1.

A B Q

2.

3.

15 1

1.

G G

G(

)

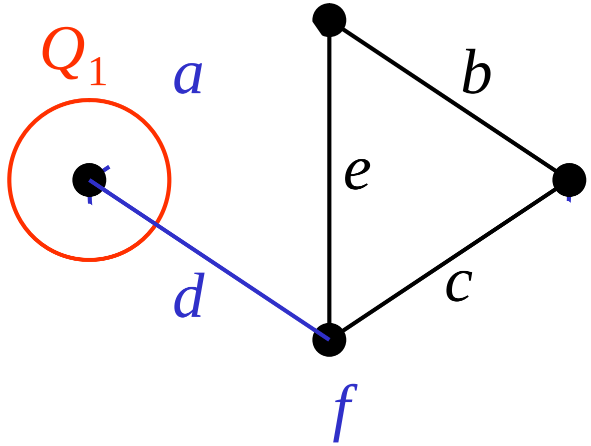
G

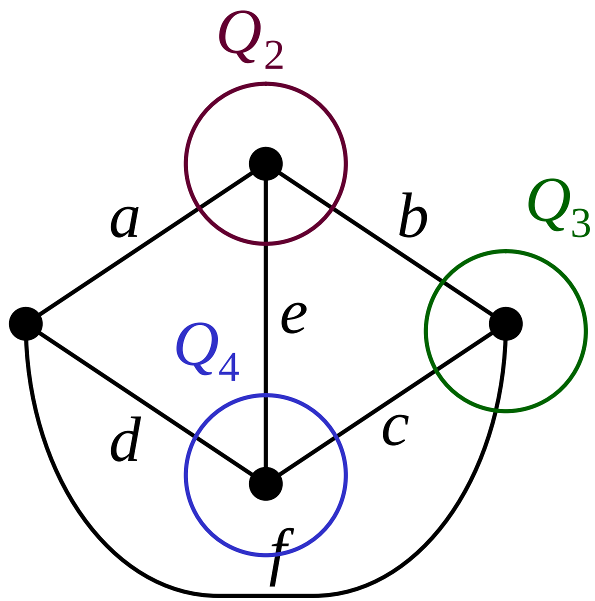
☞ $(a \quad d \quad f)$

G

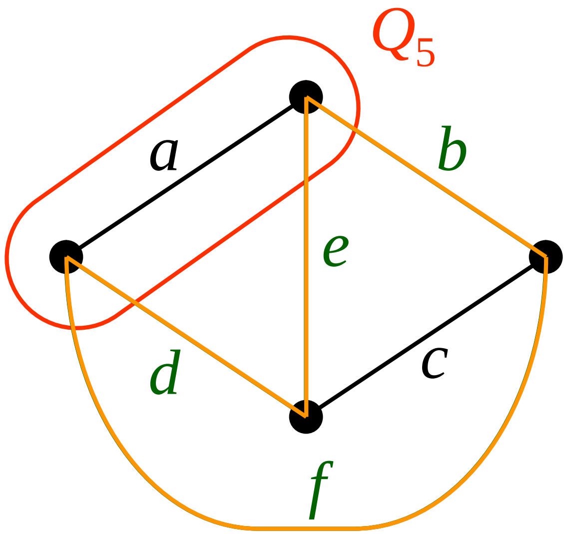
G

$(a \quad b \quad e)$ $(b \quad c \quad f)$ $(c \quad d \quad e)$

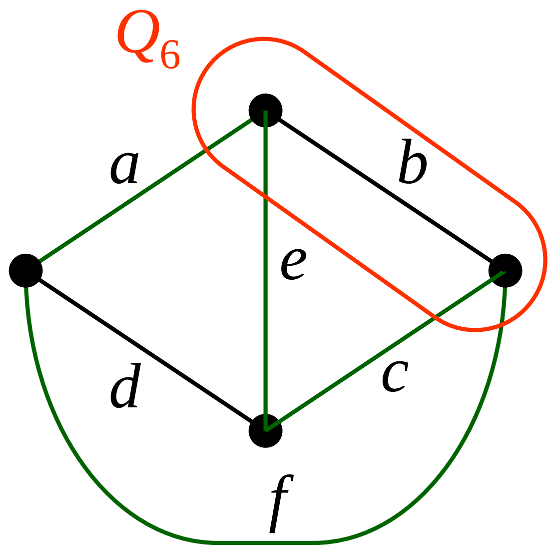


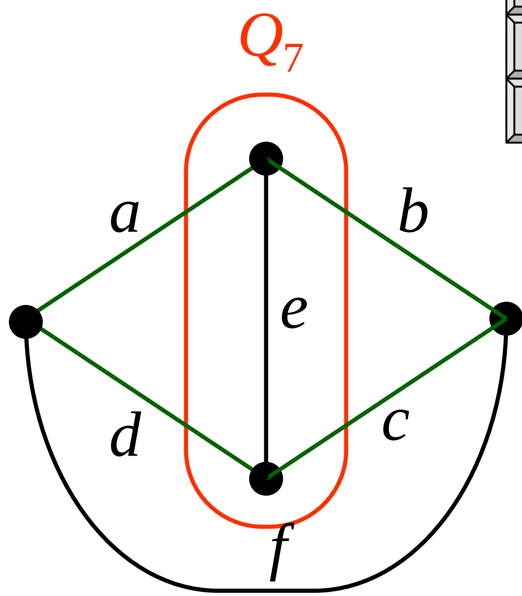


G

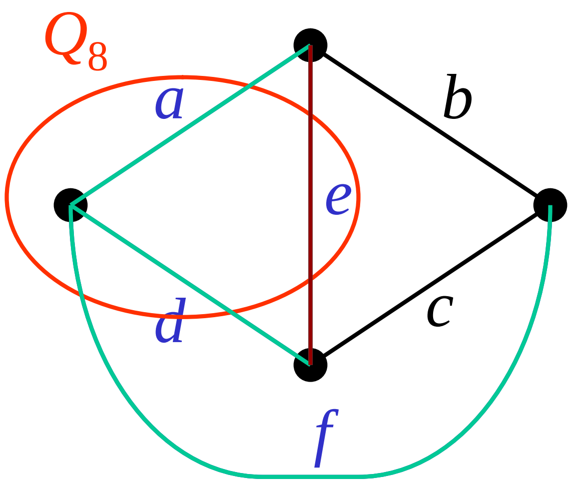


G





(b, d, e, f) (a, e, c, f) (a, b, c, d)

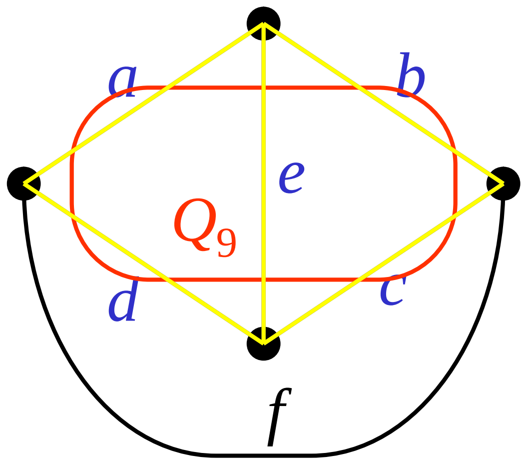


(a, d, e, f) G

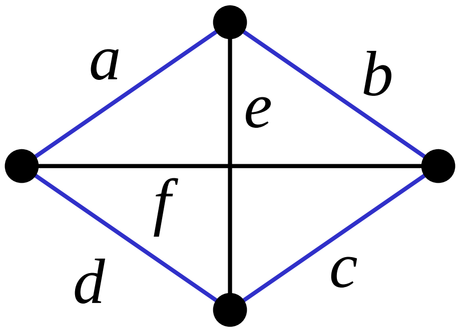
e G

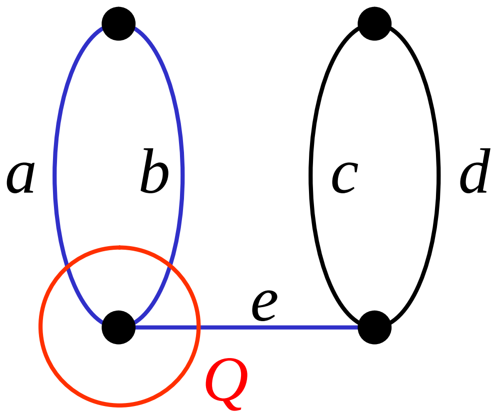
(a, b, c, d, e) G

G



2.





Q

(a, b, c, d)

(a, b, e)

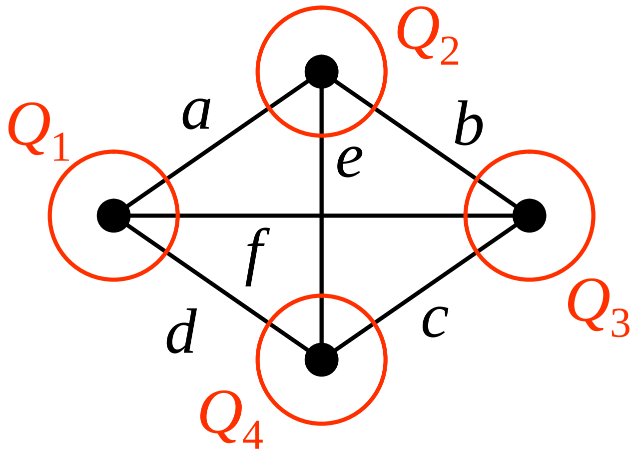
3.

