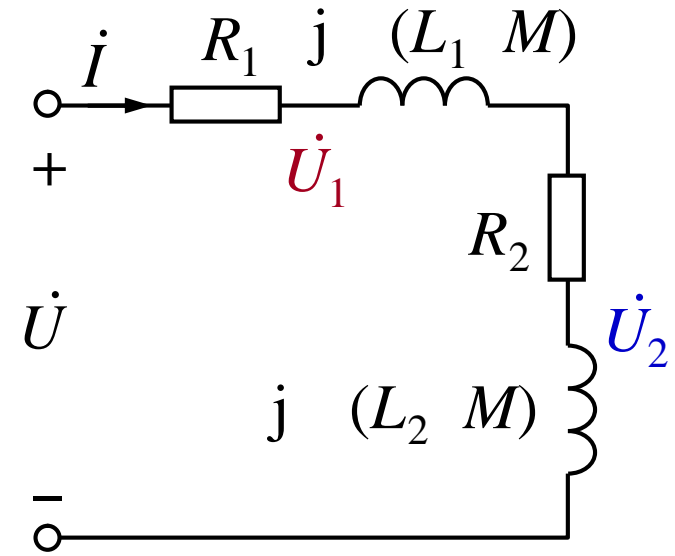




$$Z = Z_1 + Z_2 = (R_1 + R_2) + j(L_1 + L_2 + 2M)$$

“ ”

$$(Z_1 + Z_2) = Z$$



“ ”

“ ”

$$(L_1 + M) + (L_2 + M)$$



$$k = 1$$

$$(L_1 + L_2 + 2M) = 0$$

(2)

$$Z_1 \quad R_1 \quad j \quad (L_1 \quad M)$$

$$Z_2 \quad R_2 \quad j \quad (L_2 \quad M)$$

$$Z \quad (R_1 \quad R_2) \quad j \quad (L_1 \quad L_2 \quad 2M)$$

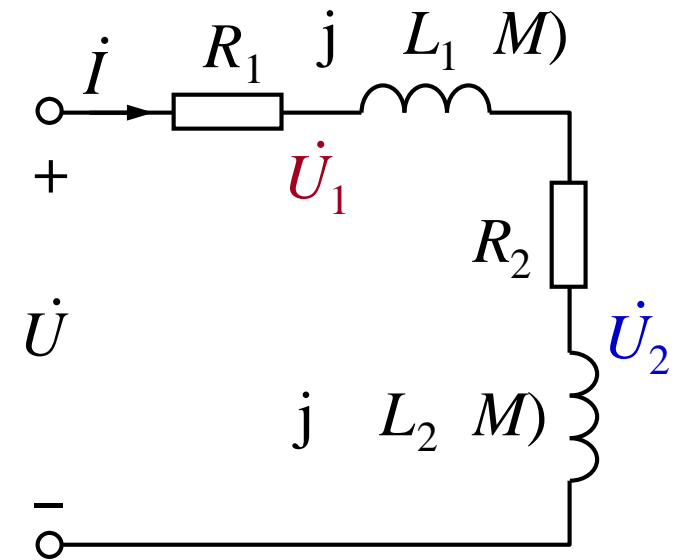
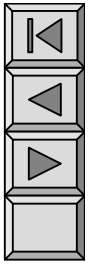
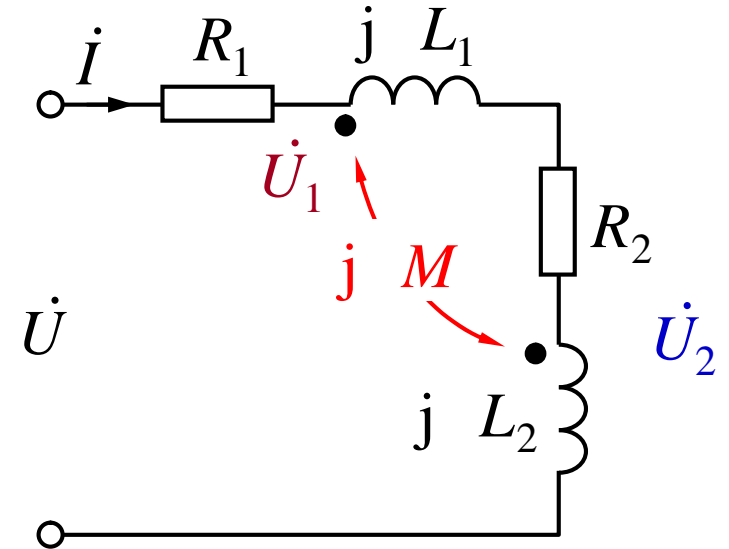


L

$$L \quad L_1 \quad L_2 \pm 2M$$

“ ”

“ ”





$$Z = 20 + j40$$

$$44.7 \angle -63.4^\circ$$

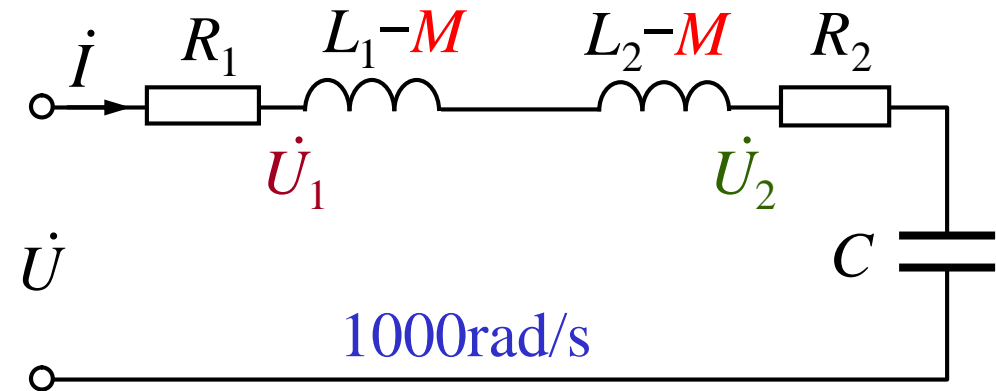
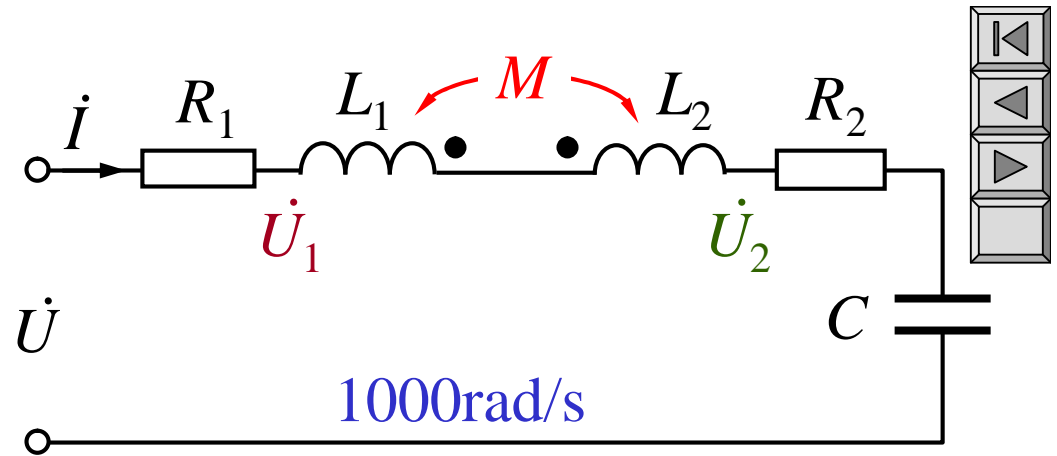
$$\dot{U} = 6 \angle 0^\circ \text{ V}$$

$$\dot{I} = \frac{\dot{U}}{Z} = \frac{6 \angle 0^\circ}{44.7 \angle -63.4^\circ}$$

