Chapitre 3 : LE TRANSFORMATEUR

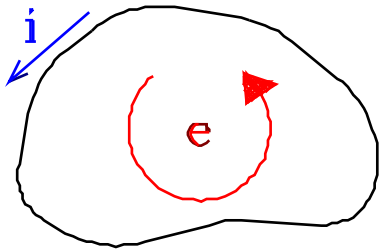
1. **Inductance**
   - 1.1. Monophasée dans l'air
   - 1.2. Monophasée à noyau manétique
   - 1.3. Phénomènes transitoires à la mise sous tension

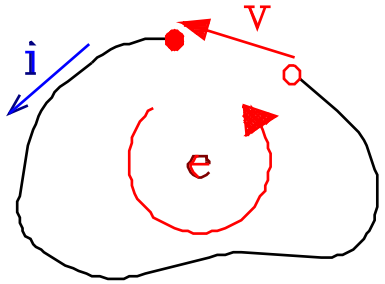
2. **Transformateur monophasé**
   - 2.1. Bobines à spires confondues, couplées dans l'air
   - 2.2. Transformateur à bobines couplées dans l'air
   - 2.3. Transformateur à noyau magnétique

3. **Transformateur triphasé**
   - 3.1. Constitution
   - 3.2. Fonctionnement en régime équilibré

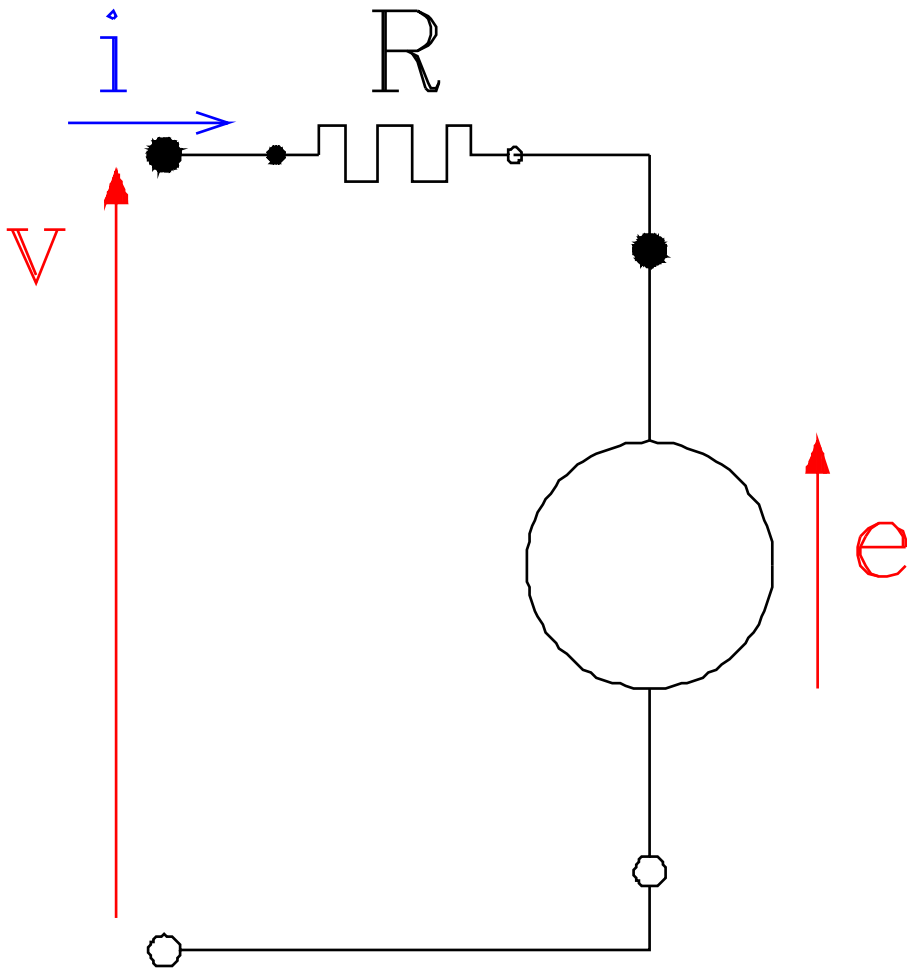
4. **Construction**
   - 4.1. Circuit magnétique
   - 4.2. Enroulements
   - 4.3. Isolement - Refroidissement

