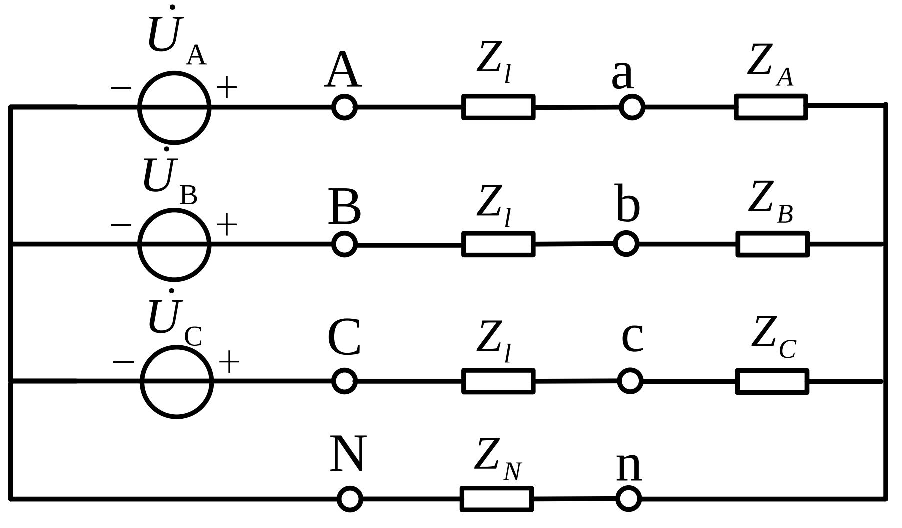
第12章小结

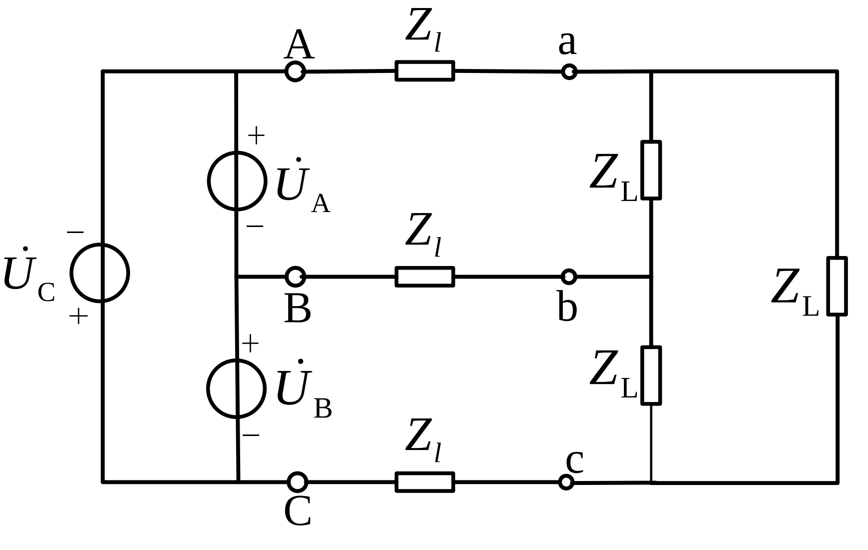
- 三相电路：三相电源、三相负载、三相输电线

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

Y-接：$\dot{I}_{al} = \dot{I}_{ap} \quad \dot{U}_{AB} = \sqrt{3}\dot{U}_{AN}\angle 30^{o}$

Δ-接：$\dot{U}_{AB} = \dot{U}_{AN} \quad \dot{I}_{al} = \sqrt{3}\dot{I}_{ap}\angle\text{-}30°$

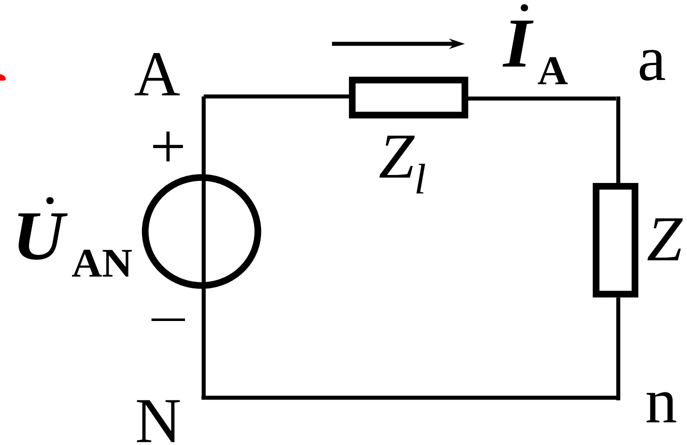




第12章小结

- 三者皆对称 ⇨ 对称三相电路 $\dot{I}_N = 0$

分相计算法



Y_N-Y_n, Y-Y, Y-Δ, Δ-Y, Δ-Δ ⇨ $\mathbf{Y_N}$-$\mathbf{Y_n}$

- 任一不对称 ⇨ 不对称三相电路 **不能分相**

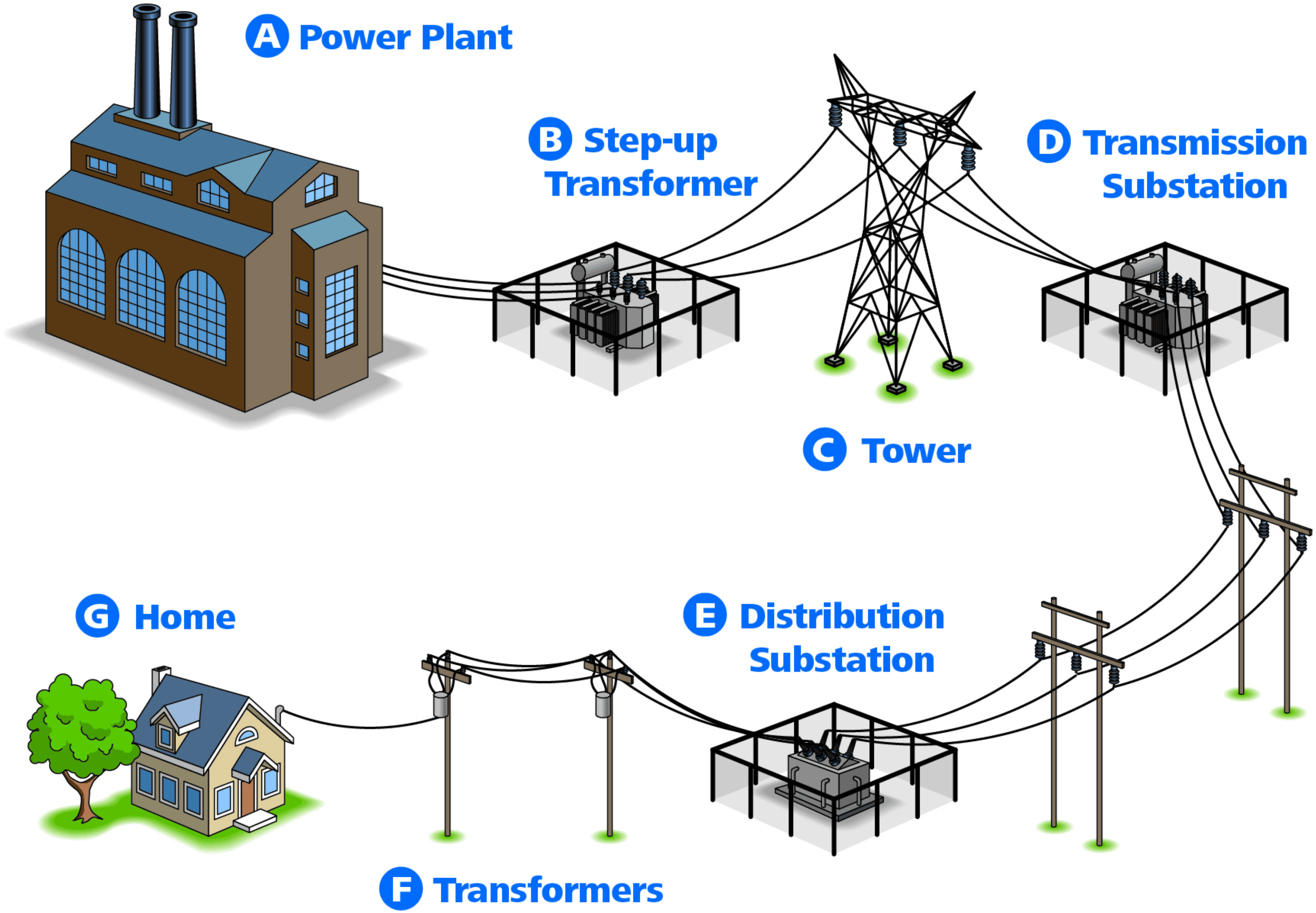
  $\dot{U}_{nN} \neq 0$ **中性点位移**

- 三相电路功率 $p = 3UI\cos\varphi$

$$P = 3U_pI_p\cos\varphi = \sqrt{3}U_lI_l\cos\varphi$$

三表法和二表法

实际电力传输系统



A Power Plant
B Step-up Transformer
C Tower
D Transmission Substation
E Distribution Substation
F Transformers
G Home

Chapter 13
含磁耦合的电路

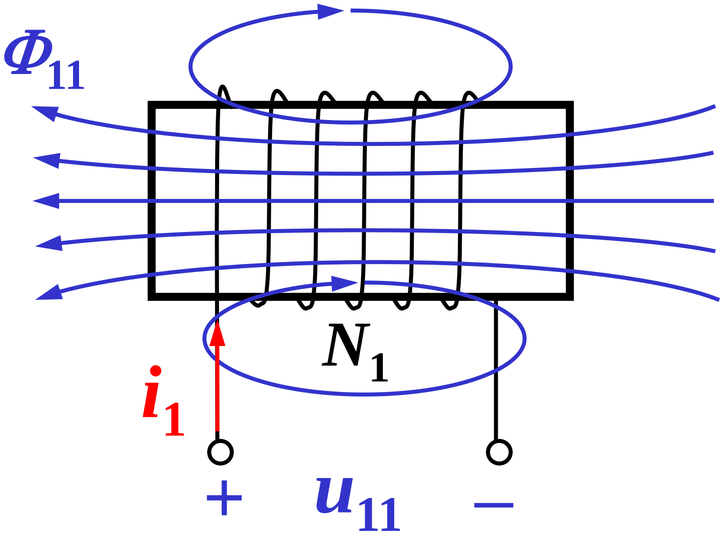
13.2 耦合电感

13.3 含耦合电感电路的分析

13.4 变压器

13.2 耦合电感

1. 自感与互感

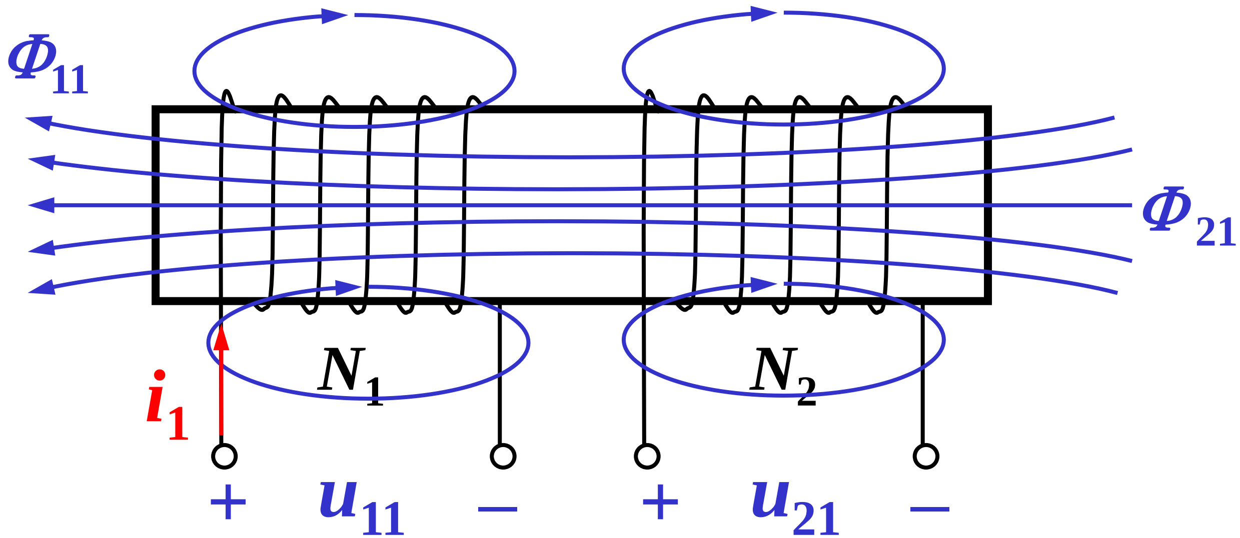


当线圈1中通入电流i_1时：

$$u_{11}=\frac{\mathrm{d}\Psi_{11}}{\mathrm{d}t}=N_1\frac{\mathrm{d}\Phi_{11}}{\mathrm{d}t}=L_1\frac{\mathrm{d}i_1}{\mathrm{d}t}$$ 自感电压

13.2 耦合电感

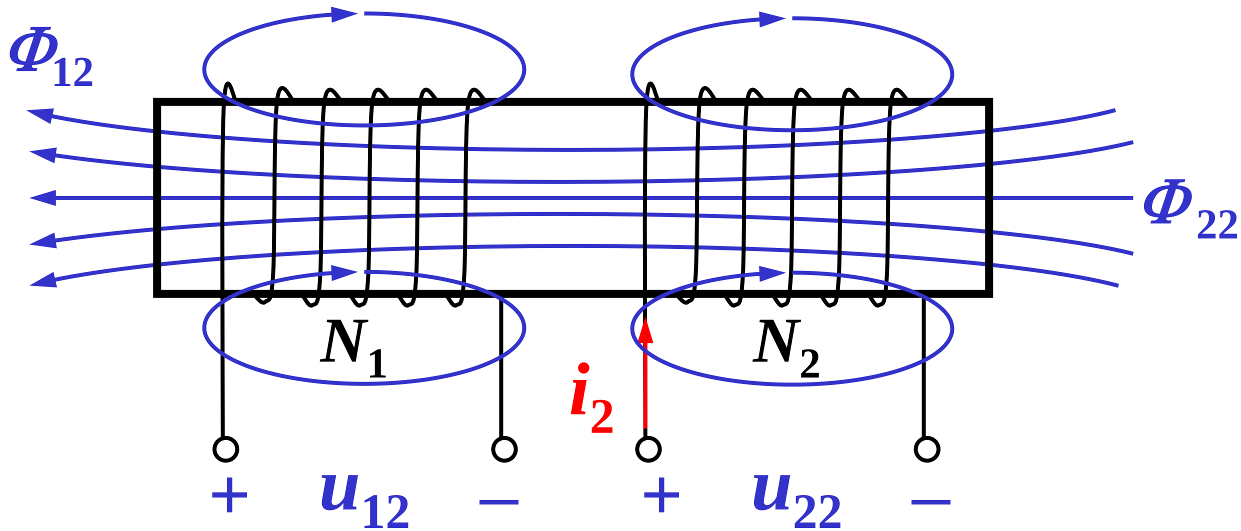
1. 自感与互感



当线圈1中通入电流i_1时： $u_{11}=\dfrac{d\Psi_{11}}{dt}=N_1\dfrac{d\Phi_{11}}{dt}=L_1\dfrac{di_1}{dt}$