KCL

KCL

G

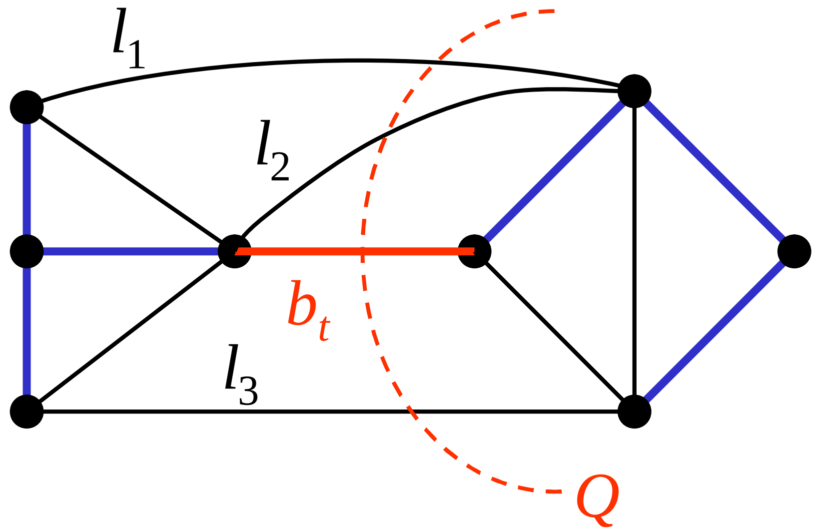
KCL



KCL KCL

(1)

KCL



(2)

-

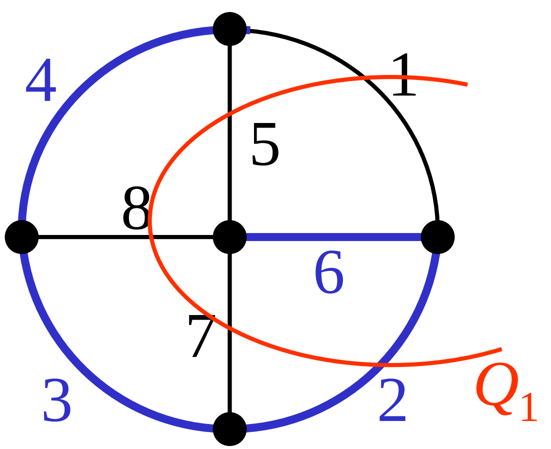
-

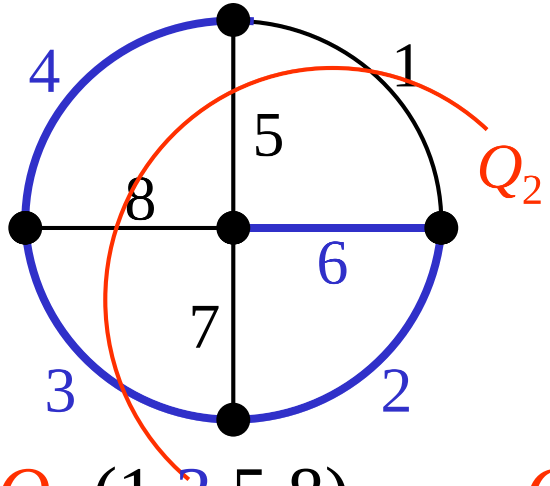
- n b

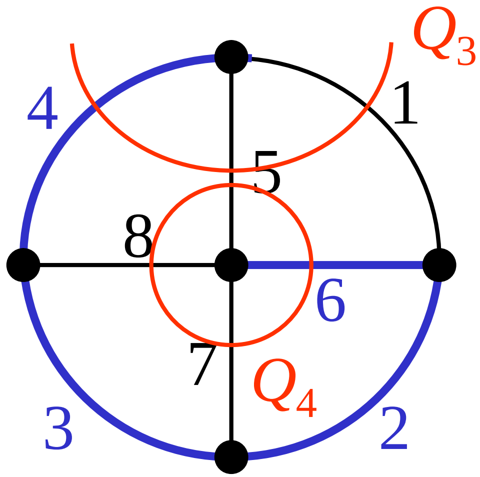
  $(n \; 1)$

- $(n \; 1)$

2,3,4,6

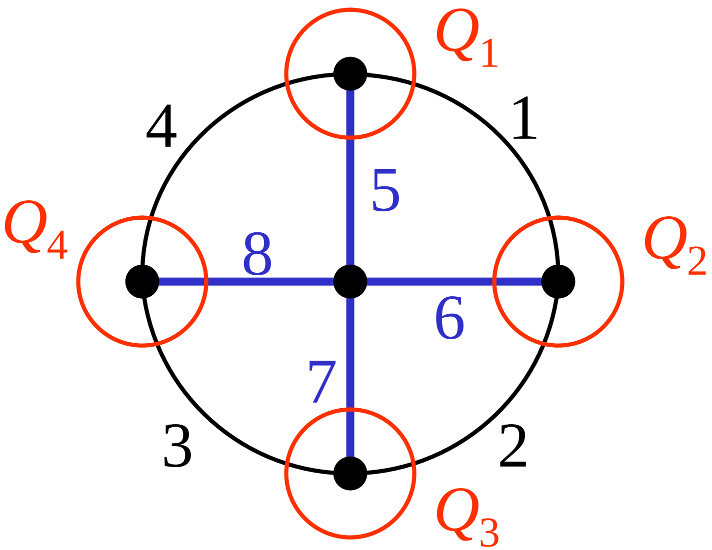






Q_1 (1,2,5,7,8) Q_2 (1,3,5,8) Q_3 (1,4,5) Q_4 (5,6,7,8)

5,6,7,8



15 2

1.

$(n \quad b)$

(1)$\boldsymbol{A}_a$

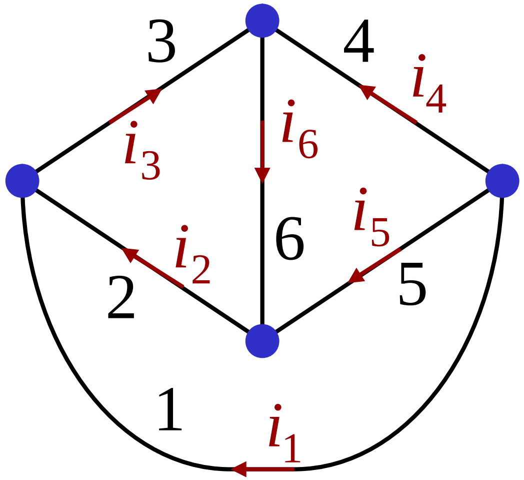
$a_{jk} = +1$ k j

$a_{jk} = -1$ k

j

$a_{jk} = 0$ k

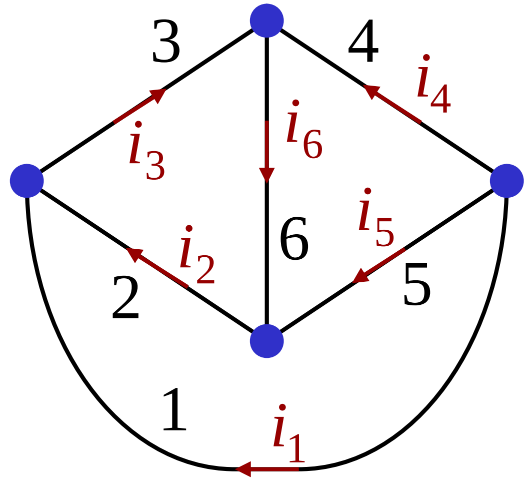
j



$\boldsymbol{A}_a =$

	1	2	3	4	5	6
1	1	1	+1	0	0	0
2	0	0	1	1	0	+1
3	+1	0	0	+1	+1	0
4	0	+1	0	0	1	1

$$\boldsymbol{A} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{bmatrix}$$



(3) $\boldsymbol{A}$ KCL

$b(=6)$

$\boldsymbol{i} = [i_1, i_2, \cdots, i_6]^{\mathrm{T}}$

$$\boldsymbol{Ai} = \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ \cdot \\ \cdot \\ \cdot \\ i_6 \end{bmatrix} = \begin{bmatrix} -i_1 - i_2 + i_3 \\ -i_3 - i_4 + i_6 \\ +i_1 + i_4 + i_5 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

$$\boldsymbol{Ai} = \begin{bmatrix} 1 \quad \text{KCL} \\ 2 \quad \text{KCL} \\ \cdots\cdots \\ (n \;\; 1) \quad \text{KCL} \end{bmatrix} \longrightarrow \boldsymbol{Ai} = \boldsymbol{0}$$

(4) $\boldsymbol{A}$ KVL

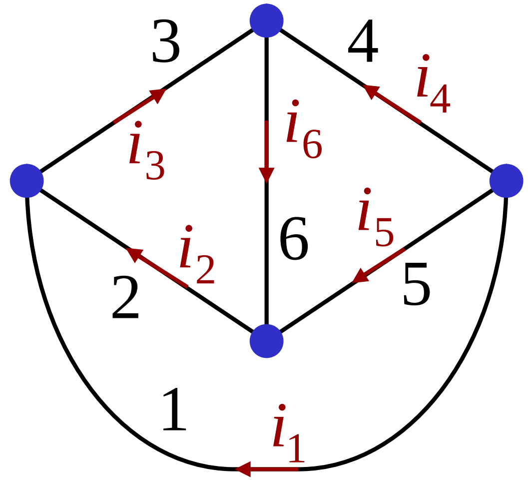
$b(=6)$

$\boldsymbol{u} = [u_1, u_2, \cdots, u_6]^{\mathrm{T}}$

( )

$(n\ \ 1=3)$

$\boldsymbol{u}_n = [u_{n1}, u_{n2}, u_{n3}]^{\mathrm{T}}$



$\boldsymbol{u} = \boldsymbol{A}^{\mathrm{T}}\boldsymbol{u}_n$

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \end{bmatrix} = \begin{bmatrix} u_{n1} + u_{n3} \\ u_{n1} \\ u_{n1}\ \ u_{n2} \\ u_{n2} + u_{n3} \\ u_{n3} \\ u_{n2} \end{bmatrix} = \underbrace{\begin{bmatrix} 1 & 0 & 1 \\ 1 & 0 & 0 \\ 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}}_{\boldsymbol{A}^{\mathrm{T}}} \begin{bmatrix} u_{n1} \\ u_{n2} \\ u_{n3} \end{bmatrix}$$

A

KVL

A

A KCL $\boldsymbol{Ai} = \mathbf{0}$

A KVL $\boldsymbol{u} = \boldsymbol{A}^{\mathrm{T}} \boldsymbol{u}_n$

2.