2.1.1. Tensions appliquées et induites





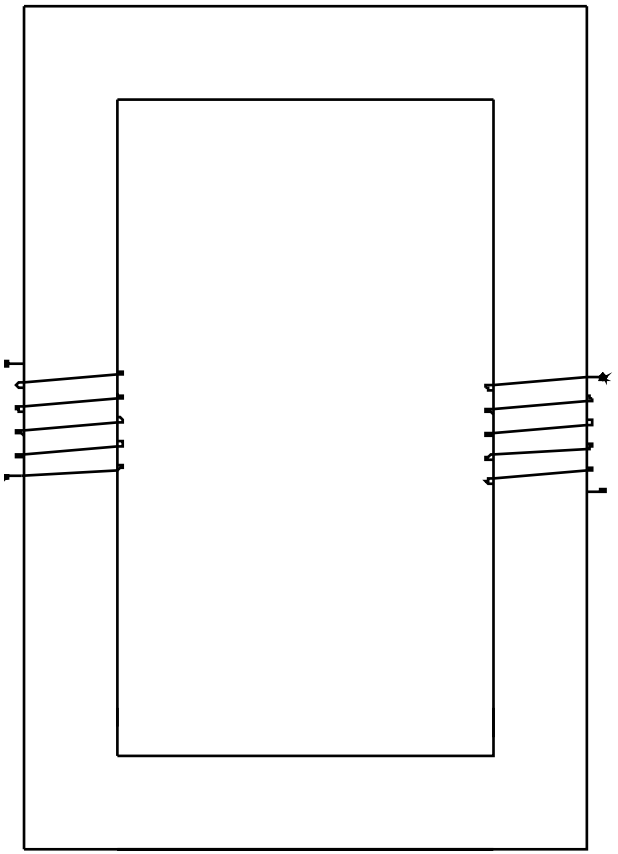
La f.e.m. est une tension appliquée



$$e = + \frac{d\phi}{dt}$$

2.1.1. Tensions appliquées et induites

Transformateur idéal ou parfait



Flux et tensions

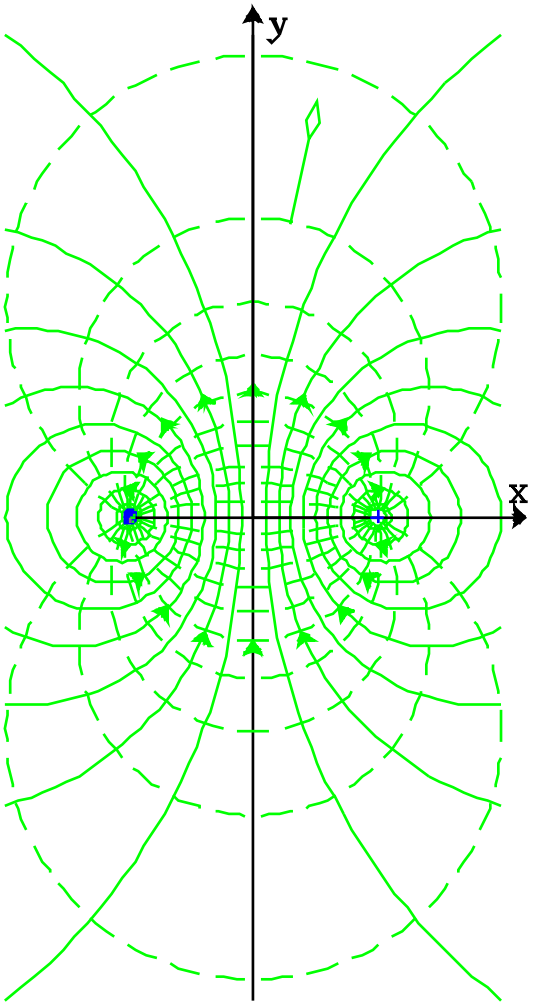
$$\frac{\psi_1}{\psi_2} = \frac{N_1}{N_2} \quad et \quad \frac{v_1}{v_2} = \frac{N_1}{N_2} = \mu$$

F.m.m. et courants

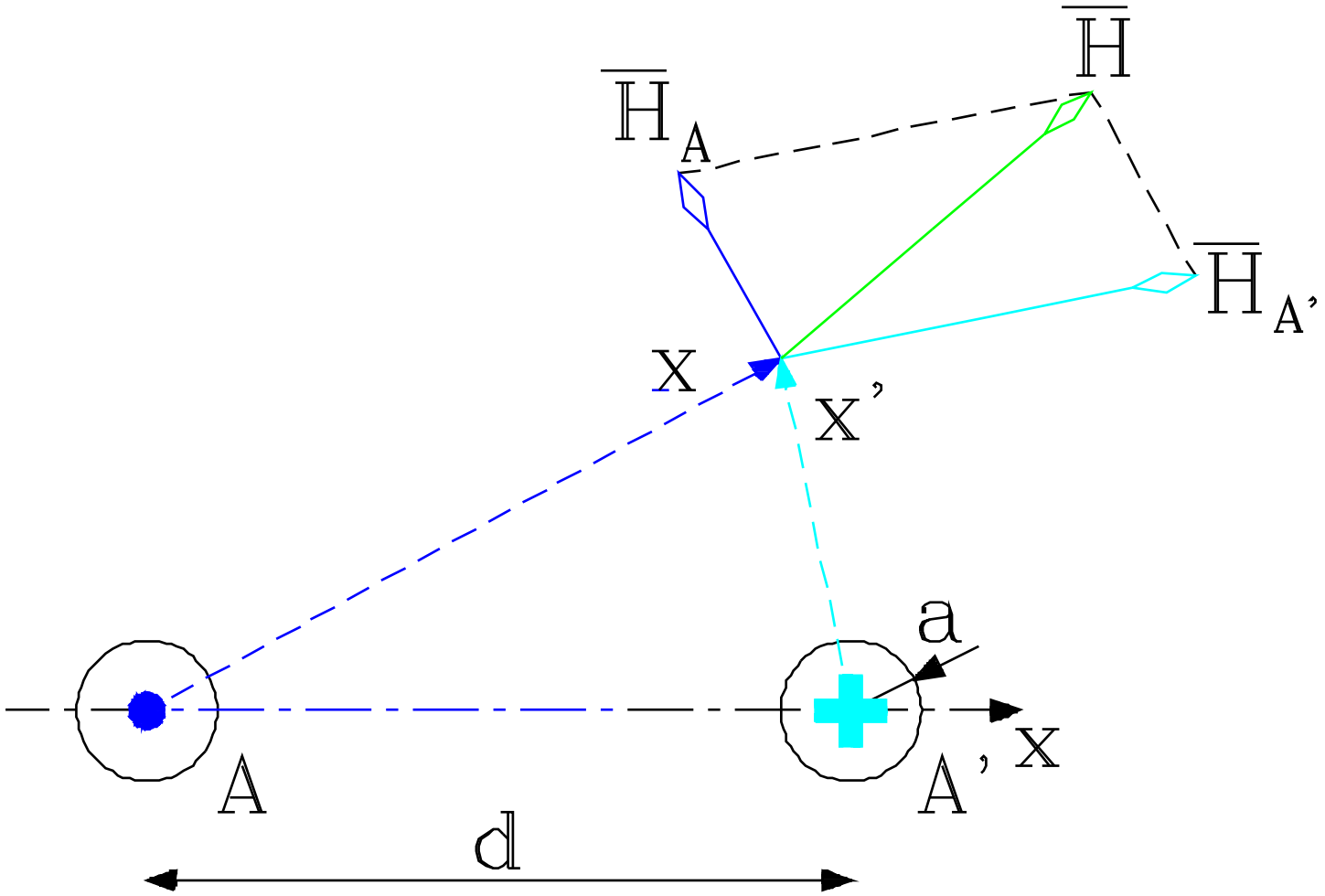
$$N_1\, i_1 + N_2\, i_2 = \oint_l H\, dl$$