$$0.134 \angle 63.4^\circ \text{ A}$$

$$\dot{U}_1 = [R_1 + j(L_1 - M)] \dot{I} = 1.34 \angle 63.4^\circ \text{ V}$$

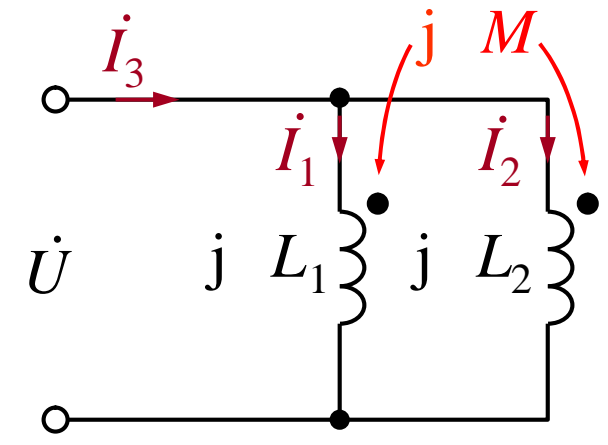
$$\dot{U}_2 = [R_2 + j(L_2 - M)] \dot{I} = 1.90 \angle 108.4^\circ \text{ V}$$





2.

(1)



$$\dot{U} = j L_1 \dot{I}_1 + j M \dot{I}_2 \dots \dots (1)$$

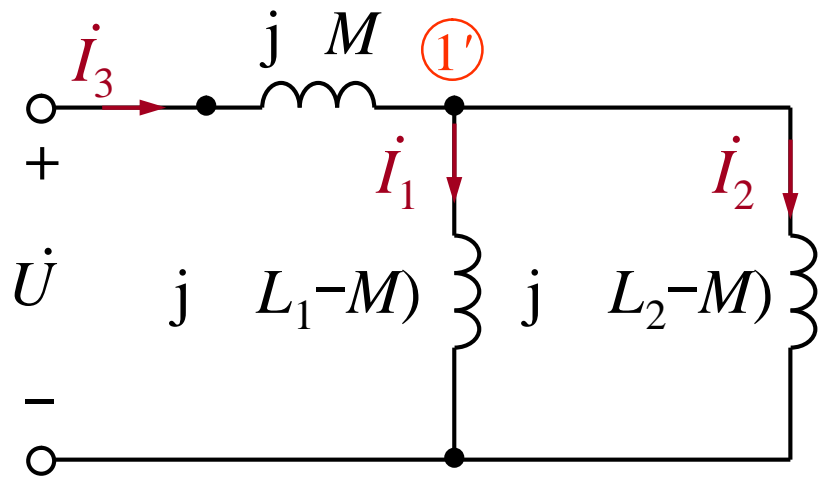
$$\dot{U} = j M \dot{I}_1 + j L_2 \dot{I}_2 \dots \dots (2)$$

$$\dot{I}_3 = \dot{I}_1 + \dot{I}_2 \dots \dots \dots (3)$$

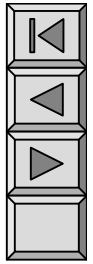
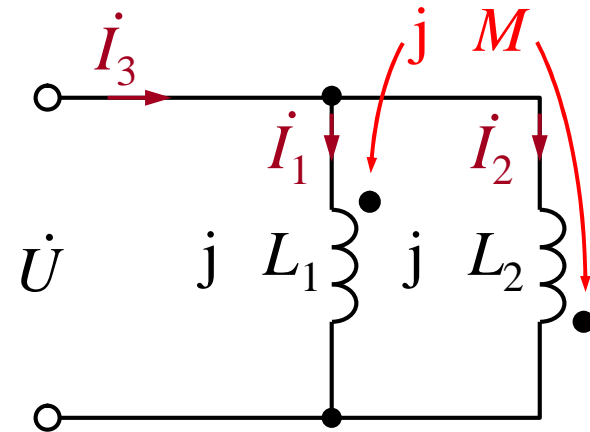
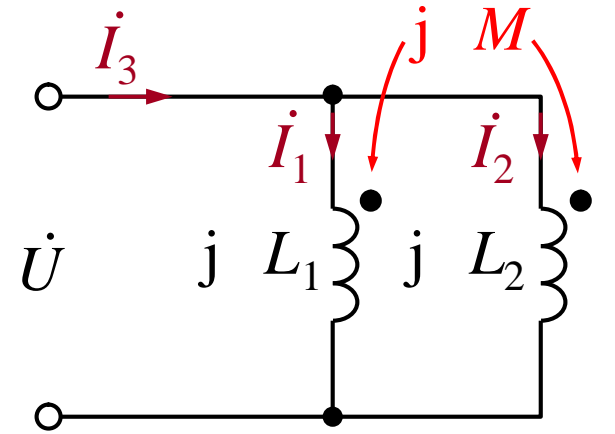
$$(3) \quad (1) \quad \dot{U} = j L_1 \dot{I}_1 + j M (\dot{I}_3 - \dot{I}_1) \\ j (L_1 - M) \dot{I}_1 + j M \dot{I}_3$$

$$(3) \quad (2) \quad \dot{U} = j M (\dot{I}_3 - \dot{I}_2) + j L_2 \dot{I}_2 \\ j M \dot{I}_3 + j (L_2 - M) \dot{I}_2$$

$$\begin{aligned} \dot{U} &= j(L_1 - M)\dot{I}_1 + jM\dot{I}_3 \\ \dot{U} &= jM\dot{I}_3 + j(L_2 - M)\dot{I}_2 \end{aligned}$$

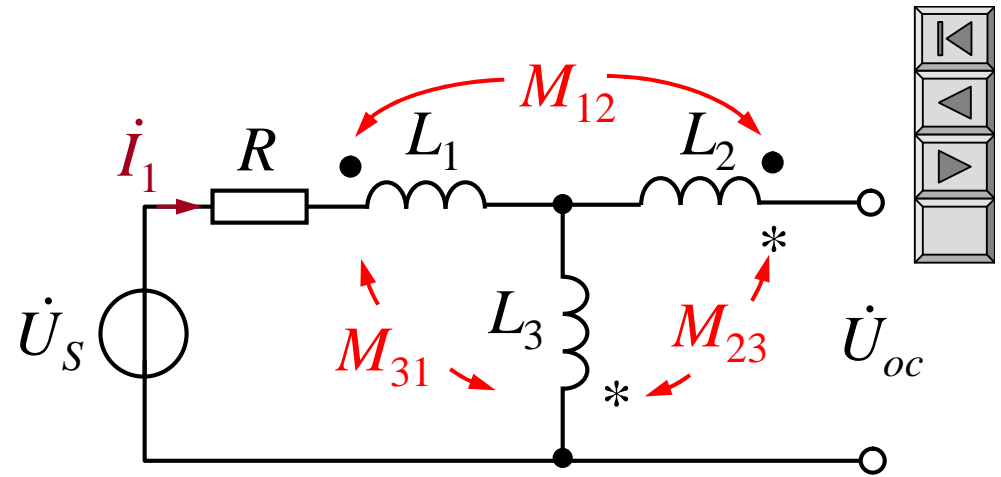


(2)