$(l \quad b)$

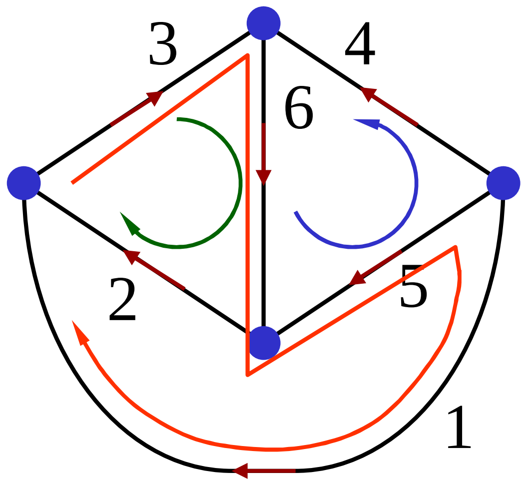
(1)***B***

$b_{jk} = +1 \qquad k \qquad j$

$b_{jk} = \quad 1 \qquad k \qquad j$

$b_{jk} = 0 \qquad k \qquad j$

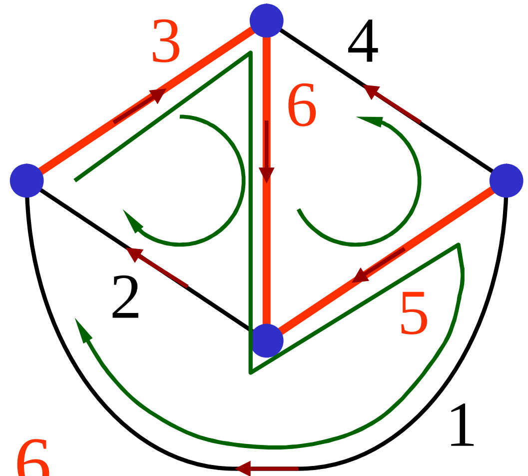
$$\boldsymbol{B} = \begin{array}{c} \\ 1 \\ 2 \\ 3 \end{array}\begin{array}{cccccc} 1 & 2 & 3 & 4 & 5 & 6 \\ 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 \end{array}$$



(2) $\boldsymbol{B}_f$

$\boldsymbol{B}_f$

$\boldsymbol{B}_f$



$\boldsymbol{B}_f = [\ \mathbf{1}_l \quad \boldsymbol{B}_t\ ]$

$\boldsymbol{B}_f =$

	1	2	4	3	5	6
1	1	0	0	1	1	1
2	0	1	0	1	0	1
3	0	0	1	0	1	1

$\boldsymbol{Bu} = \mathbf{0}$

(3) $\boldsymbol{B}$ KVL

$u_1 + u_3 - u_5 + u_6 = 0$

$u_2 + u_3 + u_6 = 0$

$u_4 - u_5 + u_6 = 0$

$$\begin{bmatrix} 1 & 0 & 1 & 0 & -1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & -1 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \\ u_5 \\ u_6 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

(4) ***B*** KCL

3. $\boldsymbol{Q}$

$\boldsymbol{Q}$ $(n\ \ 1)$ b

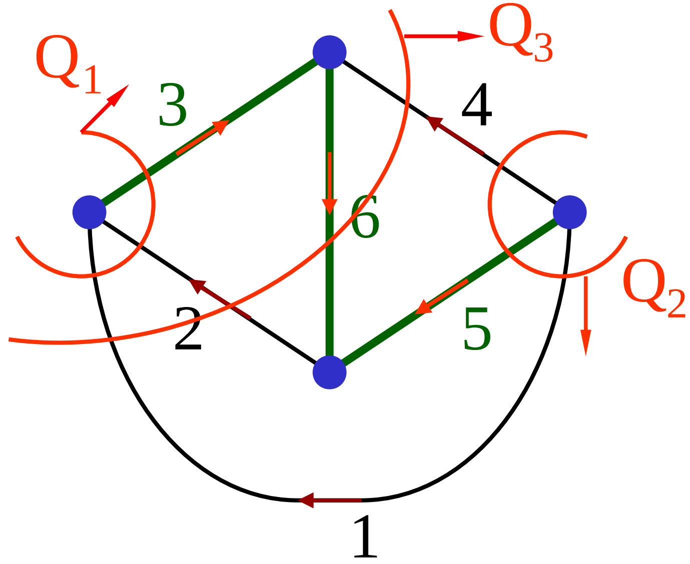
q_{jk}= +1 k j

q_{jk}= 1 k j

q_{jk}= 0 k j

$$\boldsymbol{Q} = \begin{array}{c} 1 \\ 2 \\ 3 \end{array} \begin{bmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 1 & 0 & 1 \end{bmatrix}$$

(Column labels: 1 2 3 4 5 6)



$\boldsymbol{Q}_f$

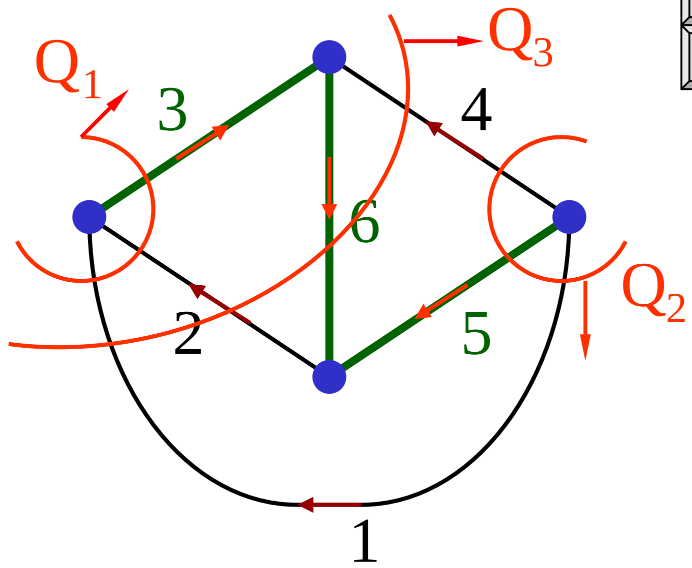
$\boldsymbol{Q}_f = [\ \mathbf{1}_t\ \ \ \boldsymbol{Q}_l\ ]$

(2) $\boldsymbol{Q}_f$ KVL

$$\boldsymbol{u} = \boldsymbol{Q}_f^{\mathrm{T}} \boldsymbol{u}_t$$

- $\boldsymbol{u}_t = [u_{t1} \ \ u_{t2} \ \ \cdots \ u_{t(n\ \ 1)}]^{\mathrm{T}}$

- $\boldsymbol{u}_t = [u_{t1} \ \ u_{t2} \ \ u_{t3}]^{\mathrm{T}}$



$$\boldsymbol{u} = [u_3 \ \ u_5 \ \ u_6 \ \ u_1 \ \ u_2 \ \ u_4]^{\mathrm{T}}$$

$$\boldsymbol{u} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 1 & 1 \\ 1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} u_{t1} \\ u_{t2} \\ u_{t3} \end{bmatrix} = \begin{bmatrix} u_{t1} \\ u_{t2} \\ u_{t3} \\ -u_{t1} + u_{t2} - u_{t3} \\ -u_{t1} - u_{t3} \\ u_{t2} - u_{t3} \end{bmatrix} \begin{matrix} = u_3 \\ = u_5 \\ = u_6 \\ = u_1 \\ = u_2 \\ = u_4 \end{matrix}$$

bƒ Ï"yo †—e1

* 15 3 $\boldsymbol{A}$ $\boldsymbol{B}_f$ $\boldsymbol{Q}_f$

1. $\boldsymbol{A}\,\boldsymbol{i} = \boldsymbol{0}$ $\boldsymbol{Q}\,\boldsymbol{i} = \boldsymbol{0}$

   $\boldsymbol{u} = \boldsymbol{A}^{\mathrm{T}}\boldsymbol{u}_n$ $\boldsymbol{u} = \boldsymbol{Q}_f^{\mathrm{T}}\,\boldsymbol{u}_t$

   G $\boldsymbol{Q}_f = \boldsymbol{A}$

2. G $\boldsymbol{A}$ $\boldsymbol{B}$ $\boldsymbol{Q}$

$\boldsymbol{A}\boldsymbol{B}^{\mathrm{T}} = \boldsymbol{0}$ $\boldsymbol{B}\boldsymbol{A}^{\mathrm{T}} = \boldsymbol{0}$

$\boldsymbol{Q}\boldsymbol{B}^{\mathrm{T}} = \boldsymbol{0}$ $\boldsymbol{B}\boldsymbol{Q}^{\mathrm{T}} = \boldsymbol{0}$

3. $\boldsymbol{A}$ $\boldsymbol{B}_f$ $\boldsymbol{Q}_f$

$$\boldsymbol{B}_t^{\mathrm{T}} = \boldsymbol{A}_t{}^{1}\boldsymbol{A}_l \qquad \boldsymbol{Q}_l = \boldsymbol{B}_t^{\mathrm{T}} = \boldsymbol{A}_t{}^{1}\boldsymbol{A}_l$$

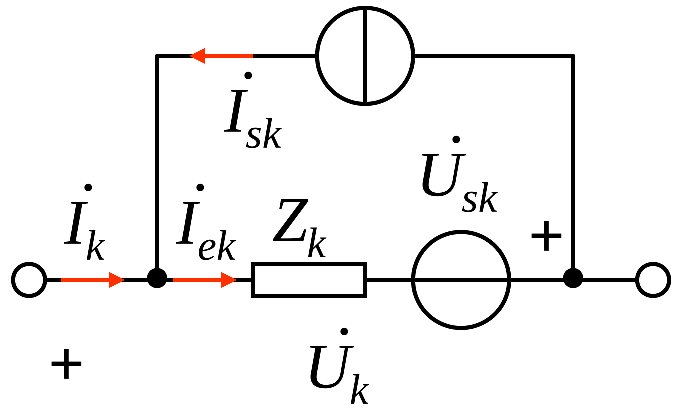
15 4

( )

(1) Z_k R L

C

(2)



$$\dot{U}_k = Z_k(\dot{I}_k + \dot{I}_{Sk}) \quad \dot{U}_{Sk}$$

k

$$\dot{\boldsymbol{I}} = [\ \dot{I}_1\ \ \dot{I}_2\ \ \cdots\ \dot{I}_b]^{\mathrm{T}}$$

$$\dot{\boldsymbol{U}} = [\dot{U}_1\ \ \dot{U}_2\ \cdots \dot{U}_b]^{\mathrm{T}}$$

$$\dot{\boldsymbol{I}}_{\boldsymbol{S}} = [\dot{I}_{S1}\ \dot{I}_{S2}\ \cdots \dot{I}_{Sb}]^{\mathrm{T}}$$

$$\dot{\boldsymbol{U}}_{\boldsymbol{S}} = [\ \ \dot{U}_{S1}\ \dot{U}_{S2} \cdots\ \dot{U}_{Sb}]^{\mathrm{T}}$$

