Chapter 12

三相正弦稳态电路

12.2 三相电路

Three-phase circuits

12.3 对称三相电路分析

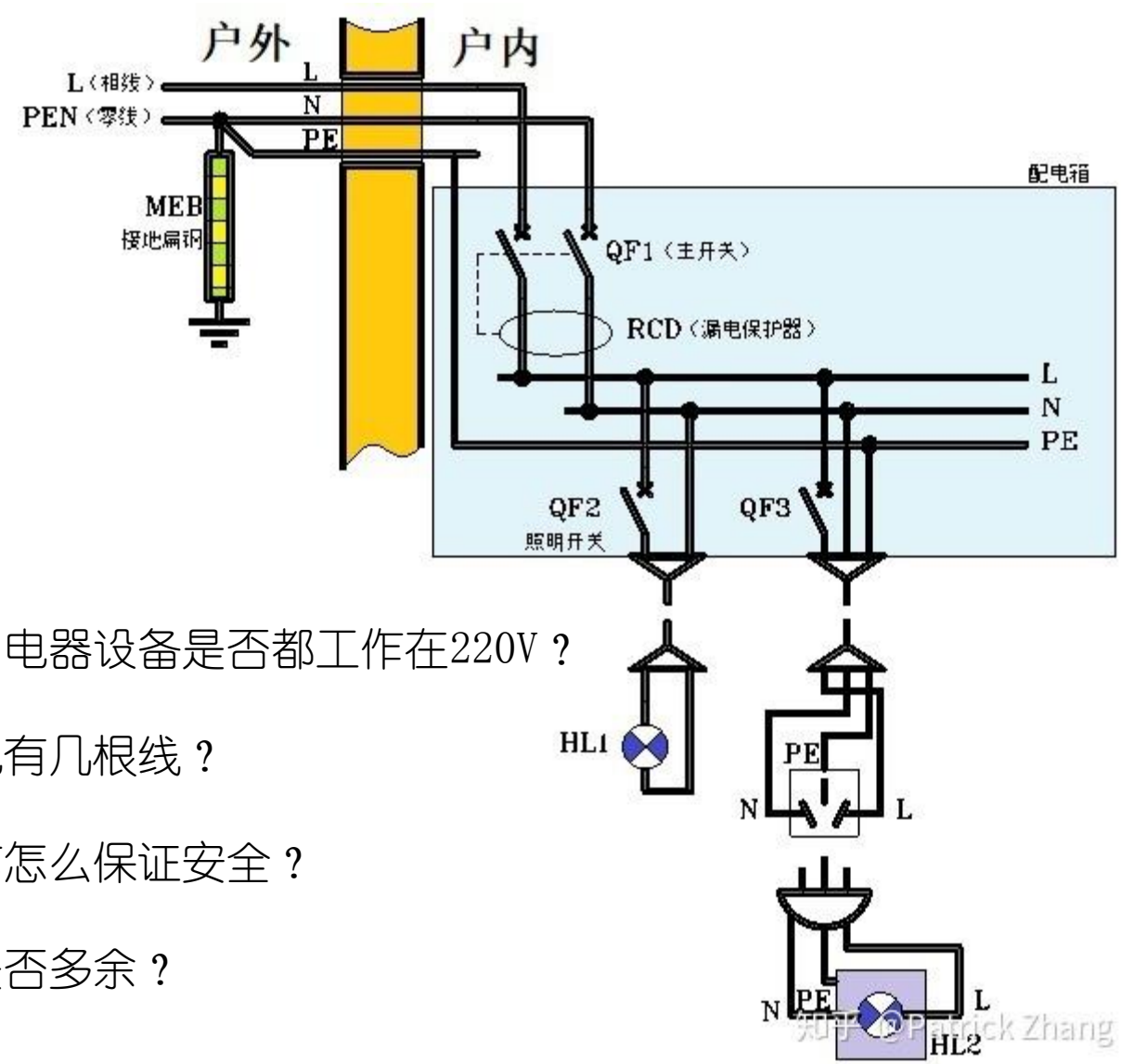
Analysis of balanced three-phase circuits

12.4 三相电路的功率及测量

Power of three-phase circuits and Measurement

12.5不对称三相电路分析

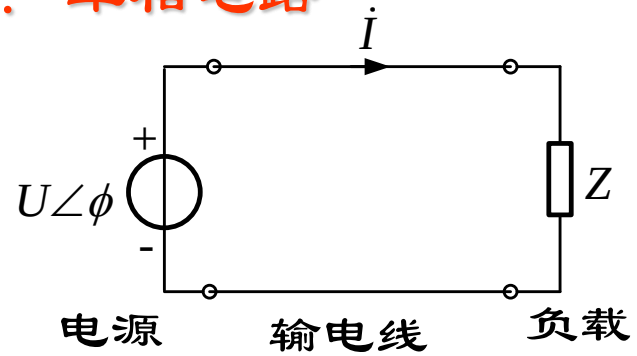
Analysis of unbalanced three-phase circuits



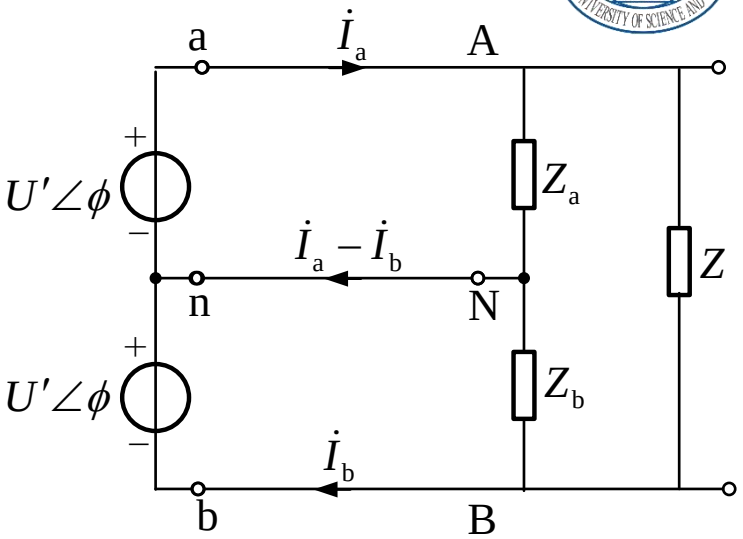
- 我国常用电器设备是否都工作在220V？
- 居民配电有几根线？
- 带电操作怎么保证安全？
- 接地线是否多余？