$$i_1 + \frac{i_2}{\mu} = 0$$

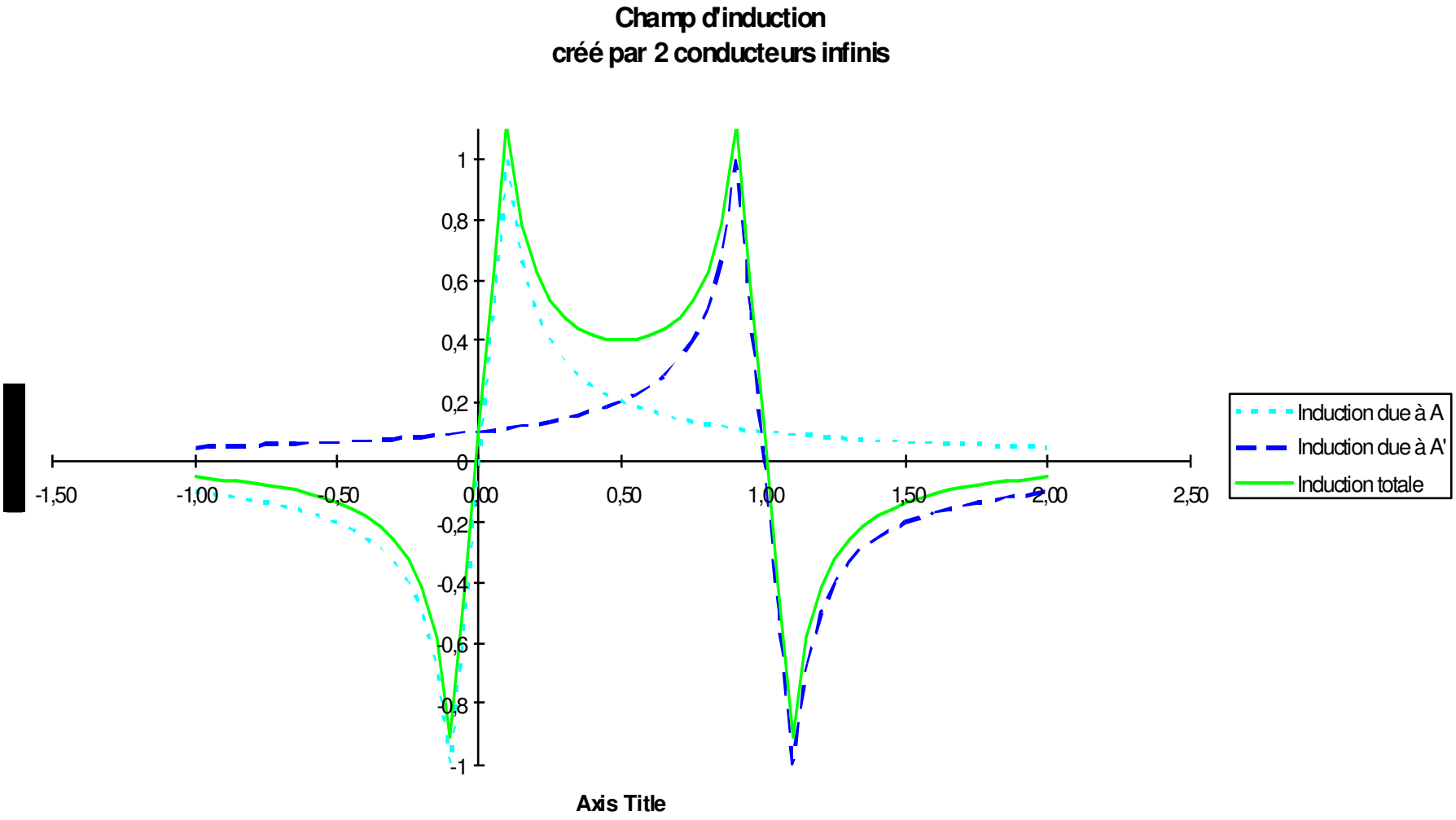
Lignes d'induction



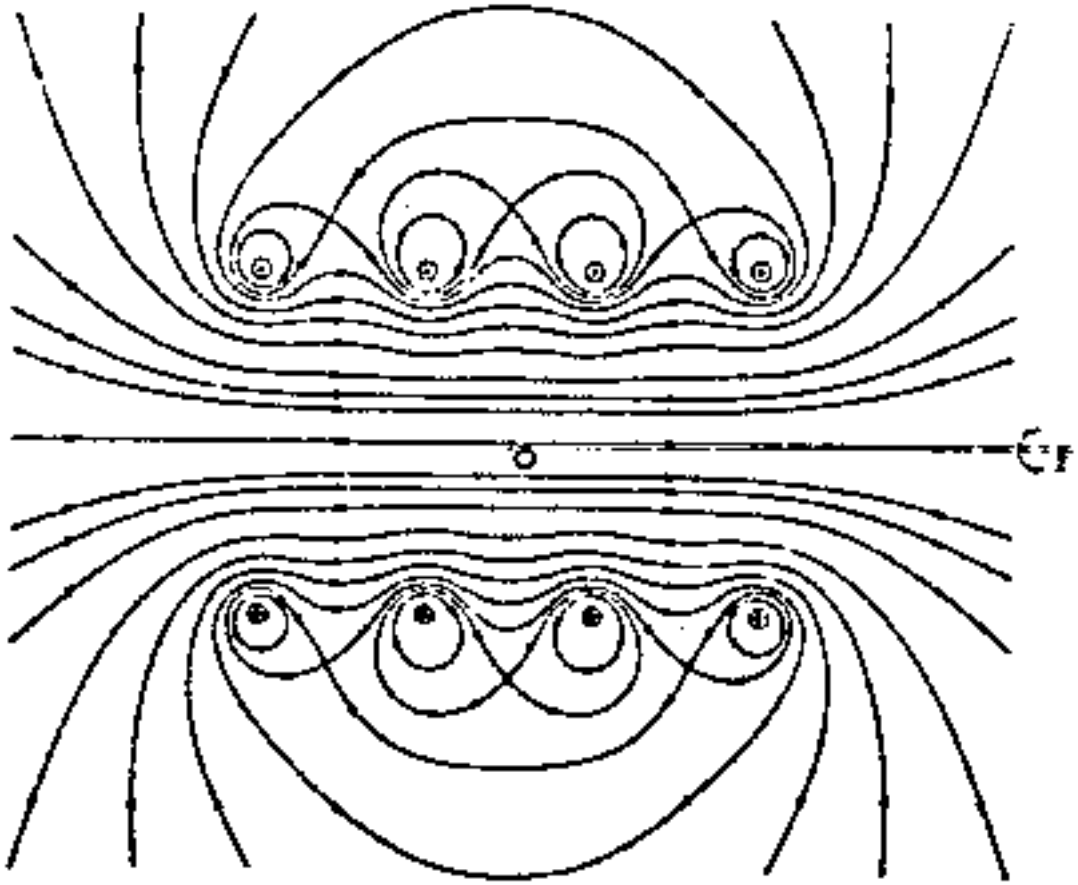
Spire bifilaire



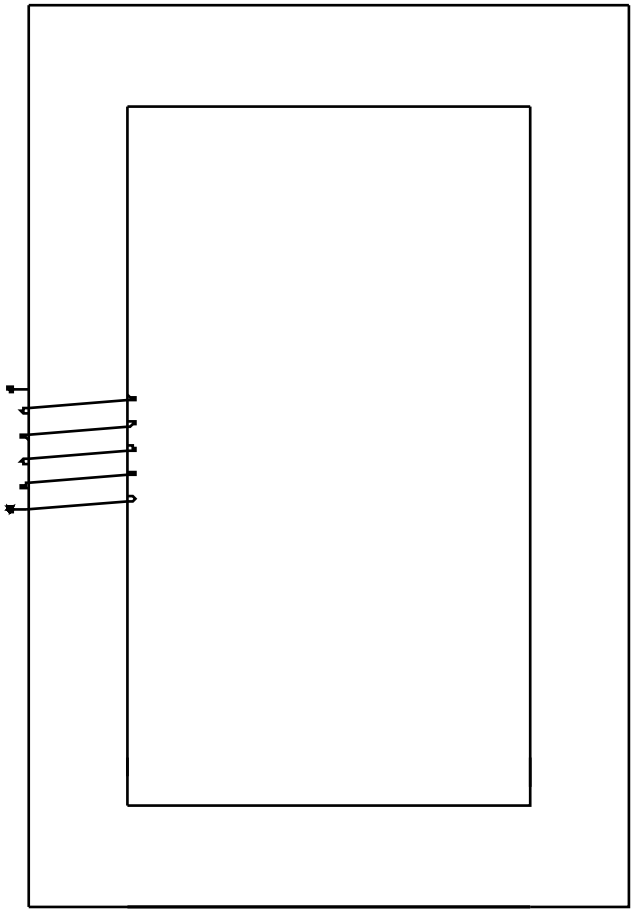
