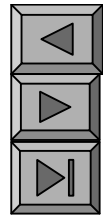

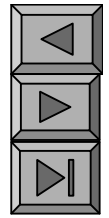

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(/)

KCL KVL

VCR

- KVL

“ (Graph)”

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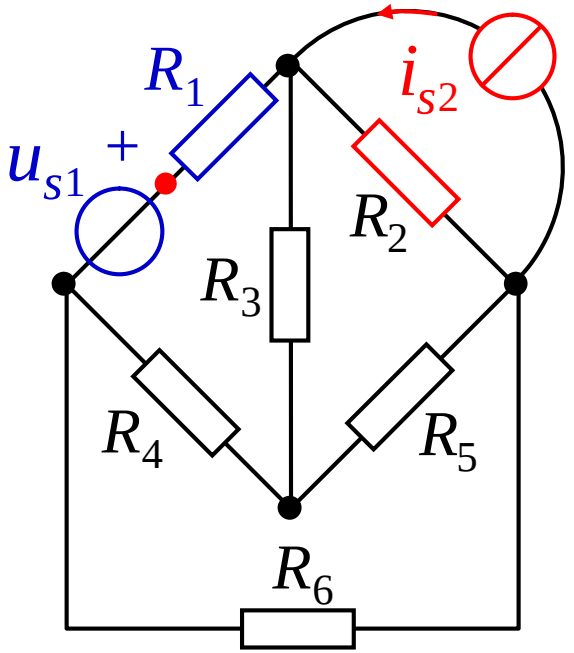

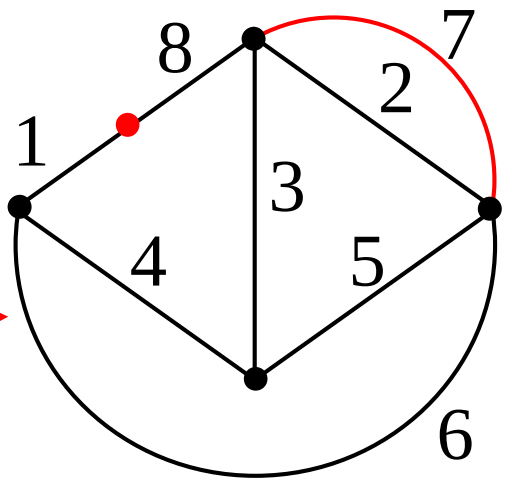

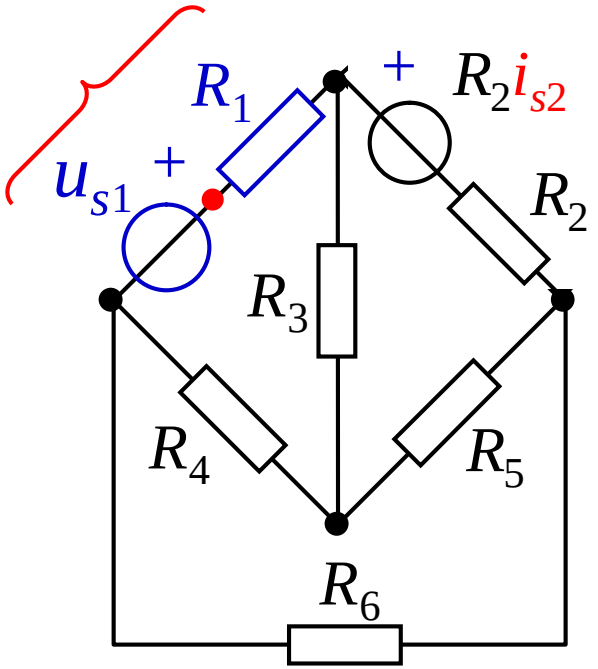

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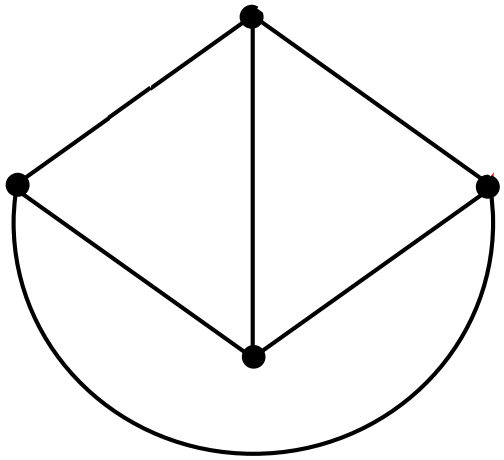

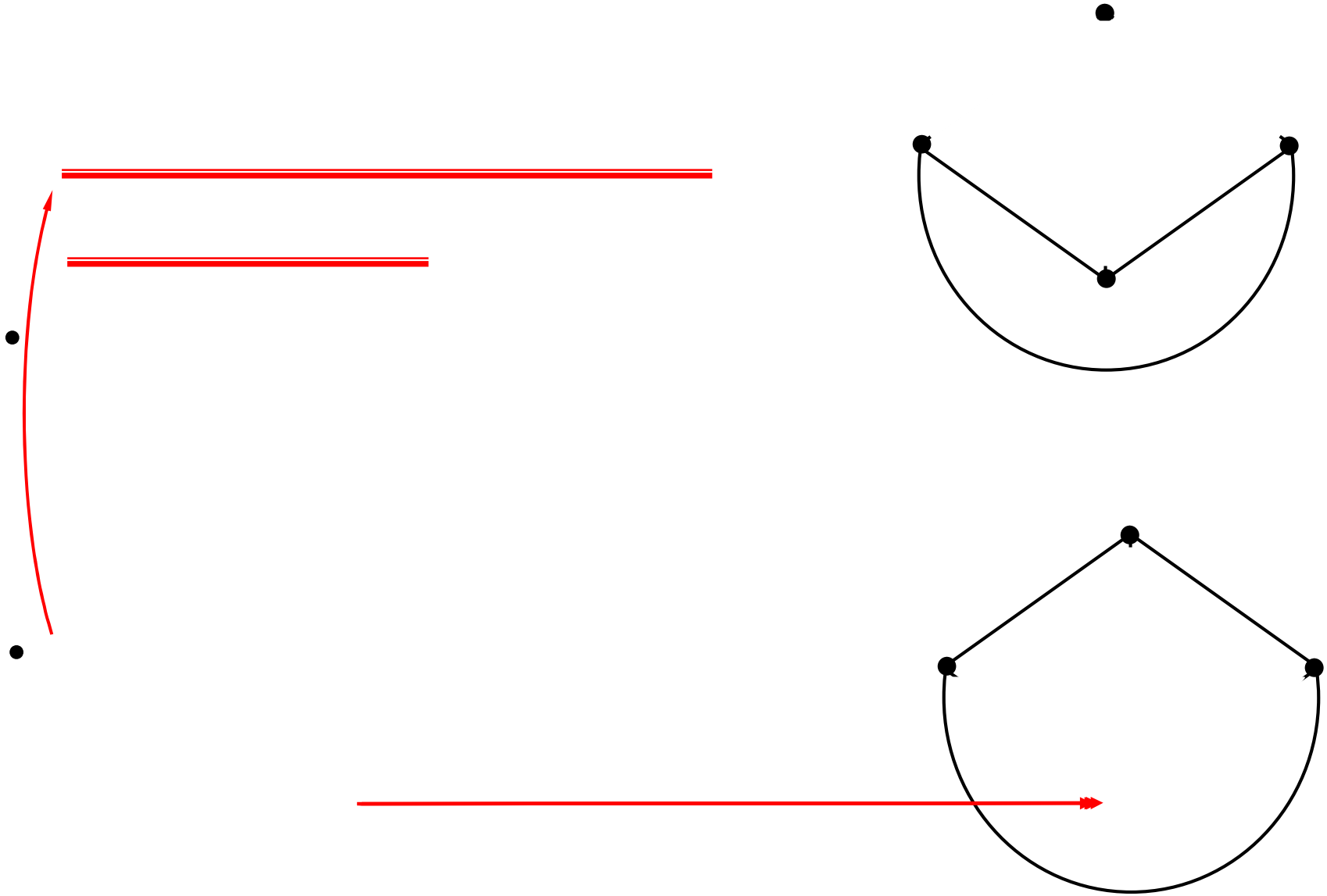

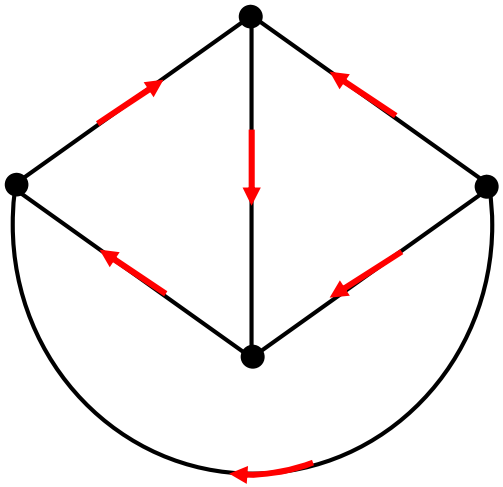

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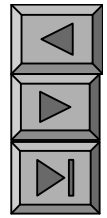


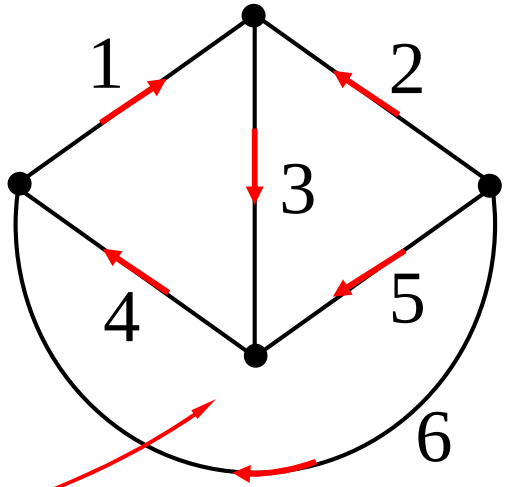
“ !@? ŸŒ

3 2 KCL KVL

KCL

- LVL

$$-i_1 - i_4 - i_6 = 0$$
$$-i_1 - i_2 + i_3 = 0$$
$$i_2 + i_5 + i_6 = 0$$
$$-i_3 + i_4 - i_5 = 0$$



- 4 0

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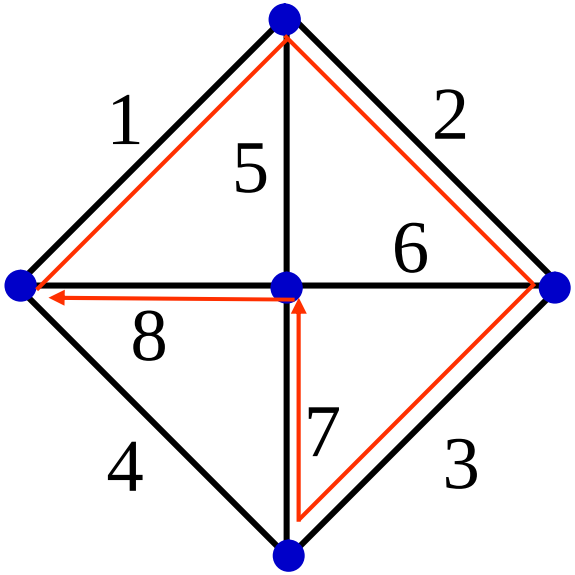
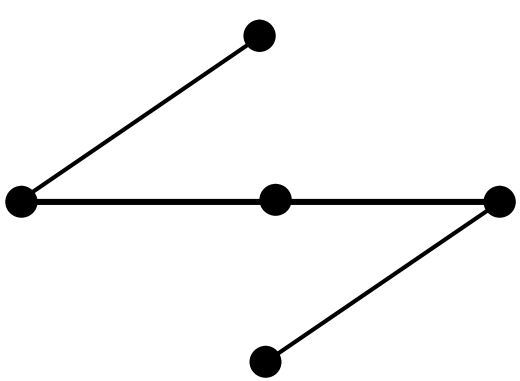
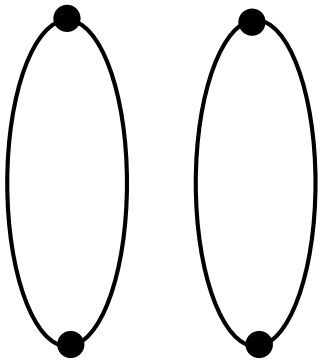