$M_{21}\overset{\text{def}}{=}\left|\dfrac{\Psi_{21}}{i_1}\right|$ 线圈1对线圈2的互感系数，单位：H

$u_{21}=\dfrac{d\Psi_{21}}{dt}=N_2\dfrac{d\Phi_{21}}{dt}=M_{21}\dfrac{di_1}{dt}$ 互感电压



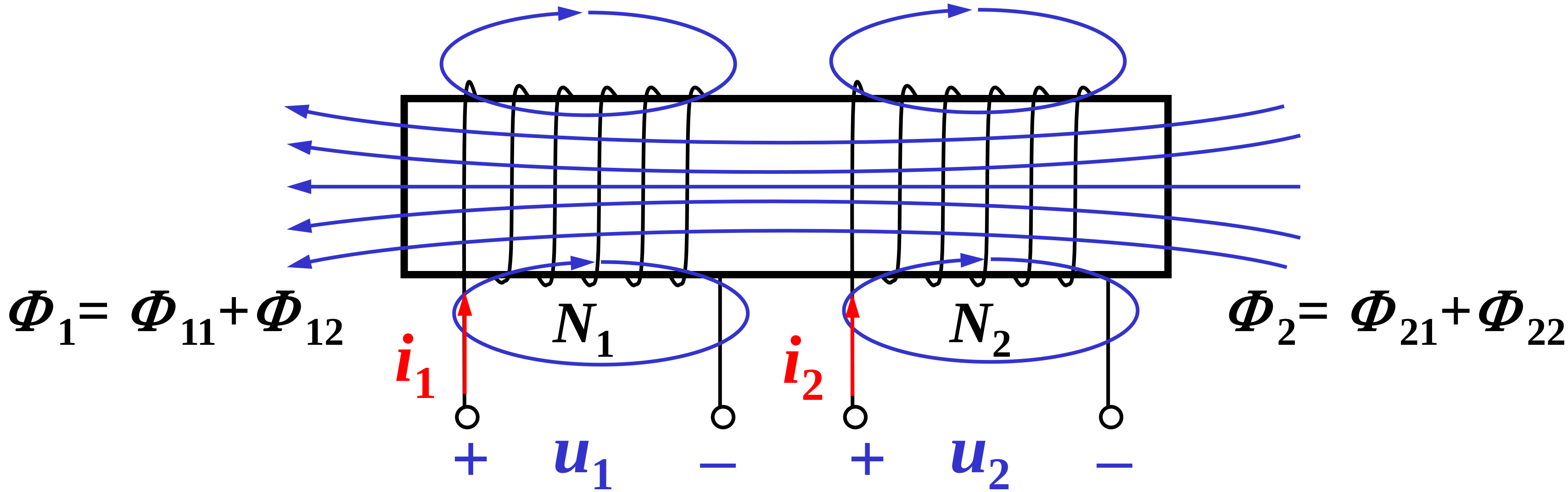
当线圈2中通电流i_2时，有：

$$M_{12} \stackrel{\text{def}}{=} \left|\frac{\Psi_{12}}{i_2}\right|$$

线圈2对线圈1的互感系数

$$\begin{cases} u_{12} = \dfrac{\mathrm{d}\Psi_{12}}{\mathrm{d}t} = N_1 \dfrac{\mathrm{d}\Phi_{12}}{\mathrm{d}t} = M_{12} \dfrac{\mathrm{d}i_2}{\mathrm{d}t} \\ u_{22} = \dfrac{\mathrm{d}\Psi_{22}}{\mathrm{d}t} = N_2 \dfrac{\mathrm{d}\Phi_{22}}{\mathrm{d}t} = L_2 \dfrac{\mathrm{d}i_2}{\mathrm{d}t} \end{cases}$$

$$M_{12} = M_{21} = M$$



当两个线圈同时通以电流时，有：

加强型耦合

削弱型耦合

自感　　互感

$$u_1 = u_{11} + u_{12} = L_1 \frac{di_1}{dt} + M \frac{di_2}{dt} \qquad \dot{U}_1 = j\omega L_1 \dot{I}_1 + j\omega M \dot{I}_2$$

$$u_2 = u_{22} + u_{21} = L_2 \frac{di_2}{dt} + M \frac{di_1}{dt} \qquad \dot{U}_2 = j\omega L_2 \dot{I}_2 + j\omega M \dot{I}_1$$

2. 耦合系数 k 表示两个线圈磁耦合的紧密程度

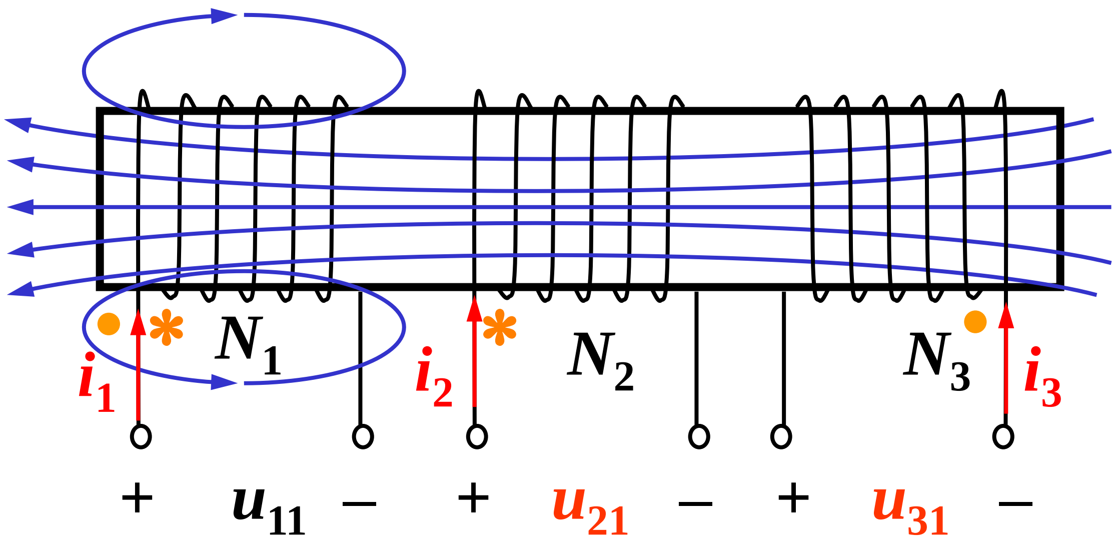
$$k = \frac{M}{\sqrt{L_1 L_2}} \quad (0 \le k \le 1)$$

$$k = \frac{M}{\sqrt{L_1 L_2}} = \sqrt{\frac{M_{12} M_{21}}{L_1 L_2}} = \sqrt{\frac{\dfrac{\psi_{12}}{\cancel{i_2}} \cdot \dfrac{\psi_{21}}{\cancel{i_1}}}{\dfrac{\psi_{11}}{\cancel{i_1}} \cdot \dfrac{\psi_{22}}{\cancel{i_2}}}}$$

$$= \sqrt{\frac{N_1 \varphi_{12} \cdot N_2 \varphi_{21}}{N_1 \varphi_{11} \cdot N_2 \varphi_{22}}} = \sqrt{\frac{\varphi_{12} \cdot \varphi_{21}}{\varphi_{11} \cdot \varphi_{22}}} \le 1$$

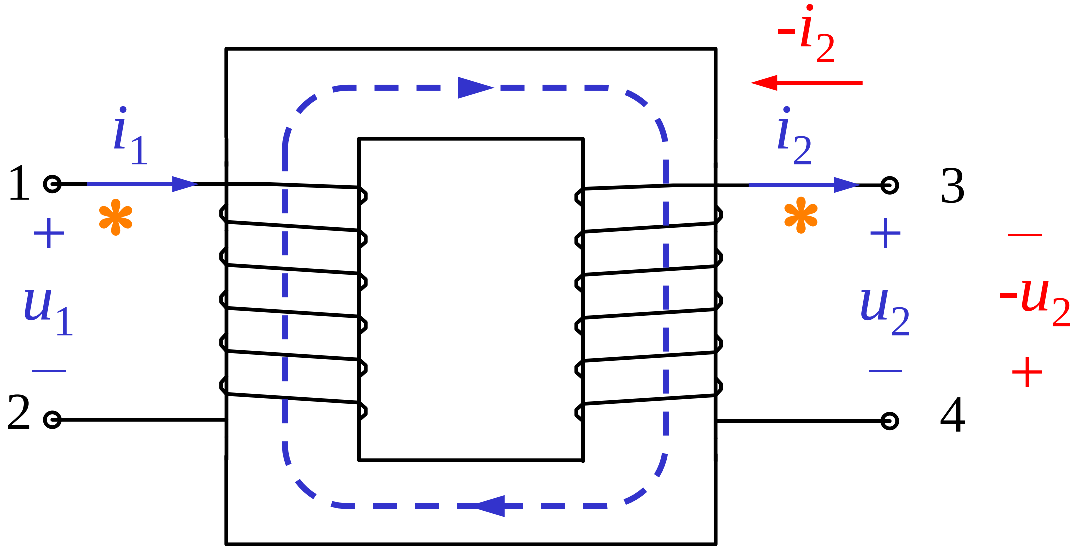
3. 互感线圈的同名端

具有磁耦合的两个线圈，当电流分别从两线圈的某一个端子流入，如两者产生磁通相同，则这两端叫做互感线圈的同名端。



$$u_{21} = M_{21}\frac{\mathrm{d}i_1}{\mathrm{d}t} \qquad u_{31} = -M_{31}\frac{\mathrm{d}i_1}{\mathrm{d}t}$$

例：标出耦合线圈的同名端，并写出耦合电感的*u*-*i*关系



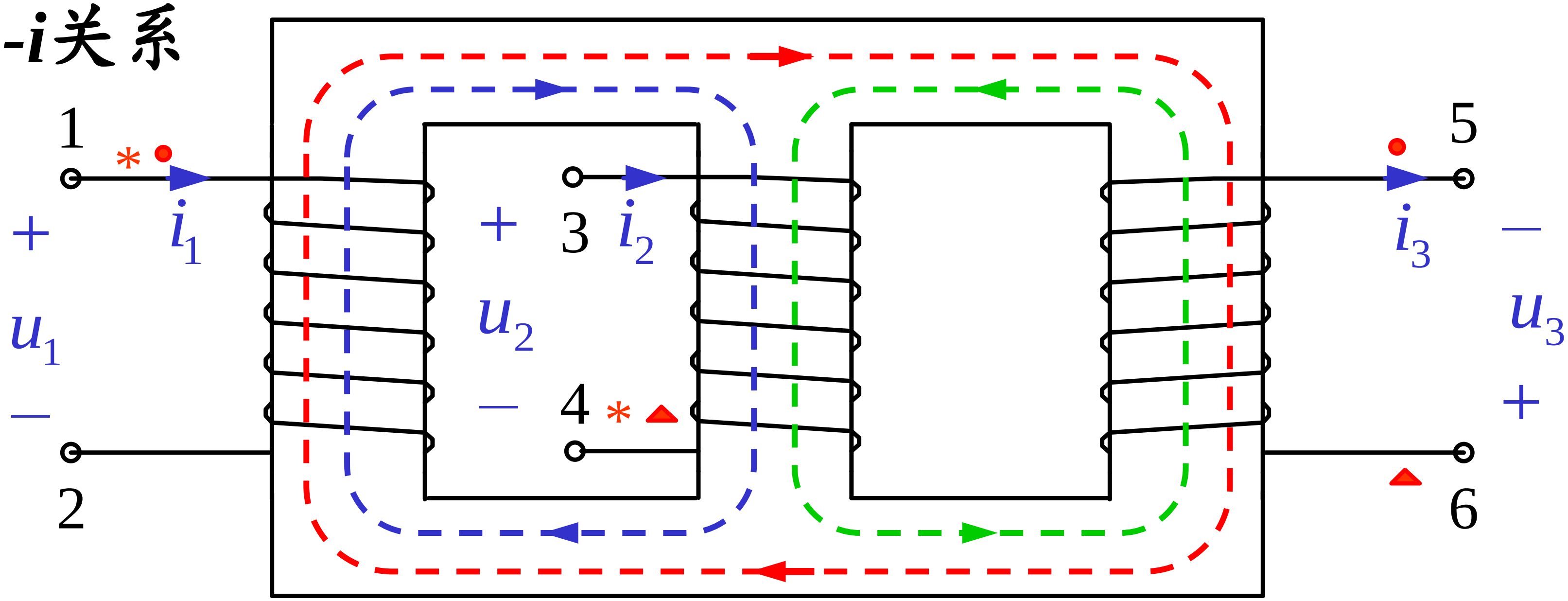
$$u_1 = L_1 \frac{di_1}{dt} + M \frac{d(-i_2)}{dt}$$