1
 L_2
 L_1 L_3



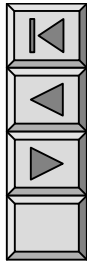
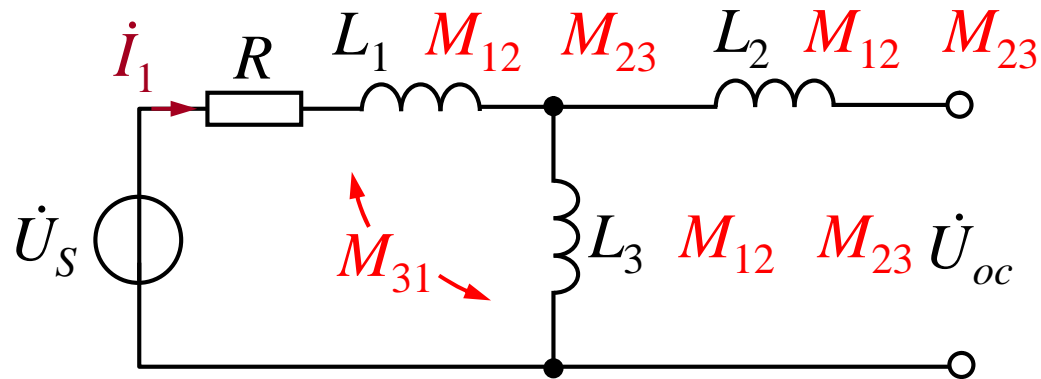
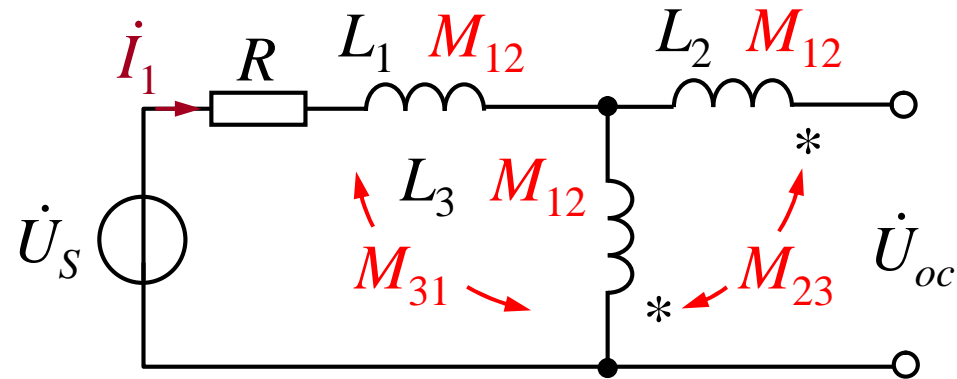
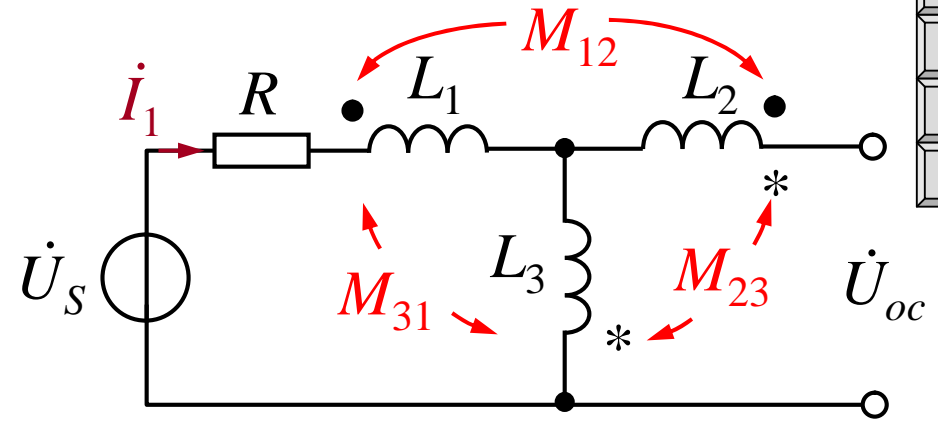
$$\dot{I}_1 \frac{\dot{U}_s}{R + j(L_1 + L_3 + 2M_{31})}$$

()

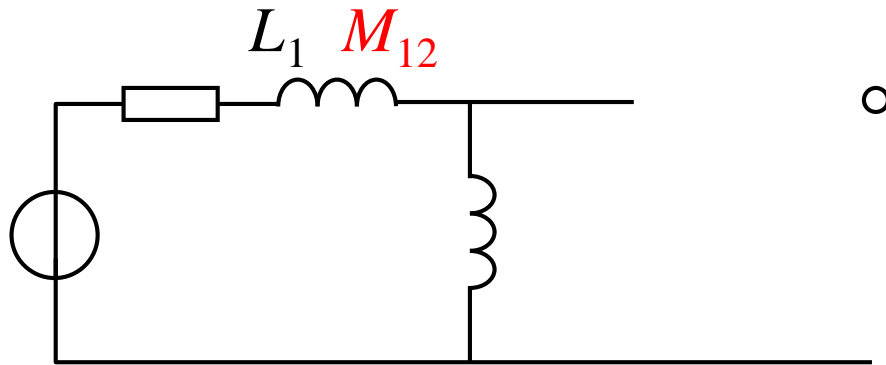
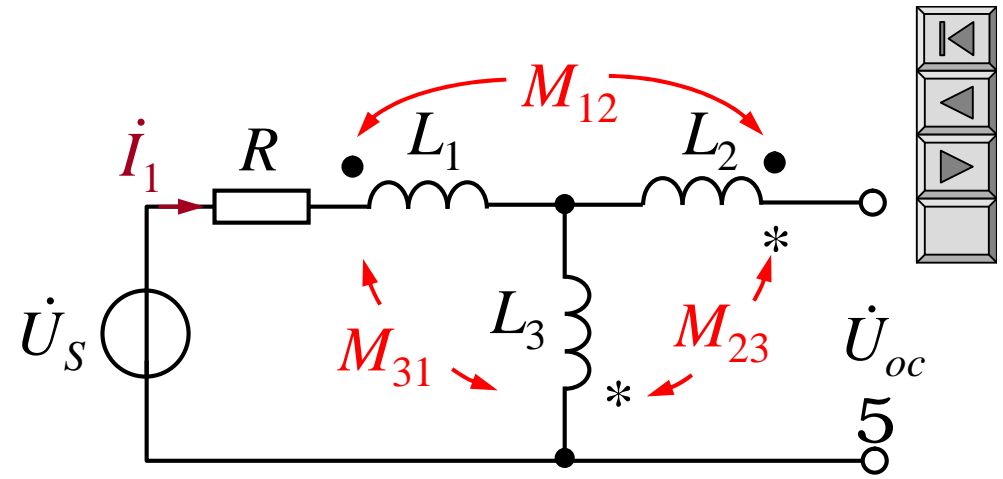
$$\dot{U}_{oc} = j M_{12} \dot{I}_1 + j M_{23} \dot{I}_1 + j M_{31} \dot{I}_1 + j L_3 \dot{I}_1$$

$$\dot{U}_{oc} = \frac{j(M_{12} + M_{23} + M_{31} + L_3) \dot{U}_s}{R + j(L_1 + L_3 + 2M_{31})}$$