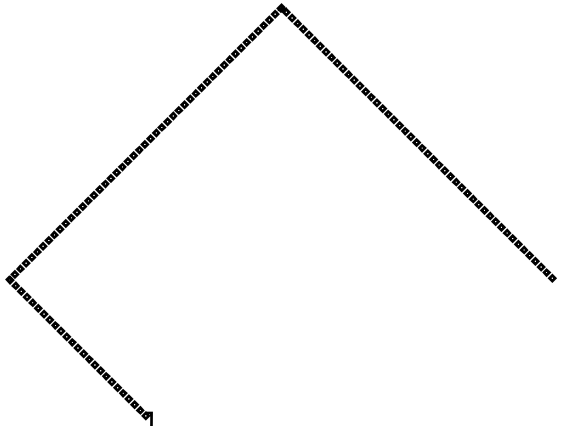
G

- G

G







G

(1,5,8) (2,5,6) (1,2,3,4)

- 13

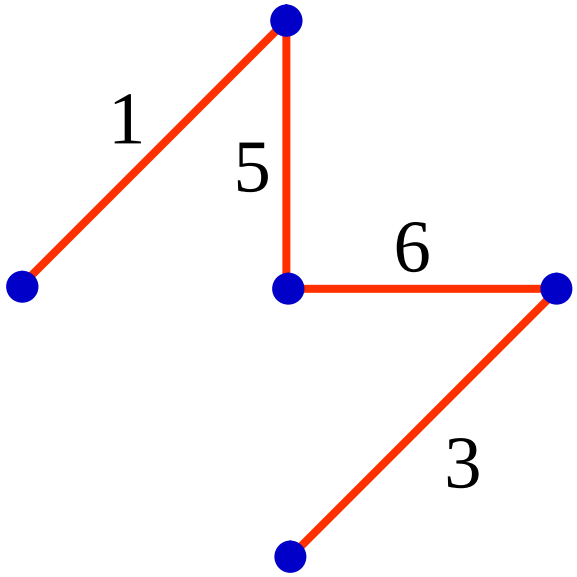
13

2. (Tree)

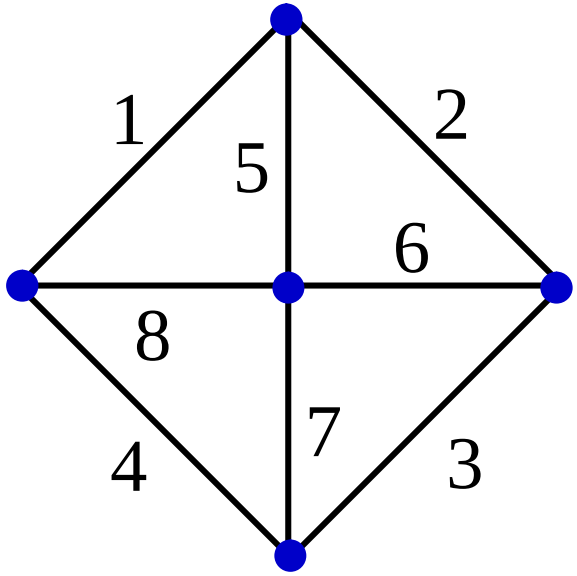
G T 5,6,7,8

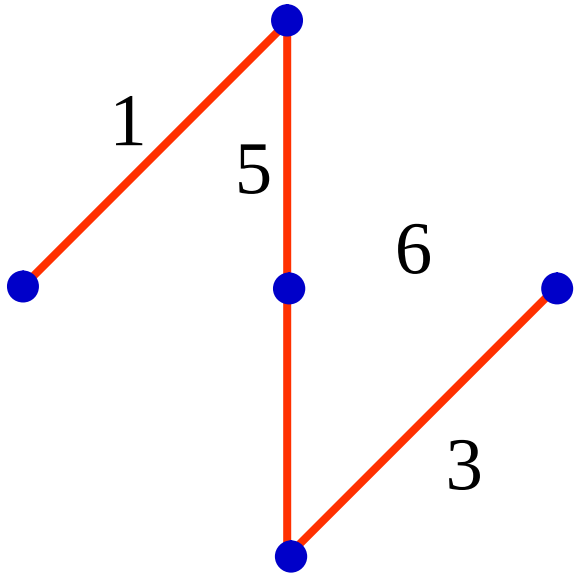
G

1,2,3,4



T





- G 5
  T 4
- *n*
  (*n* 1)

G

n (=5)

- G

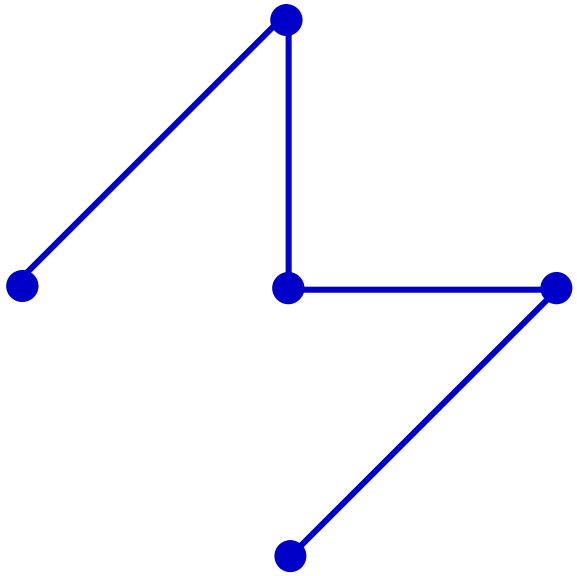
1 2

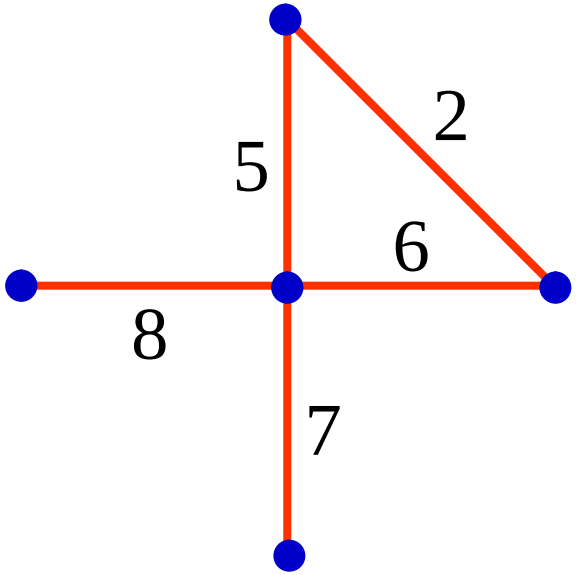
- (

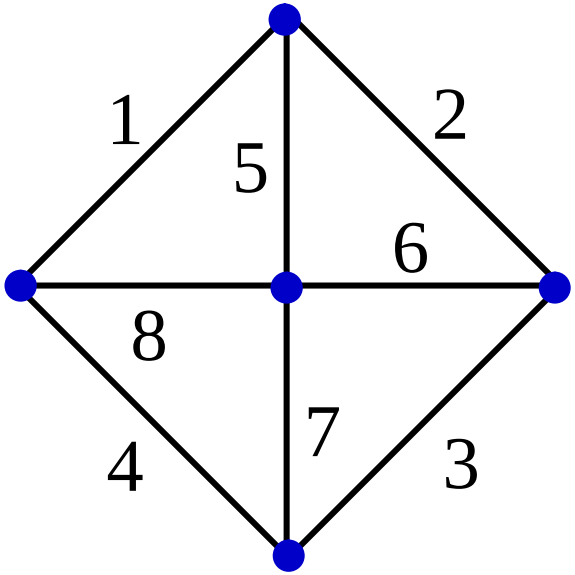
)

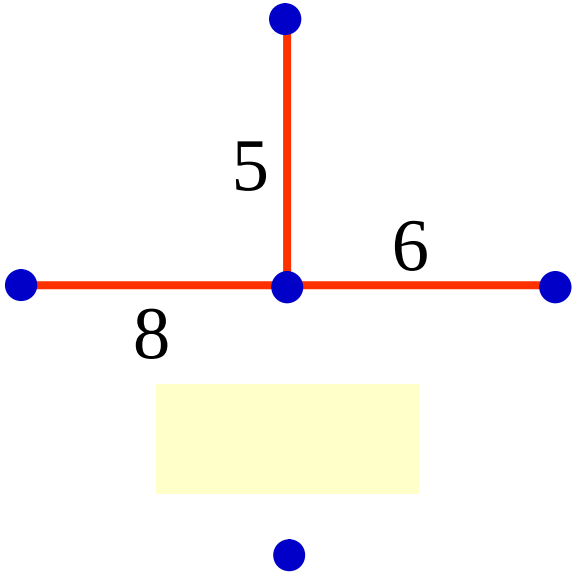
n (=5)

(n 1=4)




5
2
6
8
7


1
5
2
6
8
7
4
3


5
6
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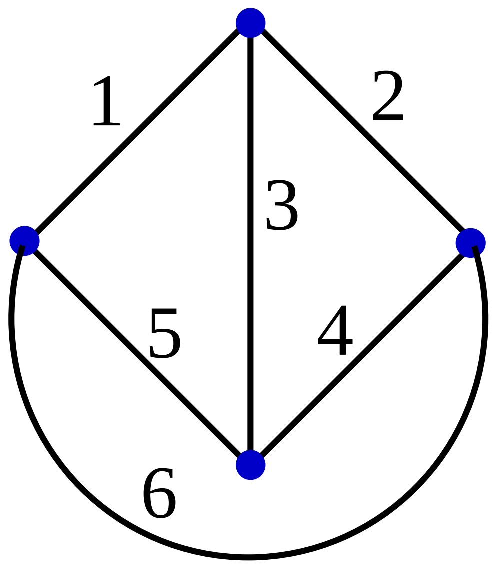
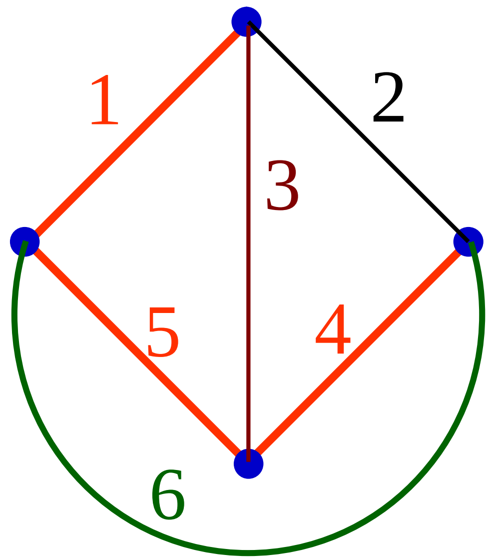