✓ 1

$$\dot{\boldsymbol{U}} = \boldsymbol{Z}\ (\dot{\boldsymbol{I}} + \dot{\boldsymbol{I}}_{\boldsymbol{S}}) \quad \dot{\boldsymbol{U}}_{\boldsymbol{S}}$$

$$\dot{U} = \mathbf{Z}\,(\dot{I} + \dot{I}_S) \quad \dot{U}_S$$

$$\mathbf{Z} = \begin{bmatrix} Z_1 & & & \mathbf{0} \\ & Z_2 & & \\ & \mathbf{0} & \ddots & \\ & & & Z_b \end{bmatrix}$$

Z **Z**

✓ 2

b 1 g

$$\dot{U}_1 = Z_1\dot{I}_{e1} \quad j\omega M_{12}\,\dot{I}_{e2} \quad j\omega M_{13}\,\dot{I}_{e3} \quad \cdots \quad j\omega M_{1g}\,\dot{I}_{eg} \quad \dot{U}_{S1}$$

$$\dot{U}_2 = \quad j\omega M_{21}\dot{I}_{e1} + Z_2\,\dot{I}_{e2} \quad j\omega M_{23}\,\dot{I}_{e3} \quad \cdots \quad j\omega M_{2g}\,\dot{I}_{eg} \quad \dot{U}_{S2}$$

$$\cdots\ \cdots\ \cdots\ \cdots$$

$$\dot{U}_g = \quad j\omega M_{g1}\dot{I}_{e1} \quad j\omega M_{g2}\,\dot{I}_{e2} \quad j\omega M_{g3}\,\dot{I}_{e3} \quad \cdots + Z_g\,\dot{I}_{eg} \quad \dot{U}_{Sg}$$

$$\dot{I}_{e1} = \dot{I}_1 + \dot{I}_{S1} \quad \dot{I}_{e2} = \dot{I}_2 + \dot{I}_{S2} \quad \cdots\ \cdots \qquad M_{12} = M_{21} \quad \cdots\ \cdots$$

$(g+1)$ b 1

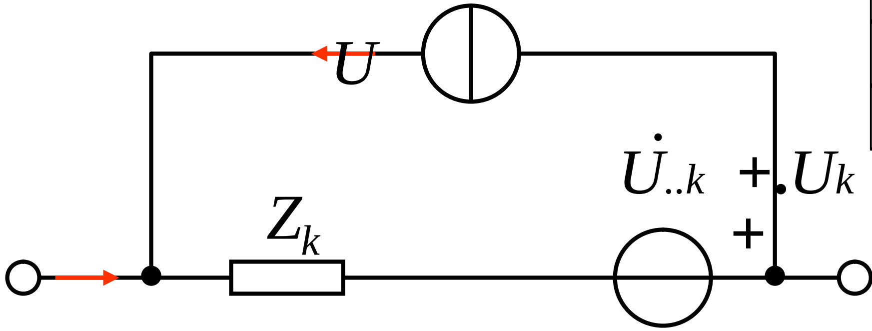
$$
\begin{bmatrix} \dot U_1 \\ \dot U_2 \\ \vdots \\ \dot U_g \\ \dot U_{g+1} \\ \vdots \\ \dot U_b \end{bmatrix}
=
\begin{bmatrix}
Z_1 & j\omega M_{12} & \cdots & j\omega M_{1g} & 0 & \cdots & 0 \\
j\omega M_{21} & Z_2 & \cdots & j\omega M_{2g} & 0 & \cdots & 0 \\
\vdots & \vdots & & \vdots & \vdots & & \vdots \\
j\omega M_{g1} & j\omega M_{g2} & \cdots & Z_g & 0 & \cdots & 0 \\
0 & 0 & \cdots & 0 & Z_{g+1} & \cdots & 0 \\
\vdots & \vdots & & \vdots & \vdots & & \vdots \\
0 & 0 & \cdots & 0 & 0 & \cdots & Z_b
\end{bmatrix}
\begin{bmatrix} \dot I_1 + \dot I_{S!} \\ \dot I_2 + \dot I_{S2} \\ \vdots \\ \dot I_g + \dot I_{Sg} \\ \dot I_{g+1} + \dot I_{S(g+1)} \\ \vdots \\ \dot I_b + \dot I_{Sb} \end{bmatrix}
-
\begin{bmatrix} \dot U_{S1} \\ \dot U_{S2} \\ \vdots \\ \dot U_{Sg} \\ \dot U_{S(g+1)} \\ \vdots \\ \dot U_{Sb} \end{bmatrix}
$$

$\dot{\boldsymbol U} = \boldsymbol Z\,(\dot{\boldsymbol I} + \dot{\boldsymbol I}_S) \quad \dot{\boldsymbol U}_S$

$\boldsymbol Z$

✓ 3

•



•

•

• ***Z***

•

( ) “+” “ ”

$\boldsymbol{B}$ KVL $\boldsymbol{B}\dot{\boldsymbol{U}} = \mathbf{0}$

$\dot{\boldsymbol{U}} = \boldsymbol{Z}(\dot{\boldsymbol{I}} + \dot{\boldsymbol{I}}_S)$ $\dot{\boldsymbol{U}}_S$

$\boldsymbol{B}\boldsymbol{Z}\dot{\boldsymbol{I}} + \boldsymbol{B}\boldsymbol{Z}\dot{\boldsymbol{I}}_S$ $\boldsymbol{B}\dot{\boldsymbol{U}}_S = \mathbf{0}$

$\boldsymbol{B}$ KCL $\dot{\boldsymbol{I}} = \boldsymbol{B}^{\mathrm{T}}\dot{\boldsymbol{I}}_l$

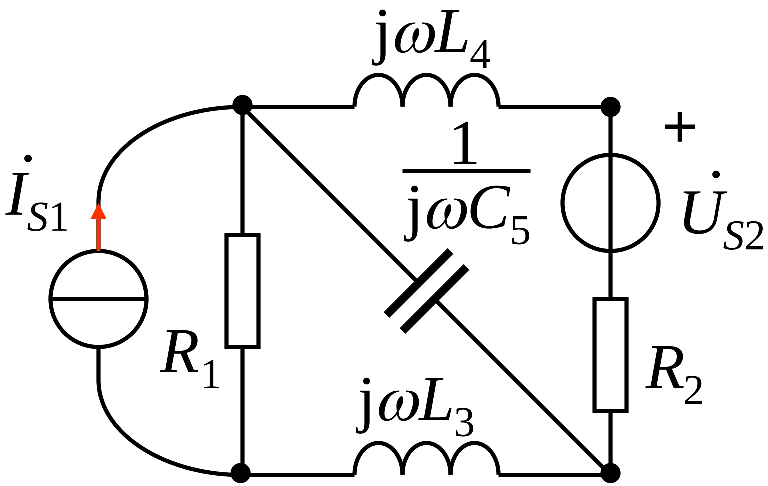
$$\boldsymbol{B}\boldsymbol{Z}\boldsymbol{B}^{\mathrm{T}}\dot{\boldsymbol{I}} = \boldsymbol{B}\dot{\boldsymbol{U}}_S \quad \boldsymbol{B}\boldsymbol{Z}\dot{\boldsymbol{I}}_S$$

$\boldsymbol{B}\boldsymbol{Z}\boldsymbol{B}^{\mathrm{T}}$ l $\boldsymbol{B}\dot{\boldsymbol{U}}_S$ $\boldsymbol{B}\boldsymbol{Z}$ l

$\boldsymbol{Z}_l = \boldsymbol{B}\boldsymbol{Z}\boldsymbol{B}^{\mathrm{T}}$ $\boldsymbol{Z}_l$

$\boldsymbol{Z}_l$

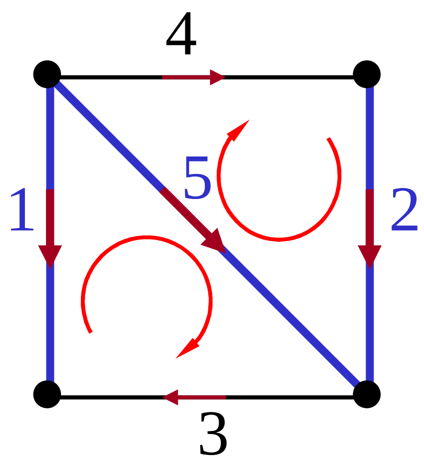
P401 15 1



(2)

(3) **B**

(1)



$$\boldsymbol{B} = \begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix}$$

$$\boldsymbol{Z} = \mathrm{diag}\left[R_1,\ R_2,\ \mathrm{j}\omega L_3,\ \mathrm{j}\omega L_4,\ \frac{1}{\mathrm{j}\omega C_5}\right]$$

$$\dot{\boldsymbol{U}}_{\boldsymbol{S}} = [0\ \ -\dot{U}_{S2}\ \ 0\ \ 0\ \ 0]^{\mathrm{T}}$$

$$\dot{\boldsymbol{I}}_{\boldsymbol{S}} = [\dot{I}_{S1}\ \ 0\ \ 0\ \ 0\ \ 0]^{\mathrm{T}}$$

(4) $Z_l = BZB^T$

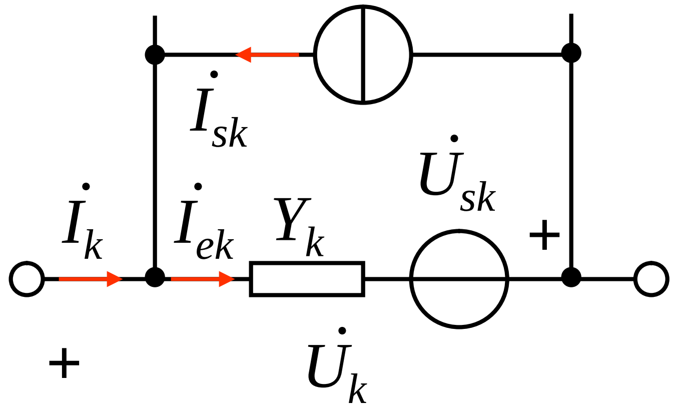
$Z_l = BZB^T$

$$= \begin{bmatrix} 1 & 0 & 1 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} R_1 & & & & \\ & R_2 & & & \\ & & j\omega L_3 & & \\ & & & j\omega L_4 & \\ & & & & \frac{1}{j\omega C_5} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{bmatrix}$$

$$\begin{bmatrix} R_1 + j\omega L_3 + \frac{1}{j\omega C_5} & -\frac{1}{j\omega C_5} \\ -\frac{1}{j\omega C_5} & R_2 + j\omega L_4 + \frac{1}{j\omega C_5} \end{bmatrix} \begin{bmatrix} \dot{I}_{l1} \\ \dot{I}_{l2} \end{bmatrix} = \begin{bmatrix} R_1 \dot{I}_{S1} \\ \dot{U}_{S2} \end{bmatrix}$$