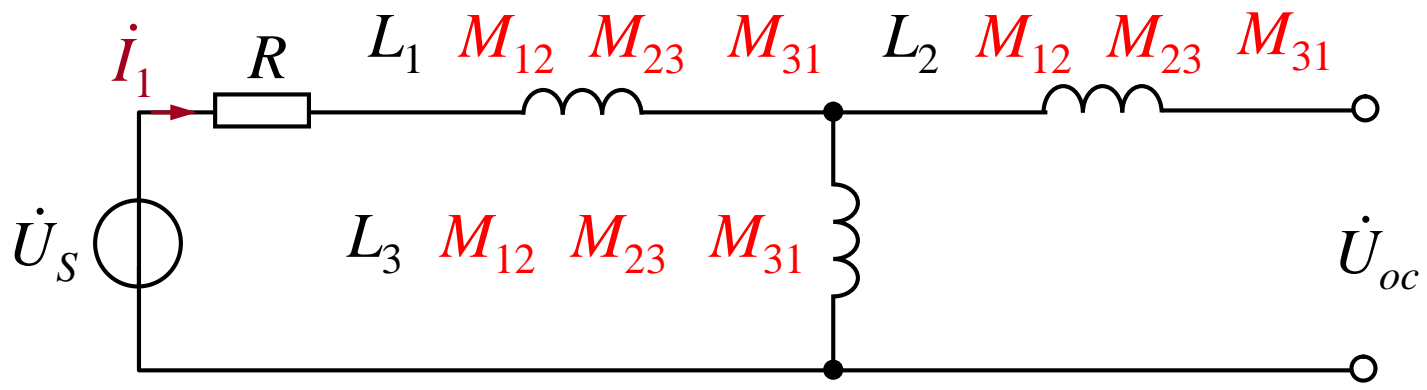
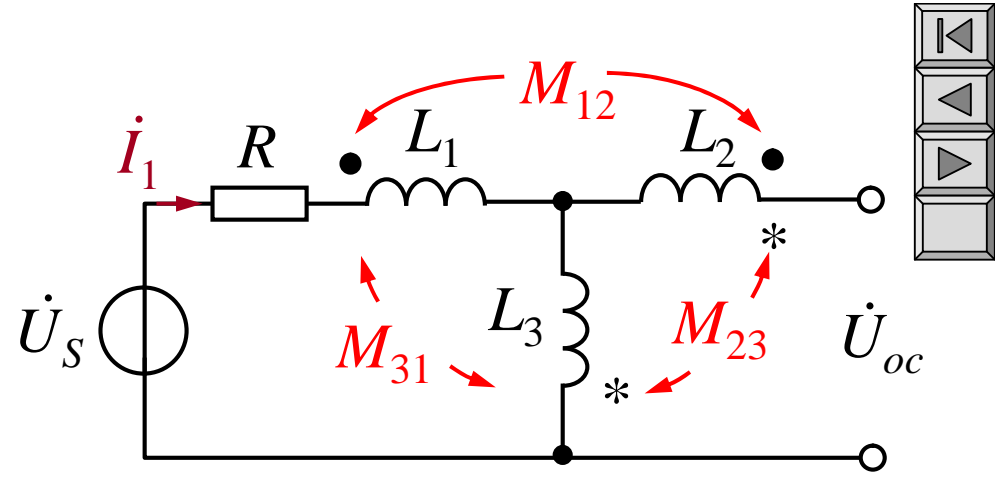
2



2

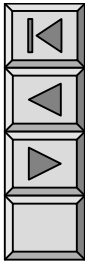


2



$$\dot{U}_{oc} = \frac{j(L_3 + M_{12} + M_{23} + M_{31})\dot{U}_s}{R + j(L_1 + L_3 + 2M_{31})}$$

§ 10-3



()



M

L C

L

L

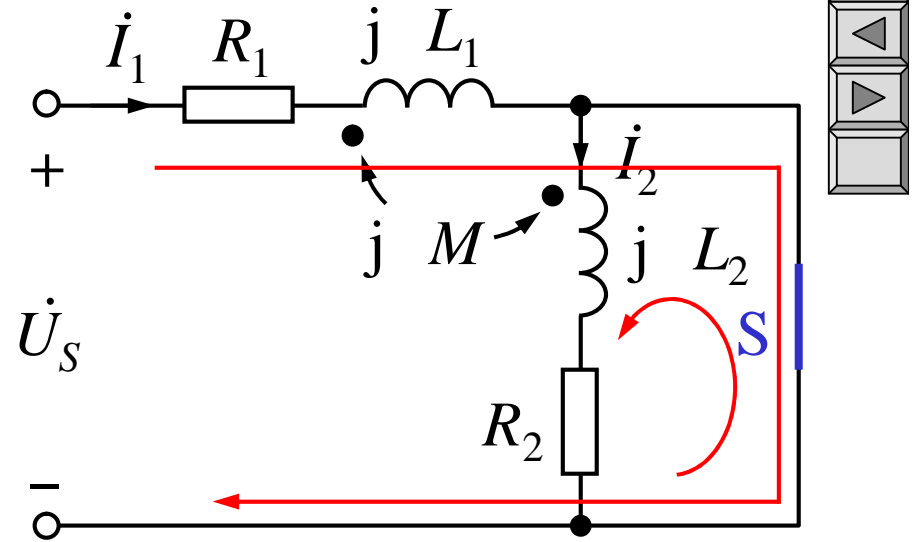
()

$$\begin{array}{rcl}
 10 & 6 & R_1 \quad 3 \quad R_2 \quad 5 \\
 L_1 & 7.5 & L_2 \quad 12.5 \\
 M & 8 & U_S \quad \text{V}
 \end{array}$$

$$\dot{U}_S = 50 \angle 0^\circ \text{ V}$$

$$\begin{array}{l}
 (R_1 + j L_1) \dot{I}_1 + j M \dot{I}_2 = \dot{U}_S \\
 j M \dot{I}_1 + (R_2 + j L_2) \dot{I}_2 = 0
 \end{array}$$

$$\dot{I}_1 = 8.81 \angle 32.93^\circ \text{ A}$$



$$\dot{I}_2 = 5.24 \angle \quad \text{A}$$

$$\begin{array}{l}
 \overline{S}_S = \dot{U}_S \dot{I}_1^* \\
 233 + j582 \quad 137 + j343 \text{ VA}
 \end{array}$$

$$\begin{array}{l}
 \overline{S}_2 = j M \dot{I}_1 \dot{I}_2^* + (R_2 + j L_2) I_2^2 \\
 37 + j343 \quad j343 \text{ VA}
 \end{array}$$

$$\overline{S}_S = \dot{U}_S \dot{I}_1^* + (R_1 + jL_1) \dot{I}_1^2 + jM \dot{I}_2 \dot{I}_1^*$$