Induction entre les conducteurs

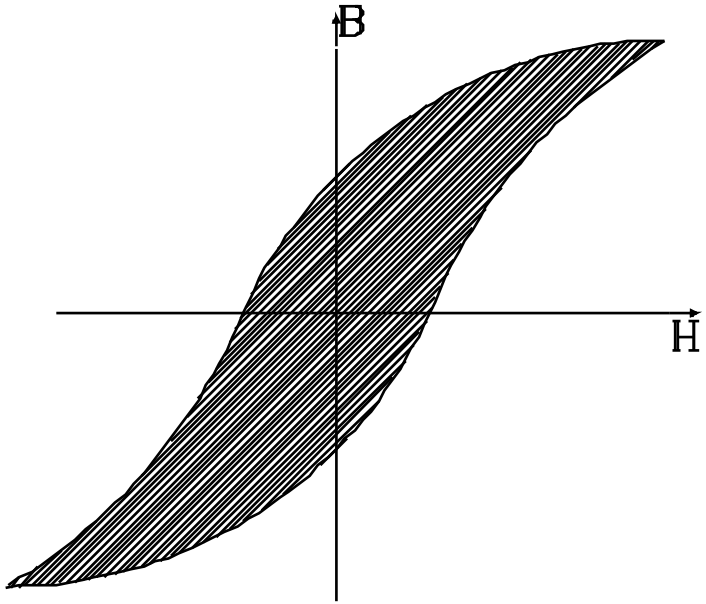


Spires non confondues

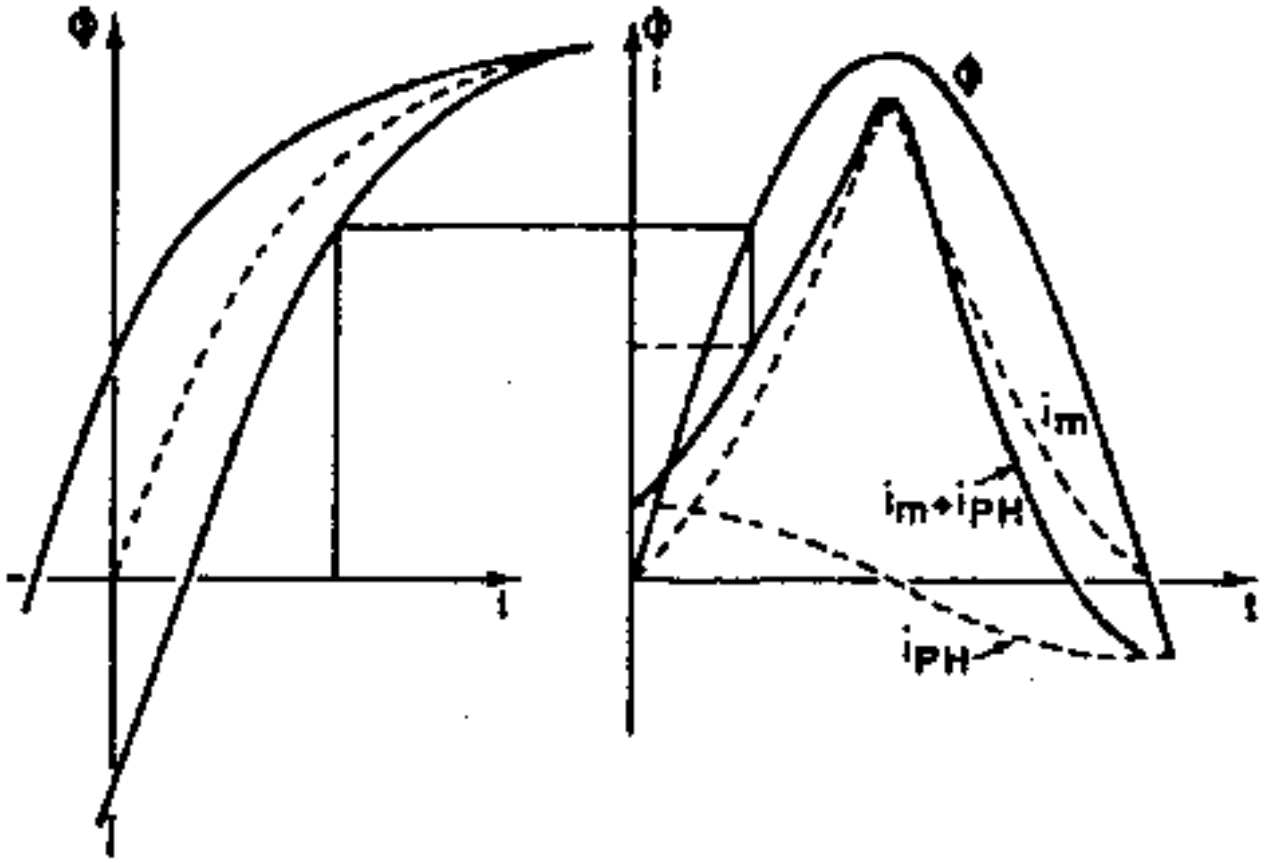


Noyau magnétique





Courant absorbé