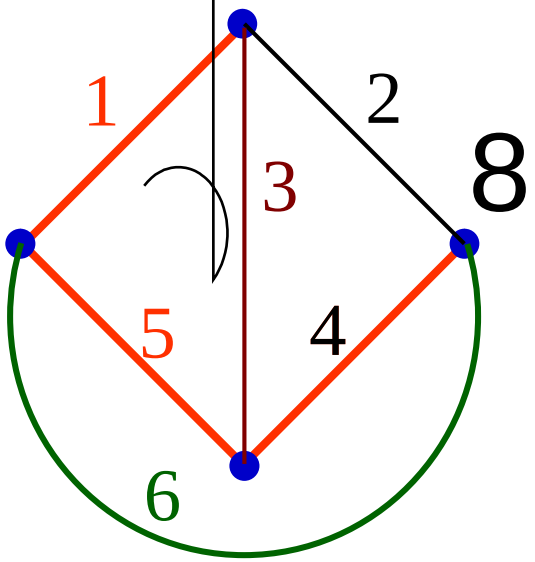
- G n b

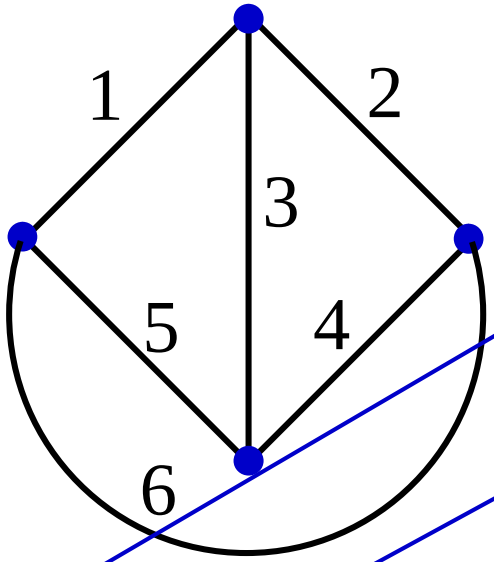
G (n 1)

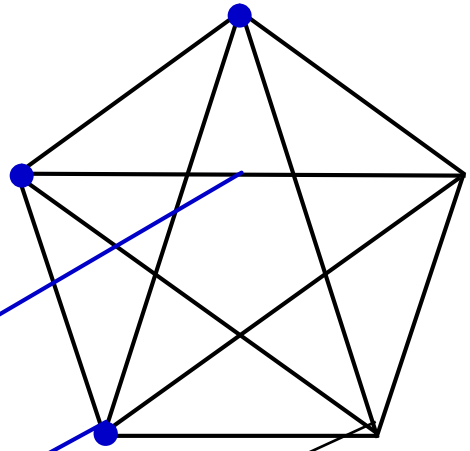
b (n 1)

- l = b (n 1)

2

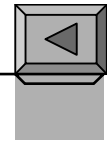






$l = b \quad (n \;\; 1)$

KVL



3 3

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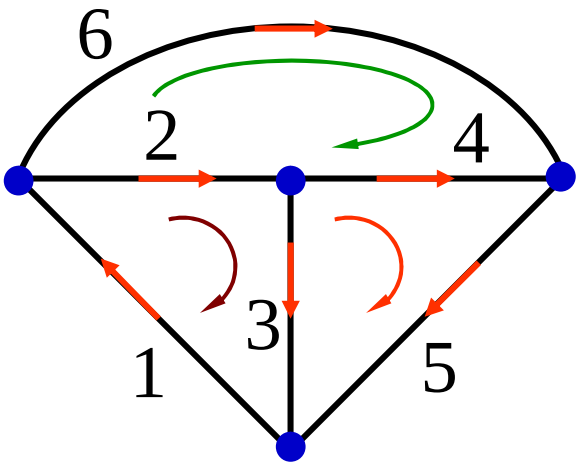
- n

b :

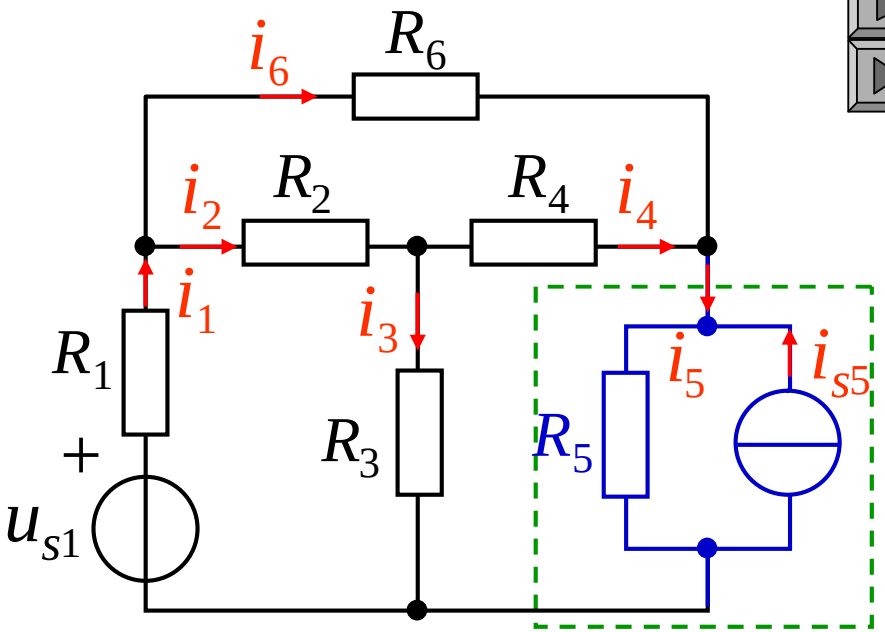
KCL:(n–1)
KVL: (b–n+1) } b

VCR: b



- $2b$
- $2b$ $2b$

$2b$



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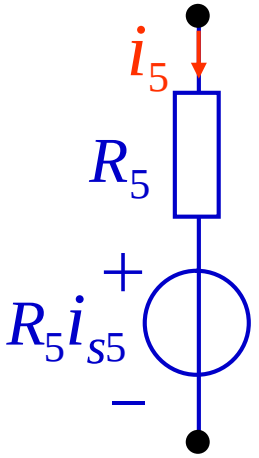
$2b$ b

VAR KCL KVL

1.

(1)

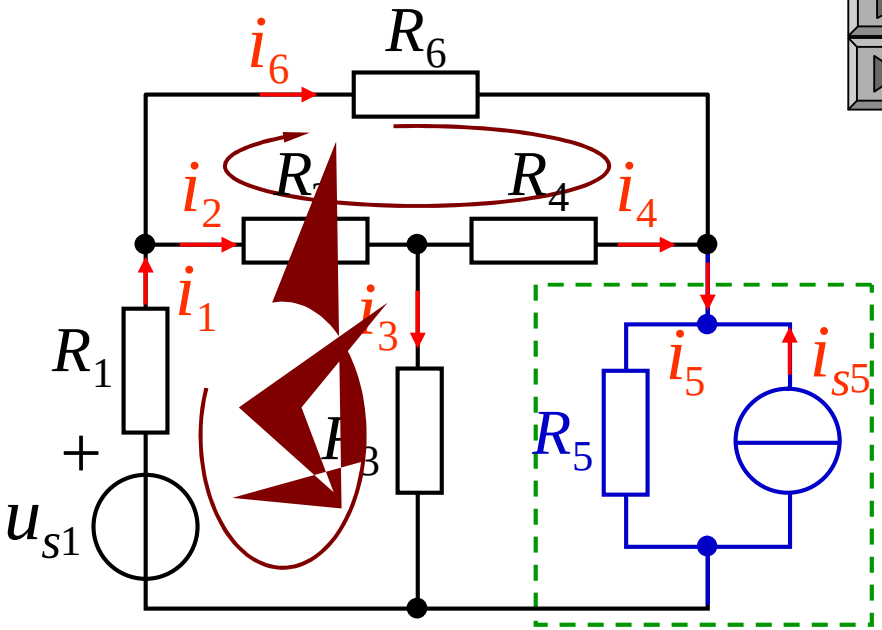


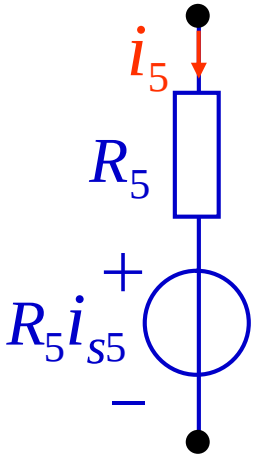
(2) KCL (n 1)

:
$$-i_1+i_2+i_6=0$$
:
$$-i_2+i_3+i_4=0$$
:
$$-i_4+i_5-i_6=0$$

(3) (b n+1)

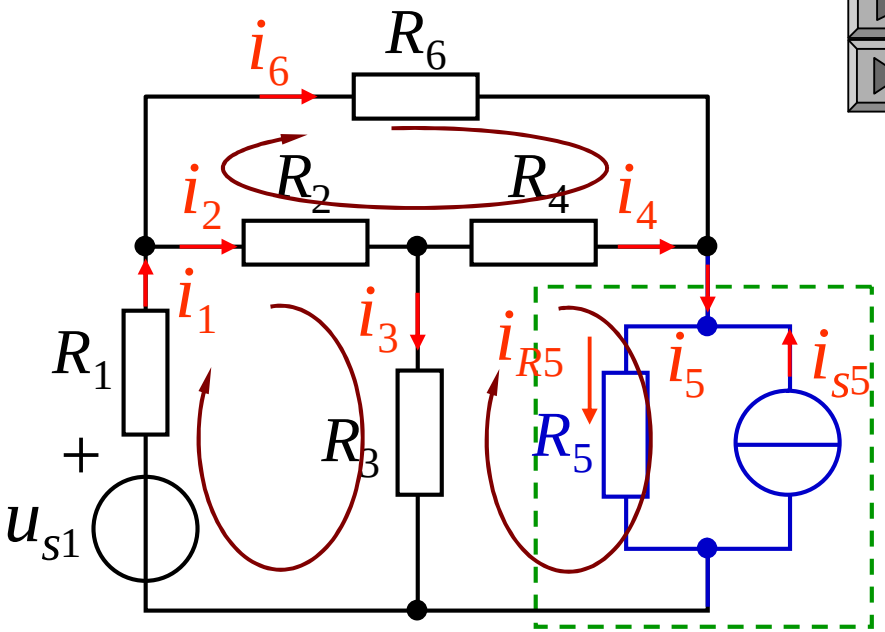
KVL





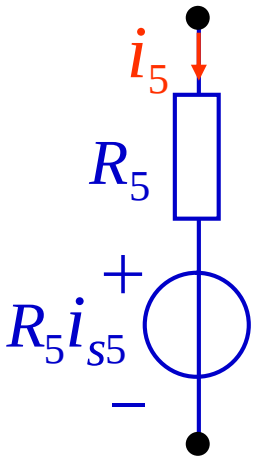
$$-i_1+i_2+i_6=0$$
$$-i_2+i_3+i_4=0$$
$$-i_4+i_5-i_6=0$$
$$R_1i_1+R_2i_2+R_3i_3=u_{s1}$$
$$-R_3i_3+R_4i_4+R_5i_5=-R_5i_{s5}$$
$$-R_2i_2-R_4i_4+R_6i_6=0$$