(5) Z_l $\dot{U}_S$ $\dot{I}_S$ $Z_l \dot{I} = B\dot{U}_S$ $BZ\dot{I}_S$

15 5



✓ 1

k $\dot{I}_k = Y_k(\dot{U}_k + \dot{U}_{Sk}) \quad \dot{I}_{Sk}$

$$\dot{I} = Y(\dot{U} + \dot{U}_S) \quad \dot{I}_S$$

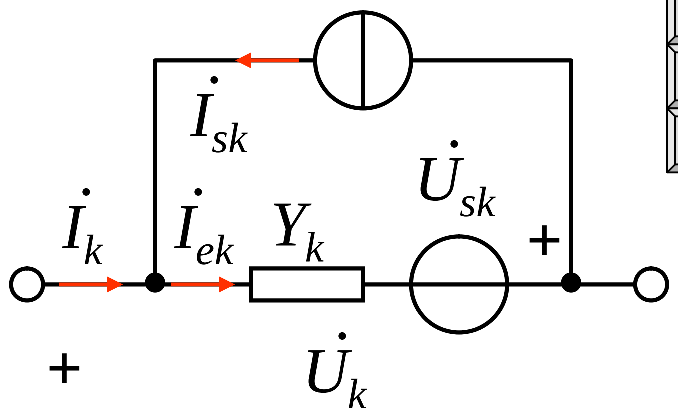
Y

Y

✓ 2

2

$\dot{U} = Z\,(\dot{I} + \dot{I}_S) \quad \dot{U}_S$



Z

Z

$Y\dot{U} = \dot{I} + \dot{I}_S \quad Y\dot{U}_S$

$\dot{I} = Y\,(\dot{U} \quad \dot{U}_S) \quad \dot{I}_S$

$Y = Z^{1}$

VCR 1

Y

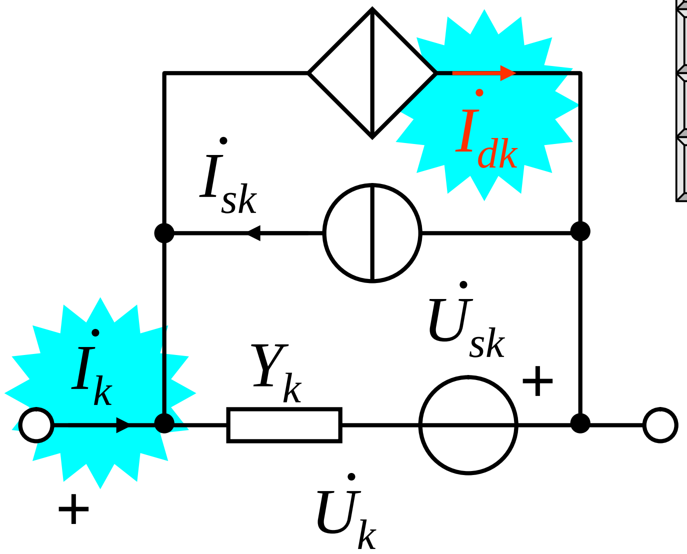
✓ 3

k j

( )

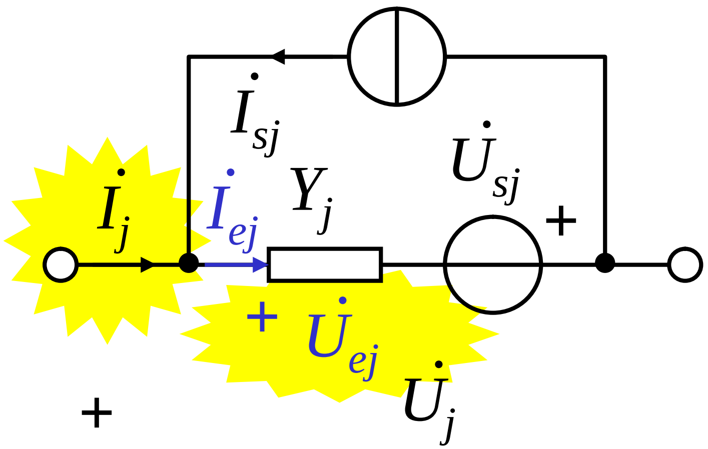
$\dot{I}_{dk} = g_{kj}\,\dot{U}_{ej}$ $\dot{I}_{dk} = \beta_{kj}\,\dot{I}_{ej}$

$\dot{I}_{ej} = Y_j\,\dot{U}_{ej}$ $\dot{I}_{dk} = \beta_{kj}\,Y_j\,\dot{U}_{ej}$



VCCS

Y_{kj} $Y_{kj} = \begin{cases} g_{kj} \\ \beta_{kj}\,Y_j \end{cases}$



k

$$\dot{I}_k = Y_k(\dot{U}_k + \dot{U}_{Sk}) + \dot{I}_{dk} \quad \dot{I}_{Sk}$$

$$\dot{I}_{dk} = Y_{kj}\,\dot{U}_{ej} = Y_{kj}\,(\dot{U}_j + \dot{U}_{Sj})$$

$$\dot{I}_k = Y_k(\dot{U}_k + \dot{U}_{Sk}) + Y_{kj}(\dot{U}_j + \dot{U}_{sj}) \quad \dot{I}_{Sk}$$

$\dot{I}_k = Y_k(\dot{U}_k + \dot{U}_{Sk}) + Y_{kj}(\dot{U}_j + \dot{U}_{sj}) \quad \dot{I}_{Sk}$ b

$$\begin{bmatrix} \dot{I}_1 \\ \dot{I}_2 \\ \vdots \\ \dot{I}_j \\ \vdots \\ \dot{I}_k \\ \vdots \\ \dot{I}_b \end{bmatrix} = \begin{bmatrix} Y_1 & & & & & \\ 0 & Y_2 & & & \mathbf{0} & \\ \vdots & \vdots & \ddots & & & \\ 0 & 0 & \cdots & Y_j & k \quad j & \\ \vdots & \vdots & & \vdots & \ddots & \\ 0 & 0 & \cdots & Y_{kj} & \cdots \; Y_k & \\ \vdots & \vdots & & \vdots & \vdots & \ddots \\ 0 & 0 & \cdots & 0 & \cdots \; 0 & \cdots \; Y_b \end{bmatrix} \begin{bmatrix} \dot{U}_1 + \dot{U}_{S1} \\ \dot{U}_2 + \dot{U}_{S2} \\ \vdots \\ \dot{U}_j + \dot{U}_{Sj} \\ \vdots \\ \dot{U}_k + \dot{U}_{Sk} \\ \vdots \\ \dot{U}_b + \dot{U}_{Sb} \end{bmatrix} - \begin{bmatrix} \dot{I}_{S1} \\ \dot{I}_{S2} \\ \vdots \\ \dot{I}_{Sj} \\ \vdots \\ \dot{I}_{Sk} \\ \vdots \\ \dot{I}_{Sb} \end{bmatrix}$$

$\dot{\boldsymbol{I}} = \boldsymbol{Y}(\dot{\boldsymbol{U}} \quad \dot{\boldsymbol{U}}_S) \quad \dot{\boldsymbol{I}}_S$ 1

- $\boldsymbol{Y}$
- (2)

A

A KCL $A\dot{I}=0$ A KVL $\dot{U}=A^{T}\dot{U}_n$

$$\dot{I}=Y(\dot{U}\quad \dot{U}_S)\quad \dot{I}_S$$

$$\dot{I}=YA^{T}\dot{U}_n\quad Y\dot{U}_S\quad \dot{I}_S$$

A KCL $AYA^{T}\dot{U}_n\quad AY\dot{U}_S\quad A\dot{I}_S=0$

$$AYA^{T}\dot{U}_n=A\dot{I}_S\quad AY\dot{U}_S$$

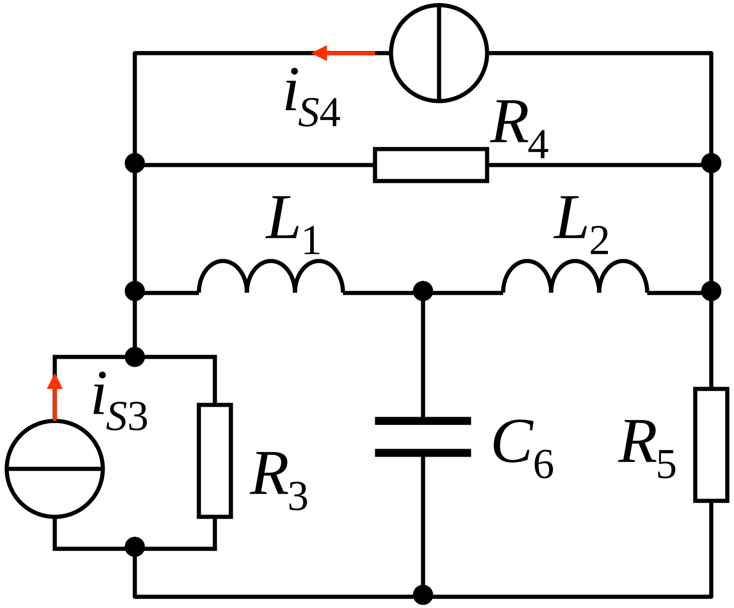
$Y_n=AYA^{T}$, $\dot{J}_n=A\dot{I}_S\quad AY\dot{U}_S$

$$Y_n\dot{U}_n=\dot{J}_n$$

Y_n

$\dot{J}_n$

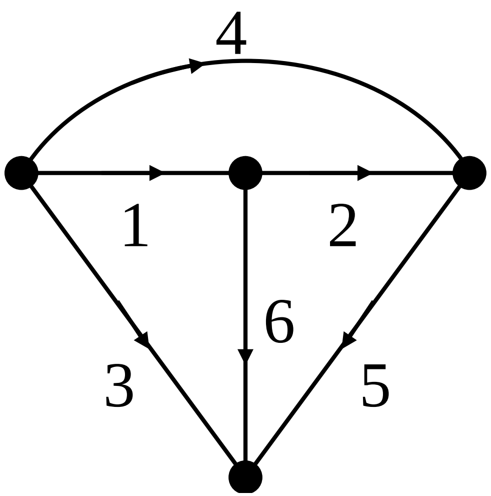
P405　15　2



(1)