Taux d'harmoniques

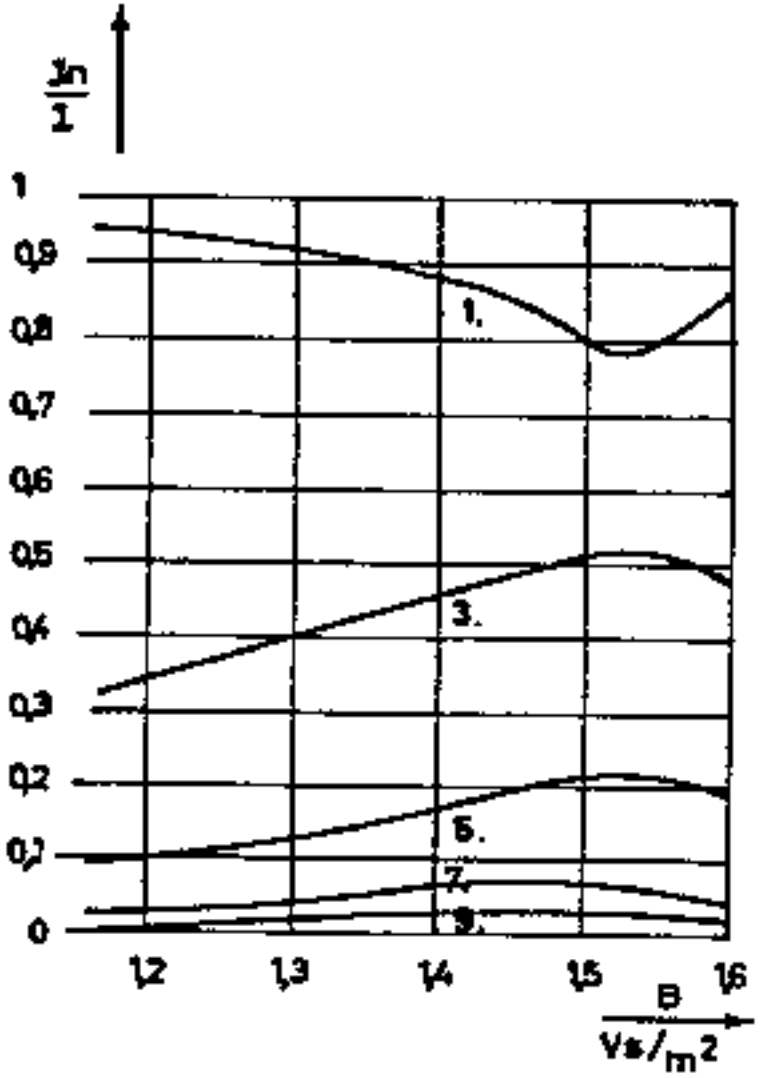
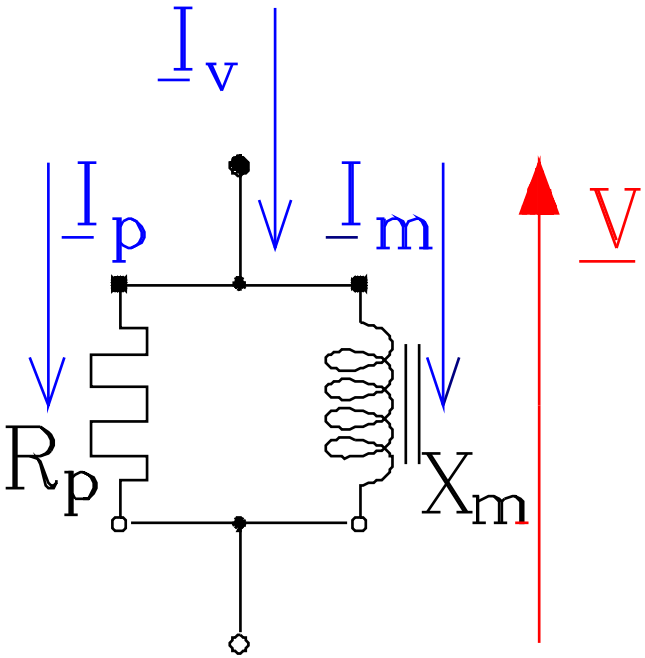
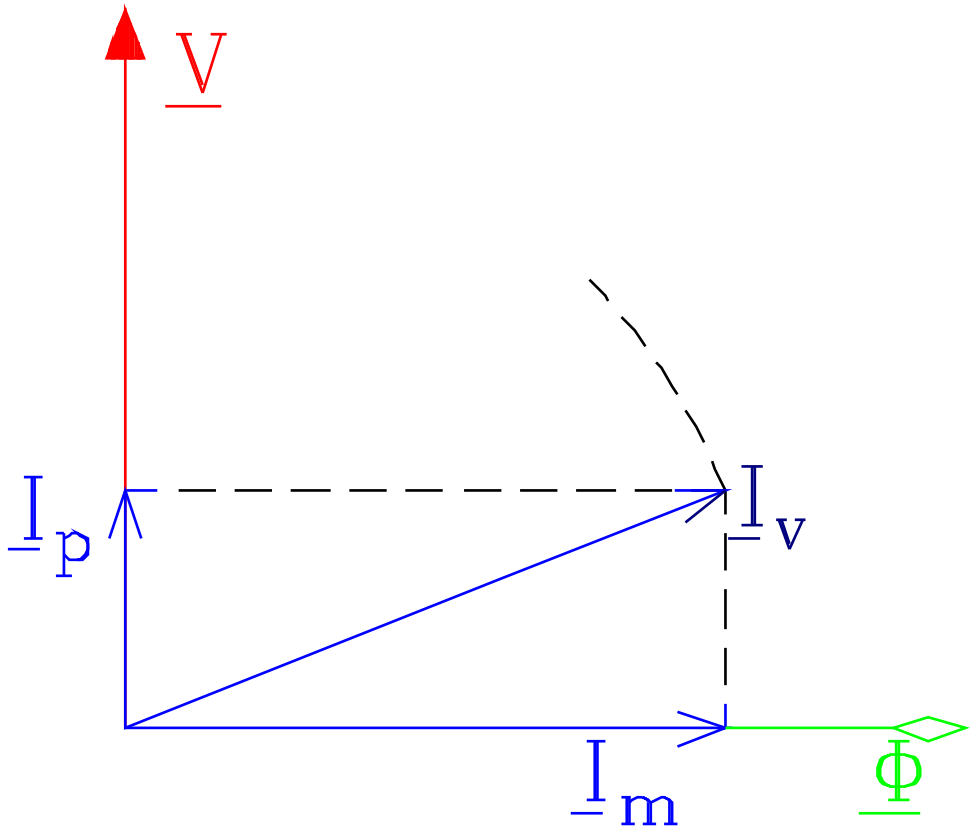
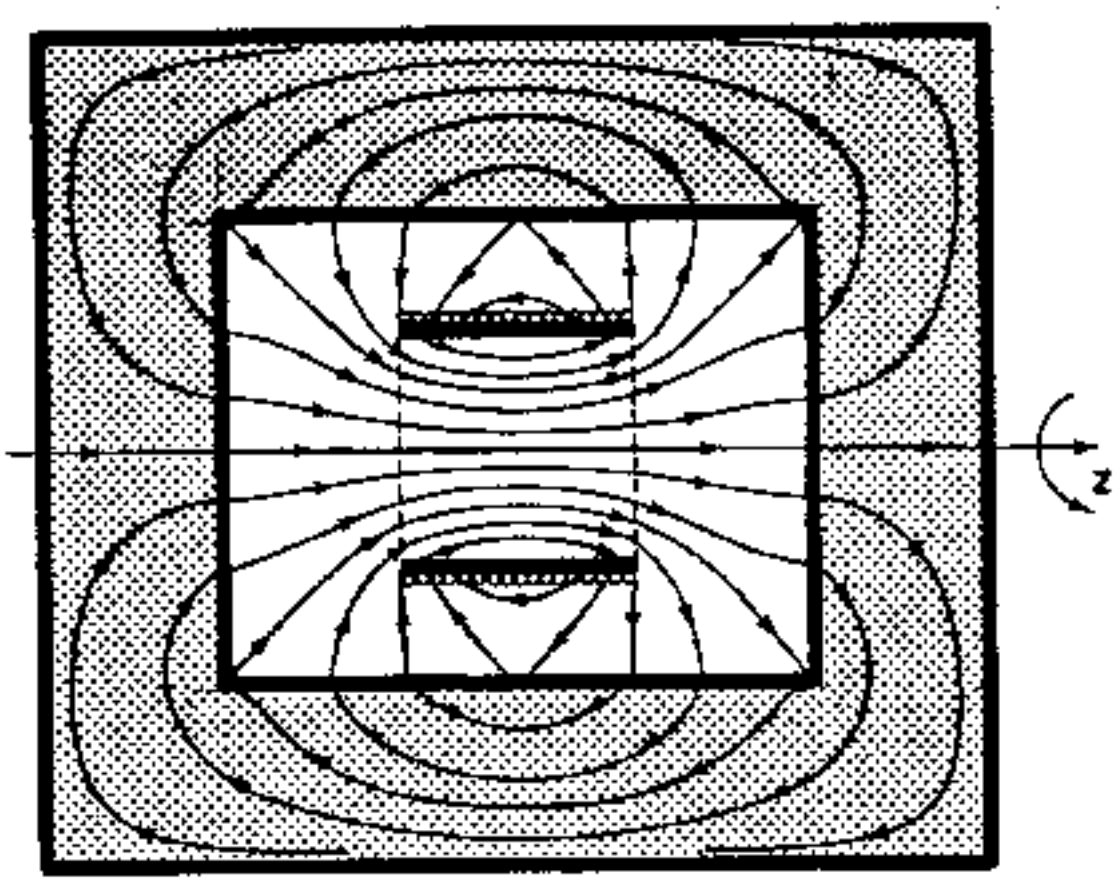