12.2三相电路

1. 单相电路



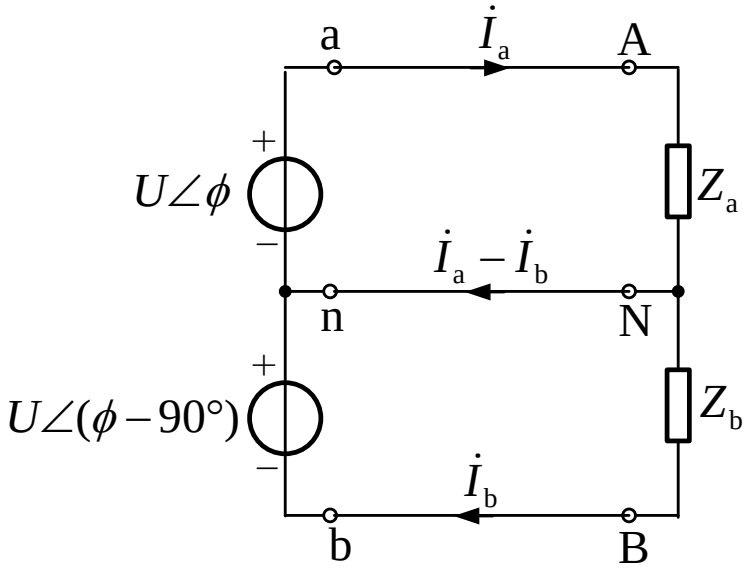
单相2线



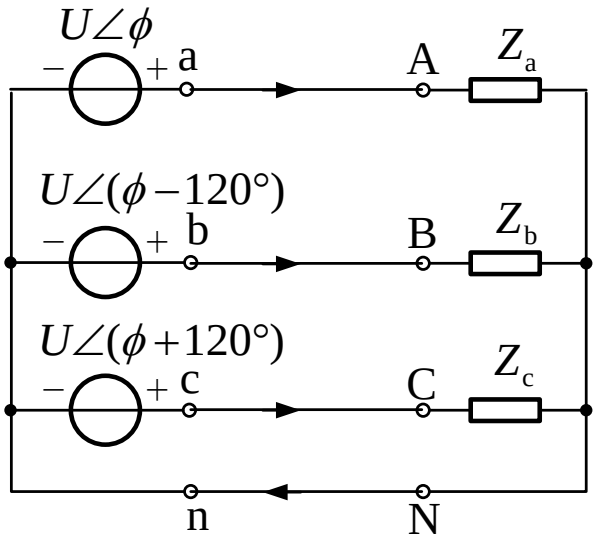
单相3线

2. 多相电路

电源不同相，频率、幅值相同

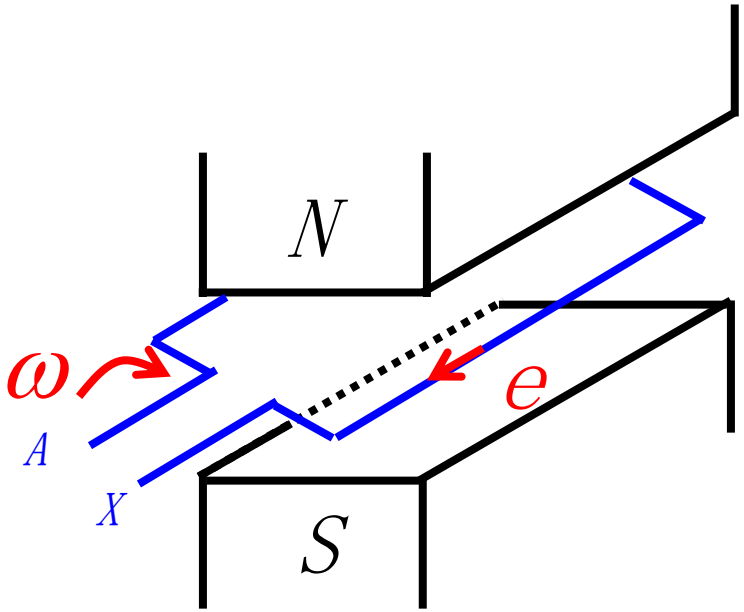


2相3线

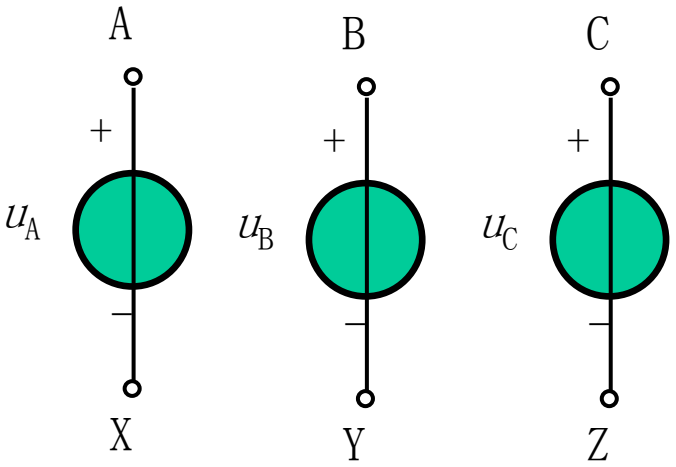


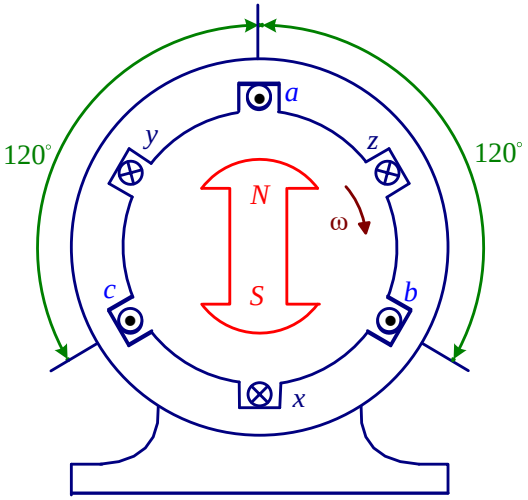
3相4线

12.2三相电路



$$e_{AX} = \sqrt{2}E\cos\omega t$$



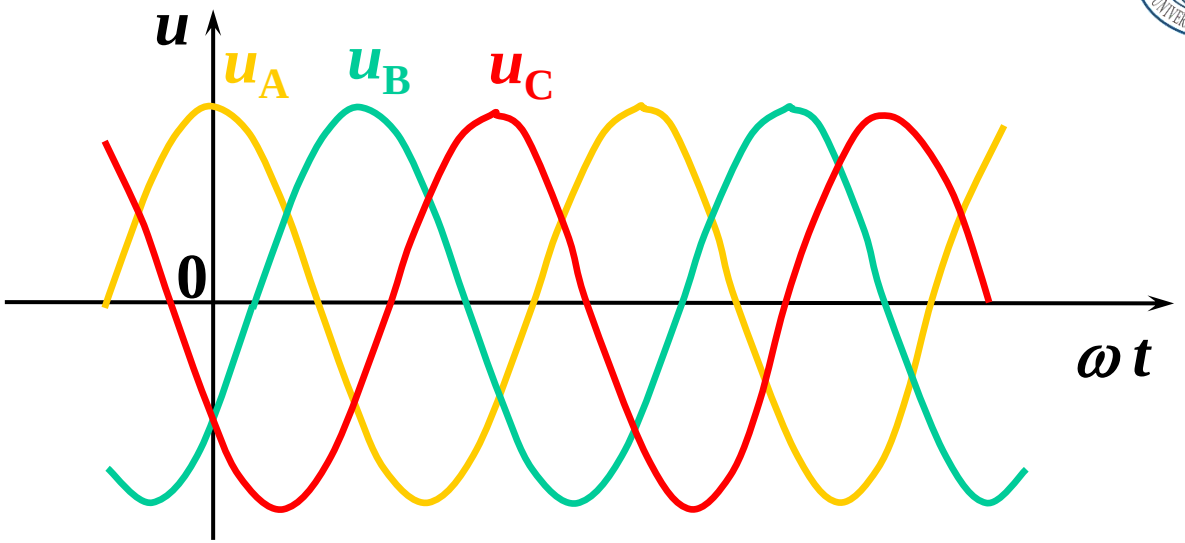


$$u_{\mathbf{A}}(t) = \sqrt{2}U\cos\omega t$$

$$u_{\mathbf{B}}(t) = \sqrt{2}U\cos(\omega t - 120^{\mathbf{o}})$$

$$u_{\mathbf{C}}(t) = \sqrt{2}U\cos(\omega t + 120^{\mathbf{o}})$$

1. 波形图

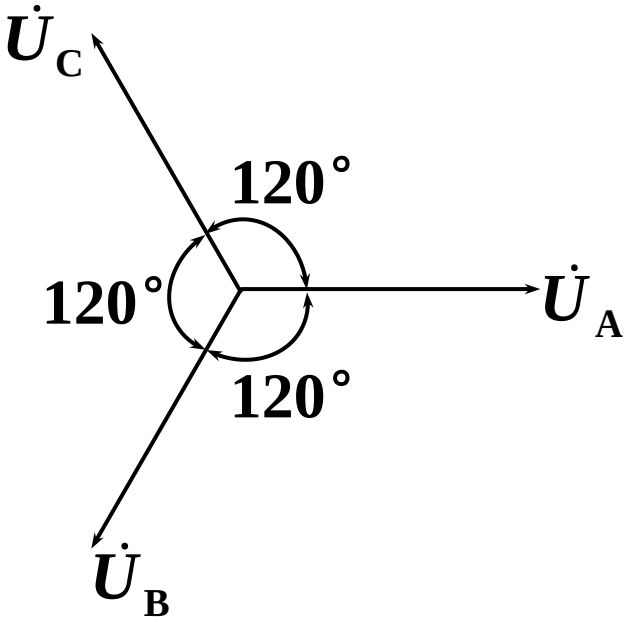


2. 相量表示

$$\dot{U}_a = U\angle\theta$$

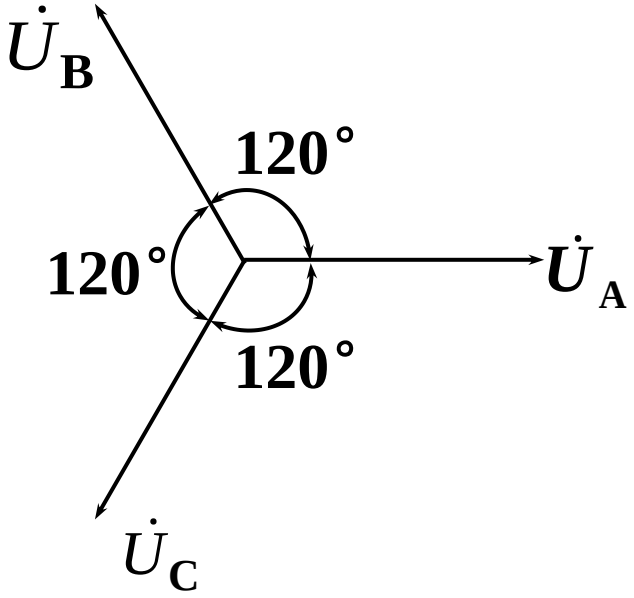
$$\dot{U}_b = U\angle(\theta-120°)$$

$$\dot{U}_c = U\angle(\theta+120°)$$



正序

$$\dot{U}_a = U\angle\theta$$
$$\dot{U}_b = U\angle(\theta+120°)$$
$$\dot{U}_c = U\angle(\theta-120°)$$

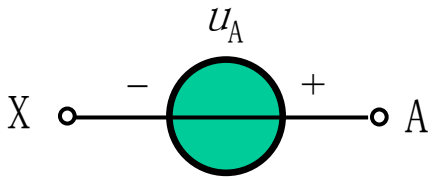


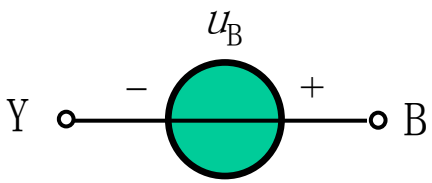
负序

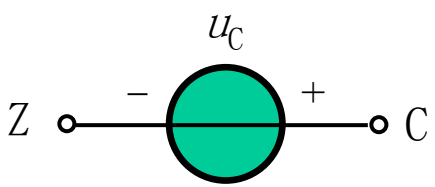
3. 对称三相电源的特点

$$u_A + u_B + u_C = 0$$
$$\dot{U}_A + \dot{U}_B + \dot{U}_C = 0$$

2. 对称三相电源



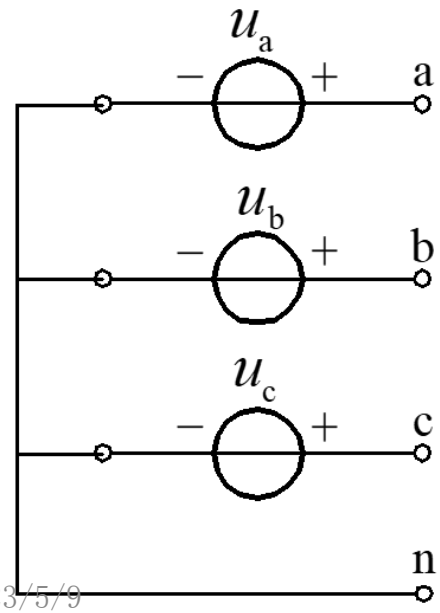




$$u_A(t)=\sqrt{2}U\cos\omega t \qquad u_B(t)=\sqrt{2}U\cos(\omega t-120^o) \qquad u_C(t)=\sqrt{2}U\cos(\omega t+120^o)$$