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

$$u_2 = +M \frac{di_1}{dt} + L_2 \frac{d(-i_2)}{dt}$$

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

例：标出耦合线圈的同名端，并写出耦合电感的*u*-*i*关系



$$u_1 = L_1 \frac{di_1}{dt} - M_{12}\frac{di_2}{dt} - M_{13}\frac{di_3}{dt}$$

$$u_2 = -M_{21}\frac{di_1}{dt} + L_2 \frac{di_2}{dt} - M_{23}\frac{di_3}{dt}$$

$$u_3 = -M_{31}\frac{di_1}{dt} - M_{32}\frac{di_2}{dt} + L_3 \frac{di_3}{dt}$$

$$\begin{bmatrix} u_1 \\ u_2 \\ u_3 \end{bmatrix} = \begin{bmatrix} L_1 & -M_{12} & -M_{13} \\ -M_{21} & L_2 & -M_{23} \\ -M_{31} & -M_{32} & L_3 \end{bmatrix} \begin{bmatrix} \frac{di_1}{dt} \\ \frac{di_2}{dt} \\ \frac{di_3}{dt} \end{bmatrix}$$

同名端的实验测定

假设线圈的同名端已知，观察实验的现象

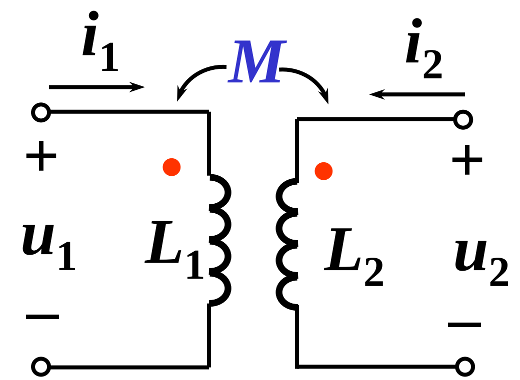
当闭合开关S时，电压表指针正偏一下，又回到零。

分析：

开关S闭合，i增加 $\dfrac{\mathrm{d}i}{\mathrm{d}t} > 0$, $\quad u_{22'} = M\dfrac{\mathrm{d}i}{\mathrm{d}t} > 0$

当两个线圈是封装的，只引出接线端子，要确定其同名端，就可以利用上面的结论来加以判断。

4. 互感线圈的储能



t 时刻互感线圈吸收的功率

$$p(t)=u_1(t)i_1(t)+u_2(t)i_2(t)$$

t~t+dt 时间段互感线圈储能的增量

$$\mathrm{d}W=p(t)\mathrm{d}t=[u_1(t)i_1(t)+u_2(t)i_2(t)]\mathrm{d}t$$

$$=\left(L_1\frac{\mathrm{d}i_1(t)}{\cancel{\mathrm{d}t}}+M\frac{\mathrm{d}i_2(t)}{\cancel{\mathrm{d}t}}\right)i_1(t)\cancel{\mathrm{d}t}$$

$$+\left(L_2\frac{\mathrm{d}i_2(t)}{\cancel{\mathrm{d}t}}+M\frac{\mathrm{d}i_1(t)}{\cancel{\mathrm{d}t}}\right)i_2(t)\cancel{\mathrm{d}t}$$

$$=L_1i_1(t)\mathrm{d}i_1(t)+Mi_1(t)\mathrm{d}i_2(t)+L_2i_2(t)\mathrm{d}i_2(t)+Mi_2(t)\mathrm{d}i_1(t)$$

$$=L_1i_1(t)\mathrm{d}i_1(t)+L_2i_2(t)\mathrm{d}i_2(t)+M\mathrm{d}[i_1(t)i_2(t)]$$

$$\mathrm{d}W = L_1 i_1(t)\mathrm{d}i_1(t) + L_2 i_2(t)\mathrm{d}i_2(t) + M\mathrm{d}[i_1(t)i_2(t)]$$

设电流由零增至$i_1(t)$、$i_2(t)$，则t时刻互感的储能为

$$W = \int_0^{i_1(t)} L_1 i_1(\xi)\mathrm{d}i_1(\xi) + \int_0^{i_2(t)} L_2 i_2(\xi)\mathrm{d}i_2(\xi) + \int_0^{i_1(t)i_2(t)} M\mathrm{d}[i_1(\xi)i_2(\xi)]$$

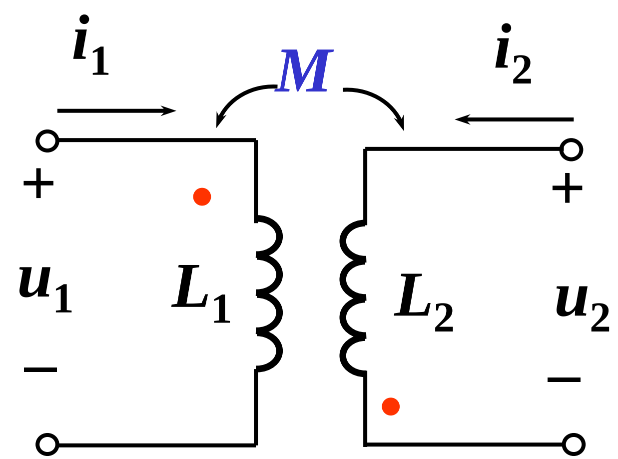
$$= \frac{1}{2}L_1 i_1^2(t) + \frac{1}{2}L_2 i_2^2(t) + M i_1(t) i_2(t)$$

加强型耦合

自感储能　　互感储能

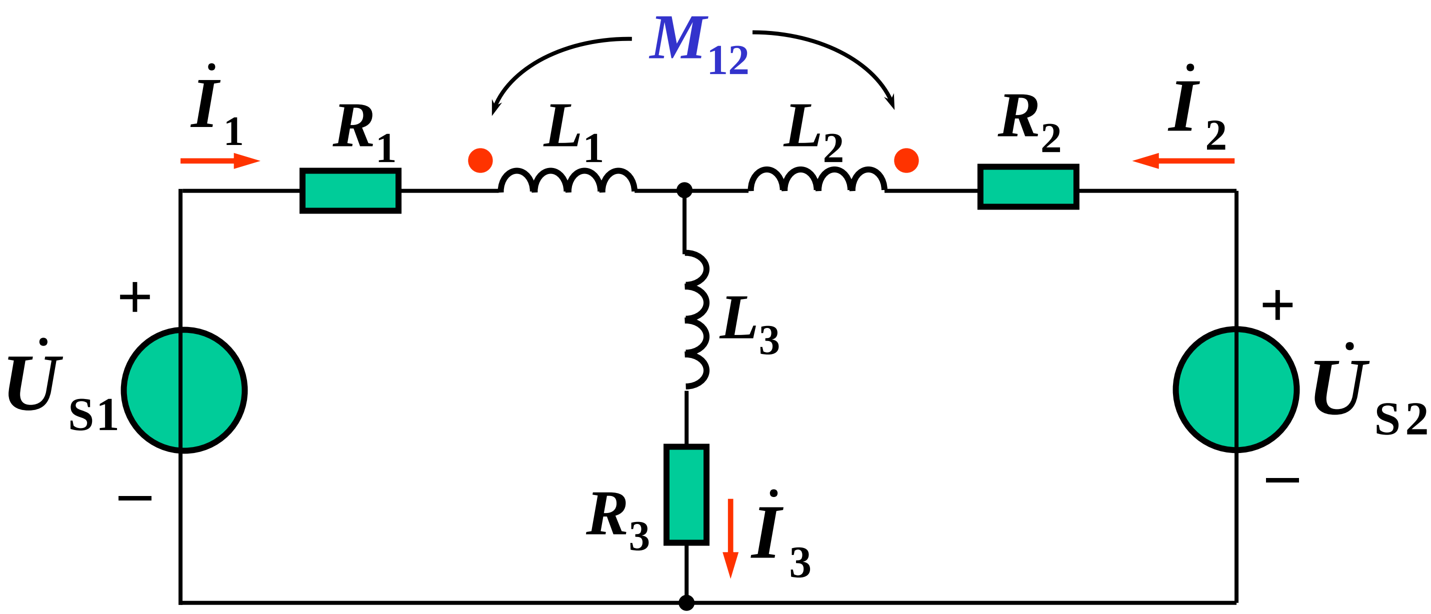
削弱型耦合

$$W = \frac{1}{2}L_1 i_1^2(t) + \frac{1}{2}L_2 i_2^2(t) - M i_1(t) i_2(t)$$

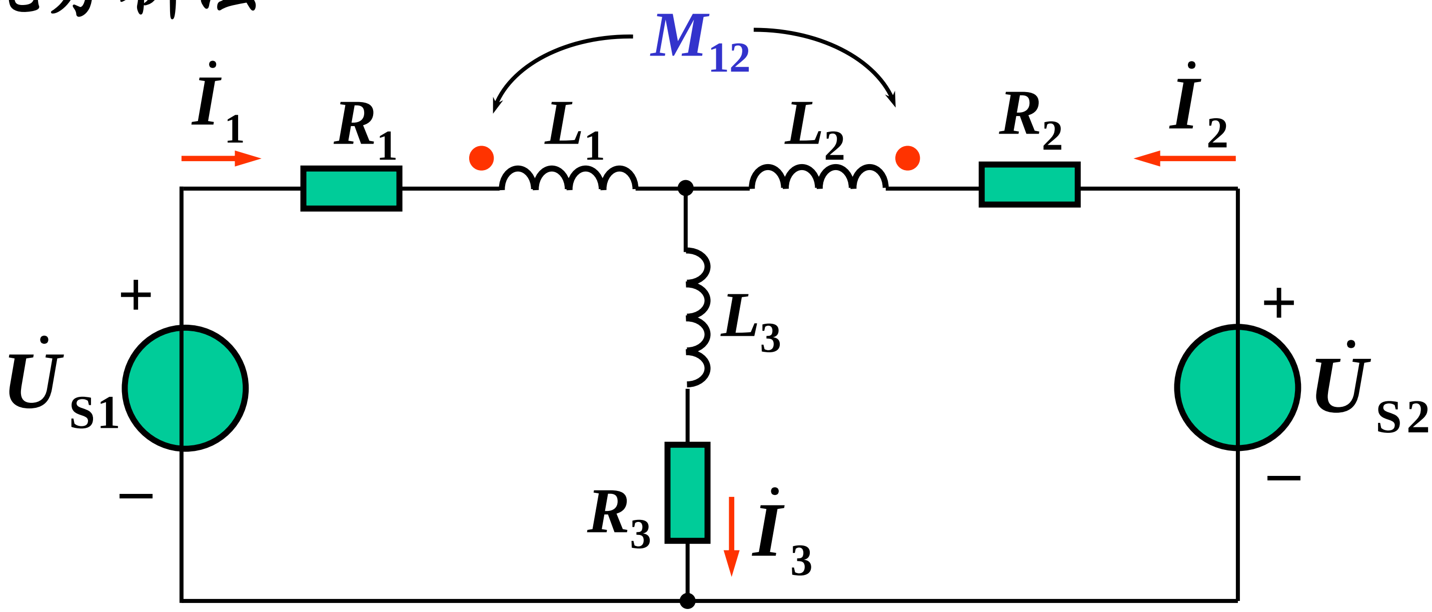


13.3 含耦合电感电路分析

- 有互感的电路的计算仍属正弦稳态分析，前面介绍的相量分析的的方法均适用。
- 需注意互感线圈上的电压除自感电压外，还应包含互感电压。



1. 网孔分析法

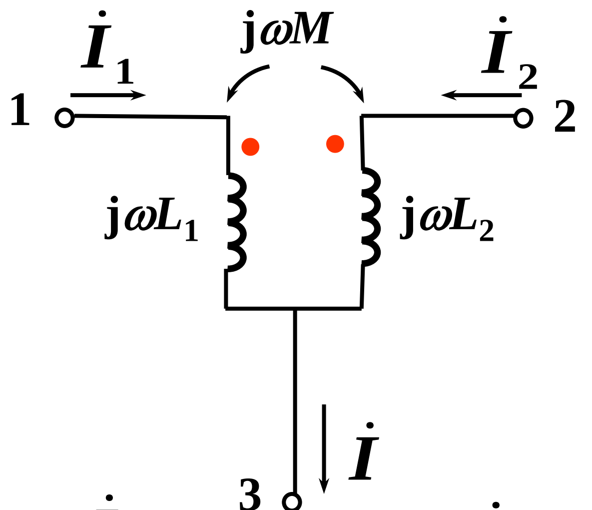


$$\begin{cases} R_1\dot{I}_1 + j\omega L_1\dot{I}_1 + j\omega M\dot{I}_2 + j\omega L_3\dot{I}_3 + R_3\dot{I}_3 = \dot{U}_{S1} \\ R_2\dot{I}_2 + j\omega L_2\dot{I}_2 + j\omega M\dot{I}_1 + j\omega L_3\dot{I}_3 + R_3\dot{I}_3 = \dot{U}_{S2} \\ \dot{I}_3 = \dot{I}_1 + \dot{I}_2 \end{cases}$$

注意：线圈上互感电压的表示式及正负号。

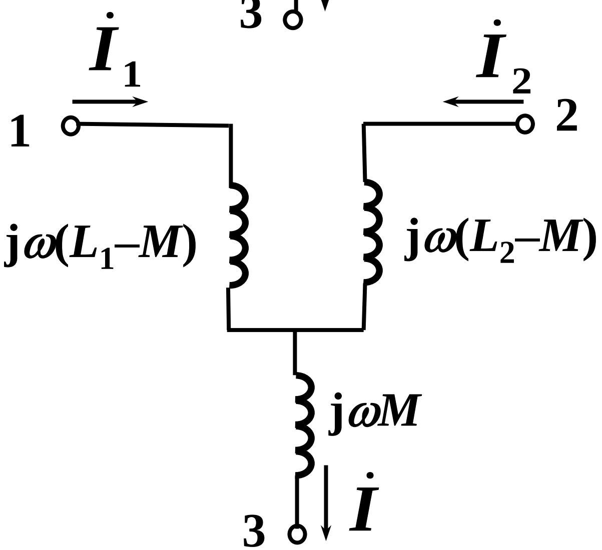
2. 去耦等效法

- 两个线圈的同名端接在公共端



$$\because \dot I = \dot I_1 + \dot I_2$$

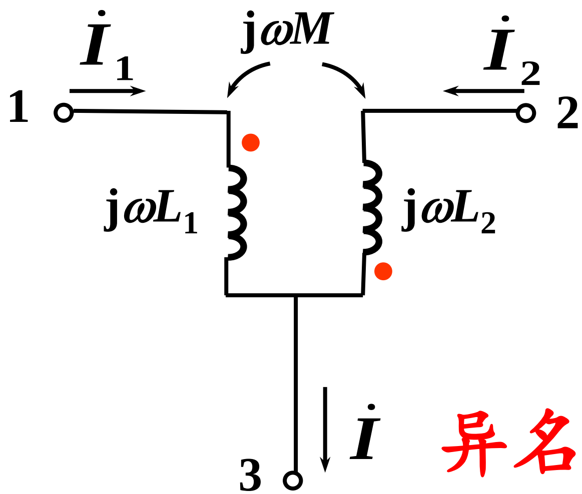
$$\begin{aligned}\therefore \dot U_{13} &= j\omega L_1\dot I_1 + j\omega M\dot I_2 \\ &= j\omega L_1\dot I_1 + j\omega M\left(\dot I - \dot I_1\right) \\ &= j\omega\left(L_1 - M\right)\dot I_1 + j\omega M\dot I\end{aligned}$$