Schéma équivalent

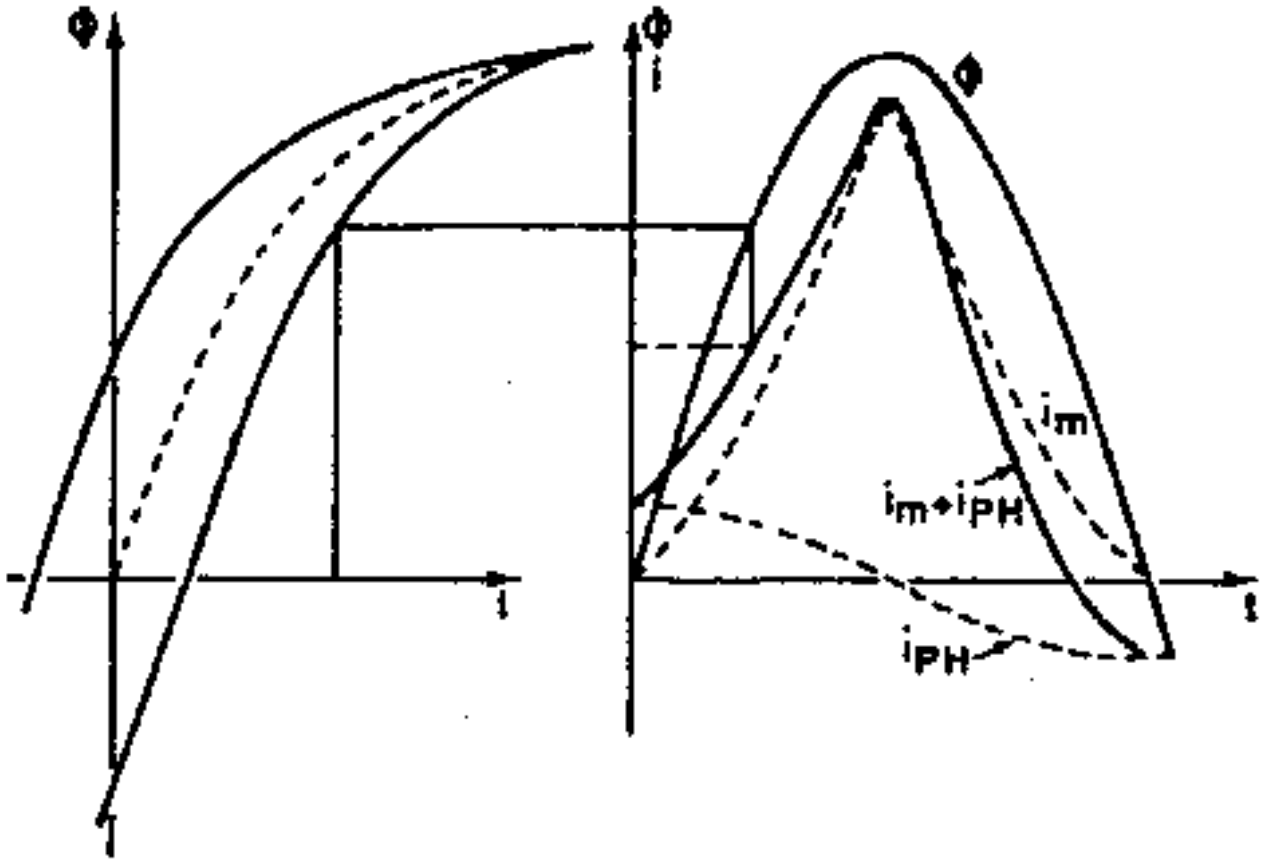




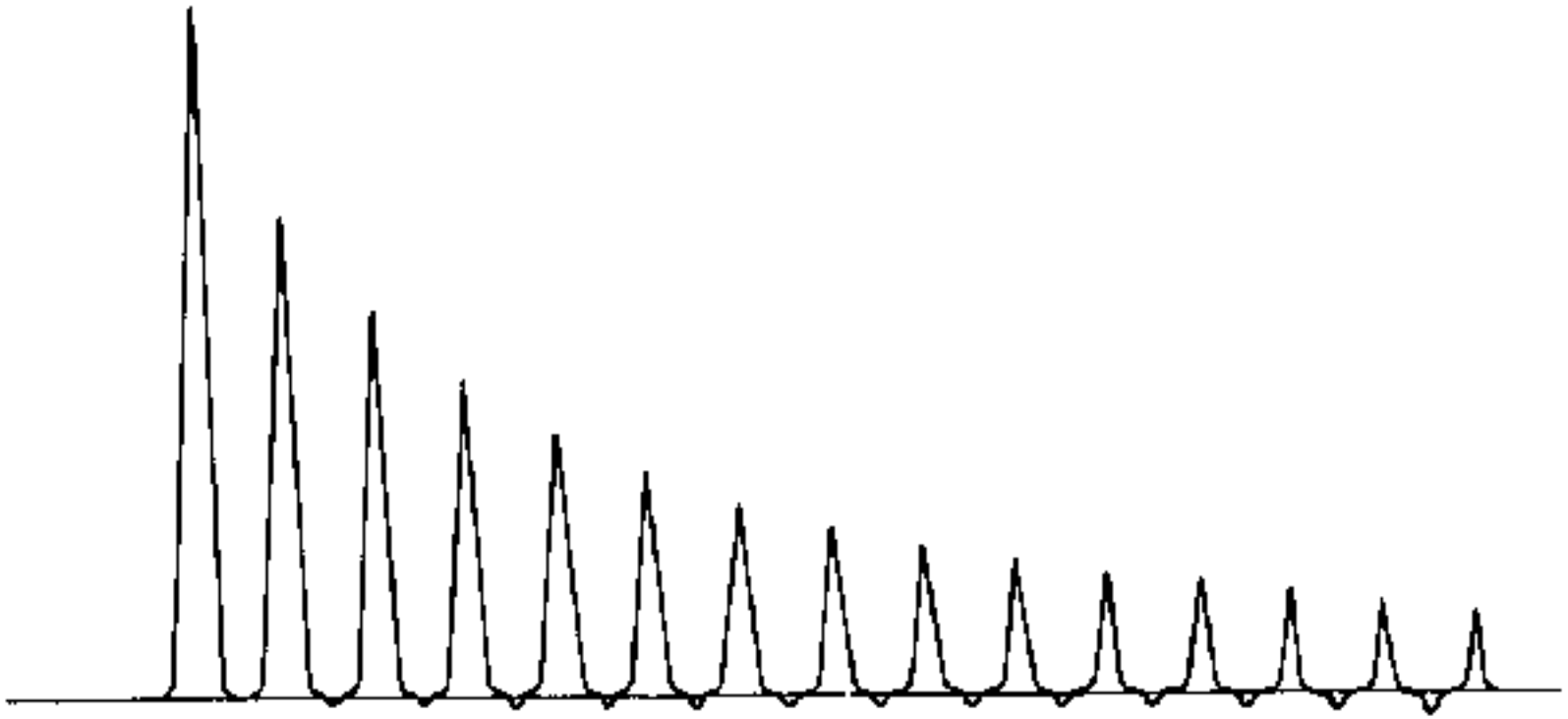
Circuit magnétique à entrefer



Courant absorbé

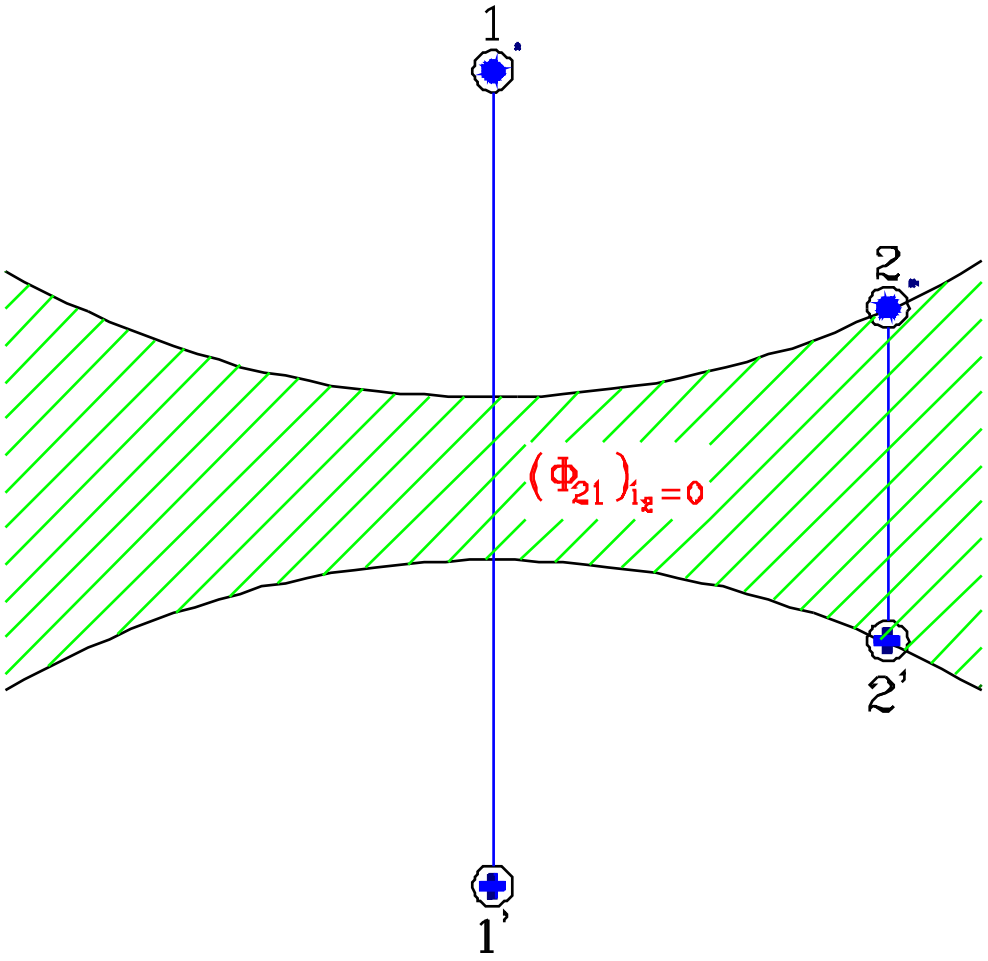


Courant d'enclenchement



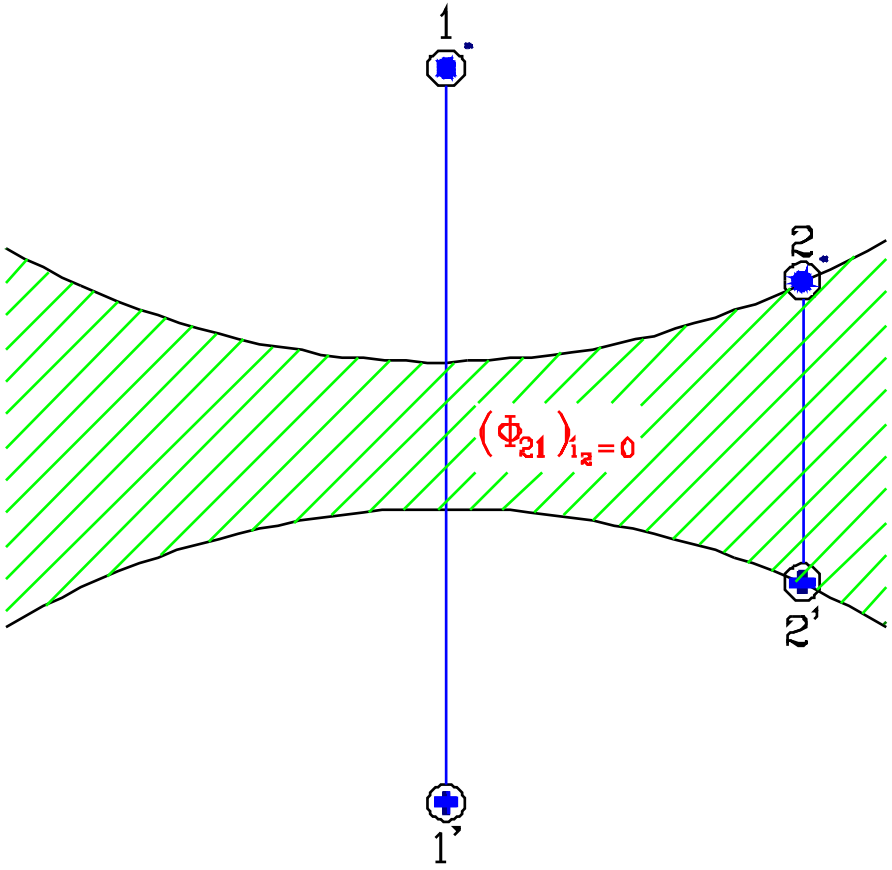
CURRENT RUSH WHEN SWITCHING IN A 20 kVA TRANSFORMER WITHOUT A RESISTOR

Couplage de deux circuits



Bobines à spires confondues, couplées dans l'air

Couplage de deux circuits