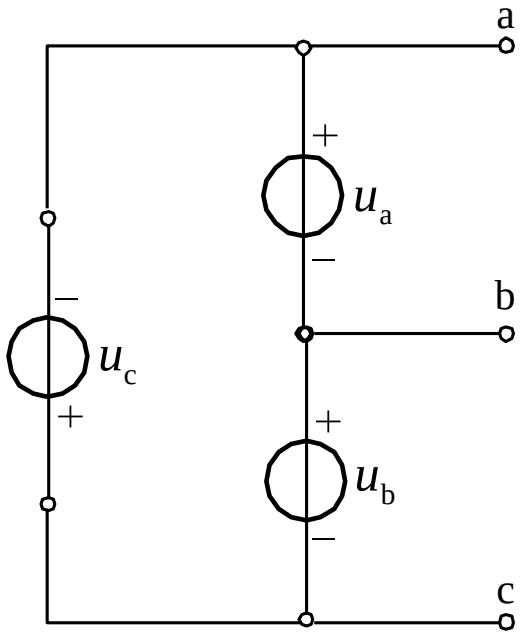
星形（Y connection）

对称三相电压源



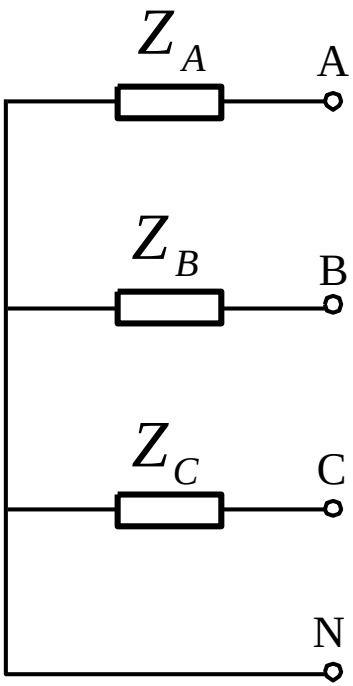
三角形（Δ connection）

对称三相电压源

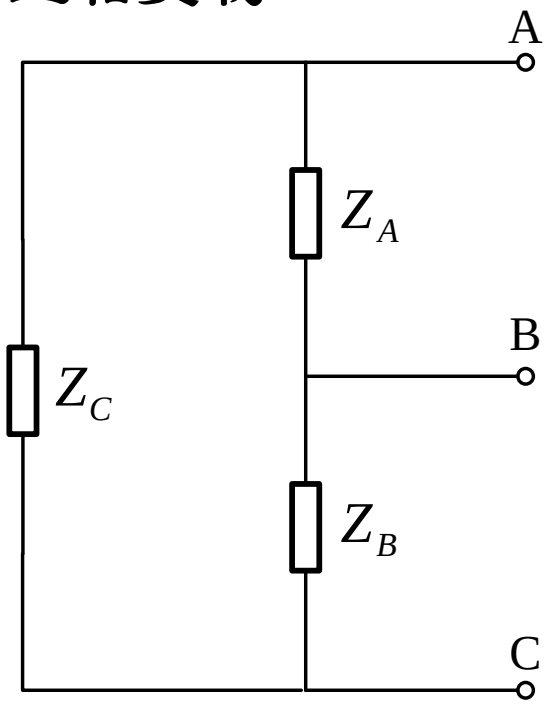


3. 三相负载

星形（Y connection）
三相负载

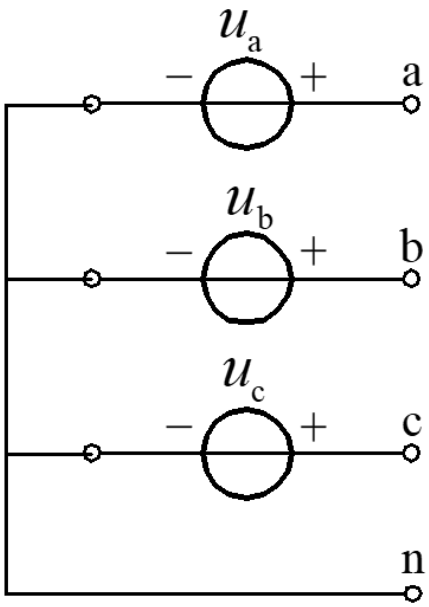


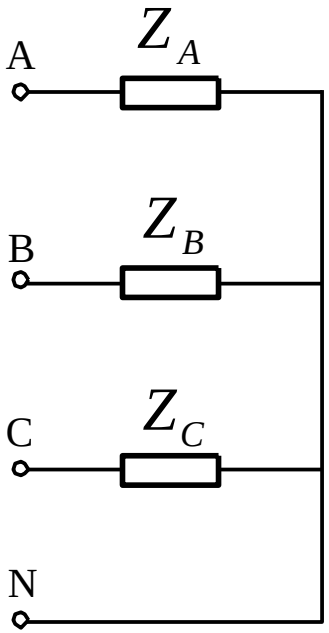
三角形（Δ connection）
三相负载



对称负载（Balanced load）：$Z_A = Z_B = Z_C$

连接方式





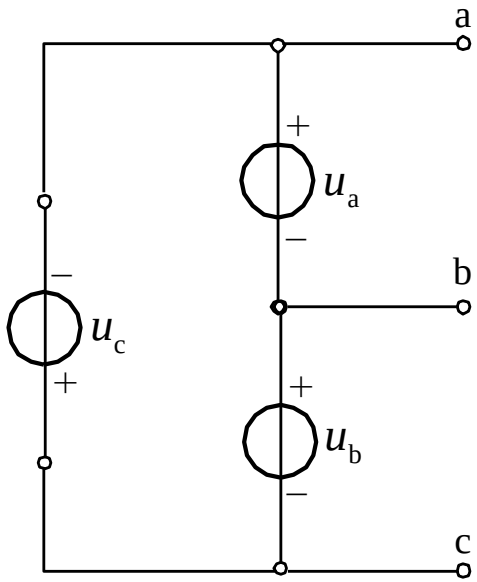
$Y_n - Y_N$

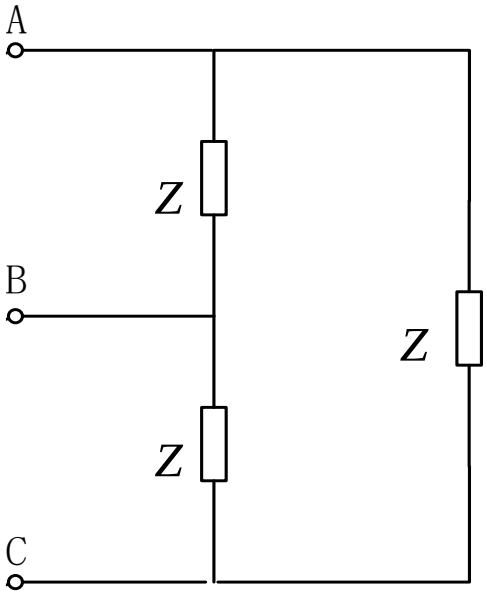
$Y - Y$

$Y - \Delta$

$\Delta - Y$

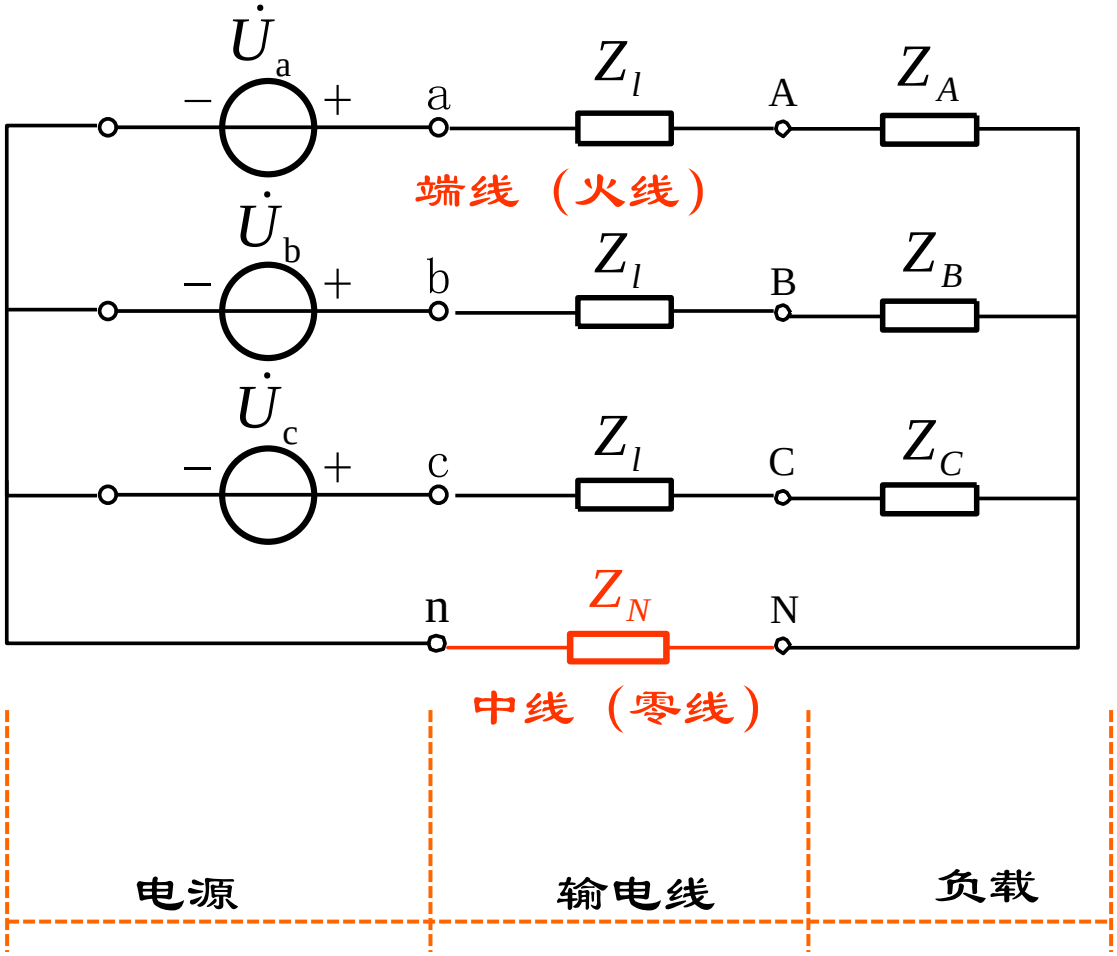
$\Delta - \Delta$





4. 三相电路

- 对称三相电路



名词介绍：

① 火线(端线)：
a，b，c 三端引出线。

② 中线：
公共连接点引出线。

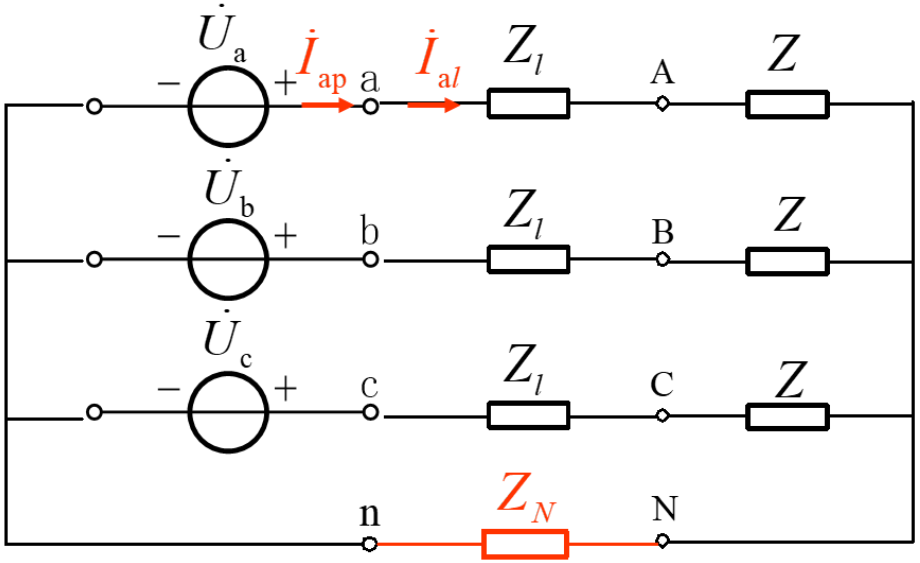
名词介绍：

③ 线电压(line voltage)：火线与火线之间的电压。