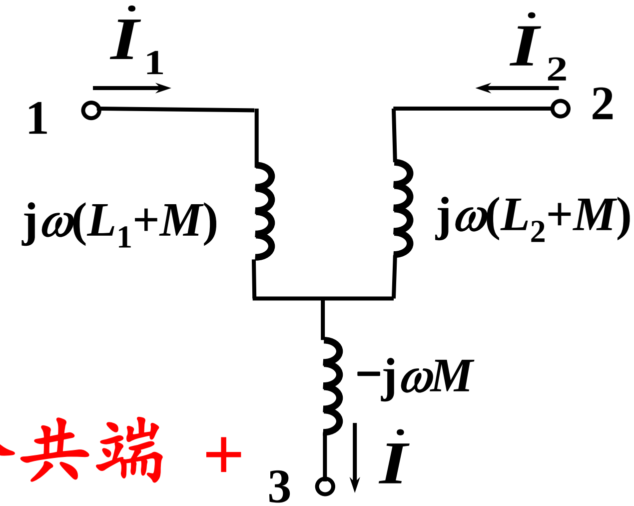


$$\begin{aligned}\dot U_{23} &= j\omega L_2\dot I_2 + j\omega M\dot I_1 \\ &= j\omega\left(L_2 - M\right)\dot I_2 + j\omega M\dot I\end{aligned}$$

同名端接在公共端 –

● 两个线圈的异名端接在公共端

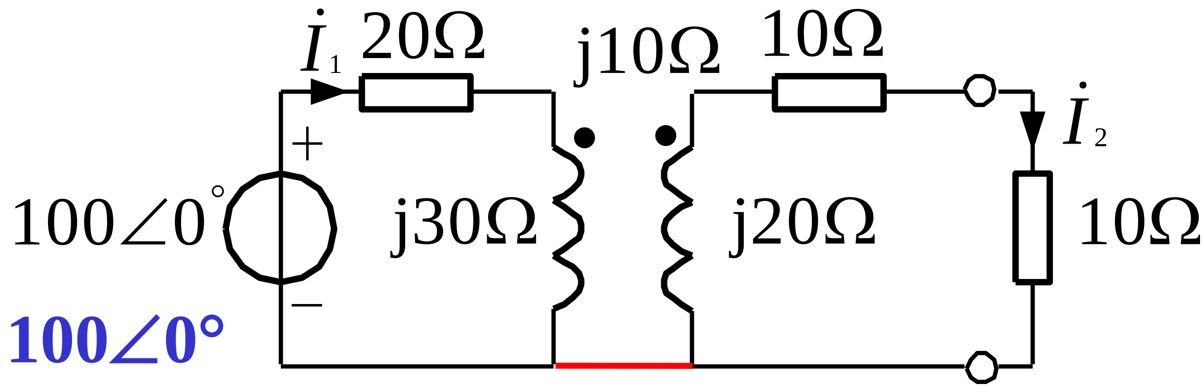




异名端接在公共端 +

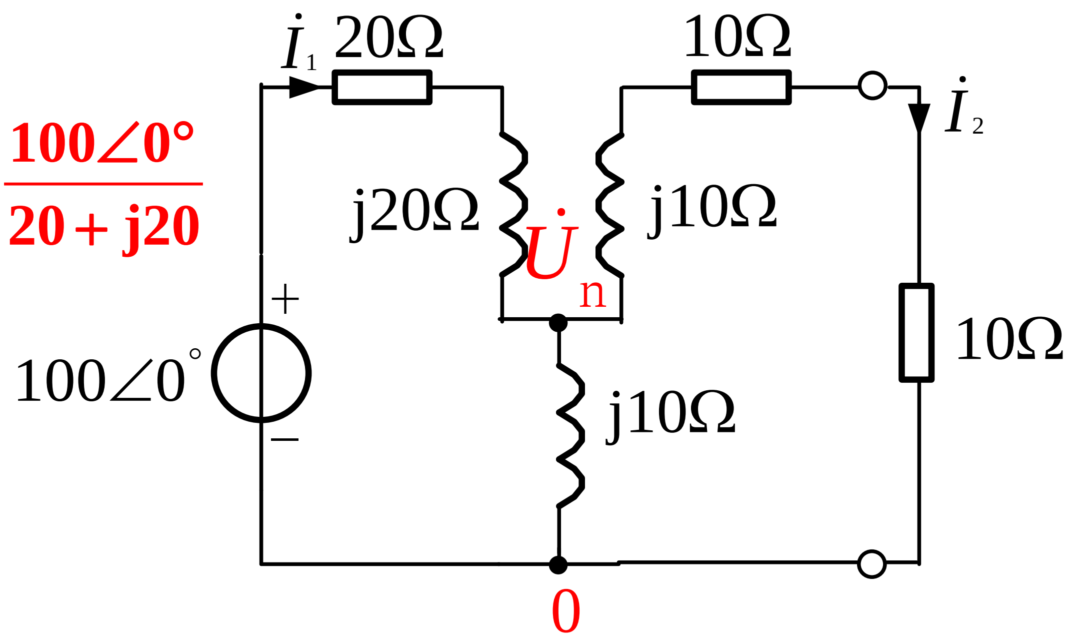
$$\begin{cases}\dot I=\dot I_1+\dot I_2\\ \dot U_{13}=\mathrm{j}\omega L_1\dot I_1-\mathrm{j}\omega M\overset{\dot I-\dot I_1}{\cancel{\dot I_2}}\\ \dot U_{23}=\mathrm{j}\omega L_2\dot I_2-\mathrm{j}\omega M\underset{\dot I-\dot I_2}{\cancel{\dot I_1}}\end{cases}\Rightarrow\begin{cases}\dot I=\dot I_1+\dot I_2\\ \dot U_{13}=\mathrm{j}\omega(L_1+M)\dot I_1-\mathrm{j}\omega M\dot I\\ \dot U_{23}=\mathrm{j}\omega(L_2+M)\dot I_2-\mathrm{j}\omega M\dot I\end{cases}$$

例：求$\dot{I}_1$和$\dot{I}_2$



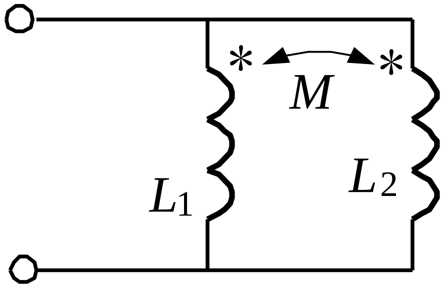
$$(20+\mathrm{j}30)\dot{I}_1-\mathrm{j}10\dot{I}_2=100\angle 0°$$

$$-\mathrm{j}10\dot{I}_1+(20+\mathrm{j}20)\dot{I}_2=0$$

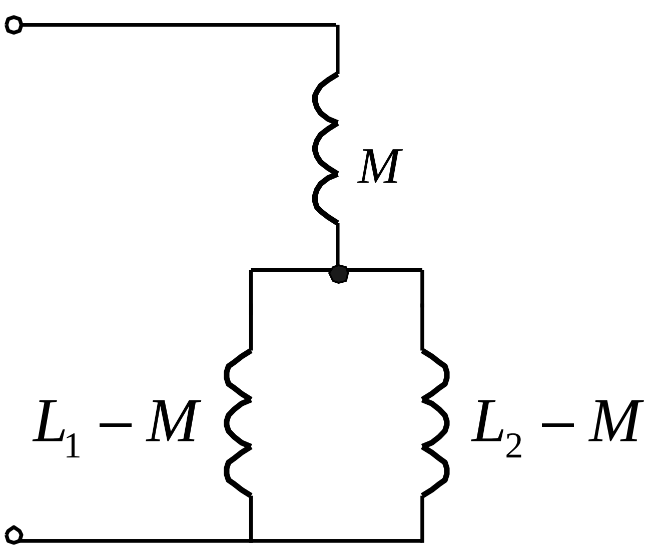


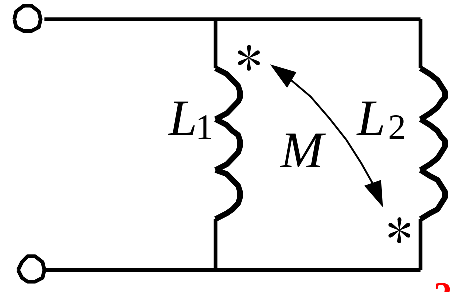
$$\left(\frac{1}{20+\mathrm{j}20}+\frac{1}{\mathrm{j}10}+\frac{1}{20+\mathrm{j}10}\right)\dot{U}_n=\frac{100\angle 0°}{20+\mathrm{j}20}$$

例：求等效电感

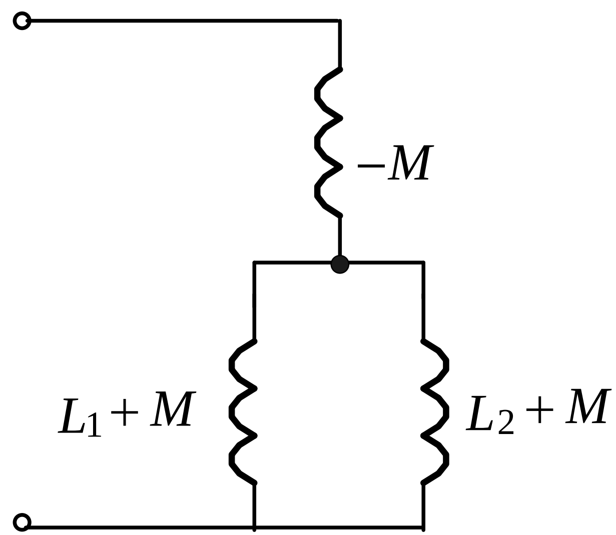


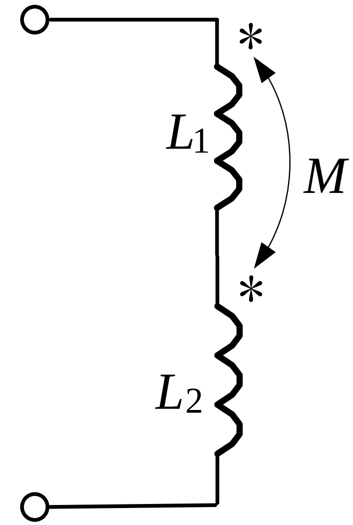
$$L_{eq}=\frac{L_1L_2-M^2}{L_1+L_2-2M}$$



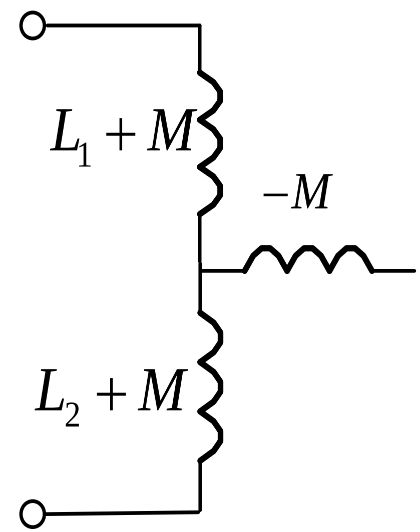


$$L_{eq}=\frac{L_1L_2-M^2}{L_1+L_2+2M}$$

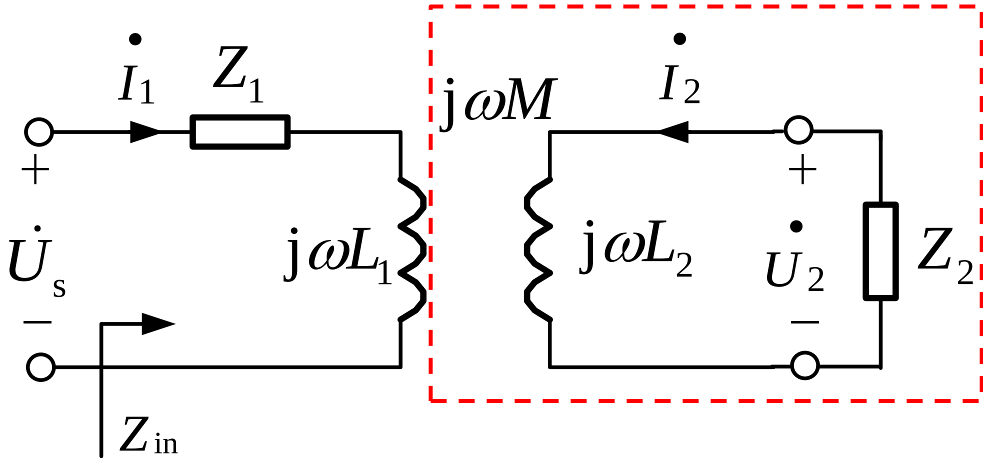


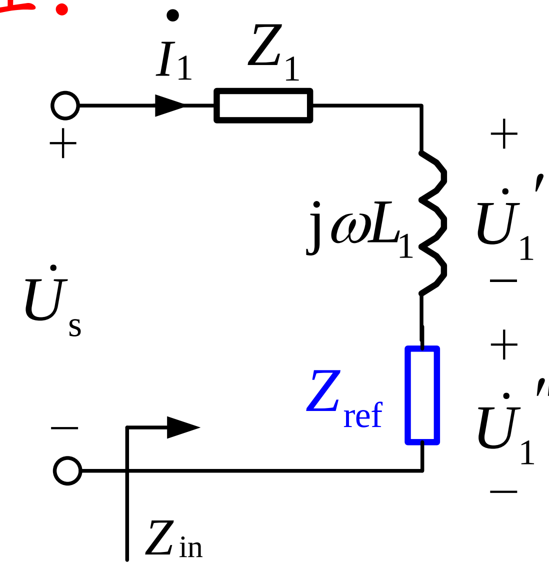


$$L_{eq}=L_1+L_2+2M$$



3. 映射阻抗法 $Z_{\mathrm{ref}}=\dfrac{(\omega M)^2}{Z_{22}}$ 要记住！





$$Z_{in}=\frac{\dot U_S}{\dot I_1}=Z_1+\frac{j\omega L_1\dot I_1\pm j\omega M\dot I_2}{\dot I_1}=(Z_1+j\omega L_1)+(\pm j\omega M)\frac{\dot I_2}{\dot I_1}$$