(4) i_1 i_6



R_5

$$u_{14}=u_{s1}-R_1i_1$$

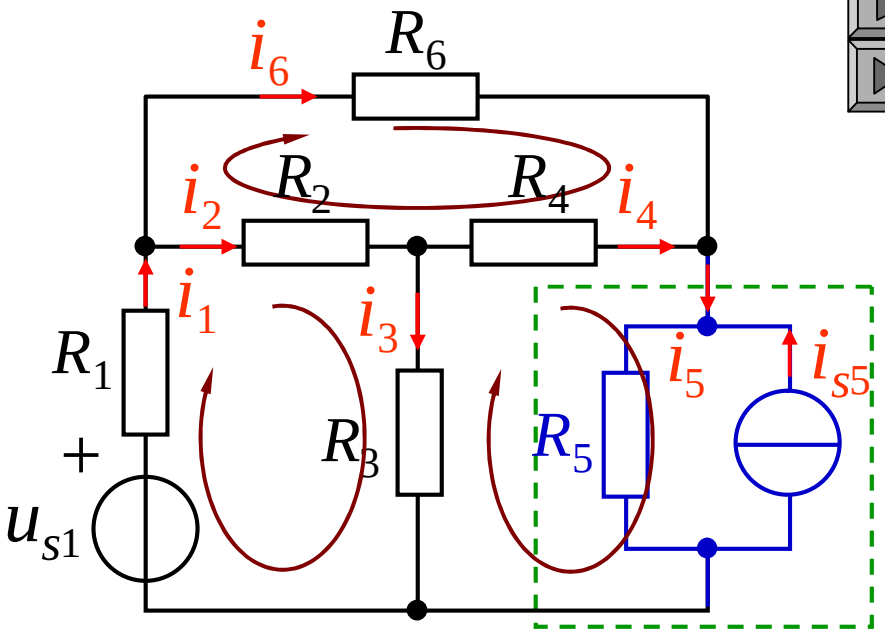


$$i_{R5}=i_{s5}+i_5$$

KVL

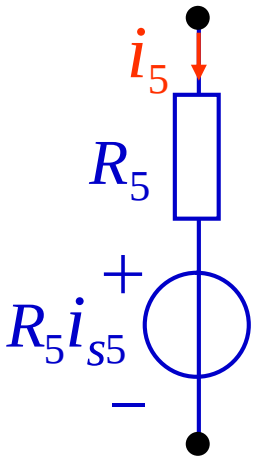
$$R_1 i_1 + R_2 i_2 + R_3 i_3 = u_{s1}$$
$$-R_3 i_3 + R_4 i_4 + R_5 i_5 = -R_5 i_{s5}$$
$$-R_2 i_2 - R_4 i_4 + R_6 i_6 = 0$$

$$R_k i_k = \quad u_{sk}$$



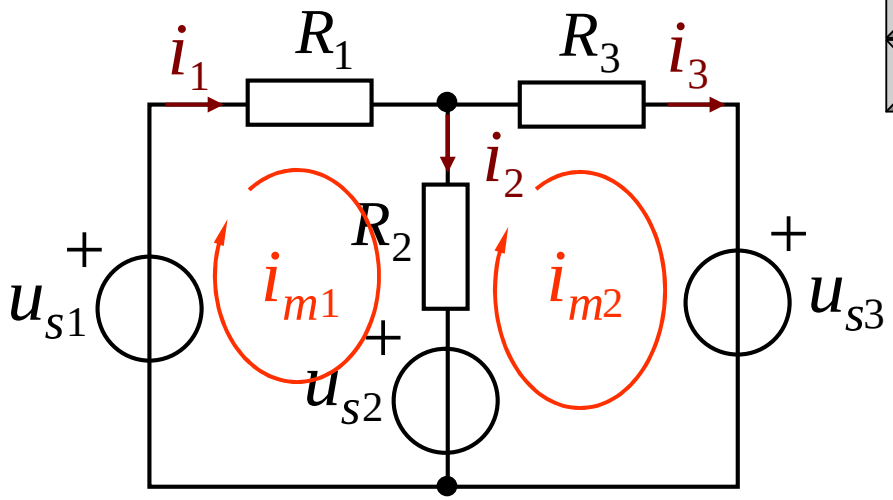
- i_k $R_k i_k$

- u_{sk} u_{sk}



KVL

CL



KVL

1.

(1)

(2)

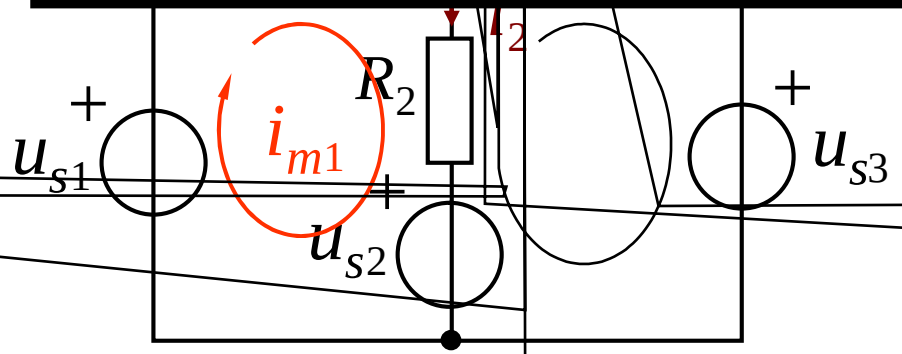
KVL

i_{m1} i_{m2} R_2

$$1 \quad R_1 i_{m1} + R_2 i_{m1} \; R_2 i_{m2} = u_{s1} - u_{s2}$$

$$2 \quad R_2 i_{m1} + R_2 i_{m2} + R_3 i_{m2} = u_{s2} - u_{s3}$$

$$R_{11} i_{m1} + R_{12} i_{m2} = u_{s11}$$
$$R_{21} i_{m1} + R_{22} i_{m2} = u_{s22}$$



$$R_1 i_{m1} + R_2 i_{m1} \quad R_2 i_{m2} = u_{s1} - u_{s2}$$
$$R_2 i_{m1} + R_2 i_{m2} + R_3 i_{m2} = u_{s2} - u_{s3}$$

$$(R_1 + R_2) i_{m1} \quad R_2 i_{m2} = u_{s1} - u_{s2}$$
$$R_2 i_{m1} + (R_2 + R_3) i_{m2} = u_{s2} - u_{s3}$$

$$R_{11}i_{m1}+R_{12}i_{m2}=u_{s11}$$
$$R_{21}i_{m1}+R_{22}i_{m2}=u_{s22}$$

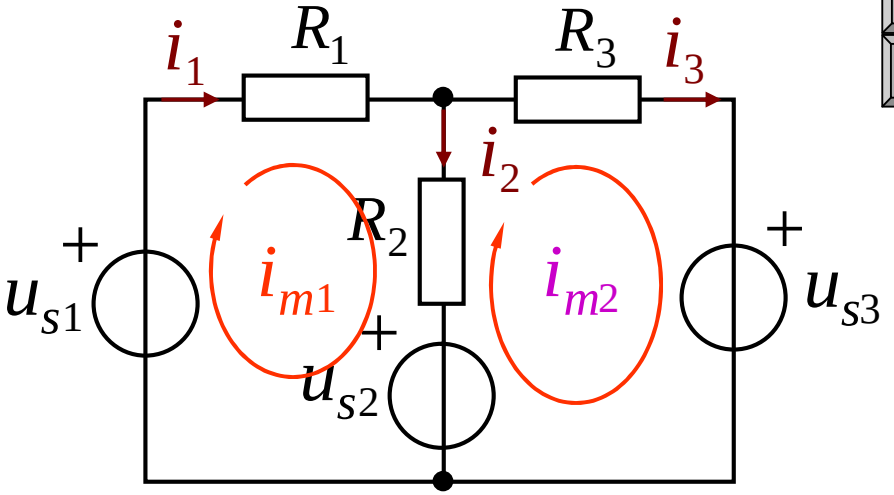
$R_{12}i_{m2}$ i_{m2} 1

$R_{21}i_{m1}$ i_{m1} 2

R_{12} R_{21}

i_{m2} (i_{m1})

$$R_{12}=R_{21}=R_2$$



1 (2)

$$(R_1+R_2)\,i_{m1}\;\;R_2i_{m2}=u_{s1}-u_{s2}$$
$$R_2\,i_{m1}+(R_2+R_3)\,i_{m2}=u_{s2}-u_{s3}$$

2. m

$$R_{11}i_{m1}+R_{12}i_{m2}+R_{13}i_{m3}+\cdots+R_{1m}i_{mm}=u_{s11}$$
$$R_{21}i_{m1}+R_{22}i_{m2}+R_{23}i_{m3}+\cdots+R_{2m}i_{mm}=u_{s22}$$
$$R_{31}i_{m1}+R_{32}i_{m2}+R_{33}i_{m3}+\cdots+R_{3m}i_{mm}=u_{s33}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$R_{m1}i_{m1}+R_{m2}i_{m2}+R_{m3}i_{m3}+\cdots+R_{mm}i_{mm}=u_{smm}$$

- R_{11} R_{mm} ——— ———————
- R_{12} R_{1m} R_{21} R_{m1}

———

(1)

“ ”

(2)

(3)

0

(4) $R_{ik}= R_{ki}$

- u_{s11} u_{smm} 1 m

“+”

“ ”

3–1 (P60)

1. *(T)*

G

(1)

(2) *G*

(3) 1

2. *(L)*

G

(1)

(2) *2*

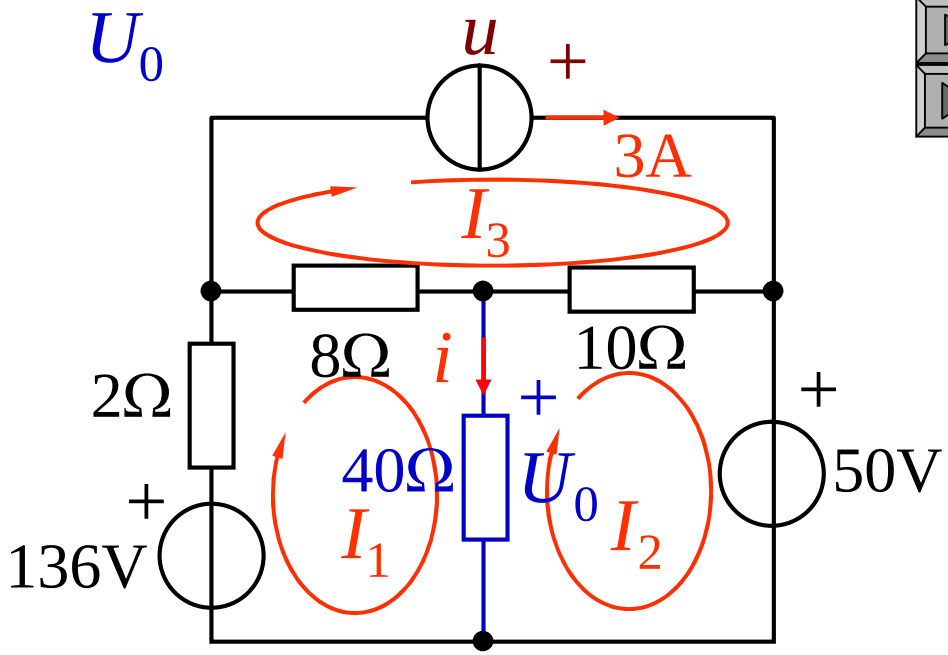
3. KCL $n-1$

KVL $b \quad (n \quad 1)$

4.