④相电压(phase voltage)：每相电源(负载)的电压。

⑤线电流(line current)：流过火线的电流。

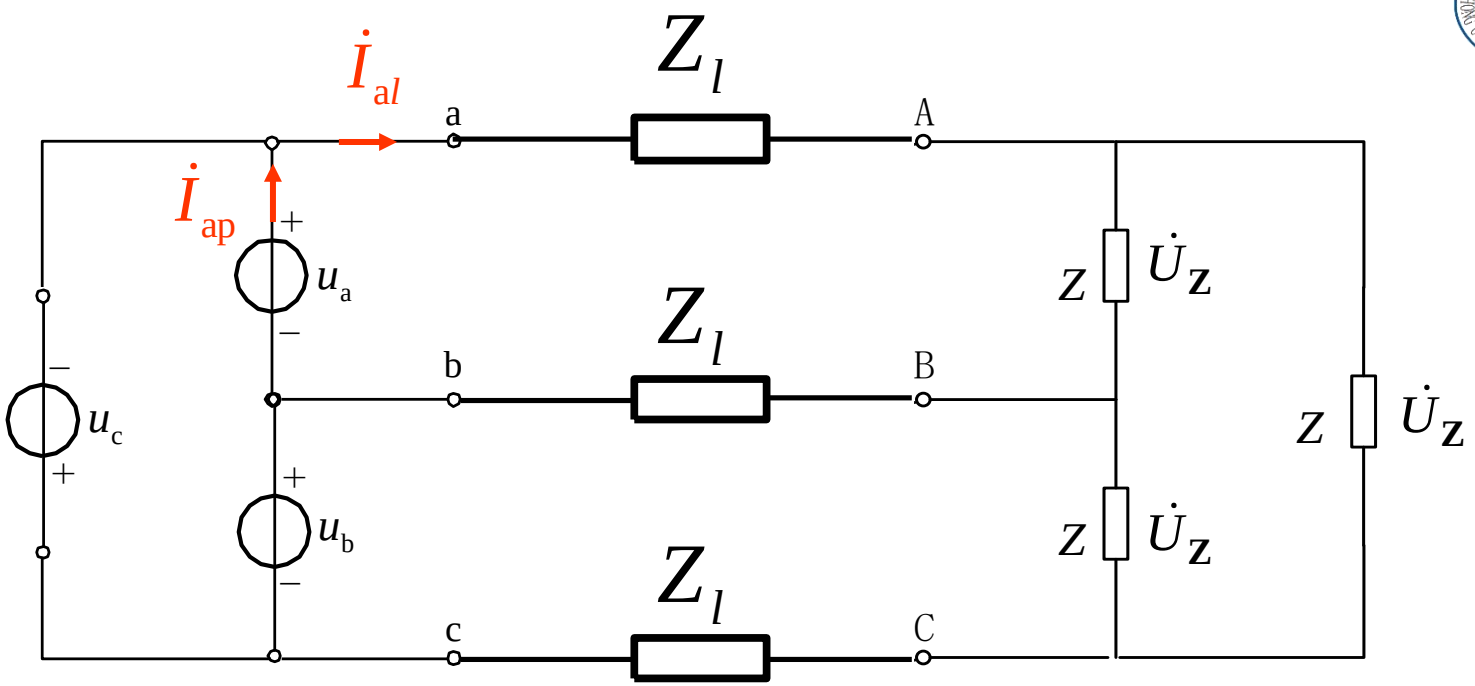
⑥相电流(phase current)：流过每相电源(负载)的电流。



$\dot{U}_{an}$ $\dot{U}_{bn}$ $\dot{U}_{cn}$ $\dot{U}_{ab}$

$\dot{U}_{AN}$ $\dot{U}_{AB}$

$\dot{I}_{ap}$ $\dot{I}_{al}$



$\dot{U}_{\mathbf{a}}$ $\dot{U}_{\mathbf{b}}$ $\dot{U}_{\mathbf{c}}$ $\dot{U}_{ab}$

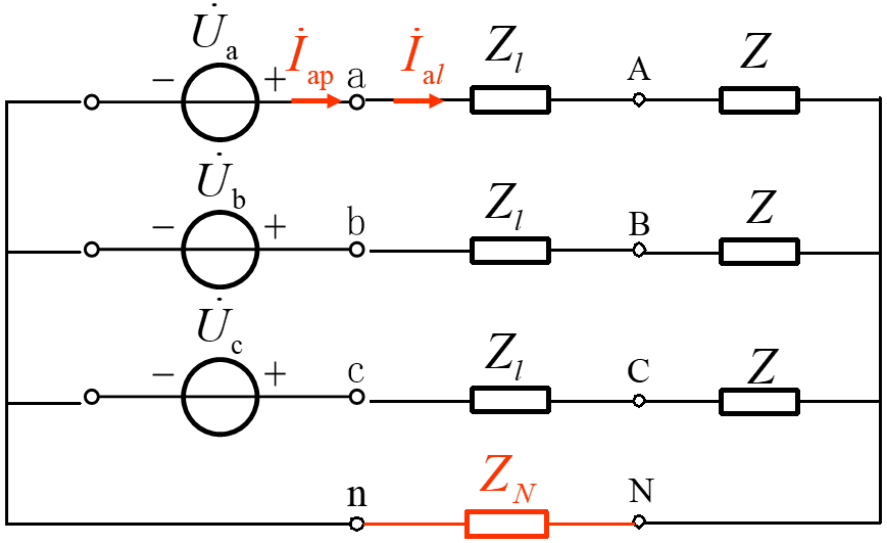
$\dot{U}_{\mathbf{Z}}$ $\dot{U}_{AB}$

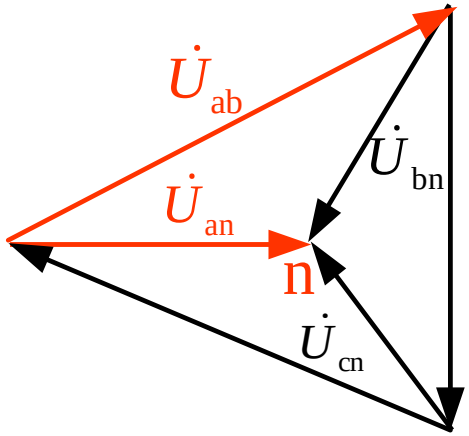
$\dot{I}_{ap}$ $\dot{I}_{al}$

12.3对称三相电路分析

1. 线电压与相电压，线电流与相电流的关系

Y型连接：





$$\dot{U}_{ab} = \sqrt{3}\dot{U}_{an}\angle 30°$$

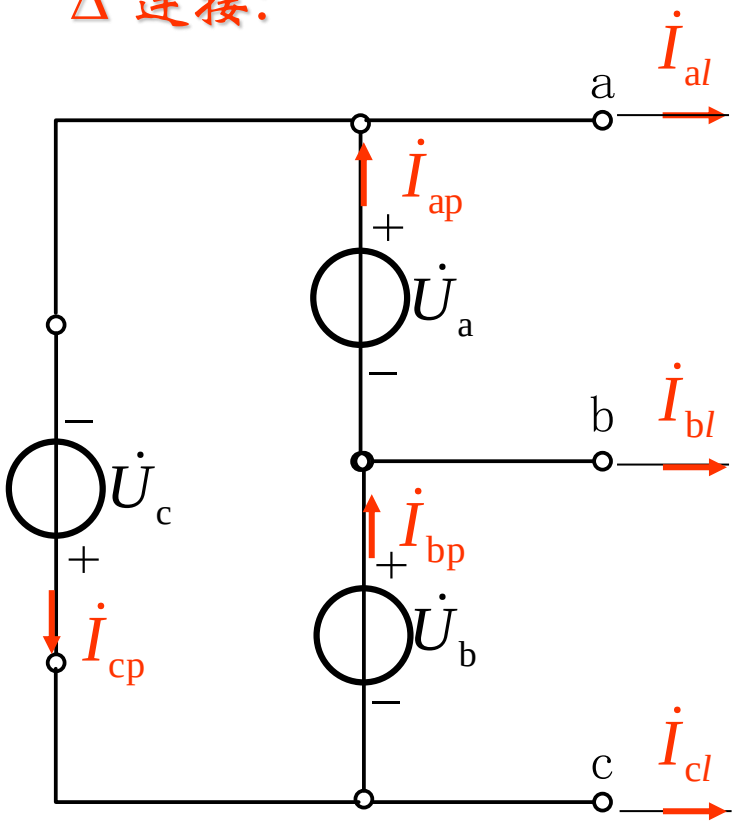
$$\dot{U}_{AB} = \sqrt{3}\dot{U}_{AN}\angle 30°$$