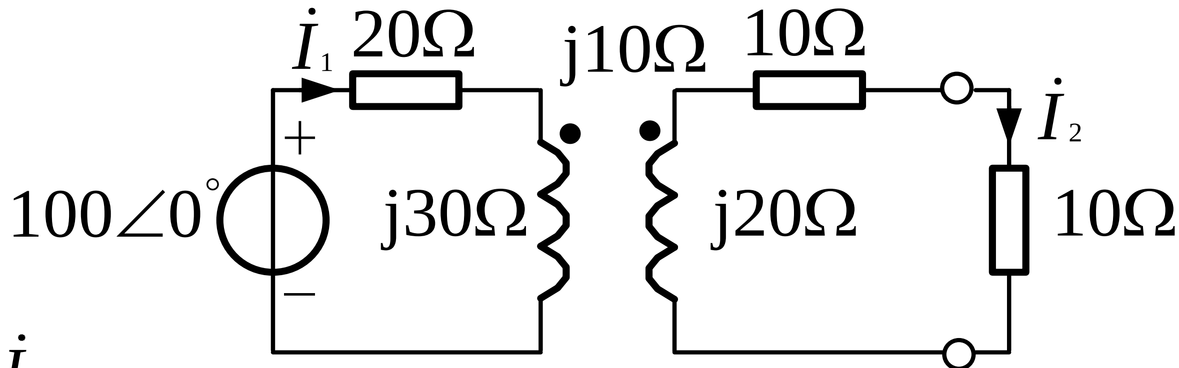
$$\dot U_2=j\omega L_2\dot I_2\pm j\omega M\dot I_1=-Z_2\dot I_2$$

$$Z_{\mathrm{ref}}=(\pm j\omega M)\left(-\frac{(\pm j\omega M)}{Z_2+j\omega L_2}\right)$$

$$\frac{\dot I_2}{\dot I_1}=-\frac{(\pm j\omega M)}{Z_2+j\omega L_2}$$

$$=\frac{(\omega M)^2}{Z_2+j\omega L_2}=\frac{(\omega M)^2}{Z_{22}}$$

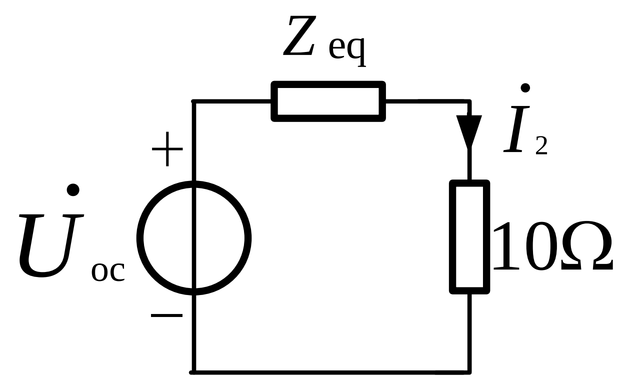
例：求 $\dot{I}_1$ 和 $\dot{I}_2$



解 $\dot{U}_s = [Z_{11} + \dfrac{(\omega M)^2}{Z_{22}}]\dot{I}_1$

$$100\angle 0^\circ = [(20 + \mathrm{j}30) + \frac{10^2}{(10 + 10 + \mathrm{j}20)}]\dot{I}_1$$

$$10\dot{I}_2 + 10\dot{I}_2 + (\mathrm{j}20\dot{I}_2 - \mathrm{j}10\dot{I}_1) = 0$$



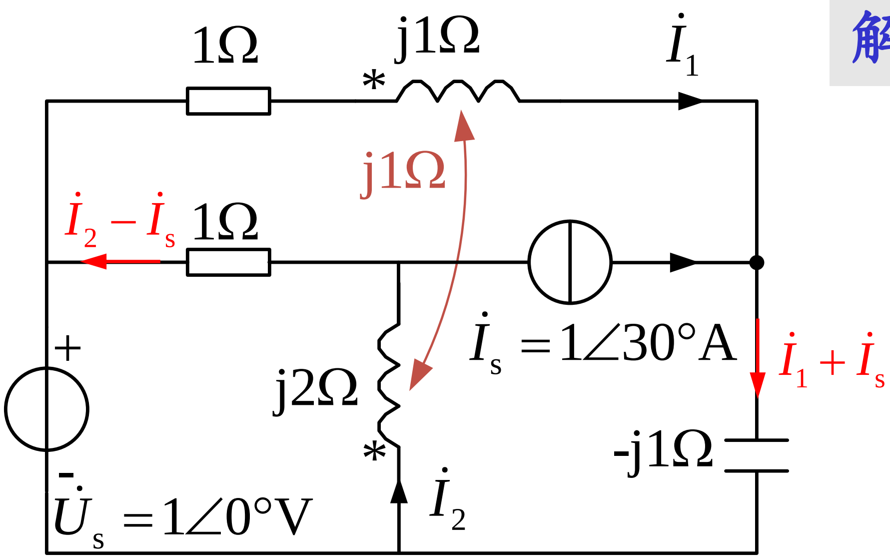
如何先求 $\dot{I}_2$?

$$\dot{U}_{oc} = \mathrm{j}\omega M\dot{I}_1 = \mathrm{j}\omega M\frac{\dot{U}_s}{Z_{11}} = \mathrm{j}10 \times \frac{100\angle 0^\circ}{20 + \mathrm{j}30}$$

$$Z_{eq} = (10 + \mathrm{j}20) + \frac{10^2}{20 + \mathrm{j}30} \qquad \dot{I}_2 = \frac{\dot{U}_{oc}}{10 + Z_{eq}}$$

$$20\dot{I}_1 + \mathrm{j}30\dot{I}_1 - \mathrm{j}10\dot{I}_2 = 100\angle 0^\circ$$

例：求$\dot{I}_1$、$\dot{I}_2$，及两个电感所在支路消耗的有功功率。



解 能否去耦？**不能去耦！**

网孔法，列KVL方程

$$\dot{I}_1+(\text{j}1\dot{I}_1+\text{j}1\dot{I}_2)-\text{j}1(\dot{I}_1+\dot{I}_s)=\dot{U}_s$$

$$(\text{j}2\dot{I}_2+\text{j}1\dot{I}_1)+(\dot{I}_2-\dot{I}_s)=-\dot{U}_s$$

$$\dot{I}_1=0.753\angle 65.1°\ \text{A}$$

$$\dot{I}_2=0.259\angle 45°\ \text{A}$$

$\cancel{P_1=I_1^2\times 1}$

$$P_1=\text{Re}\left[\left(\dot{I}_1+\text{j}1\dot{I}_1+\text{j}1\dot{I}_2\right)\times\dot{I}_1^*\right]=0.75\ \text{W}$$

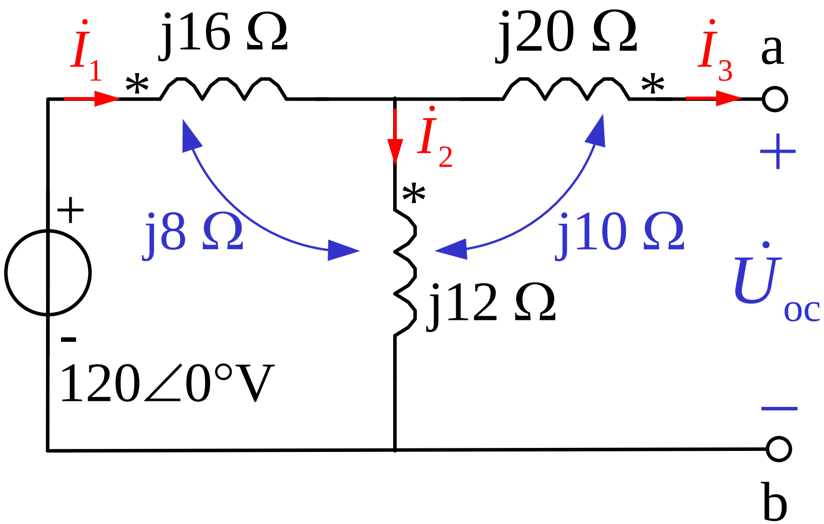
$\cancel{P_2=0}$

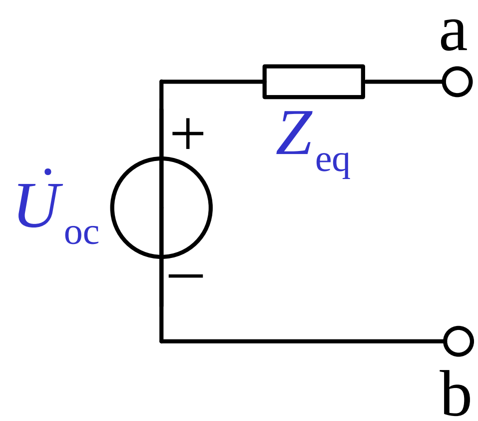
$$P_2=\text{Re}\left[\left(\text{j}2\dot{I}_2+\text{j}1\dot{I}_1\right)\times\dot{I}_2^*\right]=-0.183\ \text{W}$$

是否正确？

$$P_1+P_2=0.567\ \text{W}=I_1^2\times 1$$

例：求ab端口的戴维南等效电路。





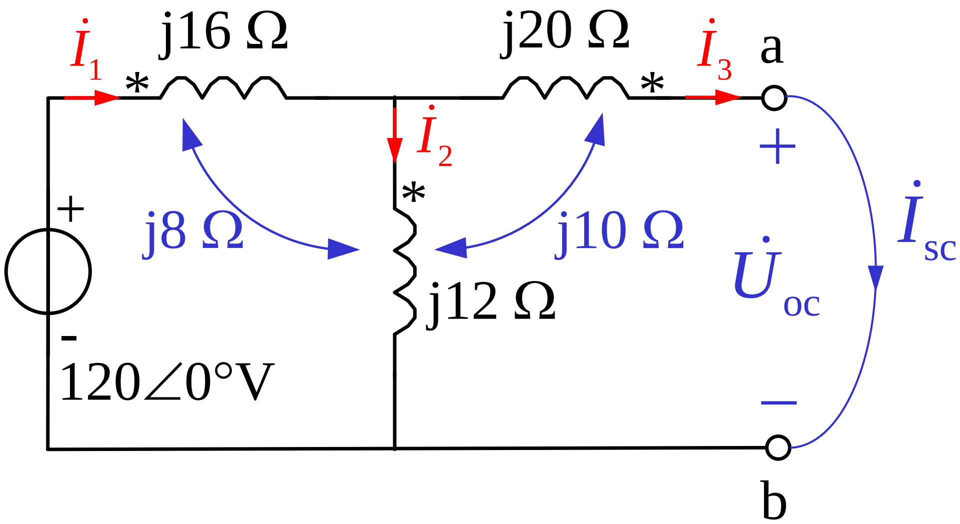
解 **1）计算开路电压**

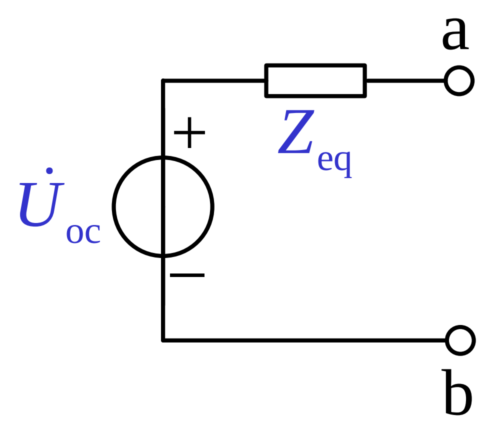
$\dot{I}_3=0 \quad \dot{I}_1=\dot{I}_2$

$$\dot{U}_{oc}=\frac{900}{11}\angle 0°\ \mathrm{V}$$

$$\dot{U}_{oc}=-\left(\mathrm{j}20\dot{I}_3-\mathrm{j}10\dot{I}_2\right)+(\mathrm{j}12\dot{I}_2+\mathrm{j}8\dot{I}_1-\mathrm{j}10\dot{I}_3)$$

$$120\angle 0°=\left(\mathrm{j}16\dot{I}_1+\mathrm{j}8\dot{I}_2\right)+(\mathrm{j}12\dot{I}_2+\mathrm{j}8\dot{I}_1-\mathrm{j}10\dot{I}_3)$$





2）计算短路电流

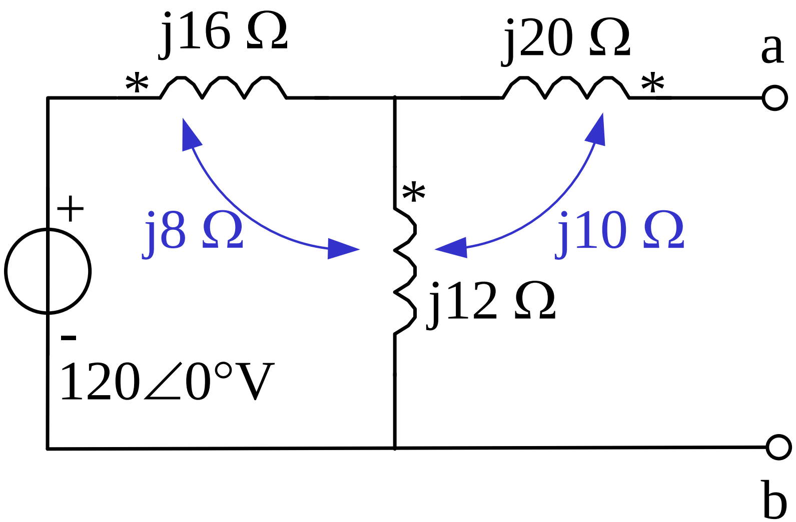
$$\mathrm{j}12\dot{I}_2 + \mathrm{j}8\dot{I}_1 - \mathrm{j}10\dot{I}_3 = \mathrm{j}20\dot{I}_3 - \mathrm{j}10\dot{I}_2$$