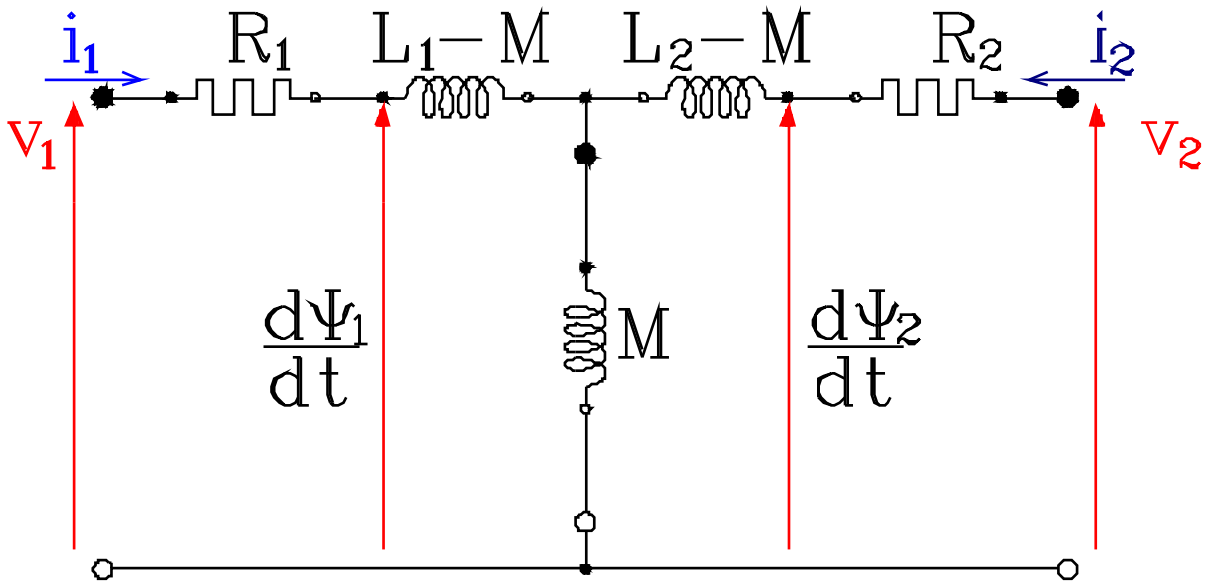


$$\psi_1 = L_1 i_1 + M i_2$$
$$\psi_2 = M i_1 + L_2 i_2$$

$$v_1 = R_1 i_1 + \frac{d\psi_1}{dt} = R_1 i_1 + L_1 \frac{di_1}{dt} + M \frac{di_2}{dt}$$
$$v_2 = R_2 i_2 + \frac{d\psi_2}{dt} = R_2 i_2 + M \frac{di_1}{dt} + L_2 \frac{di_2}{dt}$$

$$v_1 = R_1 i_1 + (L_1 - M) \frac{di_1}{dt} + M \frac{d(i_1 + i_2)}{dt}$$
$$v_2 = R_2 i_2 + (L_2 - M) \frac{di_2}{dt} + M \frac{d(i_1 + i_2)}{dt}$$

Schéma équivalent sans mutuelle