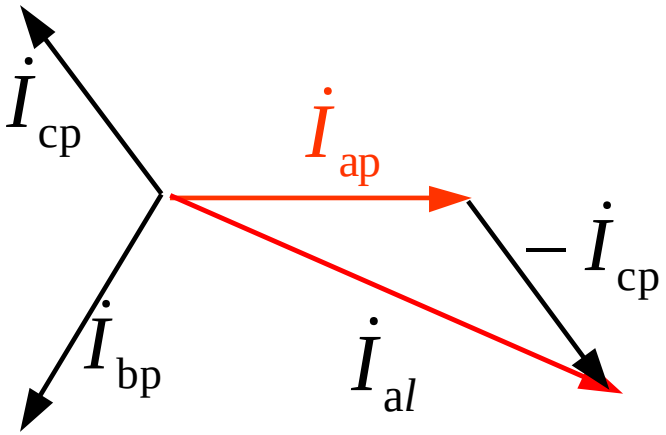
$$\dot{I}_{ap} = \dot{I}_{al}$$

12.3对称三相电路分析

1. 线电压与相电压，线电流与相电流的关系

Δ 连接：

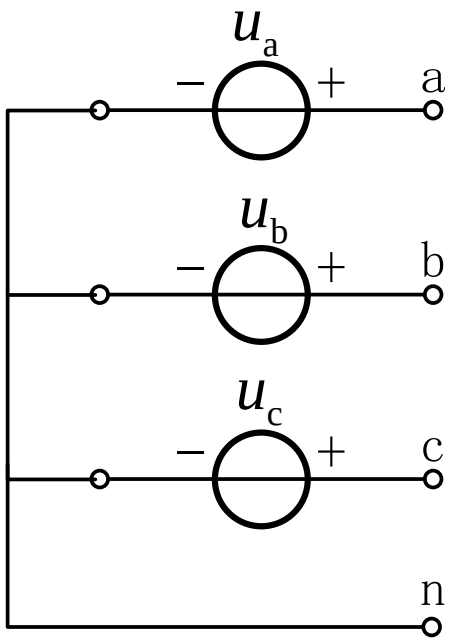




$$\dot{I}_{al} = \sqrt{3}\dot{I}_{ap}\angle -30°$$

$$\dot{U}_{ab} = \dot{U}_a$$

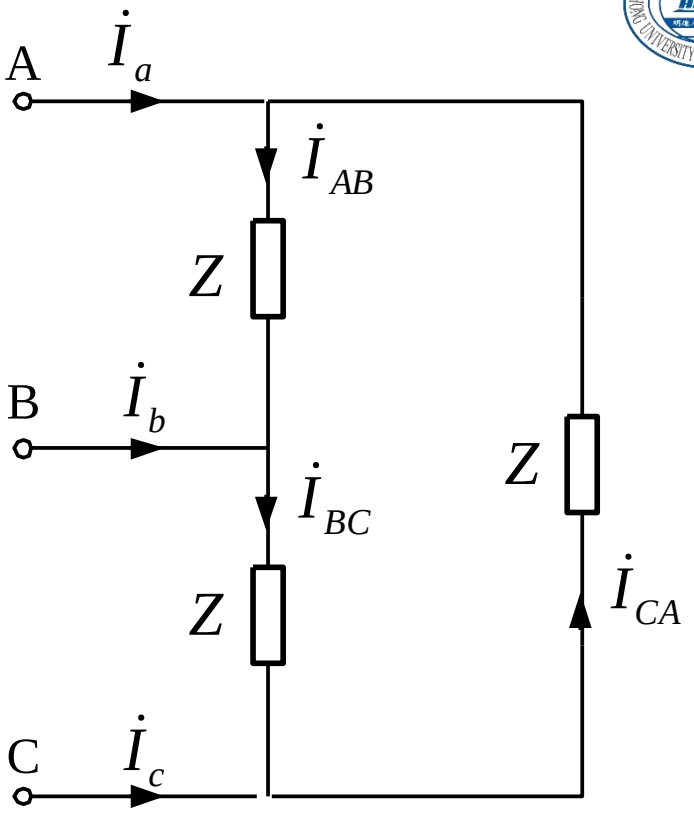
例题



$$u_a = 220\sqrt{2}\sin(100\pi t + 30°)V$$

$u_{bc} = ?$

$$u_{bc} = 220\sqrt{3}\sqrt{2}\sin(100\pi t - 60°)V$$



$$\dot{I}_{BC} = 10\angle 0°A$$

$\dot{I}_a = ?$

$$\dot{I}_a = 10\sqrt{3}\angle 90°A$$

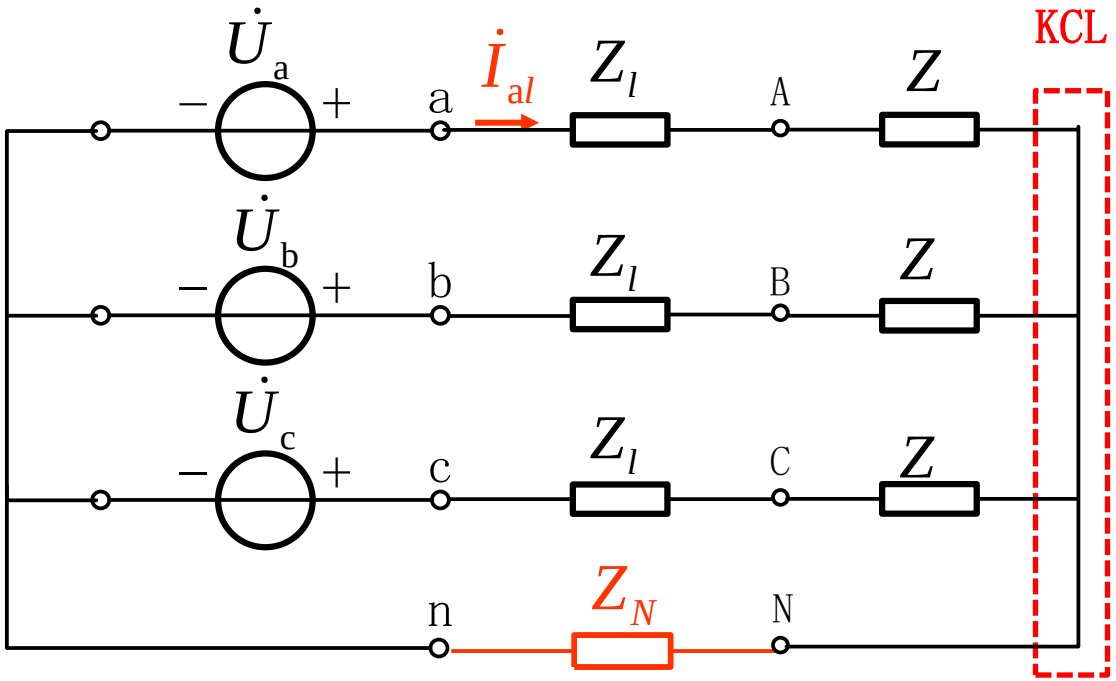
2. Y-Y 连接

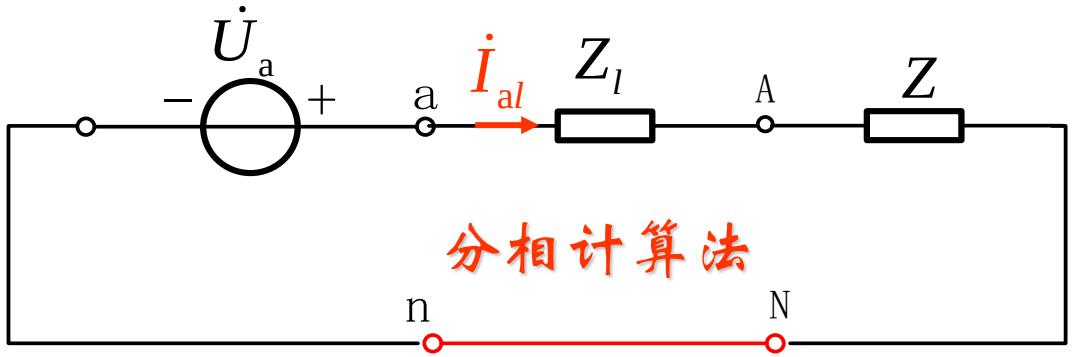
$$\left(\frac{3}{Z+Z_l}+\frac{1}{Z_N}\right)\dot{U}_{Nn}=\frac{\dot{U}_a+\dot{U}_b+\dot{U}_c}{Z+Z_l}$$