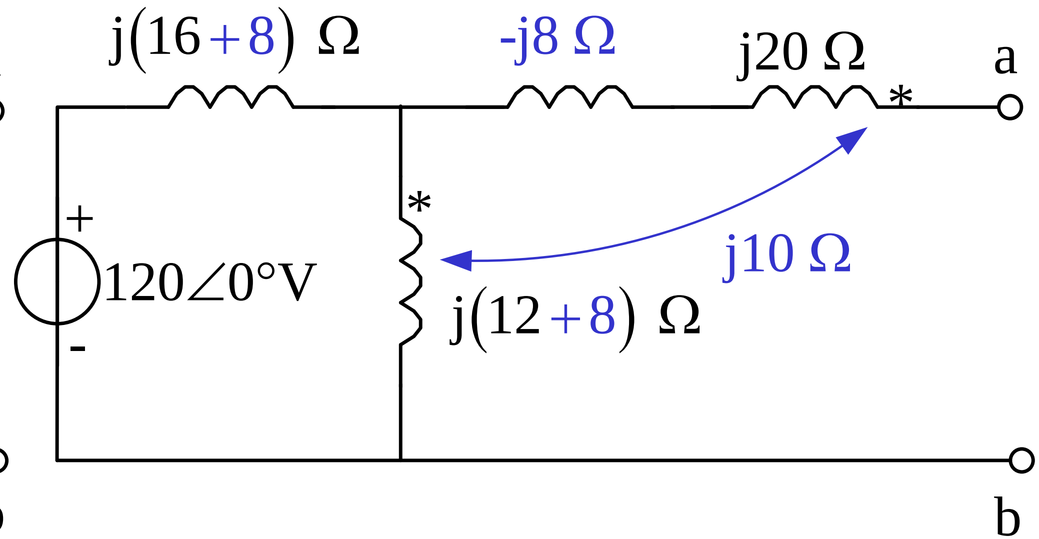
$$120\angle 0^\circ = \left(\mathrm{j}16\dot{I}_1 + \mathrm{j}8\dot{I}_2\right) + (\mathrm{j}12\dot{I}_2 + \mathrm{j}8\dot{I}_1 - \mathrm{j}10\dot{I}_3)$$

$$\dot{I}_1 = \dot{I}_2 + \dot{I}_3 \qquad \dot{I}_{sc} = \dot{I}_3 = -\mathrm{j}\frac{900}{347}\ \mathrm{A}$$

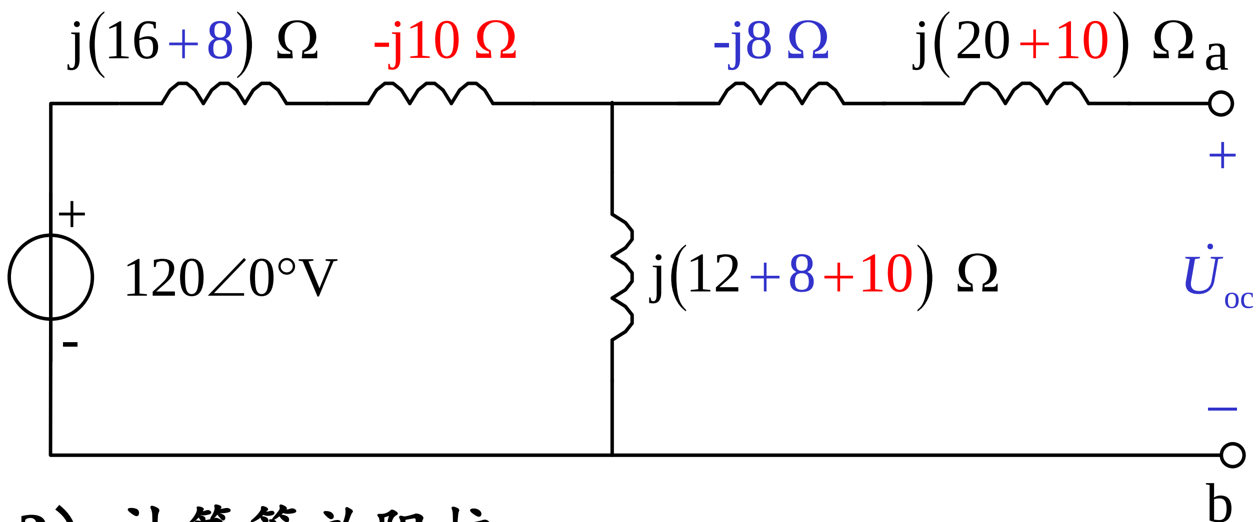
3）计算等效阻抗

$$Z_{eq} = \frac{\dot{U}_{oc}}{\dot{I}_{sc}} = \mathrm{j}\frac{347}{11}\ \Omega$$





解 去耦等效法



1）计算开路电压

$$\dot{U}_{oc}=\frac{j30}{j14+j30}\cdot 120$$

$$=\frac{900}{11}\angle 0^\circ\ \mathrm{V}$$

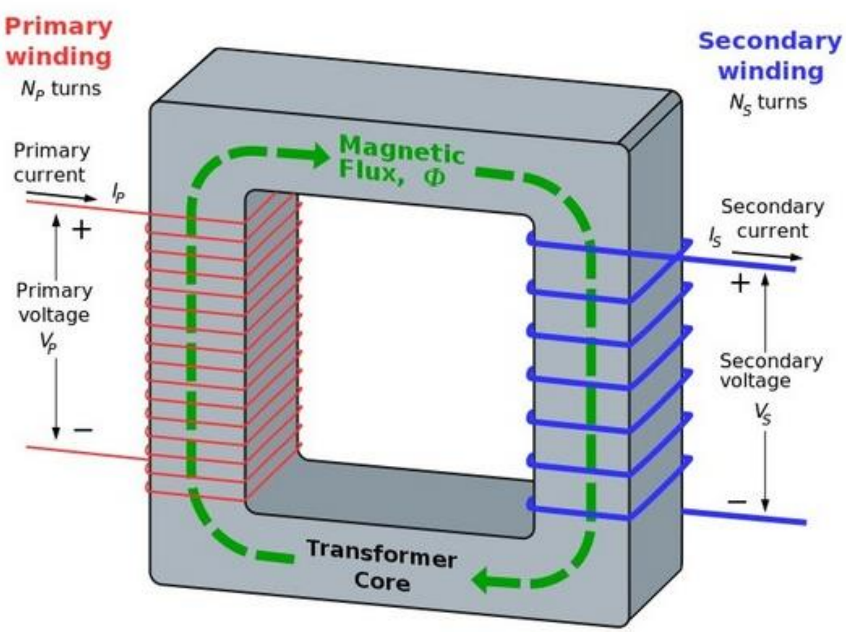
2）计算等效阻抗

$$Z_{eq}=\left[j22+\left(j30\ //\ j14\right)\right]=j\frac{347}{11}\ \Omega$$

13.4 变压器

1. 变压器原理

变压器是利用**磁耦合原理**传输电能的一类电器件。变压器的两个线圈绕在同一个磁心上，且一个线圈接电压源，另一个线圈接负载。变压器工作于交流下，**在电源和负载之间进行电压变换**。



- 交流变压、变流
- 传送功率
- 电隔离
- 阻抗匹配

油浸式三相电力变压器

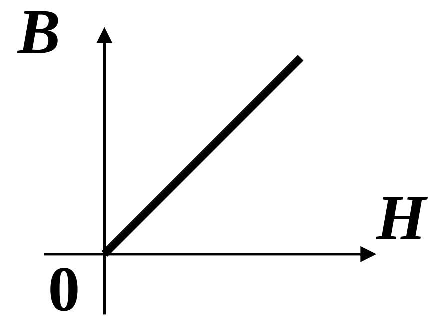
2. 变压器分类

➢ 线性变压器

磁心：磁导率低、但等于常数的线性磁介质

塑料、木材、陶瓷等

自感小、无铁心损耗



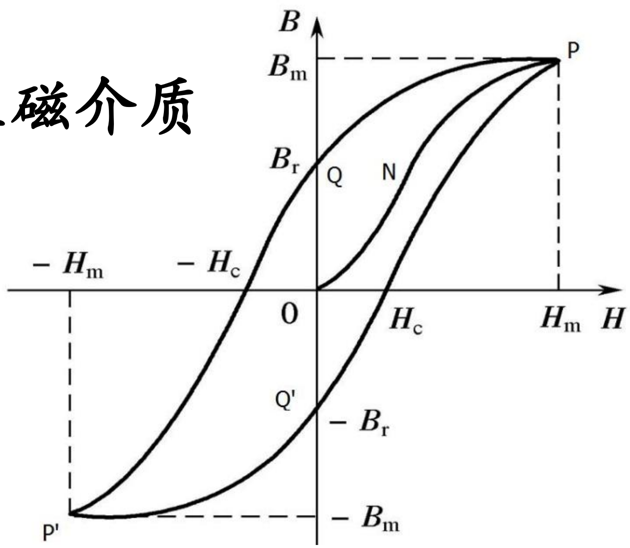
➢ 铁心变压器

磁心：磁导率高、但不为常数的非线性磁介质

硅钢片、铁氧体等

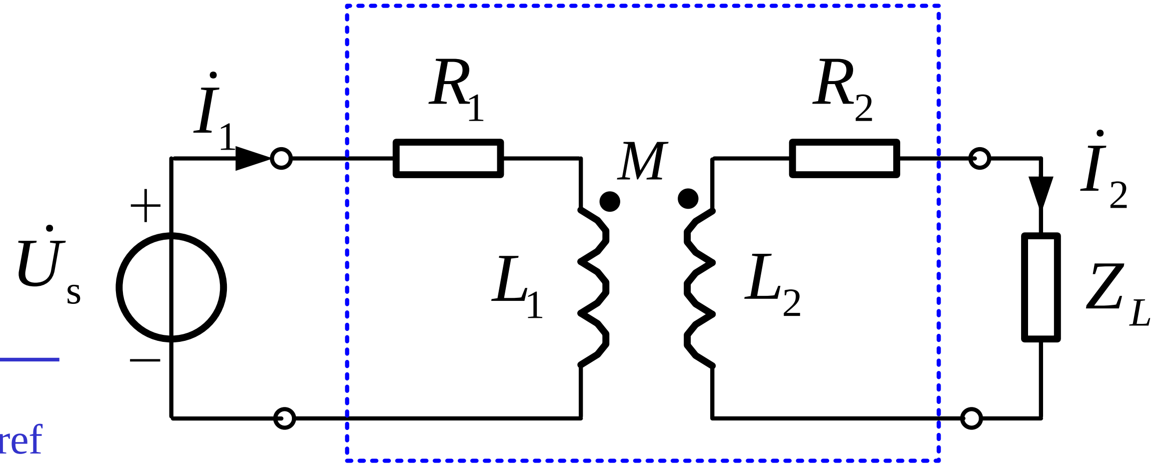
自感大、存在铁心损耗

相同电流产生的B大 → 相同体积下L比较大 → 储能大



$$\dot{I}_1 = \frac{\dot{U}_s}{Z_{11} + Z_{\text{ref}}}$$

$$= \frac{\dot{U}_s}{R_1 + \mathrm{j}\omega L_1 + Z_{\text{ref}}}$$

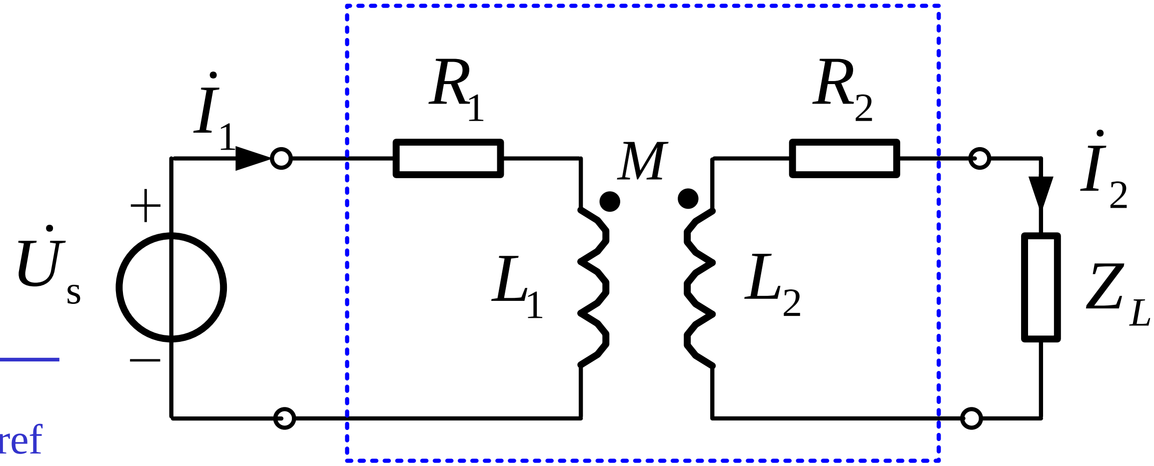


假定：$Z_L = R_L,\ R_1 \approx 0,\ R_2 \approx 0$ $\quad Z_{\text{ref}} = \dfrac{(\omega M)^2}{R_2 + Z_L}$

当$R_L \to \infty$时，$\dot{I}_{1\text{oc}} = \dfrac{\dot{U}_s}{\mathrm{j}\omega L_1}$ 一次绕组最小电流

由于线性变压器自感小，只有当U_s低、ω高时，才能使得I_{1oc}较小。因而，线性变压器只能用在电压低、频率高的场合。

$$\dot{I}_1 = \frac{\dot{U}_s}{Z_{11} + Z_{\text{ref}}} = \frac{\dot{U}_s}{R_1 + \mathrm{j}\omega L_1 + Z_{\text{ref}}}$$