233 + j582 + 137 + j343 VA

$$\overline{S}_2 = jM \dot{I}_1 \dot{I}_2^* + (R_2 + jL_2) \dot{I}_2^2$$

37 + j343 + 137 + j343 VA

L_1

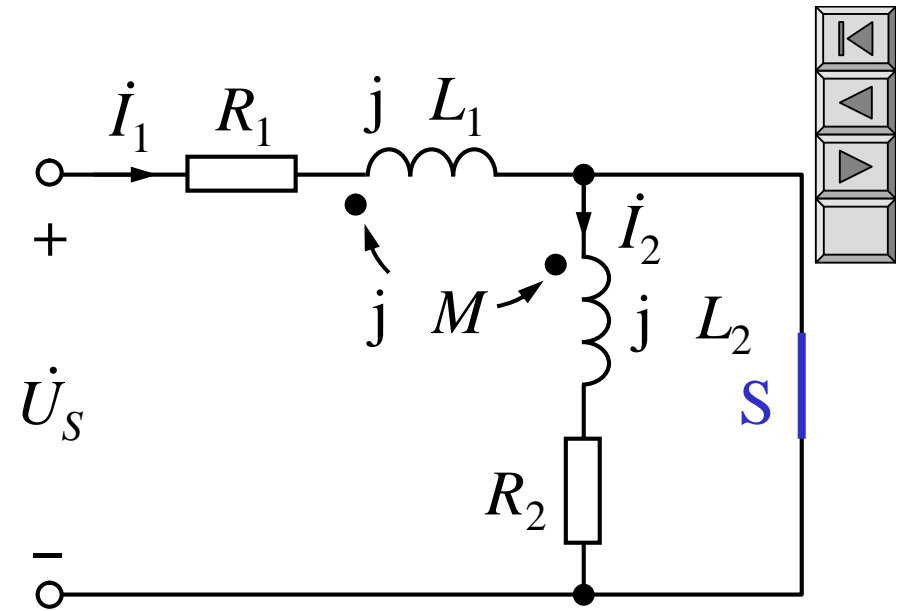
582

239

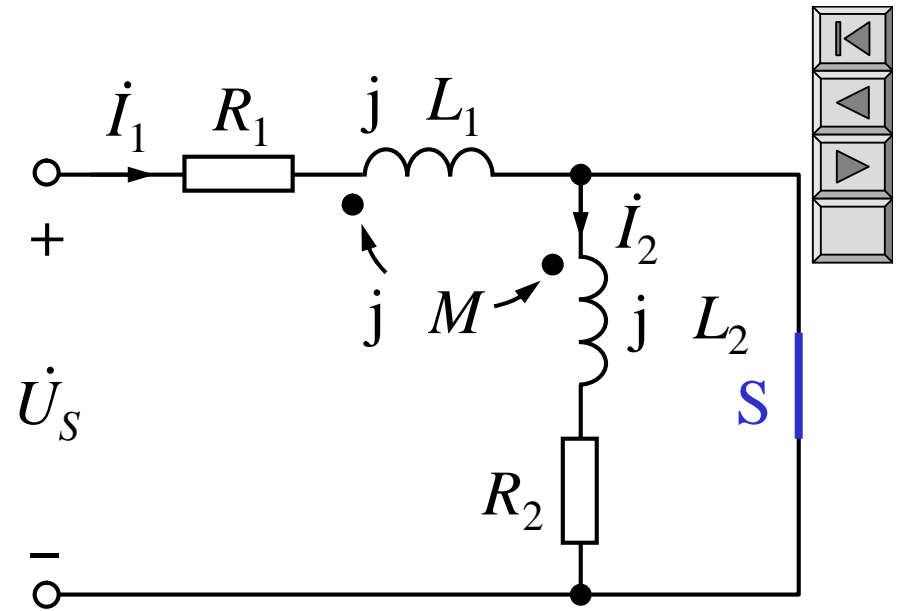
L_1 L_2

1 137W

2 R_2



$$\begin{aligned} \dot{U}_S &= 50 \angle 0^\circ \text{ V} \\ \dot{I}_1 &= 8.81 \angle 32.93^\circ \text{ A} \\ \dot{I}_2 &= 5.24 \angle \quad \quad \quad \text{ A} \\ R_1 &= 3 \quad R_2 = 5 \end{aligned}$$



$$P = U_S I_1 \cos 32.93^\circ = 370 \text{ W}$$

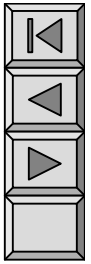
$$R_1 \quad I_1^2 R_1 = 233 \text{ W} \quad R_2 \quad I_2^2 R_2 = 137 \text{ W}$$

$$Q = U_S I_1 \sin 32.93^\circ = 239 \text{ Var}$$

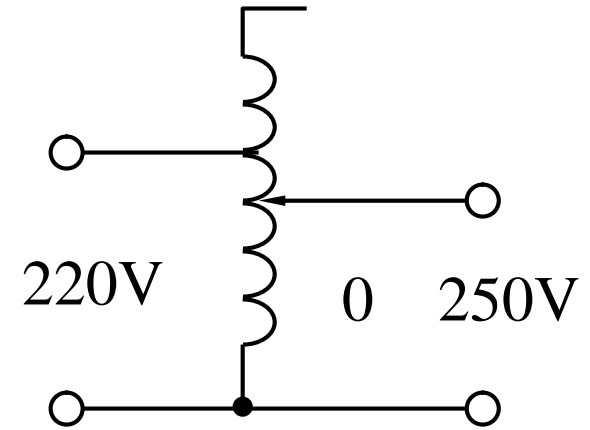
$$343 \text{ Var} \quad L_1$$

$$582 \text{ Var}$$

§ 10-4



1.



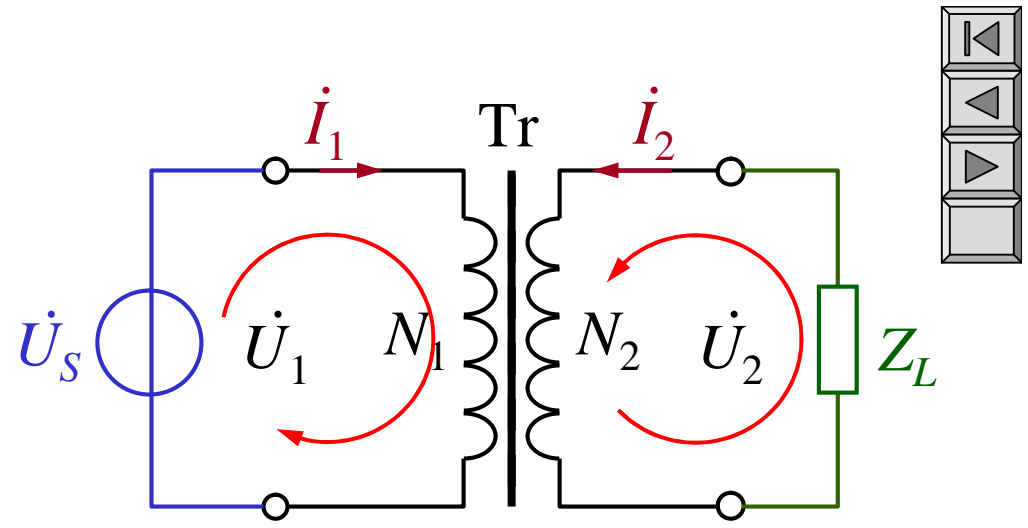
()

()

()

(N_1)

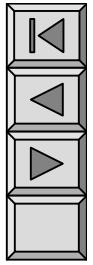
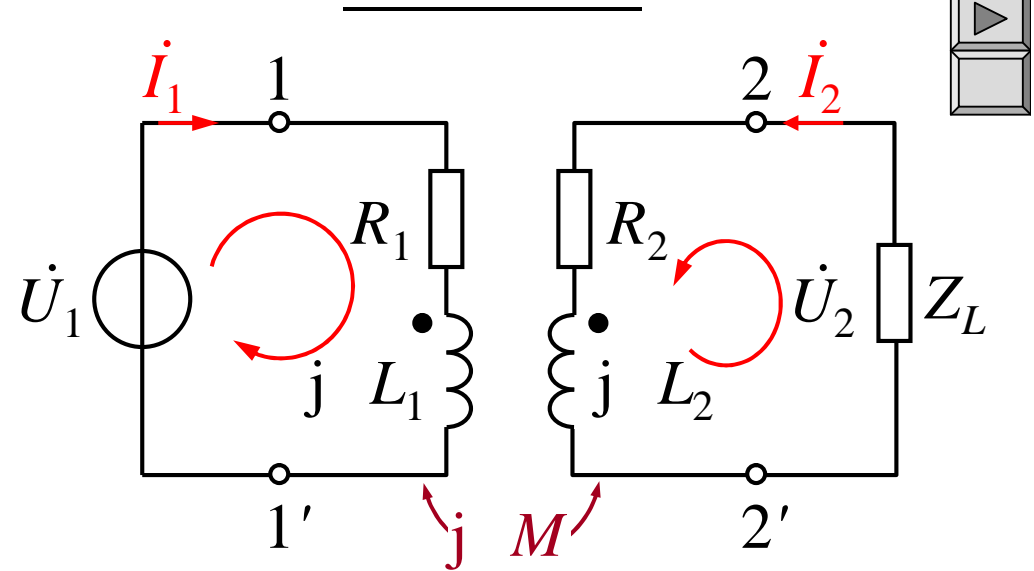
(N_2)