$$\boxed{\dot{U}_{Nn}=0}$$

$$\dot{I}_{al}=\frac{\dot{U}_a}{Z+Z_l}$$

$$\dot{I}_{bl}=\dot{I}_{al}\angle -120^\circ$$

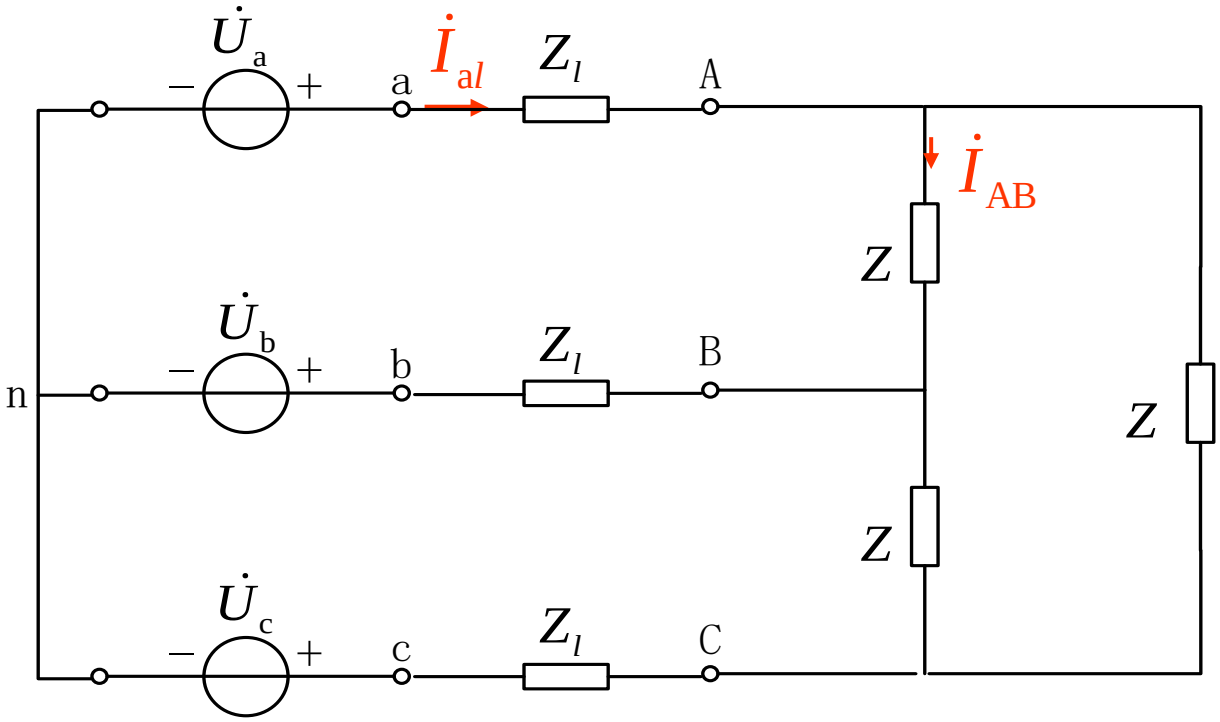


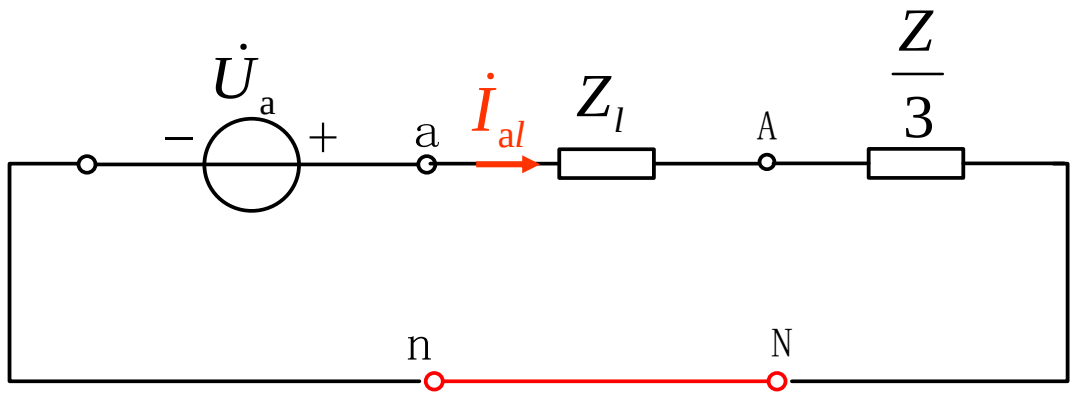


3. Y-Δ 连接

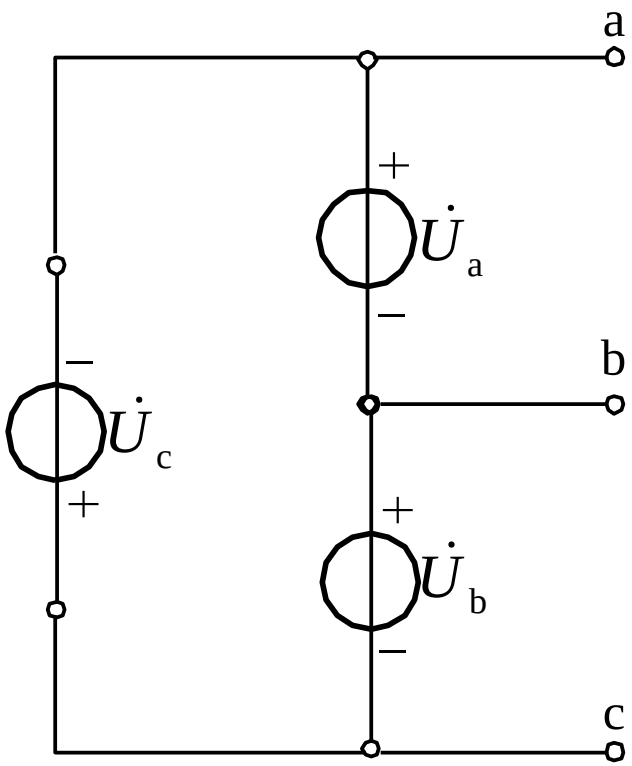
$$\dot{I}_{al}=\frac{\dot{U}_a}{\frac{Z}{3}+Z_l}$$

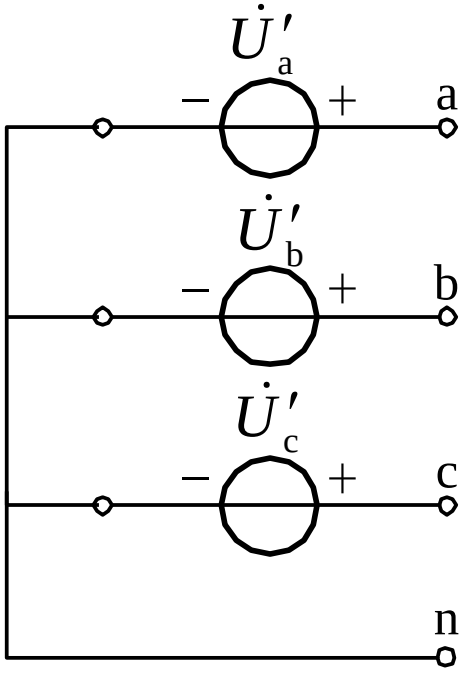
$$\dot{I}_{AB}=\frac{\dot{I}_{al}\angle 30^\circ}{\sqrt{3}}$$





4. Δ - Y 连接





$$\dot{U}'_a = \frac{\dot{U}_a \angle -30°}{\sqrt{3}}$$

Practice Balanced three-phase circuit is shown in Fig. The reading of the volt-meter is 380V. Find U_{ab} and the reading of the ampere meter.

$$Z = (15 + \mathrm{j}15\sqrt{3})\Omega$$

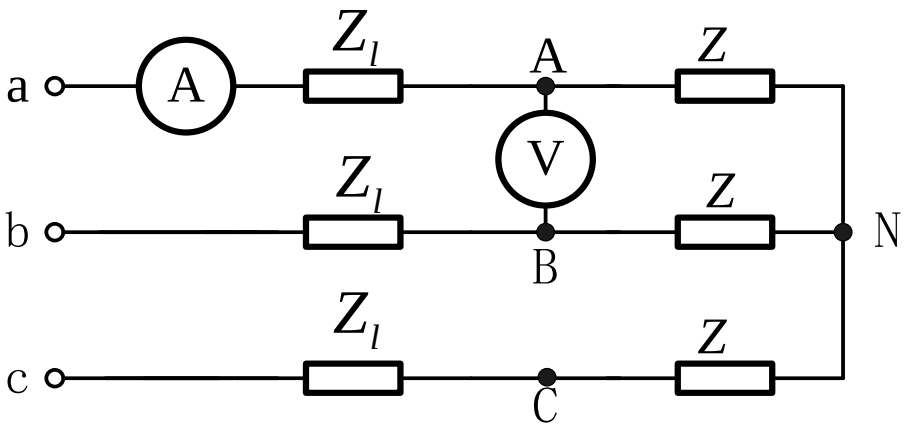
$$Z_l = (1 + \mathrm{j}2)\Omega$$

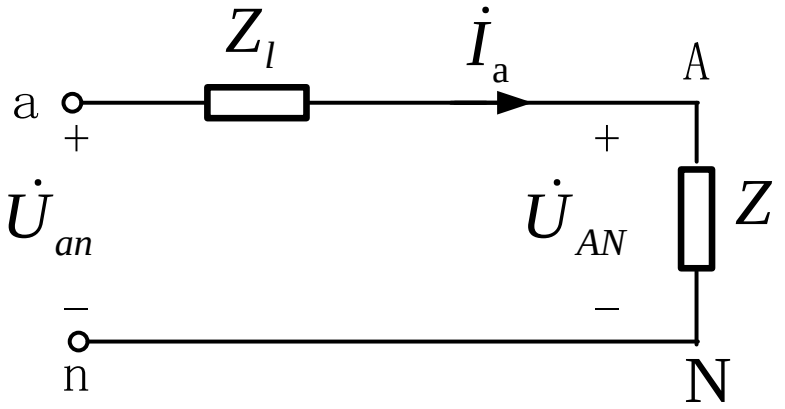
$$\dot{U}_{AN} = \frac{380}{\sqrt{3}}\angle 0°$$

$$\dot{I}_a = \frac{\dot{U}_{AN}}{Z}$$

$$\dot{U}_{an} = \dot{I}_a(Z_l + Z)$$

$$\dot{U}_{ab} = \sqrt{3}\dot{U}_{an}\angle 30°$$





Practice Balanced three-phase circuit is shown in Fig. The line voltage of source is U_l. Find the phase current of each load.

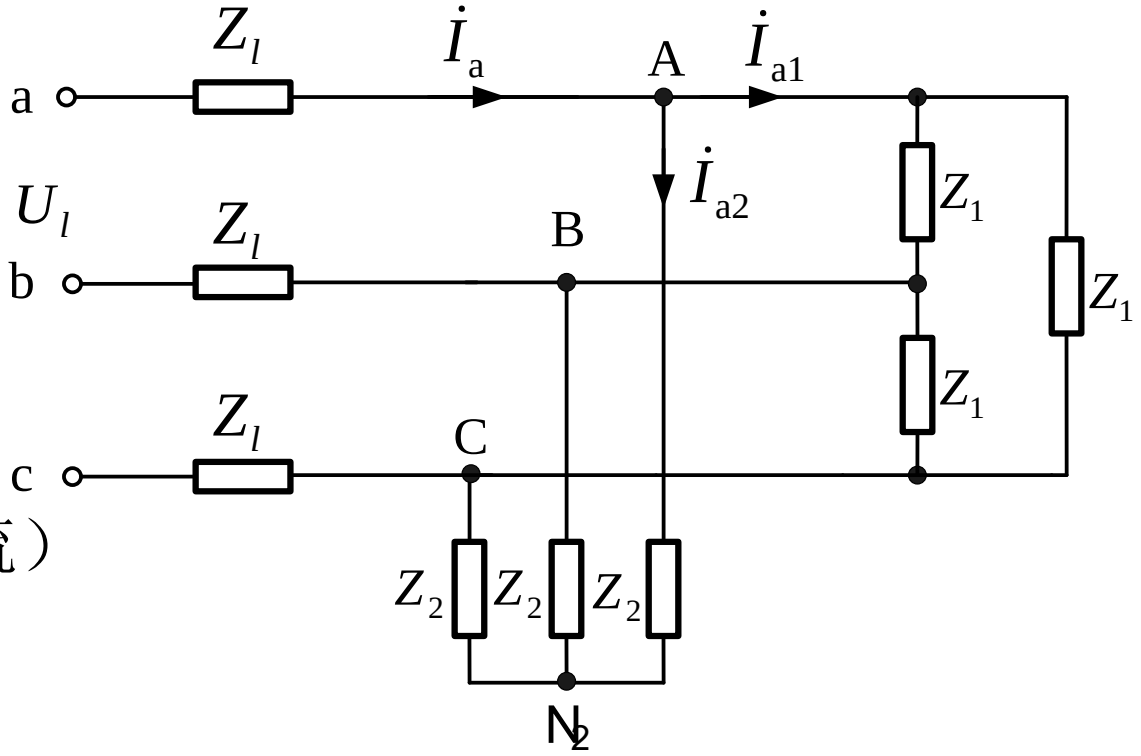
$$\dot{U}_{an} = \frac{U_l}{\sqrt{3}} \angle 0°$$