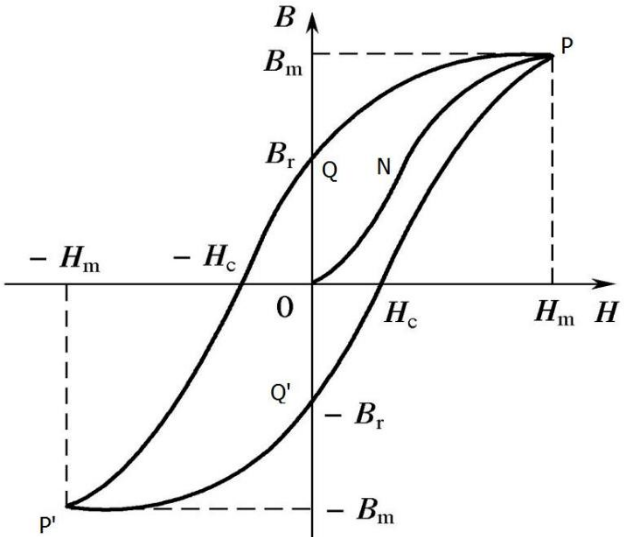
假定：$Z_L = R_L,\ R_1 \approx 0,\ R_2 \approx 0$ $\quad Z_{\text{ref}} = \dfrac{(\omega M)^2}{R_2 + Z_L}$

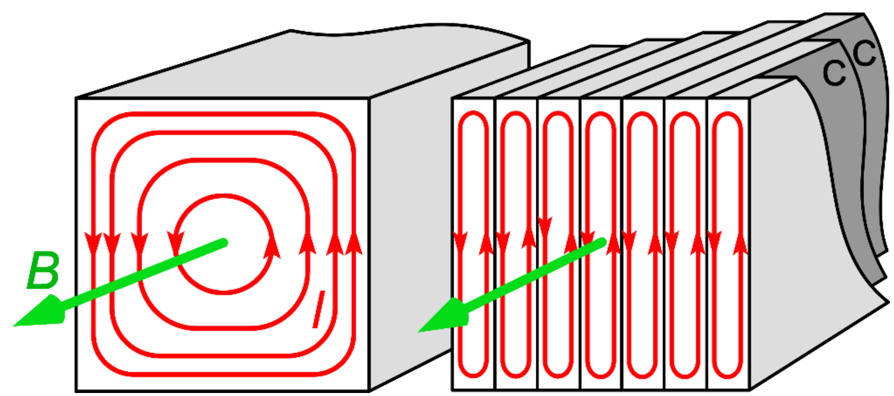
当$R_L \to \infty$时，$\dot{I}_{1\text{oc}} = \dfrac{\dot{U}_s}{\mathrm{j}\omega L_1}$ 一次绕组最小电流

在电压高、频率低的场合，必须通过加大线圈自感来限制I_{1oc}，需要采用磁导率高的铁合金磁心，并合理增加线圈匝数。铁心变压器

但铁心变压器内，存在两类损耗：

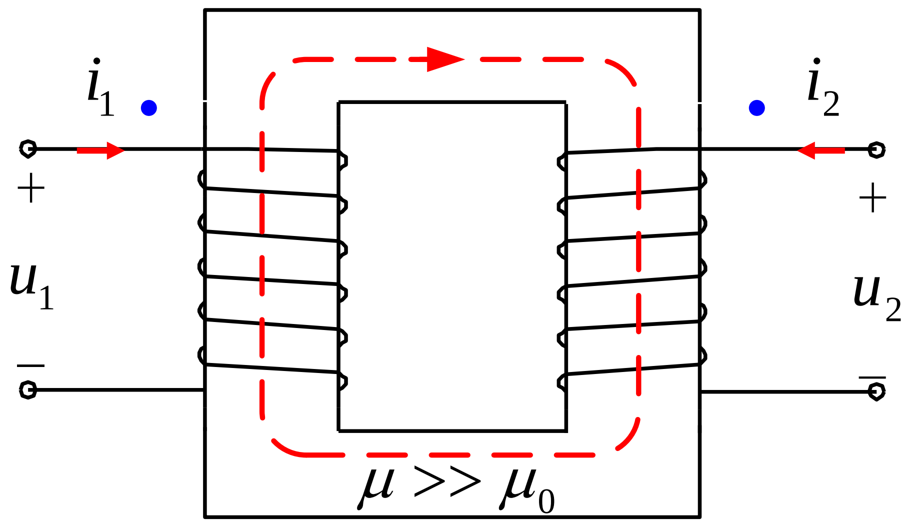
- 磁滞损耗：交变磁场中的非线性磁介质，其磁畴在反复转向中因摩擦而发热。
- 涡流损耗：铁合金具有良好的导电性，磁场交变而产生的感应电压，在铁合金中形成涡旋电流。





3. 理想变压器

- 线圈和磁心均是无损耗的
- 线圈自感无限大，L_1、$L_2 \rightarrow \infty$
- 线圈间是全耦合的，$k=1$



$$u_1 = \frac{d\psi_1}{dt} = \frac{d(N_1\varphi)}{dt} = N_1\frac{d\varphi}{dt}$$

$$u_2 = \frac{d\psi_2}{dt} = \frac{d(N_2\varphi)}{dt} = N_2\frac{d\varphi}{dt}$$

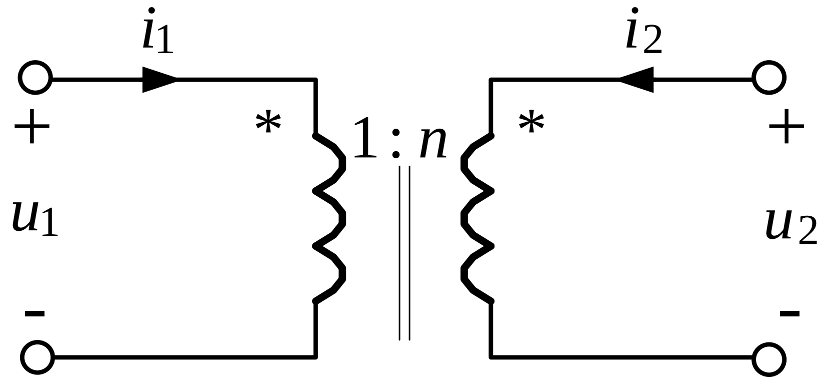
$$\Rightarrow \frac{u_1}{u_2} = \frac{N_1}{N_2} = n$$

适用于加强型耦合

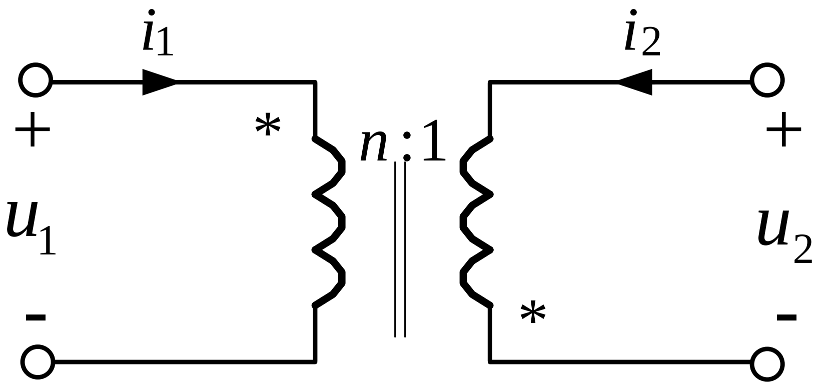
$$\because L_1, L_2 \rightarrow \infty \quad \therefore \mu \rightarrow \infty \quad H = B/\mu = 0$$

$$\oint \vec{H} \cdot d\vec{l} = \sum i = N_1 i_1 + N_2 i_2 = 0 \Rightarrow \frac{i_1}{i_2} = -\frac{N_2}{N_1} = -\frac{1}{n}$$

求原方和副方的电压比、电流比



$$\frac{u_1}{u_2}=\frac{1}{n} \qquad \frac{i_1}{i_2}=-\frac{n}{1}$$



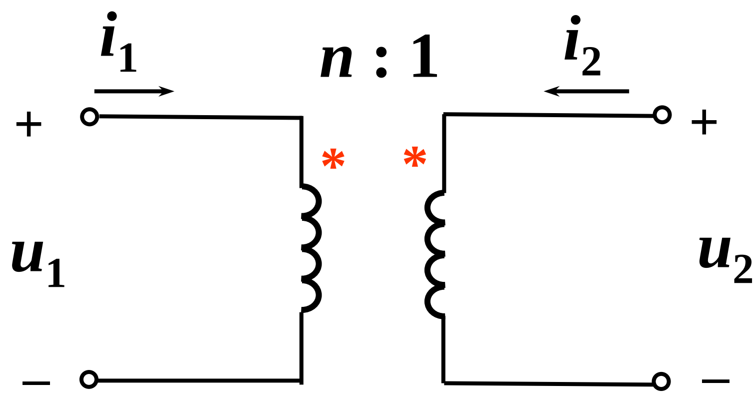
$$\frac{u_1}{u_2}=-n \qquad \frac{i_1}{i_2}=\frac{1}{n}$$

理想变压器的性质：

(a) 功率传输

理想变压器的特性方程为代数关系，无记忆作用

$$\begin{cases} u_1 = nu_2 \\ i_1 = -\dfrac{1}{n} i_2 \end{cases}$$



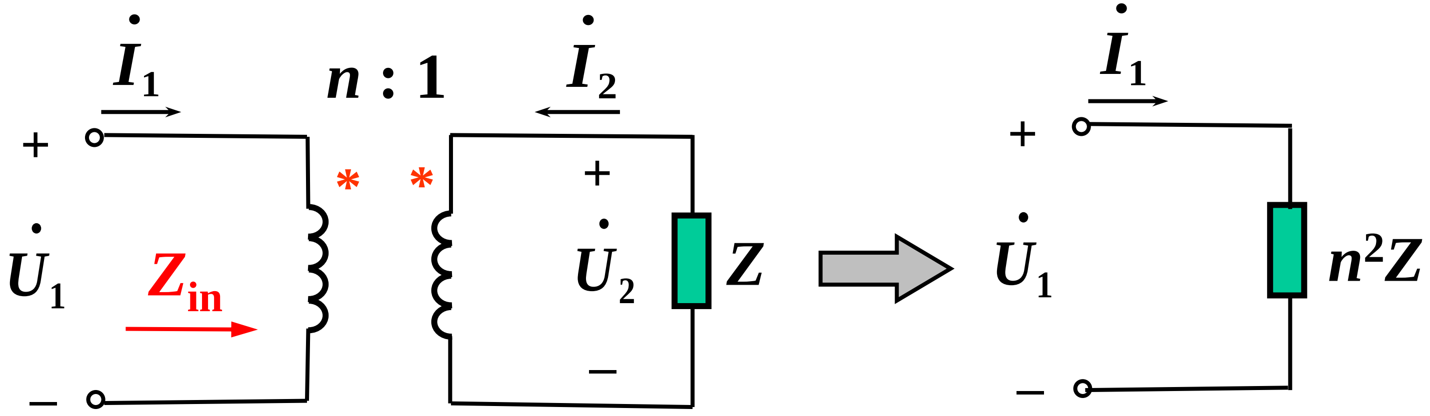
$$p = u_1 i_1 + u_2 i_2 = u_1 i_1 + \frac{1}{n} u_1 \times (-n i_1) = 0$$

理想变压器既不储能，也不耗能，在电路中只起传递信号和能量的作用。

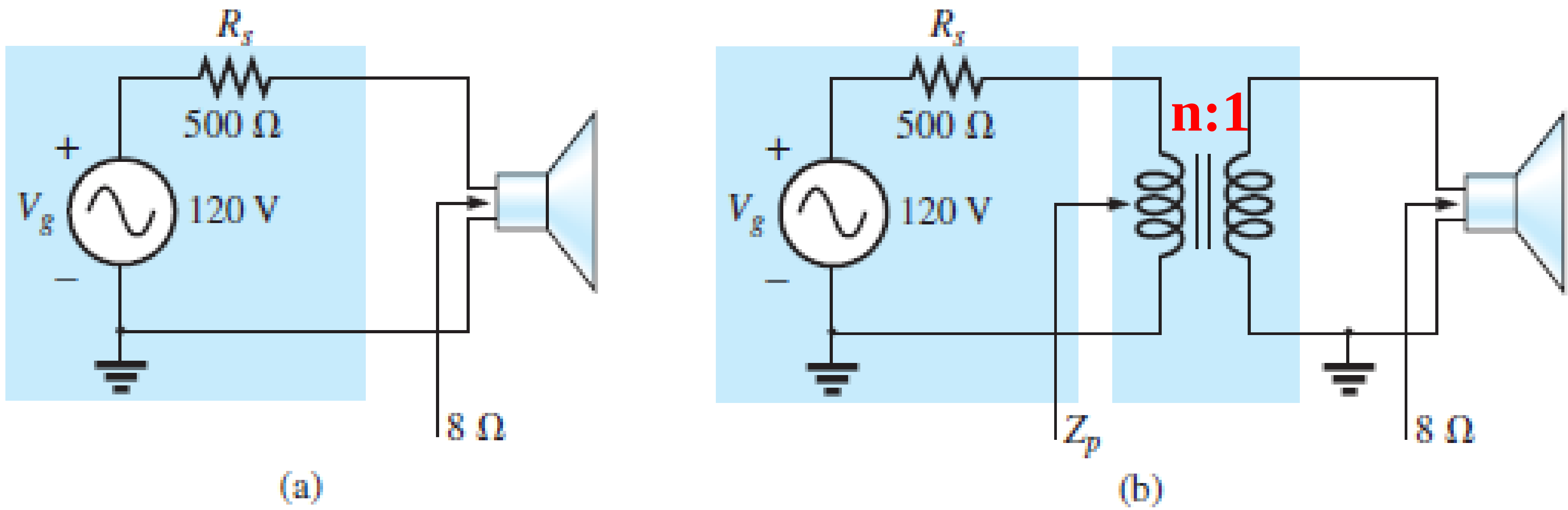
理想变压器的性质：

(b) 阻抗变换

用于提高或降低视在阻抗，
以实现最大功率传输。



$$Z_{in}=\frac{\dot{U}_1}{\dot{I}_1}=\frac{n\dot{U}_2}{-1/n\dot{I}_2}=n^2(-\frac{\dot{U}_2}{\dot{I}_2})=n^2Z$$