2. ()



$$\begin{pmatrix} (R_1 + j\omega L_1) \dot{I}_1 + j\omega M \dot{I}_2 \\ j\omega M \dot{I}_1 + (R_2 + j\omega L_2 + Z_L) \dot{I}_2 \end{pmatrix} = \begin{pmatrix} \dot{U}_1 \\ 0 \end{pmatrix}$$



$$Z_M = j\omega M$$

$$Z_{11} = R_1 + j\omega L_1$$

$$Z_{22} = R_2 + j\omega L_2 + Z_L$$

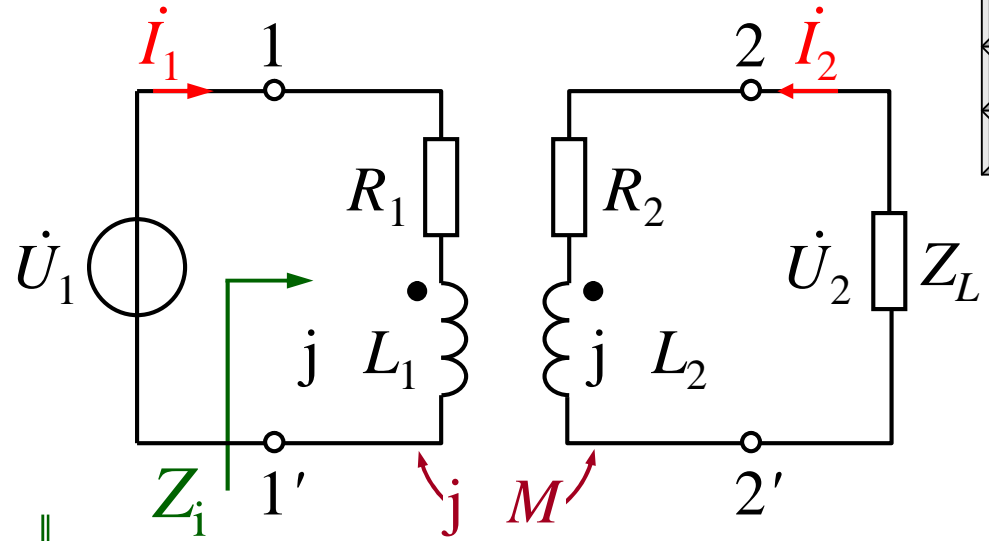
$$\begin{pmatrix} Z_{11} \dot{I}_1 + Z_M \dot{I}_2 \\ Z_M \dot{I}_1 + Z_{22} \dot{I}_2 \end{pmatrix} = \begin{pmatrix} \dot{U}_1 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} \dot{U}_1 \\ 0 \end{pmatrix} = \begin{pmatrix} Z_{11} \dot{I}_1 + Z_M \dot{I}_2 \\ Z_M \dot{I}_1 + Z_{22} \dot{I}_2 \end{pmatrix}$$

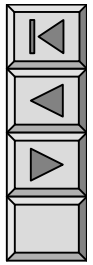
$$\dot{I}_1 = \frac{\dot{U}_1}{Z_{11} + Z_M^2 Y_{22}}$$

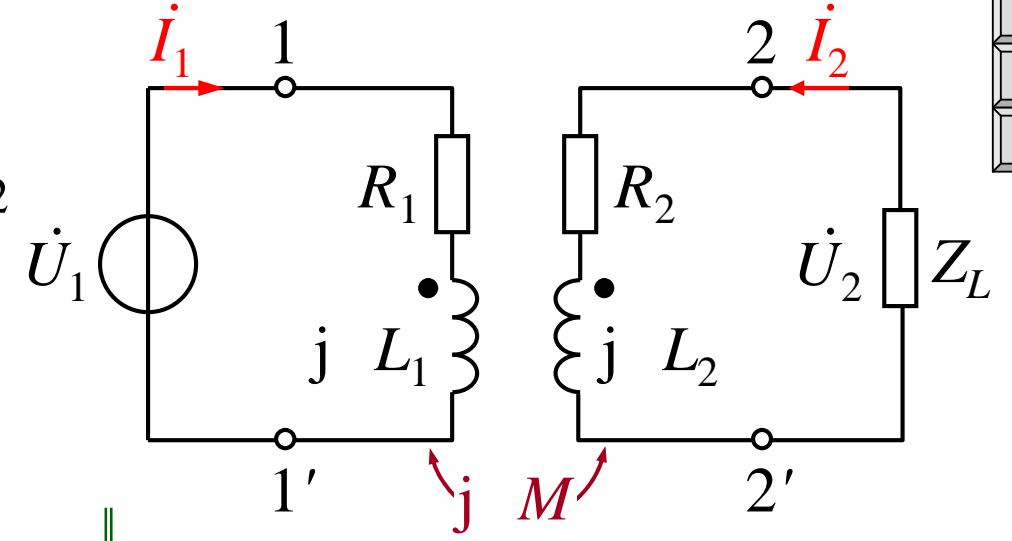
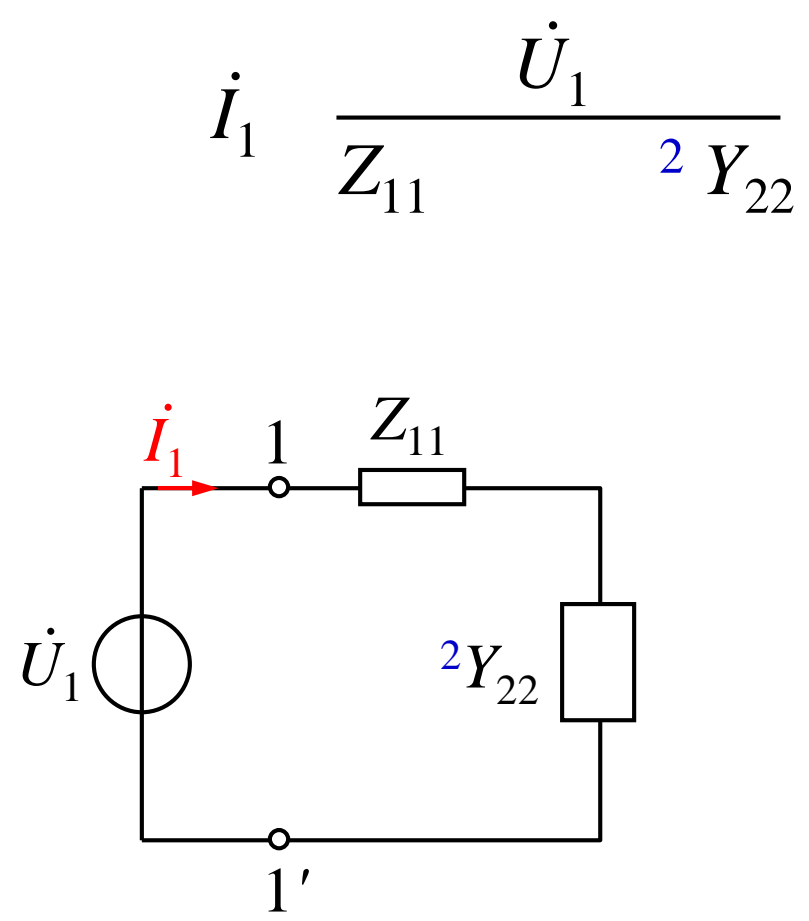
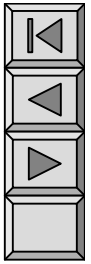
$$Z_i = \frac{\dot{U}_1}{\dot{I}_1} = Z_{11} + (M)^2 Y_{22}$$

$$(M)^2 Y_{22}$$



$$Z_{22} = (M)^2 \frac{1}{|Z_{22}|}$$



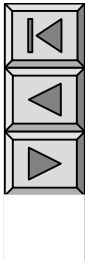


$$\begin{bmatrix} Z_{11} & Z_M & \dot{U}_1 \\ Z_M & Z_{22} & 0 \end{bmatrix} \begin{bmatrix} \dot{I}_1 \\ \dot{I}_2 \end{bmatrix} = \begin{bmatrix} \dot{U}_1 \\ 0 \end{bmatrix}$$

$$\dot{I}_2 = \frac{Z_M}{Z_{22}} \dot{I}_1$$

$$\dot{U}_2 = Z_L \dot{I}_2 = \frac{Z_M Z_L}{Z_{22}} \dot{I}_1$$





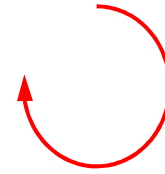
$$\dot{U}_{oc} = j \omega M Y_{11} \dot{U}_1$$