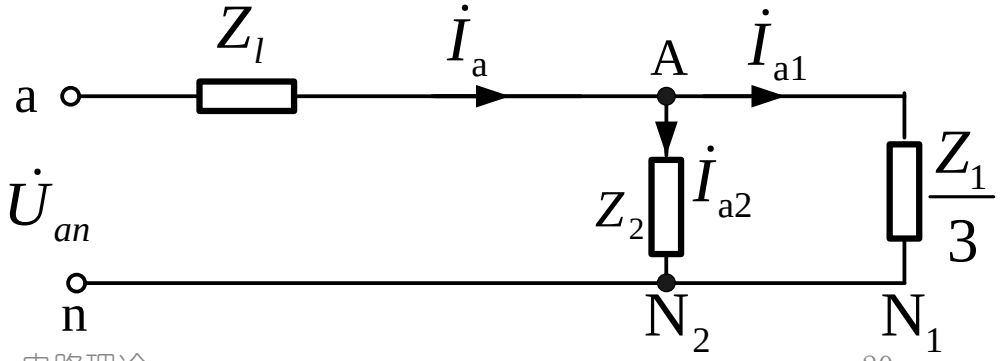
$$\dot{I}_a = \frac{\dot{U}_{an}}{Z_l + (Z_2 // \frac{Z_1}{3})}$$

$$\dot{I}_{a1} = \frac{Z_2}{Z_2 + \frac{Z_1}{3}} \dot{I}_a \quad （线电流）$$

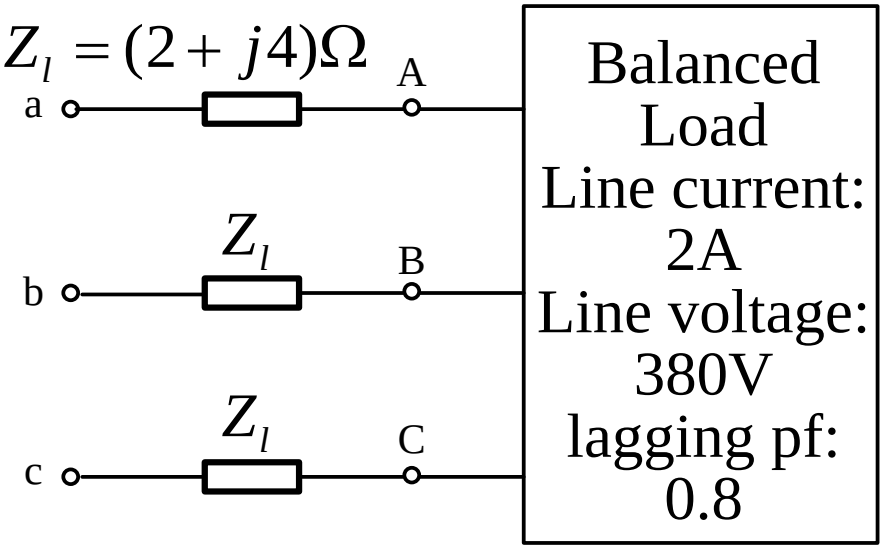
$$\dot{I}_{a1p} = \frac{\dot{I}_{a1}}{\sqrt{3}} \angle 30° \quad （相电流）$$

$$\dot{I}_{a2} = \frac{\frac{Z_1}{3}}{Z_2 + \frac{Z_1}{3}} \dot{I}_a \text{ (相电流)}$$





Practice Balanced three-phase circuit is shown in Fig. Find the line voltage of source.

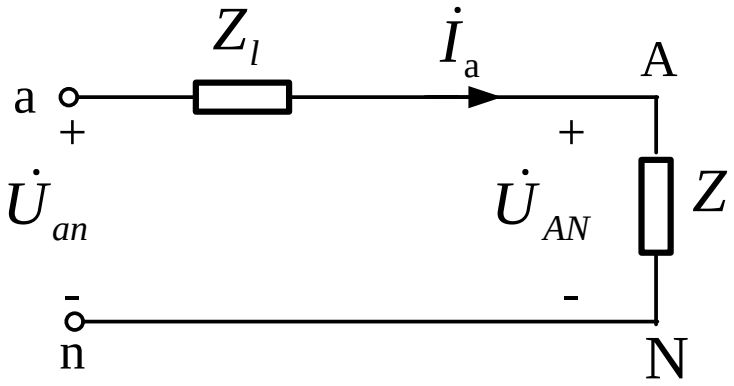


$$\dot{U}_{AN} = \frac{380}{\sqrt{3}} \angle 0°$$

$$\dot{I}_a = 2 \angle -\arccos 0.8$$

$$\dot{U}_{an} = \dot{I}_a Z_l + \dot{U}_{AN}$$

$$\dot{U}_{ab} = \sqrt{3}\dot{U}_{an} \angle 30°$$



1. 将三相电源、负载都化为等值Y－Y接电路；

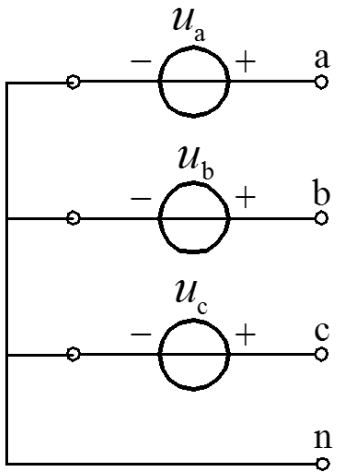
2. 连接各负载和电源中点，中线上若有阻抗则不计；

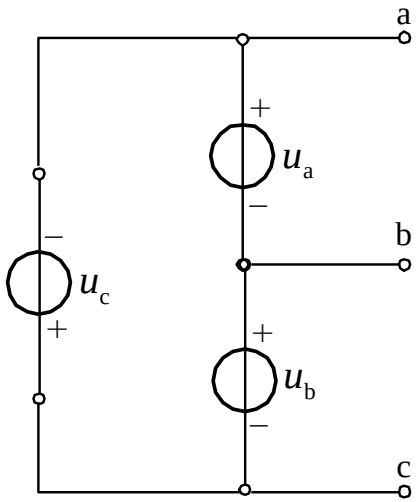
3. 画出单相计算电路，求出一相的电压、电流。

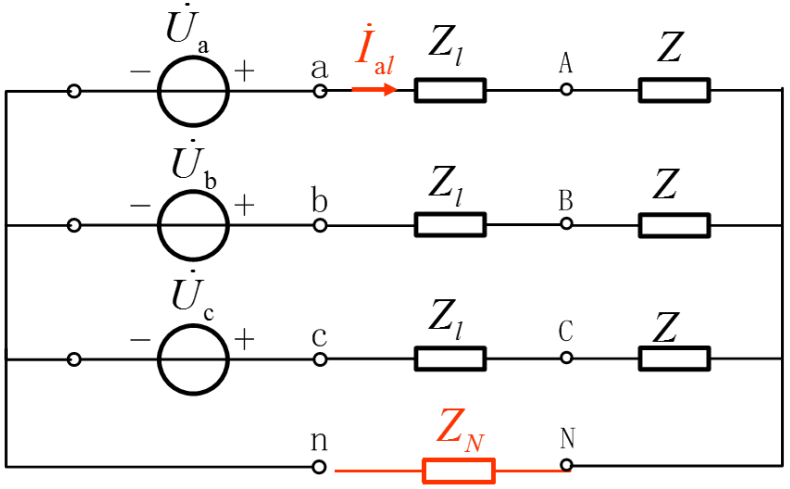
4. 根据Δ 、Y接 线（相）电压及线（相）电流之间的关系，求出原电路的电流、电压。

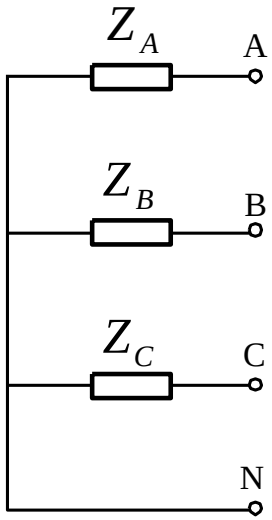
5. 由对称性，得出其它两相的电压、电流。

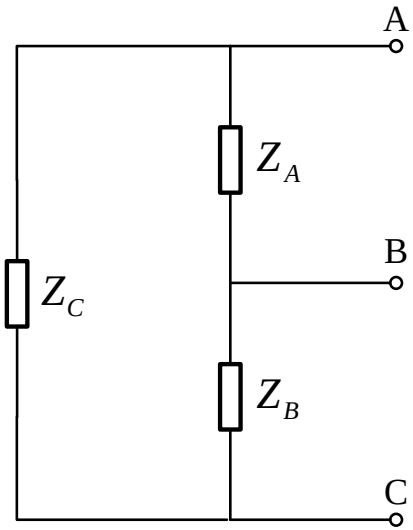
总结

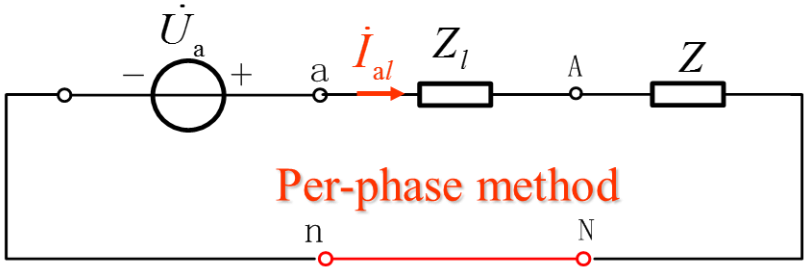

u_a
u_b
u_c
a
b
c
n


a
b
c
u_a
u_b
u_c


$\dot{U}_a$
$\dot{U}_b$
$\dot{U}_c$
$\dot{I}_{al}$
Z_l
Z
a
b
c
A
B
C
n
N
Z_N


Z_A
Z_B
Z_C
A
B
C
N


A
B
C
Z_A
Z_B
Z_C

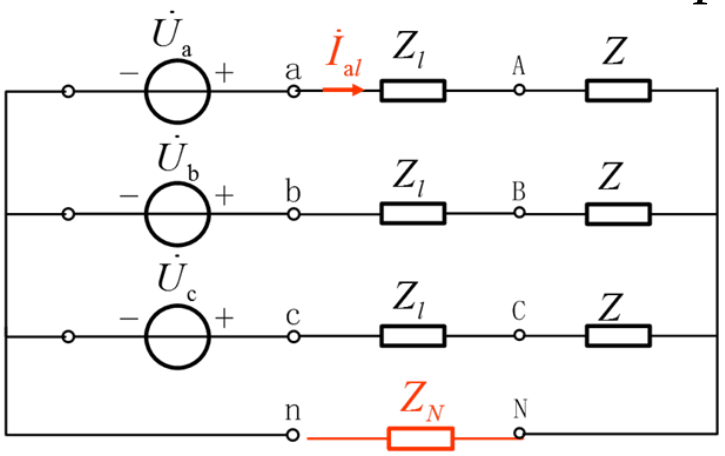

$\dot{U}_a$
$\dot{I}_{al}$
Z_l
Z
a
A
n
N
Per-phase method

12.4 对称三相电路的功率

1. 计算

$$p(t)=u_{AN}i_A+u_{BN}i_B+u_{CN}i_C$$

$$p(t)=2U_pI_p\cos(\omega t)\cos(\omega t-\phi)$$
$$+2U_pI_p\cos(\omega t-120^\circ)\cos(\omega t-\phi-120^\circ)$$
$$+2U_pI_p\cos(\omega t+120^\circ)\cos(\omega t-\phi+120^\circ)$$