$$P = I^2R = \left(\frac{120}{500+8}\right)^2 \times 8 = 0.45\ \text{W}$$

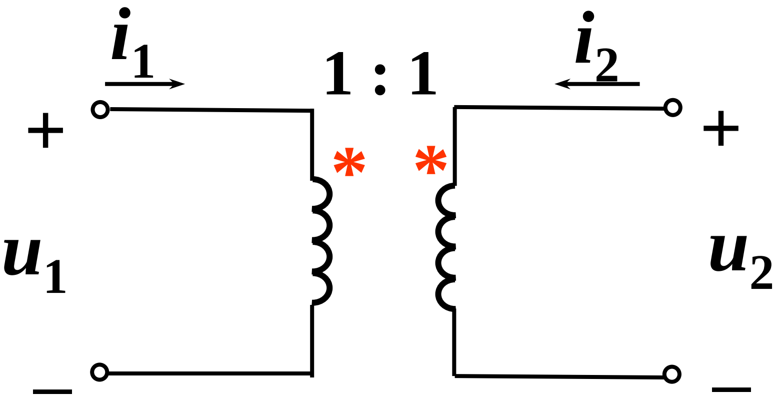
$$R_{in} = n^2 R_L \Rightarrow n = 7.9$$

$$P = I^2R = \left(\frac{120}{500+500}\right)^2 \times 500 = 7.2\ \text{W}$$

理想变压器的性质：

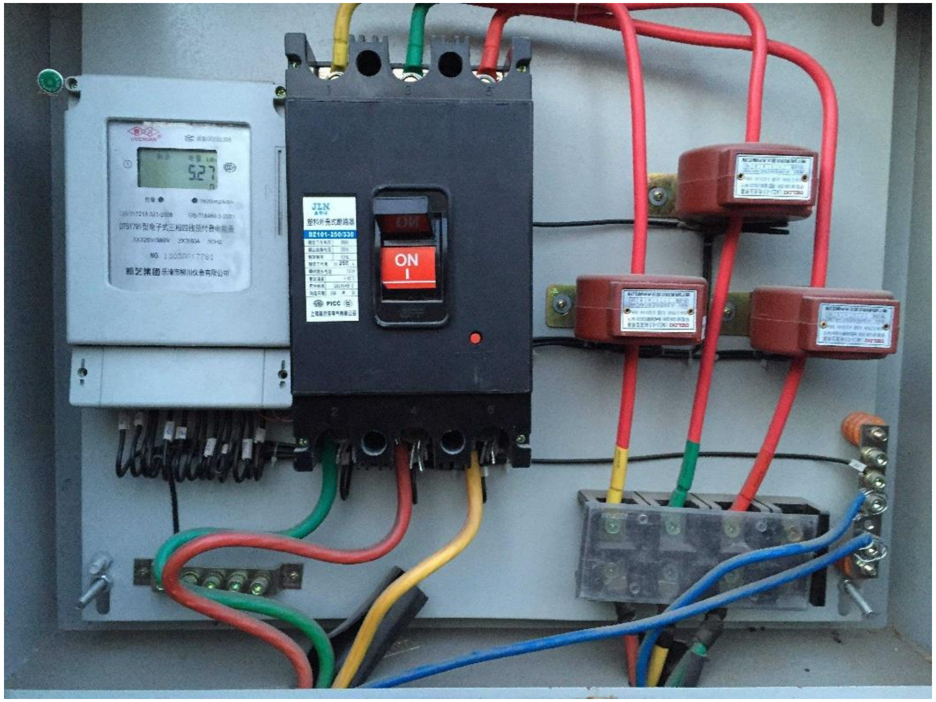
(c) 电气隔离　用于测量高电压和大电流

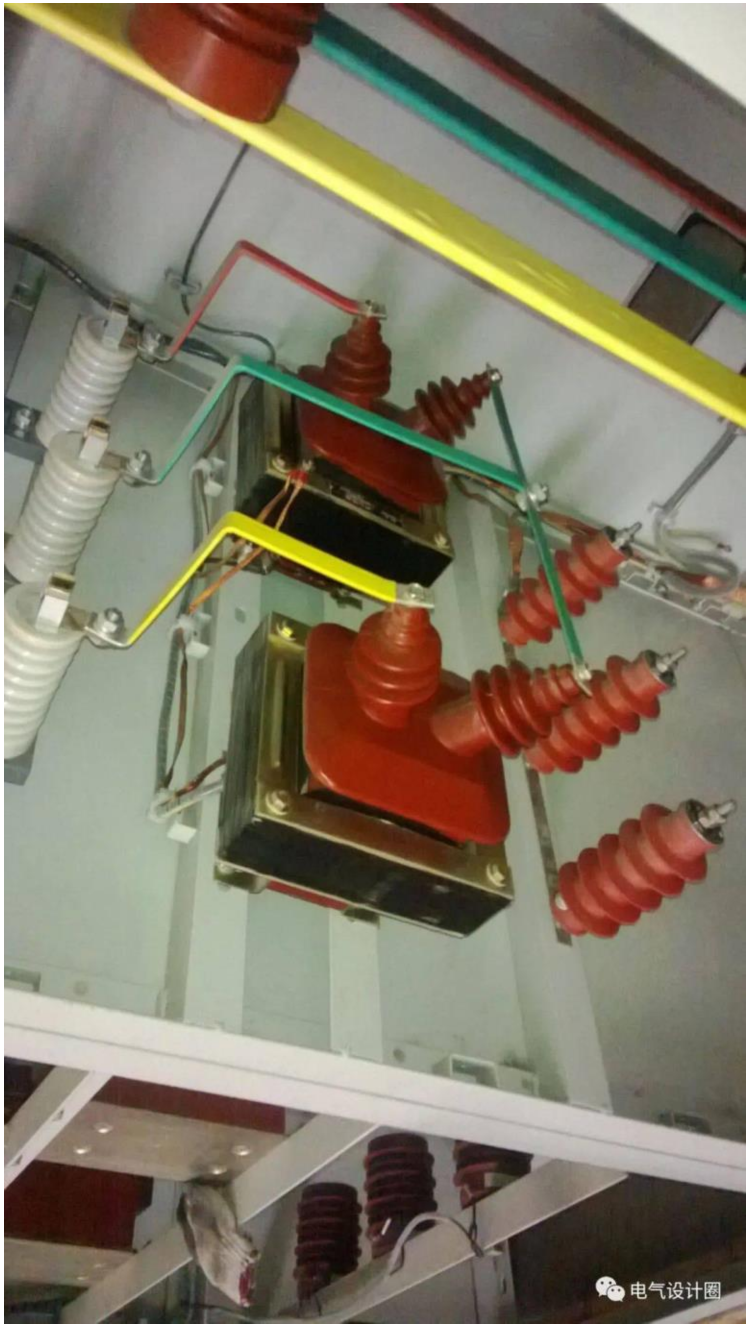
一次绕组、二次绕组的匝数比为1



隔离变压器的作用为对电源回路和负载回路进行电气隔离

- **电流互感器：**
  匝比1:n 升压变压器
- **电压互感器：**
  匝比n:1 降压变压器





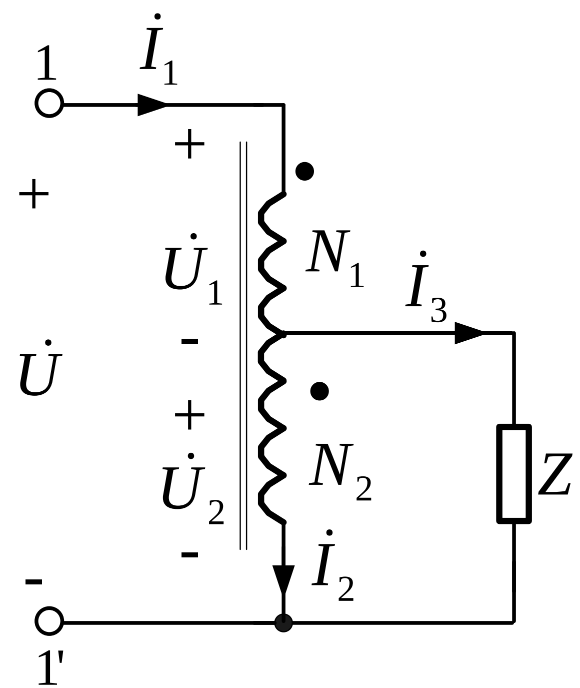
4. 自耦变压器

单相变压器闭合铁心上的两个线圈在电气上是不相连的，而自耦变压器是闭合铁心上只有一个线圈，从线圈中间接出一个抽头，线圈的一部分为一次绕组（或二次绕组），线圈的全部为二次绕组（或一次绕组）。

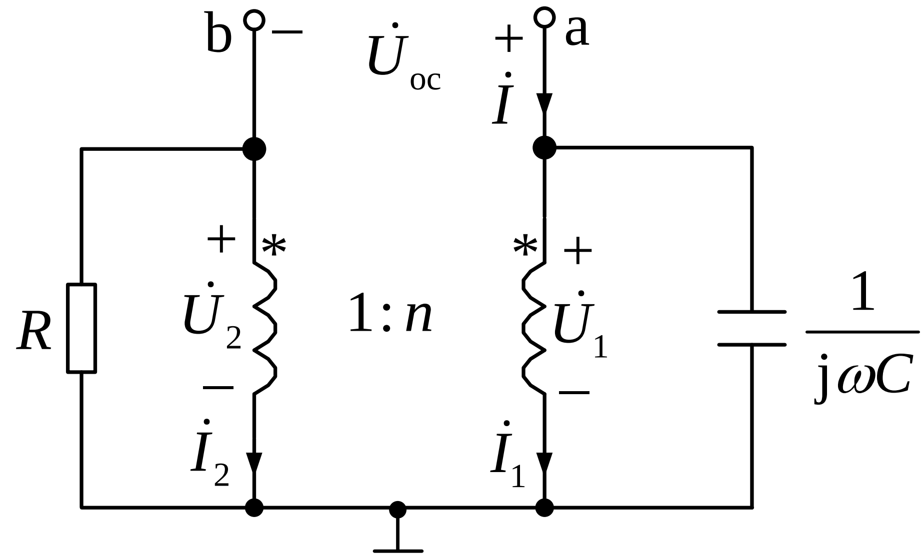
$$\frac{\dot{U}_1}{\dot{U}_2}=\frac{N_1}{N_2} \Rightarrow \frac{\dot{U}}{\dot{U}_2}=\frac{N_1+N_2}{N_2}$$

$$\oint \vec{H}\cdot d\vec{l}=\sum i=N_1\dot{I}_1+N_2\left(\dot{I}_1-\dot{I}_3\right)=0$$

$$\frac{\dot{I}_1}{\dot{I}_3}=\frac{N_2}{N_1+N_2}$$



例：求从端口a、b看进去的输入阻抗。



解 $Z_{in} = \dfrac{\dot{U}_{oc}}{\dot{I}}$

$$j\omega C\dot{U}_1 + \dot{I}_1 = \dot{I}$$

$$\frac{\dot{U}_2}{R} + \dot{I}_2 = -\dot{I}$$

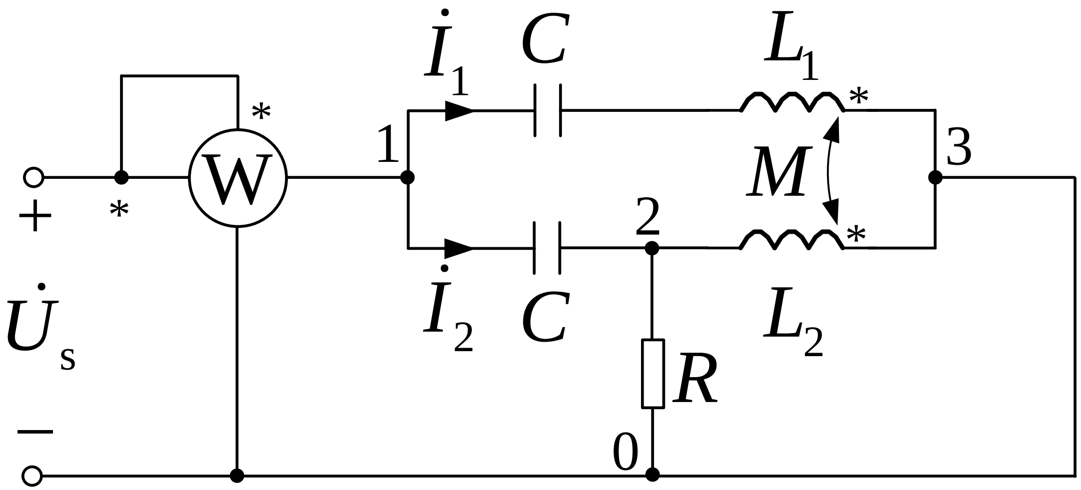
$$\dot{I}_1 = -\frac{1}{n}\dot{I}_2$$

$$\dot{U}_1 = n\dot{U}_2$$

$$\dot{I} = -\frac{\left(1 + j\omega CRn^2\right)}{R(1-n)}\dot{U}_2 \quad \dot{U} = \dot{U}_1 - \dot{U}_2 = (n-1)\dot{U}_2$$

$$Z_{in} = \frac{\dot{U}_{oc}}{\dot{I}} = \frac{(1-n)^2 R}{1 + j\omega CRn^2}$$

例：电压源的角频率为何值时，功率表W的读数为零？



解

$$P_R = 0 = I_R^2 R$$

$$\dot{I}_R = 0$$

$$\dot{U}_{20} = 0$$

$$\dot{U}_{23} = 0 \quad \dot{U}_{12} = \dot{U}_s$$

$$\left(j\omega L_1 - j\frac{1}{\omega C} \right)\dot{I}_1 + j\omega M\dot{I}_2 = \dot{U}_s$$

$$j\omega M\dot{I}_1 + j\omega L_2\dot{I}_2 = \dot{U}_{23}$$

$$\dot{I}_2 = j\omega C\dot{U}_{12} = j\omega C\dot{U}_s$$

$$\Rightarrow \omega = \sqrt{\frac{L_2 + M}{C\left(L_1 L_2 - M^2\right)}}$$

作业

- 13.2节：13-6
- 13.3节：13-9
- 13.4节：13-15
- 13.5节：13-20