$$Z_{11} \dot{I}_1 + j \omega M \dot{I}_2 = 0$$

$$(R_2 + j \omega L_2) \dot{I}_2 + j \omega M \dot{I}_1 = \dot{U}$$

$$\dot{I}_1 = -\frac{j \omega M \dot{I}_2}{Z_{11}}$$

$$Z_{eq} = \frac{\dot{U}}{\dot{I}_1}$$

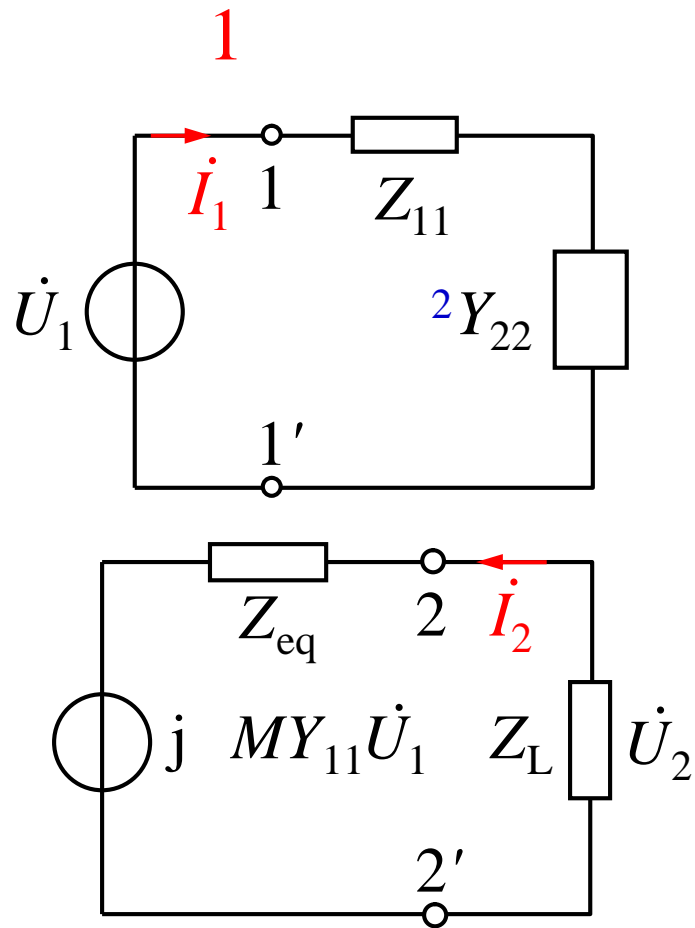
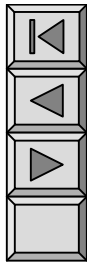
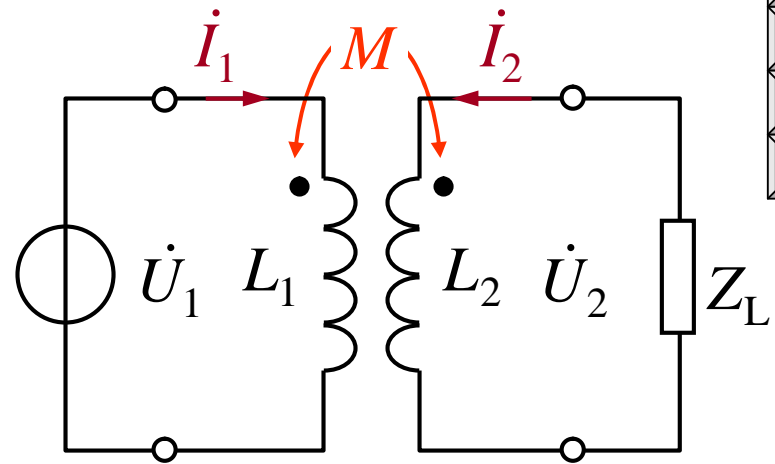




3. $u_1 = 100\cos(10t) \text{ V}$

$L_1 = 5\text{H}$ $L_2 = 2\text{H}$ $M = 2\text{H}$

$Z_L = 3$ i_1 i_2



$$Z_{11} = j\omega L_1 = j50$$

$$Z_{22} = j\omega L_2 + Z_L = 3 + j12$$

$$j\omega M = j20 \quad Z_L = 3$$

$$Z_{eq} = j\omega L_2 + (j\omega M)^2 Y_{11} = j28$$

()

$$i_1 = 4.95\cos(10t - 67.2^\circ) \text{ A}$$

$$i_2 = 8\cos(10t - 126.84^\circ) \text{ A}$$

3. $u_1 = 100\cos(10t) \text{ V}$

$L_1 = 5\text{H}$ $L_2 = 2\text{H}$ $M = 2\text{H}$

$Z_L = 3$ i_1 i_2

2

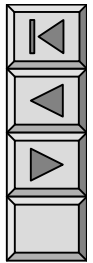
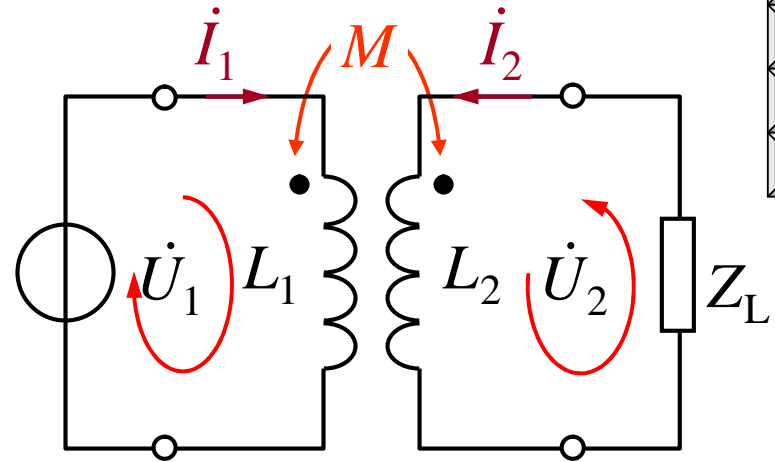
$$\left. \begin{array}{l} Z_{11} \dot{I}_{1m} + j M \dot{I}_{2m} = \dot{U}_1 \\ j M \dot{I}_{1m} + Z_{22} \dot{I}_{2m} = 0 \end{array} \right\}$$

$j M = j20$

$Z_{11} = j L_1 = j50$

$Z_{22} = j L_2 + Z_L = 3 + j12$

$\dot{U}_{1m} = 100 \angle 0^\circ \text{ V}$

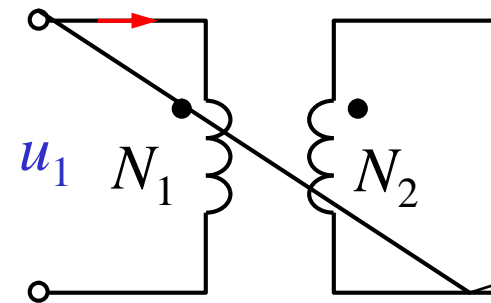
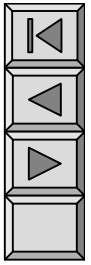


$$\left. \begin{array}{l} j50 \dot{I}_{1m} + j20 \dot{I}_{2m} = 100 \\ j20 \dot{I}_{1m} + (3 + j12) \dot{I}_{2m} = 0 \end{array} \right\}$$