(2) $\boldsymbol{A}$

$$\boldsymbol{A}=\begin{bmatrix} 1 & 0 & 1 & 1 & 0 & 0 \\ 1 & 1 & 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix}$$



$$\dot{\boldsymbol{U}}_s=\boldsymbol{0},\quad \dot{\boldsymbol{I}}_s=[\,0\ \ 0\ \ \dot{I}_{S3}\ \ \dot{I}_{S4}\ 0\ \ 0\,]^{\mathrm{T}}$$

$$\boldsymbol{Y}=\mathrm{diag}[\frac{1}{\mathrm{j}\omega L_1},\frac{1}{\mathrm{j}\omega L_2},\frac{1}{R_3},\frac{1}{R_4},\frac{1}{R_5},\ \mathrm{j}\omega C_6]$$

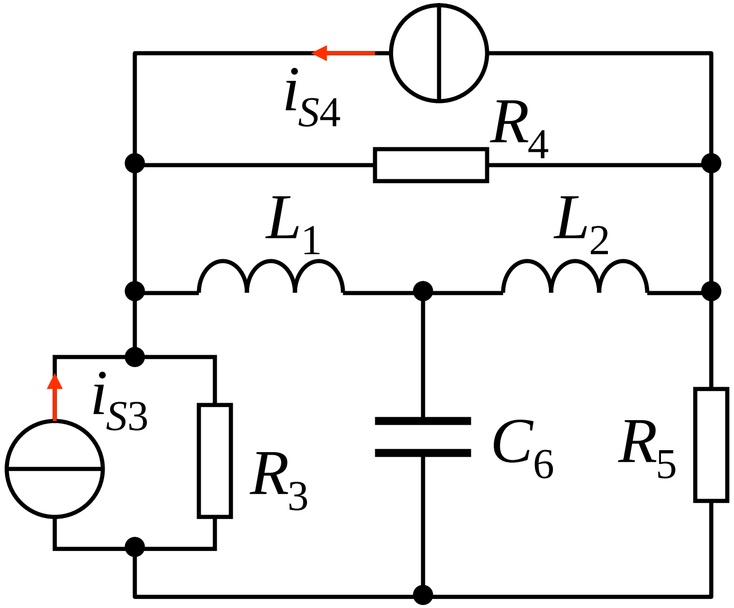
(3) $\boldsymbol{AYA}^{\mathrm{T}}$

$$\boldsymbol{AYA}^{\mathrm{T}}\dot{\boldsymbol{U}}_n=\boldsymbol{A}\dot{\boldsymbol{I}}_S\quad \boldsymbol{A}\boldsymbol{Y}\dot{\boldsymbol{U}}_S$$

$$\boldsymbol{AYA}^{\mathrm{T}}\dot{\boldsymbol{U}}_n=\boldsymbol{A}\dot{\boldsymbol{I}}_S$$

$$\begin{bmatrix} \frac{1}{R_3}+\frac{1}{R_4}+\frac{1}{j\omega L_1} & -\frac{1}{j\omega L_1} & -\frac{1}{R_4} \\ -\frac{1}{j\omega L_1} & \frac{1}{j\omega L_1}+\frac{1}{j\omega L_2}+j\omega C_6 & -\frac{1}{j\omega L_2} \\ -\frac{1}{R_4} & -\frac{1}{j\omega L_2} & \frac{1}{R_4}+\frac{1}{R_5}+\frac{1}{j\omega L_2} \end{bmatrix} \begin{bmatrix} \dot{U}_{n1} \\ \dot{U}_{n2} \\ \dot{U}_{n3} \end{bmatrix} = \begin{bmatrix} \dot{I}_{S3}+\dot{I}_{S4} \\ 0 \\ -\dot{I}_{S4} \end{bmatrix}$$

$$\boldsymbol{AYA}^{\mathrm{T}} \qquad \dot{\boldsymbol{U}}_n \qquad \boldsymbol{A}\dot{\boldsymbol{I}}_S$$



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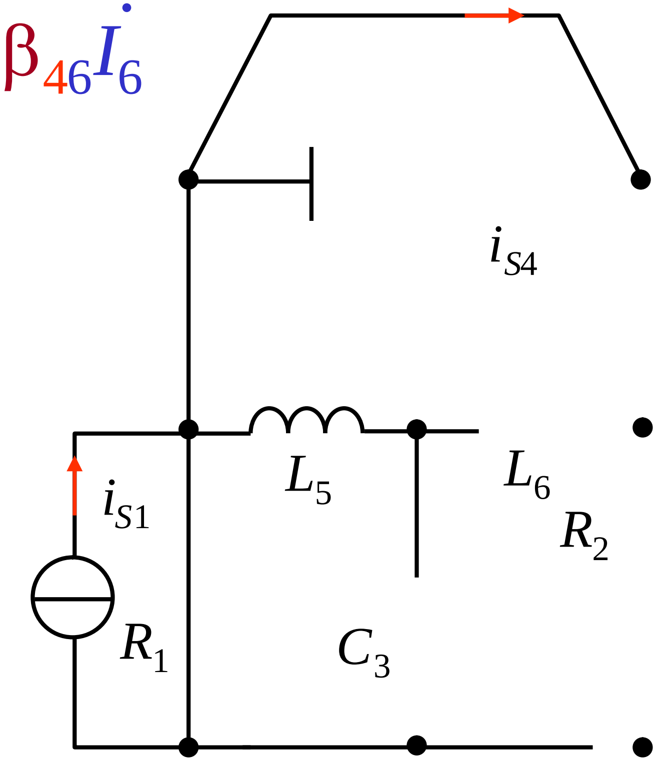
P406 15 3

$\dot{I}_{d2} = g_{21}\dot{U}_1 \, , \; \dot{I}_{d4} = \beta_{46}\dot{I}_6$



4

6

2

1

$$\boldsymbol{Y} = \begin{bmatrix} \frac{1}{R_1} & & & \mathbf{0} & & \\ -g_{21} & \frac{1}{R_2} & & & & \\ & & \mathrm{j}\omega C_3 & & & \\ & & & \mathrm{j}\omega C_4 & 0 & \frac{\beta_{46}}{\mathrm{j}\omega L_6} \\ & \mathbf{0} & & & \frac{1}{\mathrm{j}\omega L_5} & 0 \\ & & & & 0 & \frac{1}{\mathrm{j}\omega L_6} \end{bmatrix}$$

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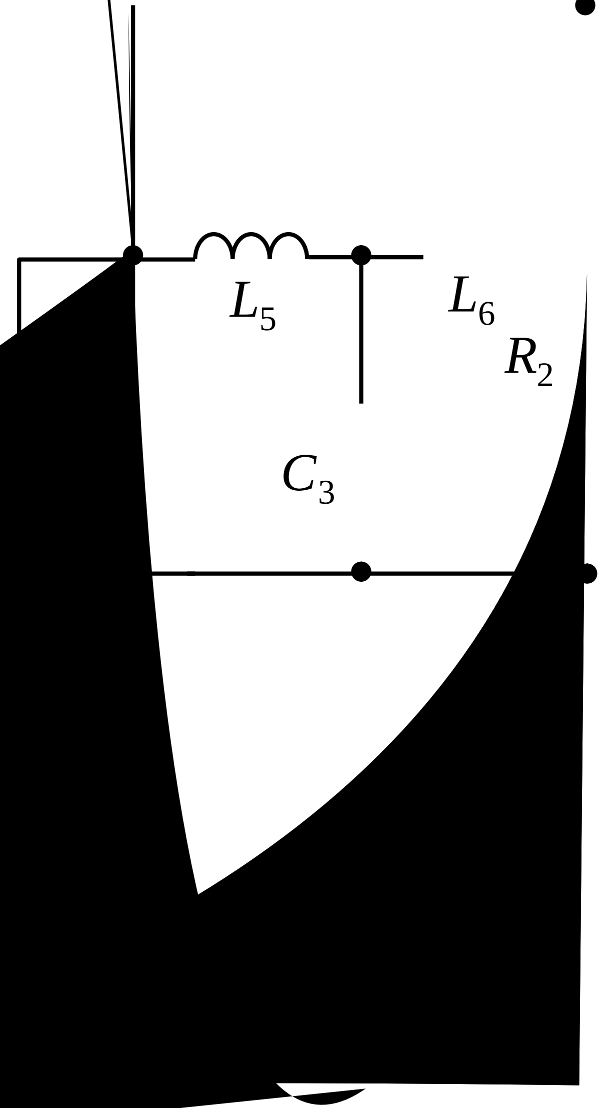
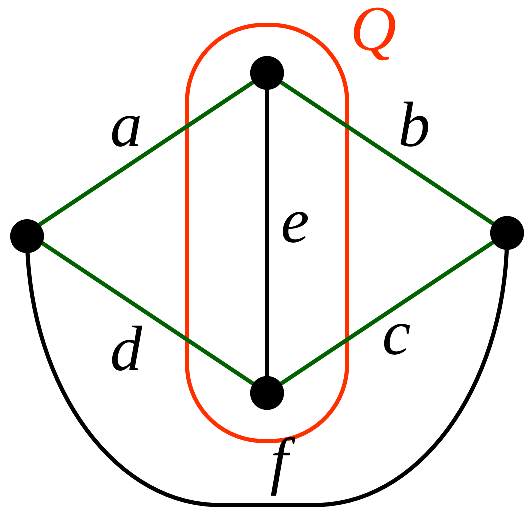
$$\dot{\boldsymbol{I}}_S = [\ \dot{I}_{S1} \quad 0 \quad 0 \quad -\dot{I}_{S4} \quad 0 \quad 0\ ]^{\mathrm{T}}$$

$$\dot{\boldsymbol{U}}_S = [\ 0 \quad -\dot{U}_{S2} \quad 0 \quad \dot{U}_{S4} \quad 0 \quad 0]^{\mathrm{T}}$$

$$\dot{\boldsymbol{I}} = \boldsymbol{Y}\,(\dot{\boldsymbol{U}} \quad \dot{\boldsymbol{U}}_S) \quad \dot{\boldsymbol{I}}_S$$