5.

P76 3 11(P77) U_0



R_{11}=50Ω

R_{22}=50Ω

R_{33} =18Ω

u

R_{12}=R_{21}= 40Ω

R_{13}=R_{31}= 8Ω

R_{23}=R_{32}= 10Ω

$$\begin{cases} 50\,I_1 - 40I_2 - 8\,I_3 = 136 \\ -40\,I_1 + 50\,I_2 - 10\,I_3 = -50 \\ -8\,I_1 - 10\,I_2 + 18\,I_3 = u \end{cases}$$

I_3=3A

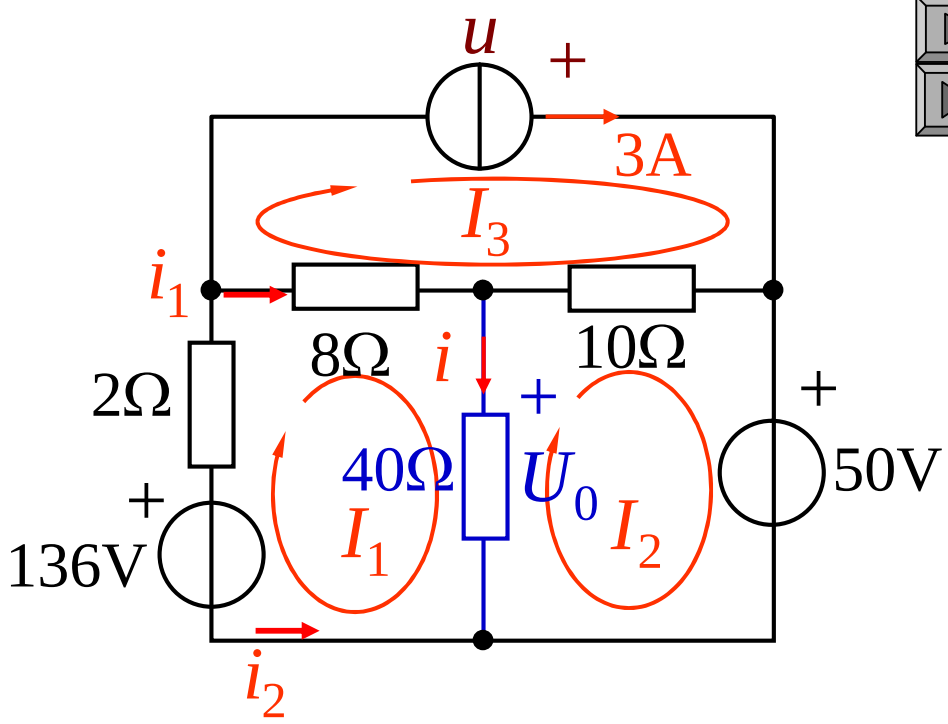
I_1=8A I_2=6A

U_0=40i =40(I_1 I_2) =80V

$$i = I_1 - I_2$$

$$i_1 = I_1 - I_3$$

$$i_2 = -I_1$$



3–5

-
-
-

  KVL
-

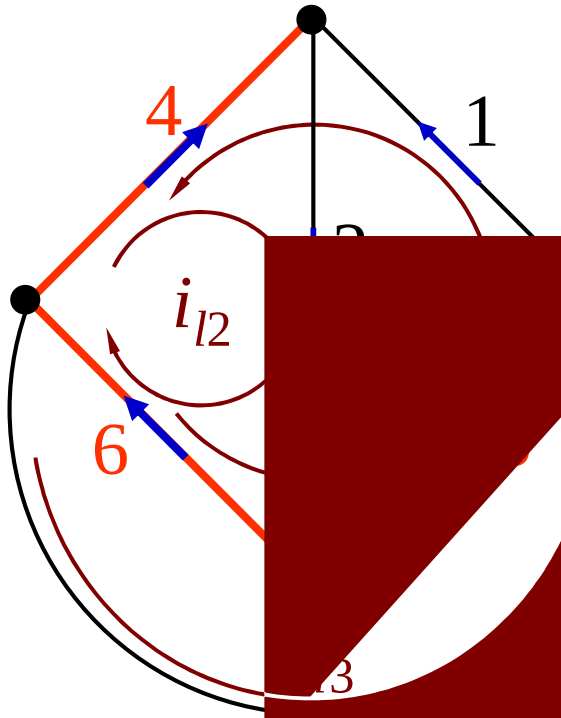
$i_1 \quad i_2 \quad i_3$

$i_{l1} \quad i_{l2} \quad i_{l3}$

$i_1 = i_{l1} \quad i_2 = i_{l2} \quad i_3 = i_{l3}$

$i_5 =$

$i_6 = -i_{l1} + i_{l2}$



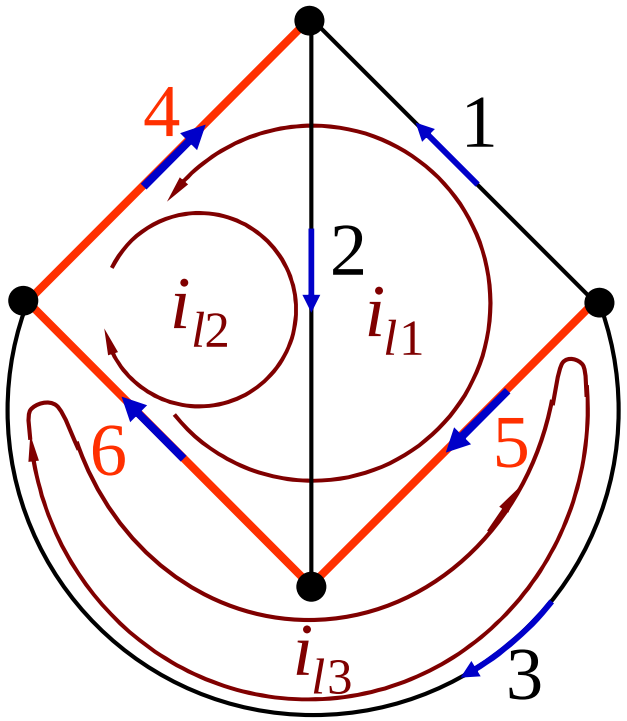
KCL

$$i_4 = -i_1 + i_2 = -i_{l1} + i_{l2}$$

$$i_5 = -i_1 - i_3 = -i_{l1} - i_{l3}$$

$$i_6 = -i_1 + i_2 - i_3 = -i_{l1} + i_{l2} - i_{l3}$$

- KCL
-



“ ”

( )

1.

- b n ( )

  $l = b \quad (n \quad 1)$ KVL

$$R_{11}i_{l1}+R_{12}i_{l2}+R_{13}i_{l3}+\cdots+R_{1l}i_{ll}=u_{s11}$$
$$R_{21}i_{l1}+R_{22}i_{l2}+R_{23}i_{l3}+\cdots+R_{2l}i_{ll}=u_{s22}$$
$$R_{31}i_{l1}+R_{32}i_{l2}+R_{33}i_{l3}+\cdots+R_{3l}i_{ll}=u_{s33}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$
$$R_{l1}i_{l1}+R_{l2}i_{l2}+R_{l3}i_{l3}+\cdots+R_{ll}i_{ll}=u_{sll}$$

R_{11} R_{ll}

R_{12} R_{13} R_{23} R_{l1} R_{1l}

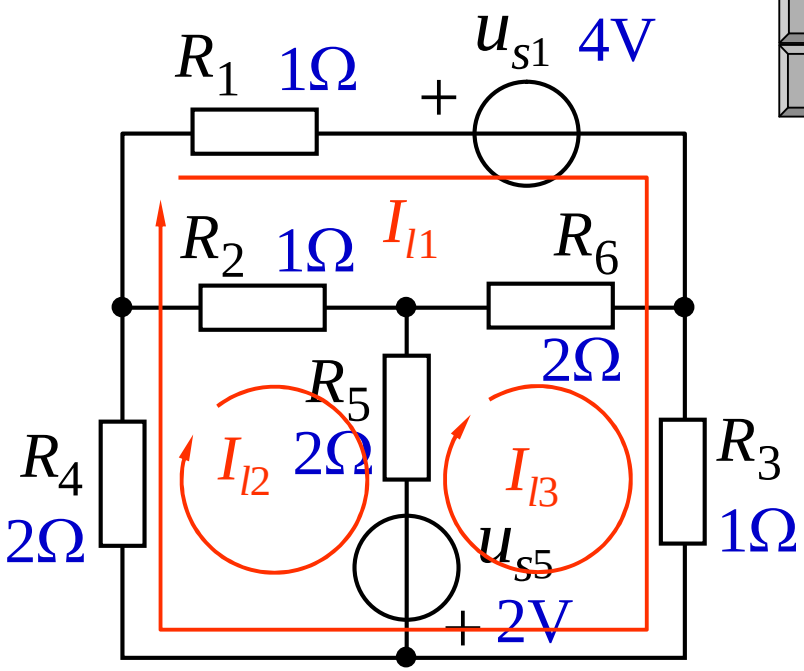
“ ”

$$\begin{bmatrix} R_{11} & R_{12} & R_{13} \cdots R_{1l} \\ R_{21} & R_{22} & R_{23} \cdots R_{2l} \\ R_{31} & R_{32} & R_{33} \cdots R_{3l} \\ & \cdots\cdots\cdots\cdots & \\ R_{l1} & R_{l2} & R_{l3} \cdots R_{ll} \end{bmatrix} \begin{bmatrix} i_{l1} \\ i_{l2} \\ i_{l3} \\ \vdots \\ i_{ll} \end{bmatrix} = \begin{bmatrix} u_{s11} \\ u_{s22} \\ u_{s33} \\ \vdots \\ u_{sll} \end{bmatrix}$$