$\dot{I}_{1m} = 4.95 \angle -67.2^\circ \text{ A}$

$\dot{I}_{2m} = 8 \angle 126.84^\circ \text{ A}$

§ 10-5

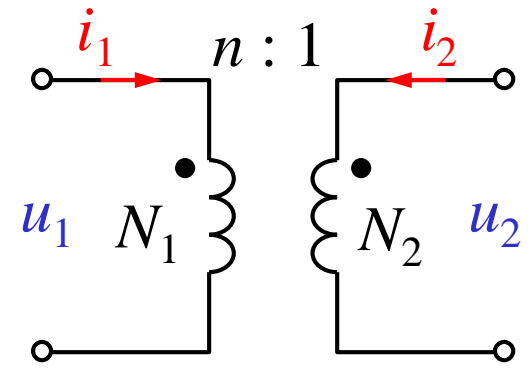




$$u_1 = \frac{N_1}{N_2} u_2 = n u_2$$

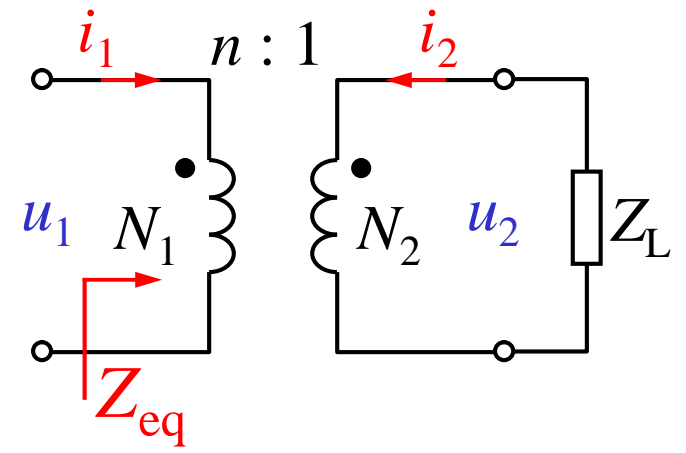
(2)

$$\begin{pmatrix} i_1 \\ i_2 \end{pmatrix} = \begin{pmatrix} \frac{N_2}{N_1} i_2 \\ \frac{1}{n} i_2 \end{pmatrix}$$

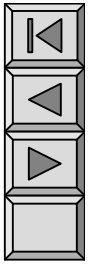
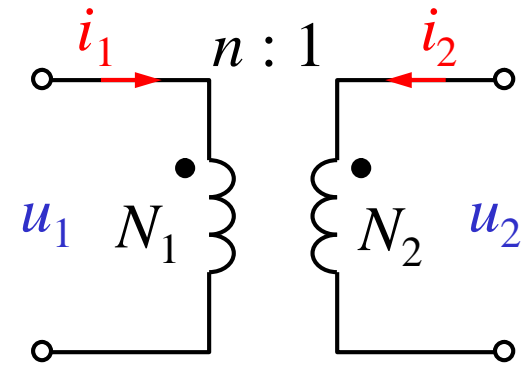


(3)

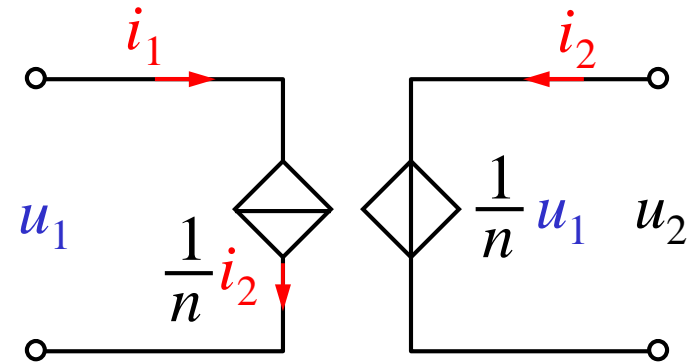
$$Z_{eq} = \frac{\dot{U}_1}{\dot{I}_1} = \frac{n \dot{U}_2}{\frac{1}{n} \dot{I}_2} = n^2 \left(\frac{\dot{U}_2}{\dot{I}_2} \right) = n^2 Z_L$$



3.



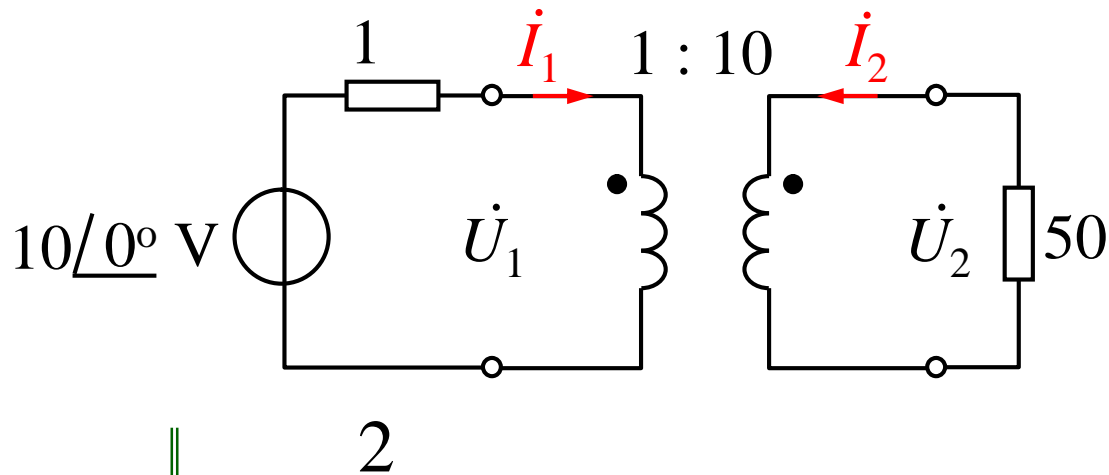
$$u_1 i_1 - u_2 i_2 = u_1 i_1 - \frac{1}{n} u_1 (n i_1) = 0$$



n

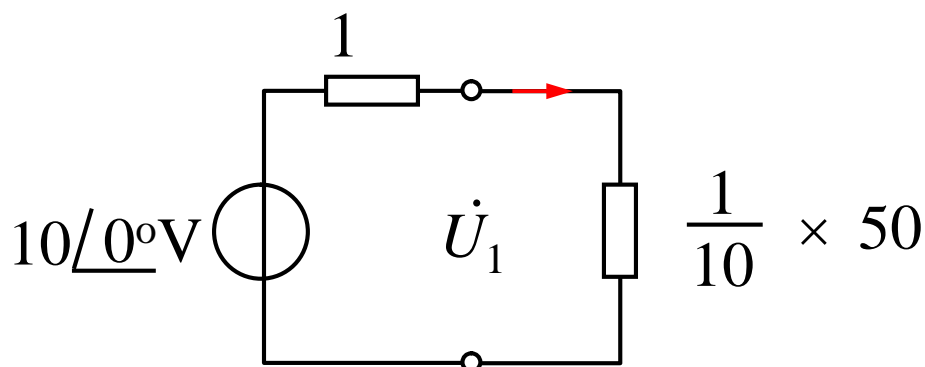


1 \dot{U}_2



\dot{I}_1 \dot{U}_1 $\underline{\quad}$

$50\dot{I}_2$ \dot{U}_2



\dot{U}_1 — \dot{U}_2 \dot{I}_1 \dot{I}_2

\dot{U}_1 $\underline{\quad}$ × 0.5 — $\underline{\quad}$ V

\dot{U}_2 33.33∠0° V

\dot{U}_2 \dot{U}_1 33.33 $\underline{\quad}$ V

$$\begin{aligned}
 & 3 \\
 & \dot{I}_2 \quad \dot{I}_1 \\
 & \dot{U}_{oc} \quad 10 \dot{U}_1 \quad 100 \angle 0^\circ \text{ V} \\
 & R_{eq} \quad \frac{\dot{U}_2}{\dot{I}_2} \quad 10 \times 1 \quad 100 \\
 & \dot{U}_2 \quad \frac{\dot{U}_{oc}}{50} \times 50 \\
 & \quad \frac{100 \angle 0^\circ}{100} \quad 50 \\
 & \quad 33.33 \angle \quad \text{V}
 \end{aligned}$$