15 6



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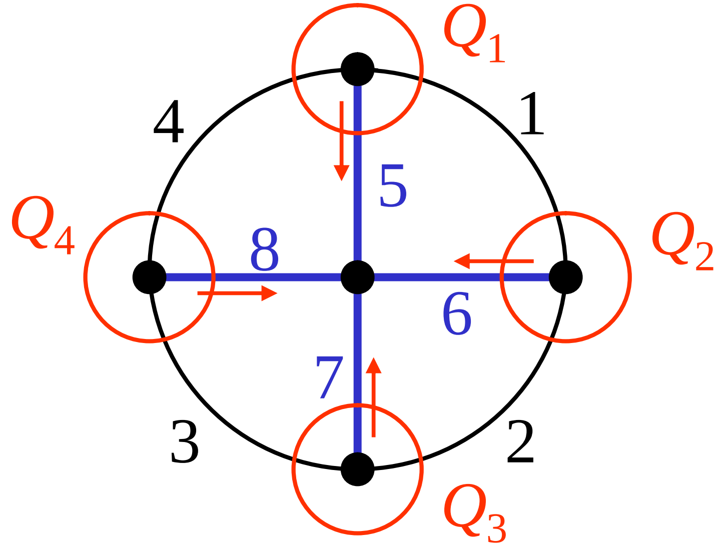
$$\boldsymbol{u} = \boldsymbol{Q}_f^{\mathrm{T}} \boldsymbol{u}_t$$

$\boldsymbol{u}_t$



$$\dot{I} = Y\,(\dot{U} \quad \dot{U}_S) \quad \dot{I}_S$$

Q_f

Q_f KCL $Q_f \dot{I} = 0$ KVL $\dot{U} = Q_f^{\mathrm{T}} \dot{U}_t$

$\dot{I} = Y(\dot{U} \quad \dot{U}_S) \quad \dot{I}_S$

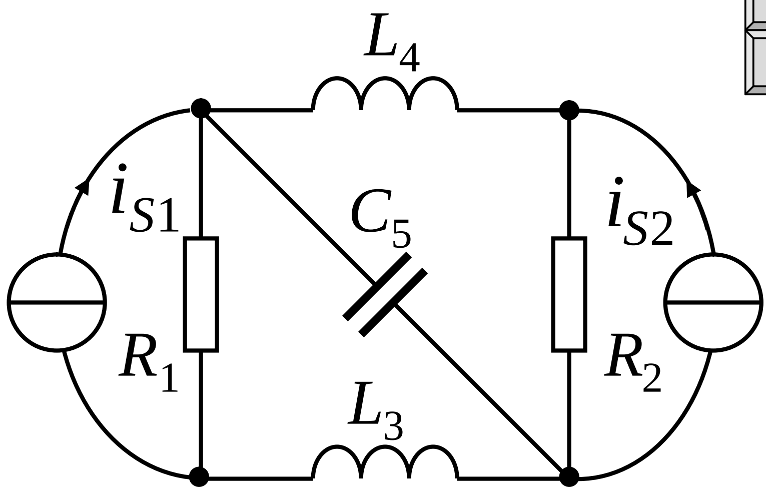
$\dot{I} = Y Q_f^{\mathrm{T}} \dot{U}_t \quad Y\dot{U}_S \quad \dot{I}_S$

Q_f KCL

$Q_f Y Q_f^{\mathrm{T}} \dot{U}_t = Q_f \dot{I}_S \quad Q_f Y \dot{U}_S$

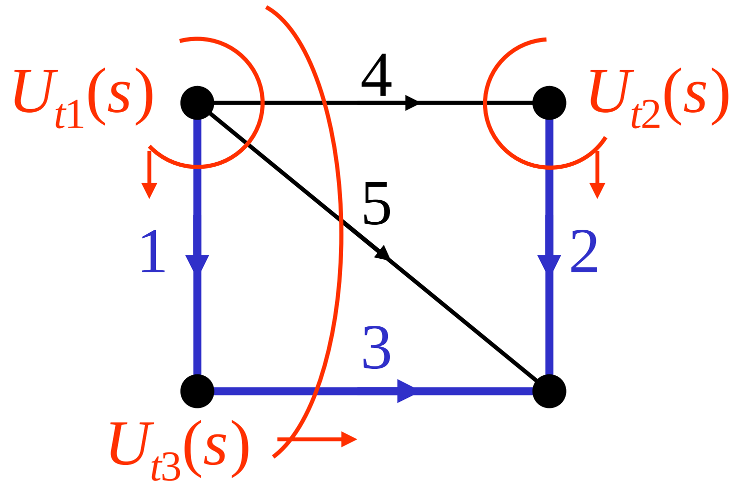
$Y_t = Q_f Y Q_f^{\mathrm{T}}$ Y_t

P408 15 4



1 2 3

$U_{t1}(s)$ $U_{t2}(s)$ $U_{t3}(s)$



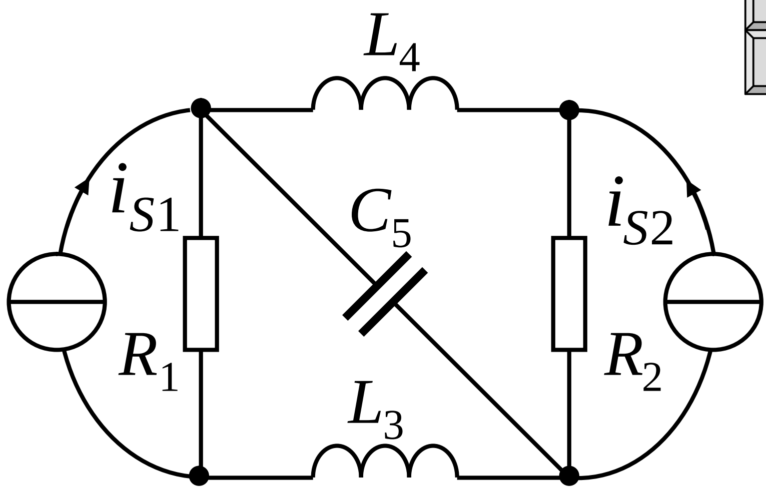
$\boldsymbol{Q}_f$

$$\boldsymbol{Q}_f = \begin{array}{c} \begin{matrix} 1 & 2 & 3 & 4 & 5 \end{matrix} \\ \begin{bmatrix} 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 \end{bmatrix} \end{array} \begin{matrix} Q_1 \\ Q_2 \\ Q_3 \end{matrix}$$

$$\boldsymbol{U}_S(s) = 0$$

$$\boldsymbol{I}_S(s) = [I_{S1}(s) \;\; I_{S2}(s) \;\; 0 \;\; 0 \;\; 0]^{\mathrm{T}}$$

$$\boldsymbol{Y}(s) = \mathrm{diag}\left[\frac{1}{R_1}, \frac{1}{R_2}, \frac{1}{sL_3}, \frac{1}{sL_4}, sC_5\right]$$

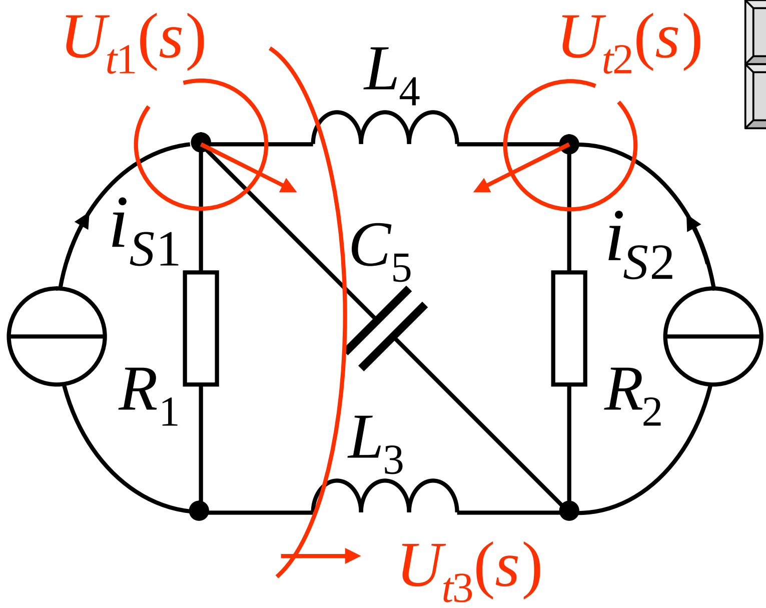


$$\boldsymbol{Q}_f \boldsymbol{Y}(s) \boldsymbol{Q}_f^{\mathrm{T}} \boldsymbol{U}_t(s) = \boldsymbol{Q}_f \boldsymbol{I}_S(s) - \boldsymbol{Q}_f \boldsymbol{Y}(s) \boldsymbol{U}_S(s)$$

$$\begin{bmatrix} \frac{1}{R_1}+\frac{1}{sL_4}+sC_5 & -\frac{1}{sL_4} & \frac{1}{sL_4}+sC_5 \\ -\frac{1}{sL_4} & \frac{1}{R_2}+\frac{1}{sL_4} & -\frac{1}{sL_4} \\ \frac{1}{sL_4}+sC_5 & -\frac{1}{sL_4} & \frac{1}{sL_3}+\frac{1}{sL_4}+sC_5 \end{bmatrix} \begin{bmatrix} U_{t1}(s) \\ U_{t2}(s) \\ U_{t3}(s) \end{bmatrix} = \begin{bmatrix} I_{S1}(s) \\ I_{S2}(s) \\ 0 \end{bmatrix}$$