0

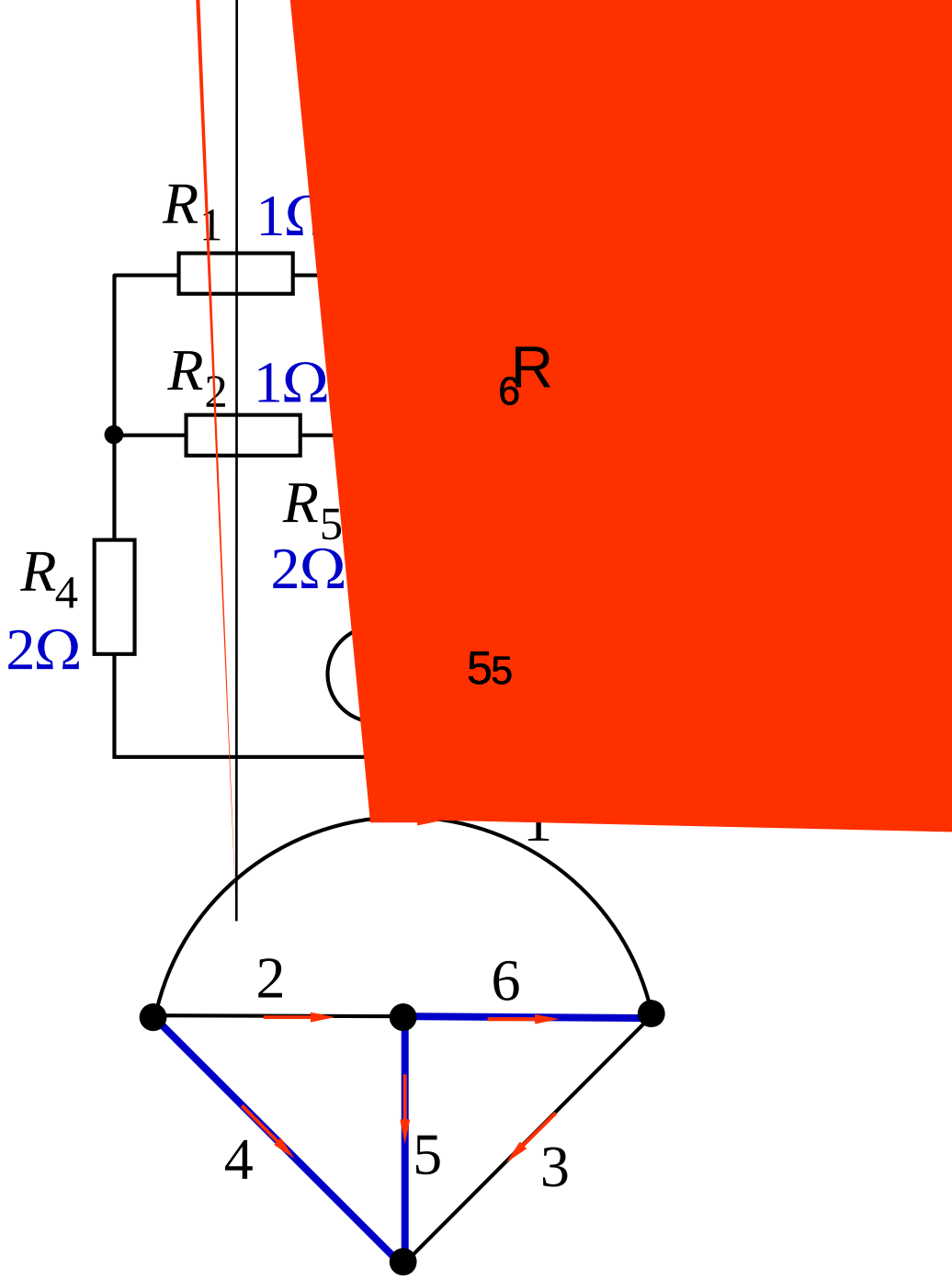
u_{s11} u_{sll} 1 l

2. P65 3 2



$$\left.\begin{array}{ll} \text{L1} & 4I_{l1}+2I_{l2}+1I_{l3}=-4 \\ \text{L2} & 2I_{l1}+5I_{l2}-2I_{l3}=2 \\ \text{L3} & 1I_{l1}-2I_{l2}+5I_{l3}=-2 \end{array}\right\}$$

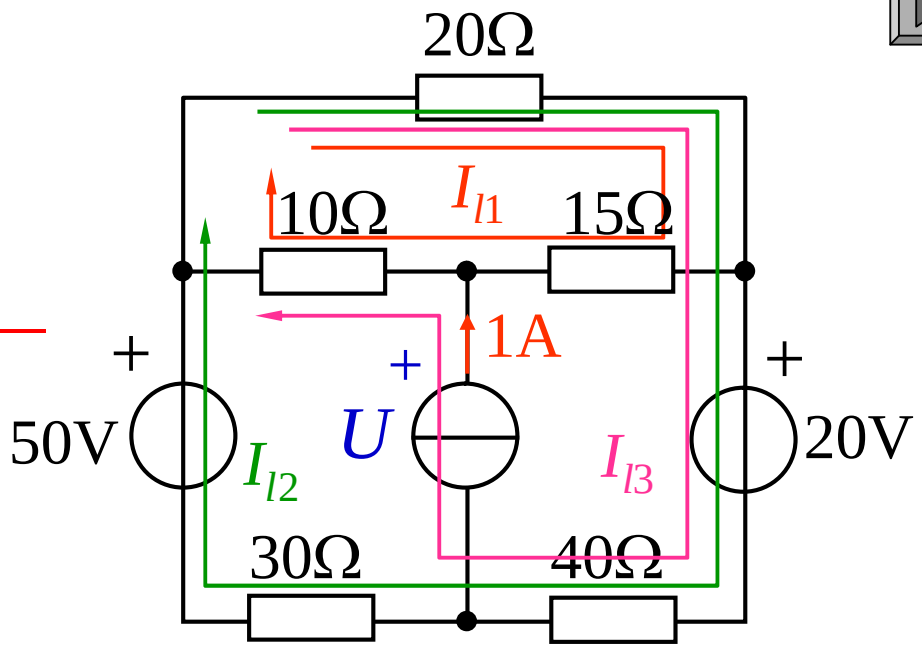
2. P65 3 2



P67 3 3

(1)

(2)

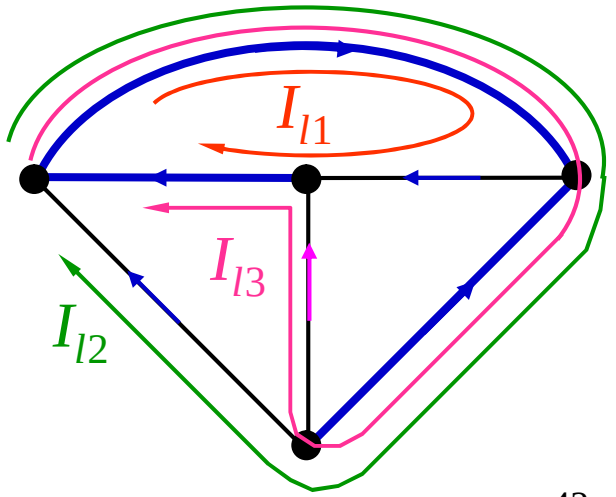


$$45I_{l1}+20I_{l2}+30I_{l3}=0$$

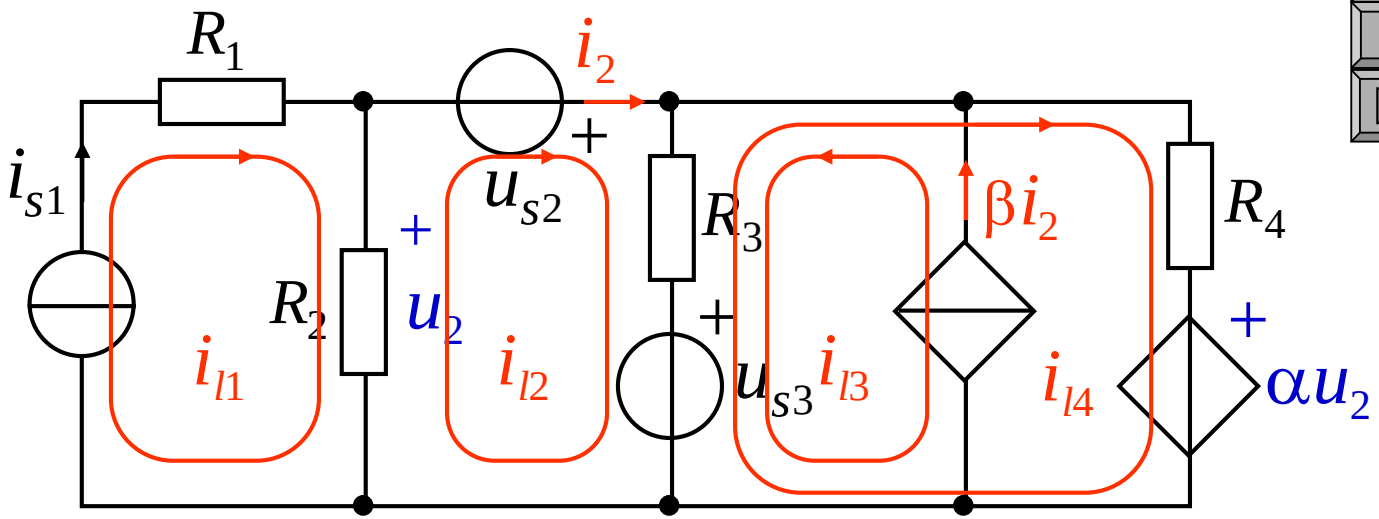
$$20I_{l1}+90I_{l2}+60I_{l3}=30$$

$$30I_{l1}+60I_{l2}+70I_{l3}=U-20$$

$$I_{l3}=1$$



P67-68 3 4



L2 $-R_2 i_{l1}+(R_2+R_3)i_{l2}+R_3 i_{l3}-R_3 i_{l4}=u_{s2}-u_{s3}$

L4 $-R_3 i_{l2}-R_3 i_{l3}+(R_3+R_4)i_{l4}=u_{s3}-\alpha u_2$

$i_{l1}=i_{s1}$ $i_{l3}=\beta i_{l2}$

1 3

KVL

$$\alpha u_2=\alpha R_2(i_{l1}-i_{l2})=\alpha R_2 i_{l1}-\alpha R_2 i_{l2}$$

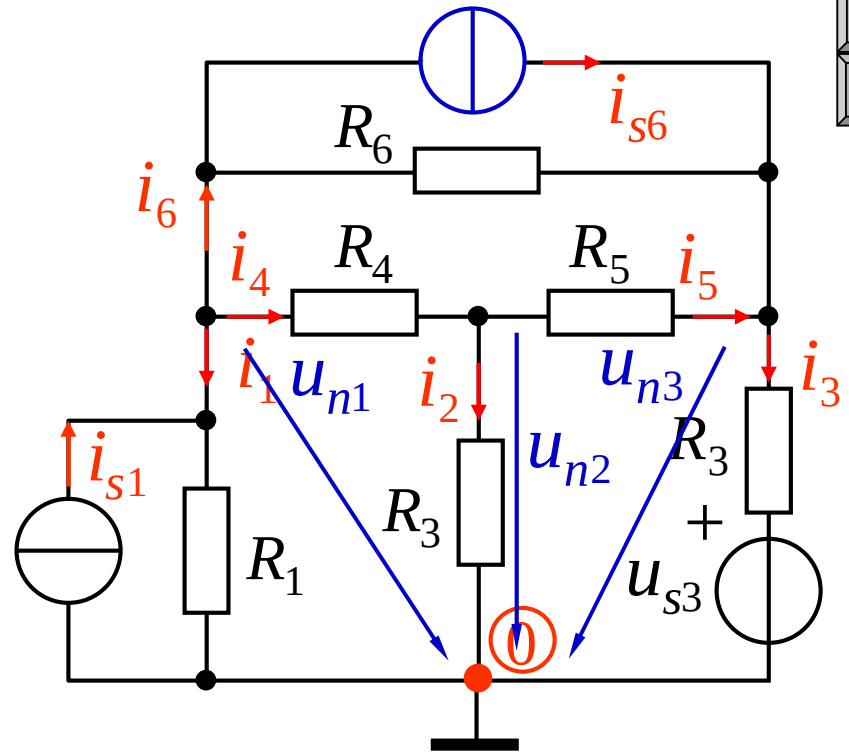
$$\alpha R_2 i_{l1}-(\alpha R_2+R_3)i_{l2}-R_3 i_{l3}+(R_3+R_4)i_{l4}=u_{s3}$$

3 6

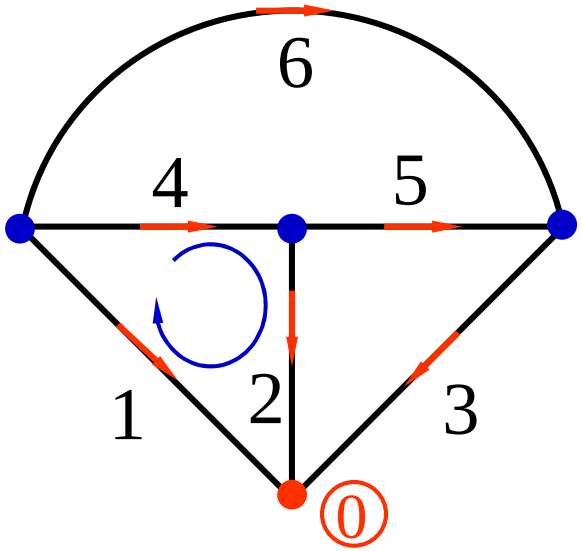
-

-

- *n* (*n* 1) (
)



1.