$$=U_pI_p\begin{bmatrix}3\cos\phi+\cos(2\omega t-\phi)+\\ \cos(2\omega t-240^\circ-\phi)+\\ \cos(2\omega t+240^\circ-\phi)\end{bmatrix}$$

$$p(t)=3U_pI_p\cos\phi=\text{constant}$$

$$P=3U_pI_p\cos\phi$$

$$Q=3U_pI_p\sin\phi$$

$$S=3U_pI_p$$

$$\tilde{S}=3U_pI_p\cos\phi+j3U_pI_p\sin\phi=3\dot{U}_p\dot{I}_p^*$$

$$P=\sqrt{3}U_lI_l\cos\phi$$

$$Q=\sqrt{3}U_lI_l\sin\phi$$

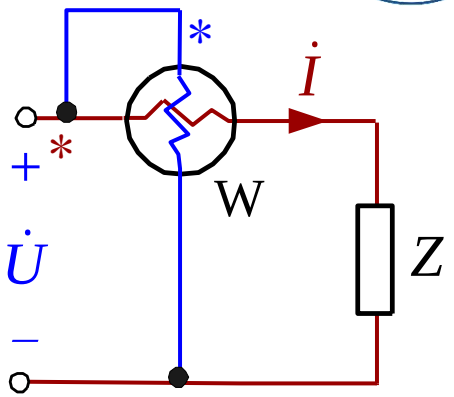
$$S=\sqrt{3}U_lI_l$$

$$\tilde{S}=\sqrt{3}U_lI_l\cos\phi+j\sqrt{3}U_lI_l\sin\phi\neq\sqrt{3}\dot{U}_l\dot{I}_l^*$$

12.4 对称三相电路的功率

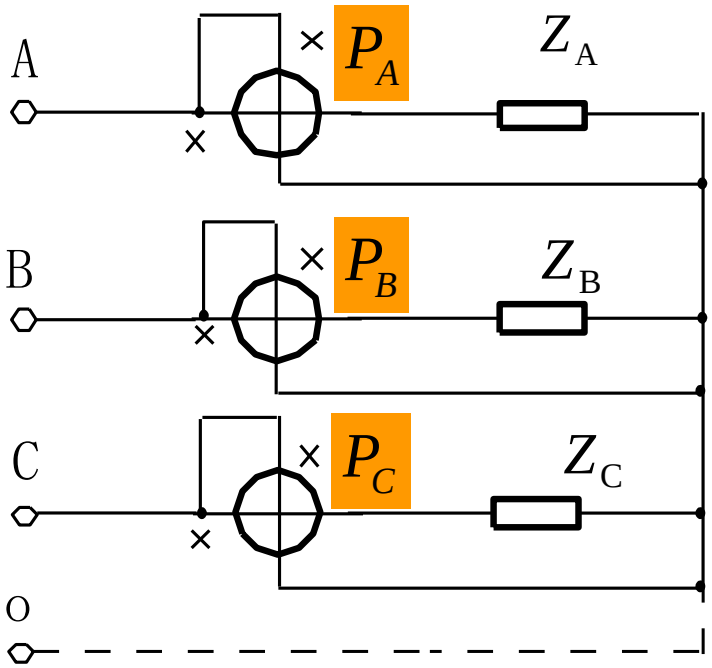
2. 测量

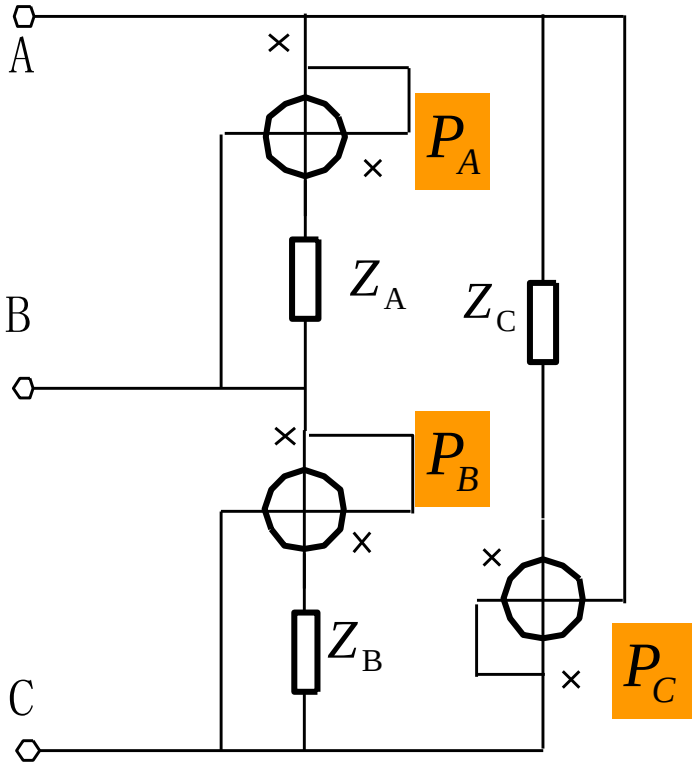
$$P = UI\cos(\dot{U}, \dot{I}) = \mathrm{Re}[\dot{U} \cdot \dot{I}^*]$$



(1) 三瓦特表法

$$P = P_A + P_B + P_C$$

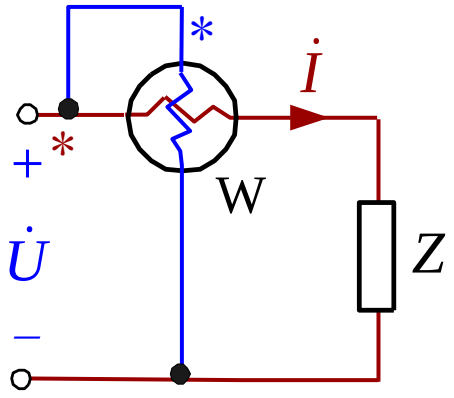




2. 测量

$$P = UI\cos(\dot{U},\dot{I}) = \mathrm{Re}[\dot{U}\cdot\dot{I}^{*}]$$

$$= \frac{1}{T}\int_0^T ui\,\mathrm{d}t$$



(2) 二瓦特表法

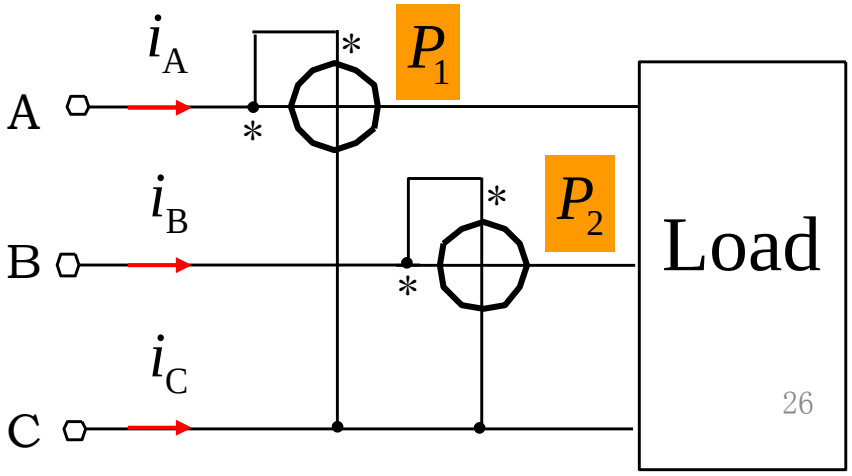
$$P = P_1 + P_2$$

$$p(t) = u_{AN}i_A + u_{BN}i_B + u_{CN}i_C$$

$$= u_{AN}i_A + u_{BN}i_B + u_{CN}(-i_A - i_B)$$

$$= u_{AC}i_A + u_{BC}i_B$$

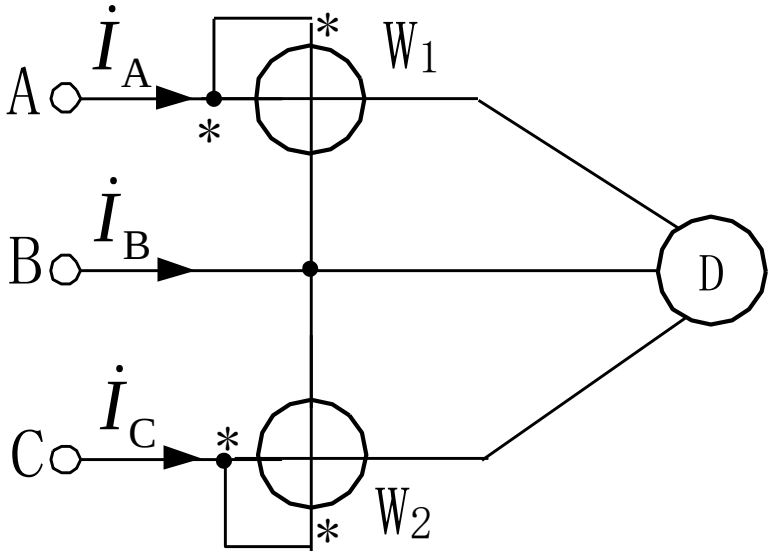
$$P = \frac{1}{T}\int_0^T (u_{AC}i_A + u_{BC}i_B)\,\mathrm{d}t = P_1 + P_2$$



Practice As shown in Fig. , a balanced source with line voltage 380V supplies a balance motor load which draws 7.5kW at 0.8 pf. Find the line current and the reading of each wattmeter.

$$P=\sqrt{3}U_{AB}I_A\cos\phi$$

$$7500=\sqrt{3}\times 380\times I_A\times 0.8$$



$$P_{W1}=\mathrm{Re}[\dot{U}_{AB}\times\dot{I}_A^{\,*}]$$

$$P_{W1}=\mathrm{Re}[(380\angle(\phi+30°))\times(I_A\angle 0°)^*]=380I_A\cos(\phi+30°)$$

$$P_{W2}=7500-P_{W1}$$

作业

- 12.3节：12-8
- 12.4节：12-20
- 12.6节：12-28
- 综合：12-34