$\boldsymbol{Y}_t$

Q_1 Q_2 Q_3



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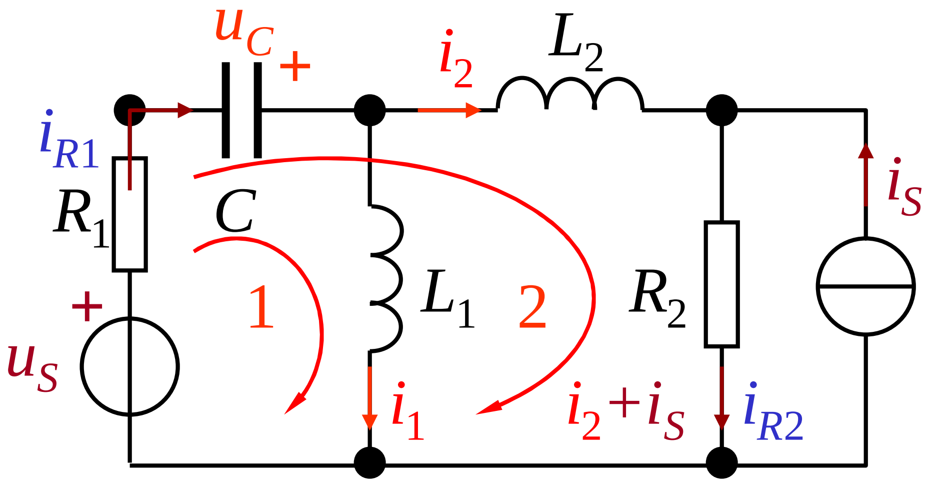
$$\begin{bmatrix} \frac{1}{R_1}+\frac{1}{sL_4}+sC_5 & -\frac{1}{sL_4} & \frac{1}{sL_4}+sC_5 \\ -\frac{1}{sL_4} & \frac{1}{R_2}+\frac{1}{sL_4} & -\frac{1}{sL_4} \\ \frac{1}{sL_4}+sC_5 & -\frac{1}{sL_4} & \frac{1}{sL_3}+\frac{1}{sL_4}+sC_5 \end{bmatrix} \begin{bmatrix} U_{t1}(s) \\ U_{t2}(s) \\ U_{t3}(s) \end{bmatrix} = \begin{bmatrix} I_{S1}(s) \\ I_{S2}(s) \\ 0 \end{bmatrix}$$



1.

$$C\frac{\mathrm{d}u_C}{\mathrm{d}t} = -i_1 - i_2$$

$$1 \quad L_1\frac{\mathrm{d}i_1}{\mathrm{d}t} = u_C - R_1\overbrace{(i_1+i_2)}^{i_{R1}} + u_S$$

$$2 \quad L_2\frac{\mathrm{d}i_2}{\mathrm{d}t} = u_C - R_1(i_1+i_2) + u_S - R_2\underbrace{(i_2+i_S)}_{i_{R2}}$$

(1) C

KCL

(2) L

KVL

(3) ( )

$$C\frac{du_C}{dt} = -i_1 - i_2 \qquad (4)$$

$$L_1\frac{di_1}{dt} = u_C - R_1(i_1+i_2) + u_S$$

$$L_2\frac{di_2}{dt} = u_C - R_1(i_1+i_2) + u_S - R_2(i_2+i_S)$$

$$\begin{bmatrix} \frac{du_C}{dt} \\ \frac{di_1}{dt} \\ \frac{di_2}{dt} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{C} & -\frac{1}{C} \\ \frac{1}{L_1} & -\frac{R_1}{L_1} & -\frac{R_1}{L_1} \\ \frac{1}{L_2} & -\frac{R_1}{L_2} & -\frac{R_1+R_2}{L_2} \end{bmatrix} \begin{bmatrix} u_C \\ i_1 \\ i_2 \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ \frac{1}{L_1} & 0 \\ \frac{1}{L_2} & -\frac{R_2}{L_2} \end{bmatrix} \begin{bmatrix} u_S \\ i_S \end{bmatrix}$$

2.

(1)

(2) KCL

(3) KVL

(4)

(5)

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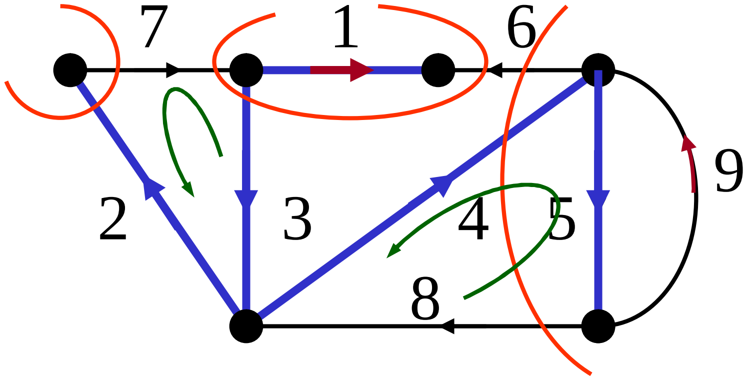
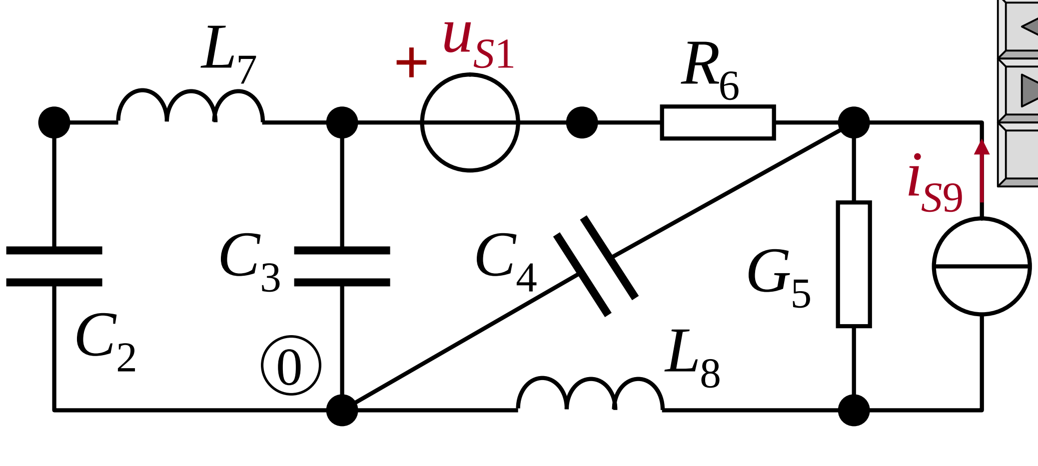




KVL

$$L_7 \frac{\mathrm{d}i_7}{\mathrm{d}t} = -u_2 - u_3 \qquad L_8 \frac{\mathrm{d}i_8}{\mathrm{d}t} = -u_4 - u_5$$

KCL

$$C_2 \frac{\mathrm{d}u_2}{\mathrm{d}t} = i_7$$

$i_6 \quad u_5$

$$i_6 = \frac{1}{R_6} u_6 = \frac{1}{R_6} (-u_4 - u_3 + u_{S1})$$

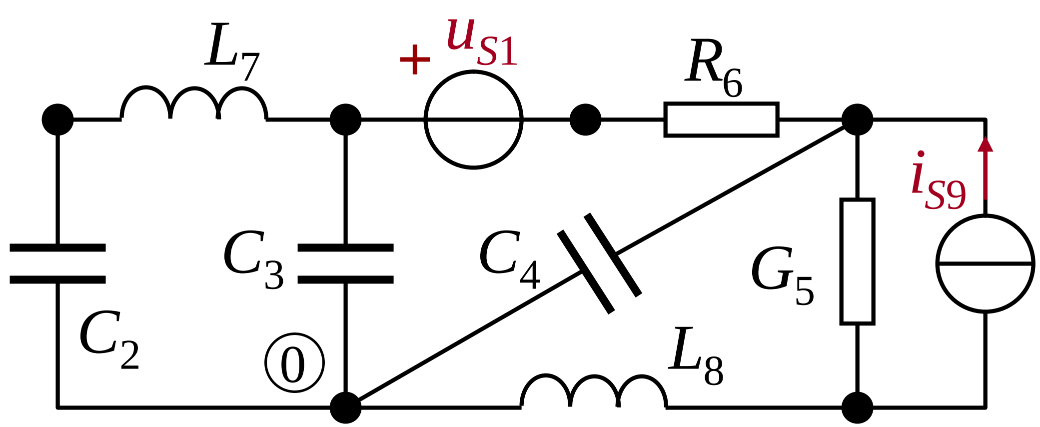
$$C_3 \frac{\mathrm{d}u_3}{\mathrm{d}t} = i_6 + i_7$$

$$u_5 = \frac{1}{G_5} i_5 = \frac{1}{G_5} (i_8 + i_9)$$

$$C_4 \frac{\mathrm{d}u_4}{\mathrm{d}t} = i_6 + i_8$$

$$
\left.
\begin{aligned}
\frac{\mathrm{d}u_2}{\mathrm{d}t} &= \frac{1}{C_2} i_7 \\
\frac{\mathrm{d}u_3}{\mathrm{d}t} &= -\frac{1}{C_3R_6} u_3 - \frac{1}{C_3R_6} u_4 + \frac{1}{C_3} i_7 + \frac{1}{C_3R_6} u_{S1} \\
\frac{\mathrm{d}u_4}{\mathrm{d}t} &= -\frac{1}{C_4R_6} u_3 - \frac{1}{C_4R_6} u_4 + \frac{1}{C_4} i_8 + \frac{1}{C_4R_6} u_{S1} \\
\frac{\mathrm{d}i_7}{\mathrm{d}t} &= -\frac{1}{L_7} u_2 - \frac{1}{L_7} u_3 \\
\frac{\mathrm{d}i_8}{\mathrm{d}t} &= -\frac{1}{L_8} u_4 - \frac{1}{G_5L_8} i_8 - \frac{1}{G_5L_8} i_{S9}
\end{aligned}
\right\}
$$

$u_2=x_1$ $u_3=x_2$ $u_4=x_3$ $i_7=x_4$ $i_8=x_5$



$$
\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \\ \dot{x}_3 \\ \dot{x}_4 \\ \dot{x}_5 \end{bmatrix}
=
\begin{bmatrix}
0 & 0 & 0 & \dfrac{1}{C_2} & 0 \\
0 & \dfrac{1}{C_3R_6} & \dfrac{1}{C_3R_6} & \dfrac{1}{C_3} & 0 \\
0 & \dfrac{1}{C_4R_6} & \dfrac{1}{C_4R_6} & 0 & \dfrac{1}{C_4} \\
\dfrac{1}{L_7} & \dfrac{1}{L_7} & 0 & 0 & 0 \\
0 & 0 & \dfrac{1}{L_8} & 0 & \dfrac{1}{G_5L_8}
\end{bmatrix}
\begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{bmatrix}
+
\begin{bmatrix}
0 & 0 \\
\dfrac{1}{C_3R_6} & 0 \\
\dfrac{1}{C_4R_6} & 0 \\
0 & 0 \\
0 & \dfrac{1}{G_5L_8}
\end{bmatrix}
\begin{bmatrix} u_{S1} \\ i_{S9} \end{bmatrix}
$$