-

- $u_{n1}=u_1 \quad u_{n2}=u_2 \quad u_{n3}=u_3$

-

KVL $u_1 + u_4 + u_2 = 0$

$u_4 = u_1 \quad u_2 = u_{n1} \quad u_{n2}$

$u_5 = u_{n2} \quad u_{n3}$

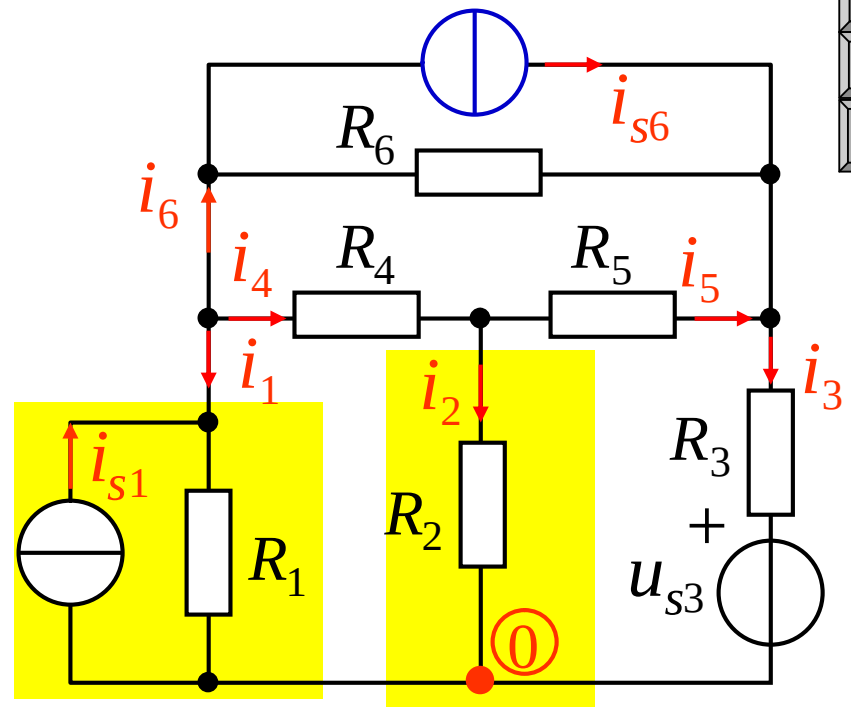
$u_6 = u_{n1} \quad u_{n3}$

$u_1 \quad u_6$

$u_{n1} \quad u_{n3}$

2.

- _____ KCL _____ !
-
-



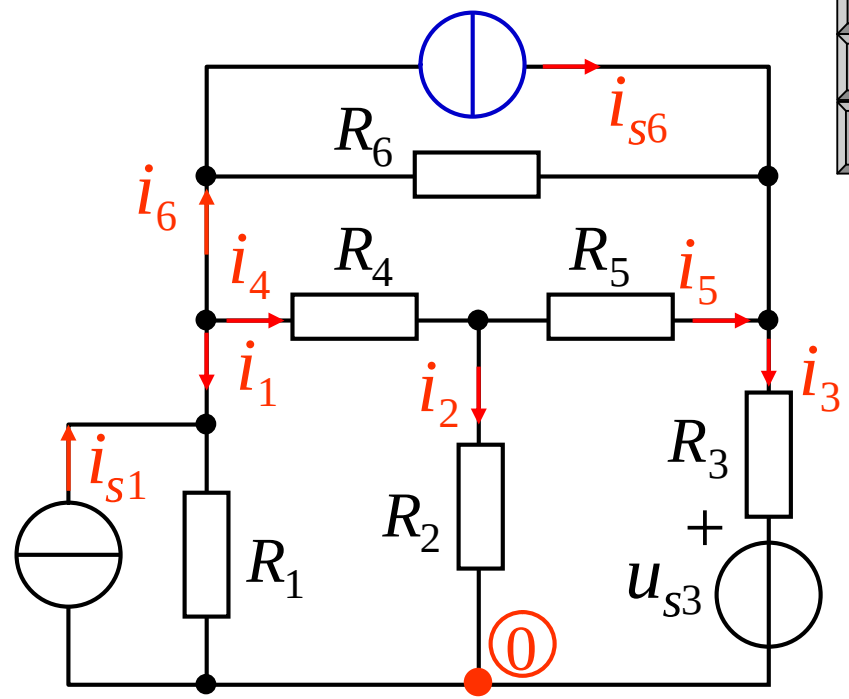
$$i_1 = \frac{u_{n1}}{R_1} - i_{s1} \qquad i_2 = \frac{u_{n2}}{R_2} \qquad i_3 = \frac{u_{n3} - u_{s3}}{R_3}$$

$$i_4 = \frac{u_{n1} - u_{n2}}{R_4} \qquad i_5 = \frac{u_{n2} - u_{n3}}{R_5} \qquad i_6 = \frac{u_{n1} - u_{n3}}{R_6} + i_{s6}$$

KCL:

$$\begin{cases} i_1+i_4+i_6=0 \\ i_2\ \ i_4+i_5=0 \\ i_3\ \ i_5\ \ i_6=0 \end{cases}$$

66



3

$$\left(\frac{1}{R_1}+\frac{1}{R_4}+\frac{1}{R_6}\right)u_{n1}-\frac{1}{R_4}u_{n2}-\frac{1}{R_6}u_{n3}=i_{s1}-i_{s6}$$

$$-\frac{1}{R_4}u_{n1}+\left(\frac{1}{R_2}+\frac{1}{R_4}+\frac{1}{R_5}\right)u_{n2}-\frac{1}{R_6}u_{n3}=0$$

$$-\frac{1}{R_6}u_{n1}-\frac{1}{R_5}u_{n2}+\left(\frac{1}{R_3}+\frac{1}{R_5}+\frac{1}{R_6}\right)u_{n3}=i_{s6}+\frac{u_{s3}}{R_3}$$

$$\frac{1}{R_1}\quad\frac{1}{R_6}\qquad G_1\quad G_6$$

$$(G_1+G_4+G_6)u_{n1}\quad G_4u_{n2}\quad G_6u_{n3}=i_{s1}\quad i_{s6}$$

$$G_4u_{n1}+(G_2+G_4+G_5)u_{n2}\quad G_5u_{n3}=0$$

$$G_6u_{n1}\quad G_5u_{n2}+(G_3+G_5+G_6)u_{n3}=i_{s6}+G_3u_{s3}$$

$$(G_1+G_4+G_6)u_{n1} - G_4u_{n2} - G_6u_{n3}=i_{s1} - i_{s6}$$
$$-G_4u_{n1}+(G_2+G_4+G_5)u_{n2} - G_5u_{n3}=0$$
$$-G_6u_{n1} - G_5u_{n2}+(G_3+G_5+G_6)u_{n3}=i_{s6}+G_3u_{s3}$$

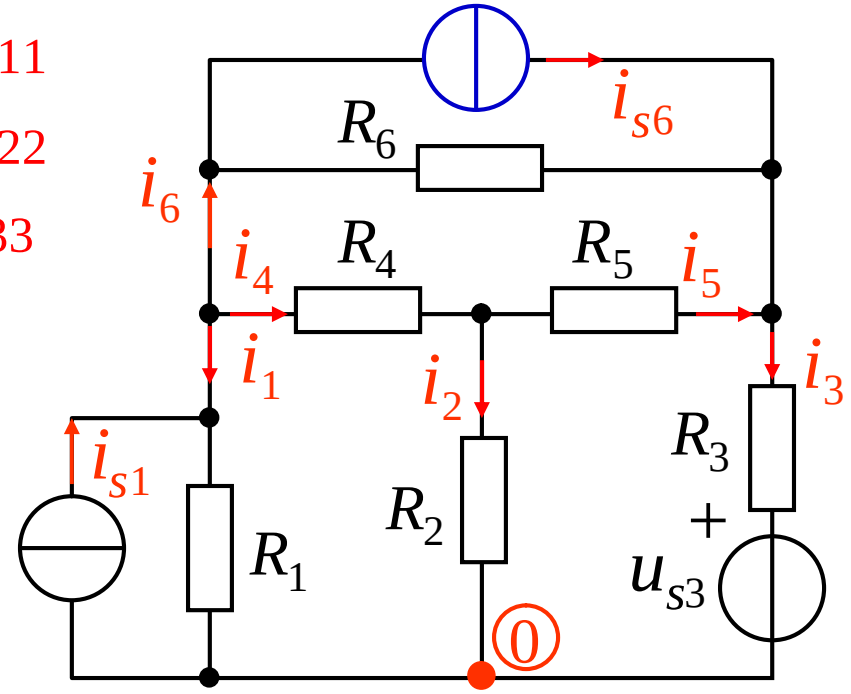
$$G_{11}u_{n1}+G_{12}u_{n2}+G_{13}u_{n3}=i_{s11}$$
$$G_{21}u_{n1}+G_{22}u_{n2}+G_{23}u_{n3}=i_{s22}$$
$$G_{31}u_{n1}+G_{32}u_{n2}+G_{33}u_{n3}=i_{s33}$$

3.

- $G_{11} = (G_1+G_4+G_6)$

$G_{22} =(G_2+G_4+G_5)$

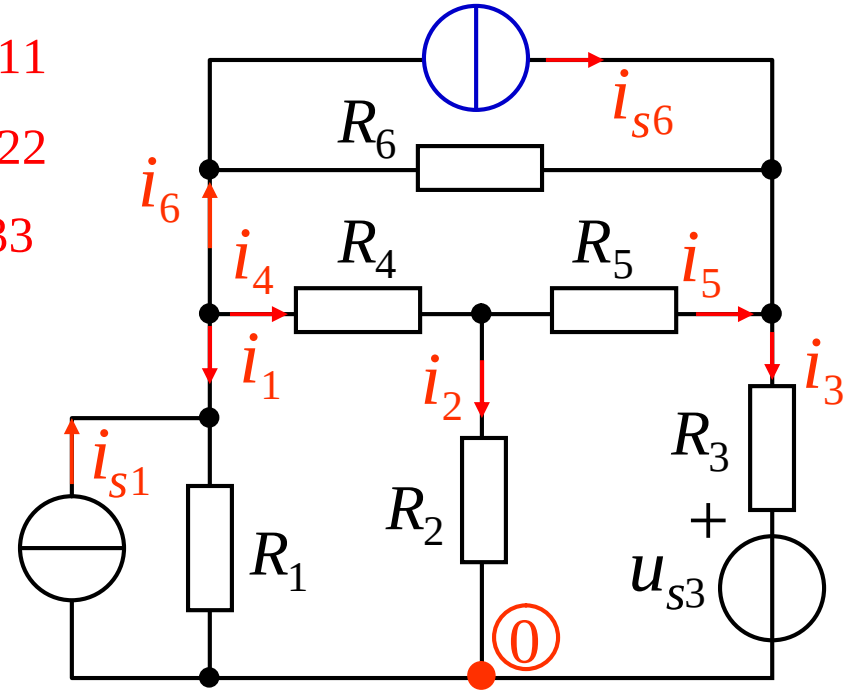
$G_{33} =(G_3+G_5+G_6)$



$$(G_1+G_4+G_6)u_{n1} - G_4u_{n2} - G_6u_{n3}=i_{s1} - i_{s6}$$
$$-G_4u_{n1}+(G_2+G_4+G_5)u_{n2} - G_5u_{n3}=0$$
$$-G_6u_{n1} - G_5u_{n2}+(G_3+G_5+G_6)u_{n3}=i_{s6}+G_3u_{s3}$$

$$G_{11}u_{n1}+G_{12}u_{n2}+G_{13}u_{n3}=i_{s11}$$
$$G_{21}u_{n1}+G_{22}u_{n2}+G_{23}u_{n3}=i_{s22}$$
$$G_{31}u_{n1}+G_{32}u_{n2}+G_{33}u_{n3}=i_{s33}$$

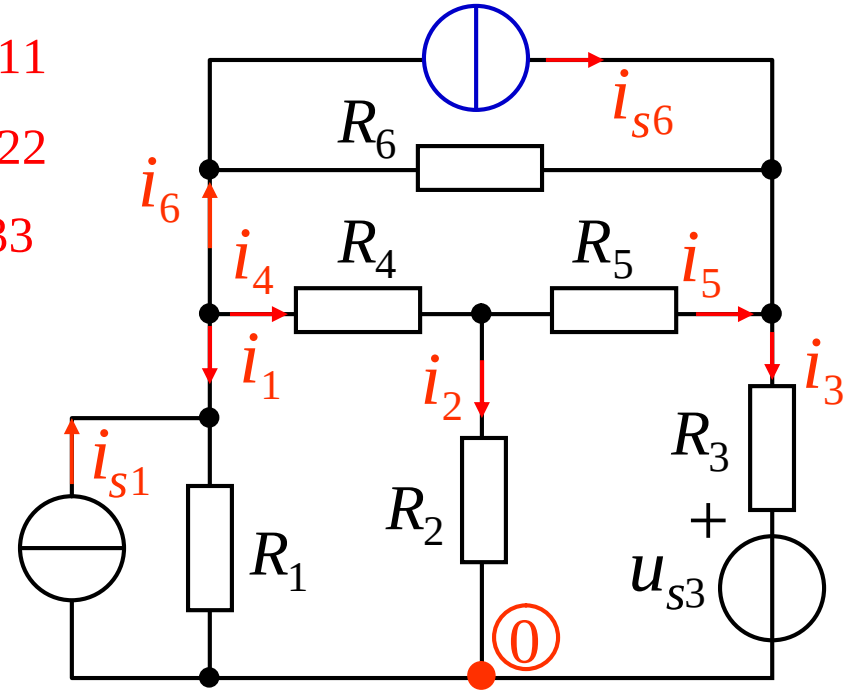
$$G_{12}=G_{21}=-G_4$$
$$G_{23}=G_{32}=-G_5$$
$$G_{13}=G_{31}=-G_6$$



$$(G_1+G_4+G_6)u_{n1} - G_4u_{n2} - G_6u_{n3}=i_{s1} - i_{s6}$$
$$-G_4u_{n1}+(G_2+G_4+G_5)u_{n2} - G_5u_{n3}=0$$
$$-G_6u_{n1} - G_5u_{n2}+(G_3+G_5+G_6)u_{n3}=i_{s6}+G_3u_{s3}$$

$$G_{11}u_{n1}+G_{12}u_{n2}+G_{13}u_{n3}=i_{s11}$$
$$G_{21}u_{n1}+G_{22}u_{n2}+G_{23}u_{n3}=i_{s22}$$
$$G_{31}u_{n1}+G_{32}u_{n2}+G_{33}u_{n3}=i_{s33}$$

$$i_{s11}=i_{s1}-i_{s6} \qquad i_{s22}=0$$
$$i_{s33}=i_{s6}-G_3u_{s3}$$



4.

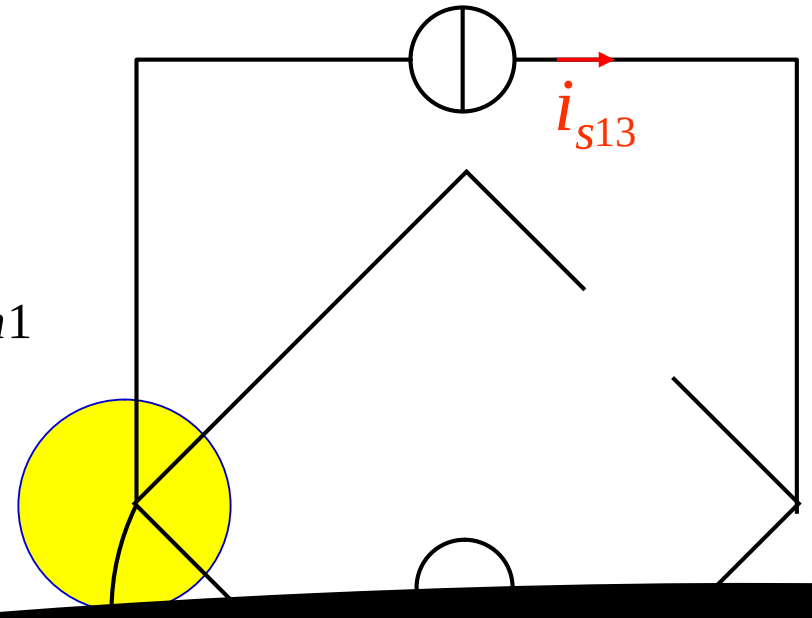
- n 1

$$
\begin{aligned}
&G_{11}u_{n1}+G_{12}u_{n2}+G_{13}u_{n3}+\cdots+G_{1(n\ 1)}u_{n(n\ 1)}=i_{s11}\\
&G_{21}u_{n1}+G_{22}u_{n2}\ \ G_{23}u_{n3}+\cdots+G_{2(n\ 1)}u_{n(n\ 1)}=i_{s22}\\
&G_{31}u_{n1}+G_{32}u_{n2}+G_{33}u_{n3}+\cdots+G_{3(n\ 1)}u_{n(n\ 1)}=i_{s33}\\
&\qquad\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\\
&G_{(n\ 1)1}u_{n1}+G_{(n\ 1)2}u_{n2}+G_{(n\ 1)3}u_{n3}+\\
&\qquad\qquad\cdots+G_{(n\ 1)(n\ 1)}\ u_{(n\ 1)(n\ 1)}=i_{s(n\ 1)(n\ 1)}
\end{aligned}
$$

- $G_{ij}=G_{ji}$

P71 3 5

⓪



: $(G_1+G_4+G_8)u_{n1}$

$-G_1 u_{n2} - G_4 u_{n4} = i_{s4} - i_{s13}$

: $(G_1+G_2+G_5)u_{n2}$

$-G_1 u_{n1} - G_2 u_{n3} = 0$

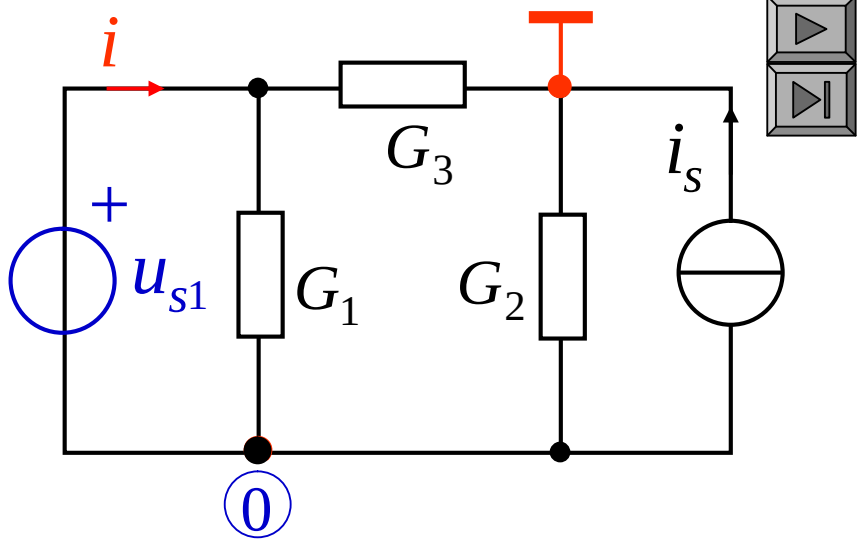
: $(G_3+G_4+G_7)u_{n4} - G_4 u_{n1} - G_3 u_{n3}$

$= G_3 u_{s3} + G_7 u_{s7} - i_{s4}$

3 6 ( )

5.

P73 3 7



$$(G_1+G_3)u_{n1}-G_3u_{n2}=i$$

$$-G_3u_{n1}+(G_2+G_3)u_{n2}=i_{s2}$$

$$u_{n1}=u_{s1}$$

u_{s1}

$u_{n1}=u_{s1}$

u_{n2}

$$(G_1+G_3)u_{n1}-G_1u_{n0}=i$$

$$-G_1u_{n1}+(G_1+G_2)u_{n0}=-i_{s2}-i$$

$$u_{n1}-u_{n0}=u_{s1}$$

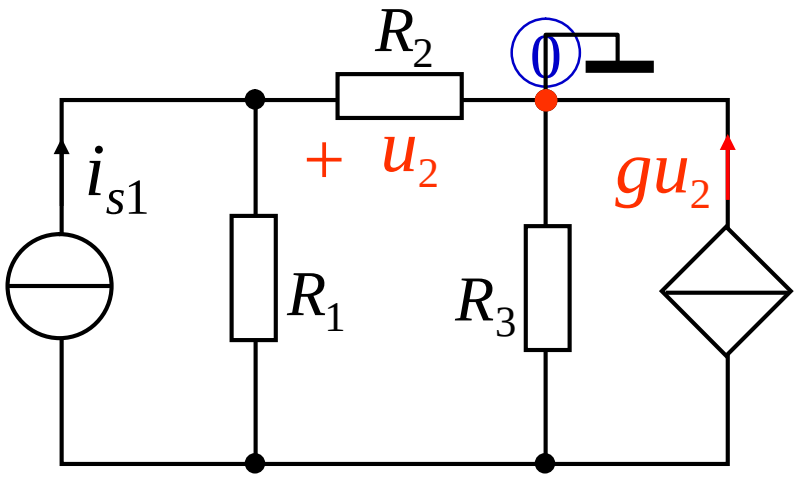
3 7

6. P74 3 8

(1)

“0”

$u_{n1} = u_2$



(2)

$$: \quad \left(\frac{1}{R_1}+\frac{1}{R_2}\right)u_{n1} - \frac{1}{R_1}u_{n2} = i_{s1} \qquad (3)$$

$$: \quad +\left(\frac{1}{R_2}+\frac{1}{R_3}\right)u_{n2} = -i_{s1} - gu_{n1}$$

$$\left(-\frac{1}{R_1}+g\right)u_{n1}$$

1. (“–”)

2. :

3.

4.