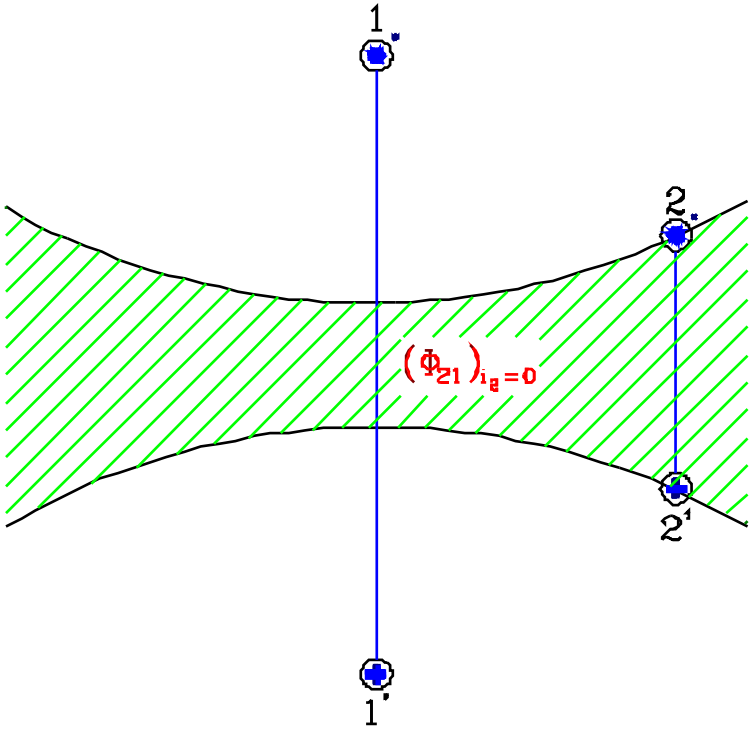


$$v_1 = R_1 i_1 + (L_1 - M)\frac{di_1}{dt} + M\frac{d(i_1 + i_2)}{dt}$$

$$v_2 = R_2 i_2 + (L_2 - M)\frac{di_2}{dt} + M\frac{d(i_1 + i_2)}{dt}$$

Bobines à spires confondues, couplées dans l'air

Couplage de deux circuits



$$k_1 = \frac{(\Phi_{21})_{i_2=0}}{(\Phi_1)_{i_2=0}}$$

Puisque

$$(\Psi_1)_{i_2=0} = N_1 (\Phi_1)_{i_2=0} = L_1 i_1$$

$$(\Psi_2)_{i_2=0} = N_2 (\Phi_{21})_{i_2=0} = N_2 k_1 (\Phi_1)_{i_2=0} = M i_1$$

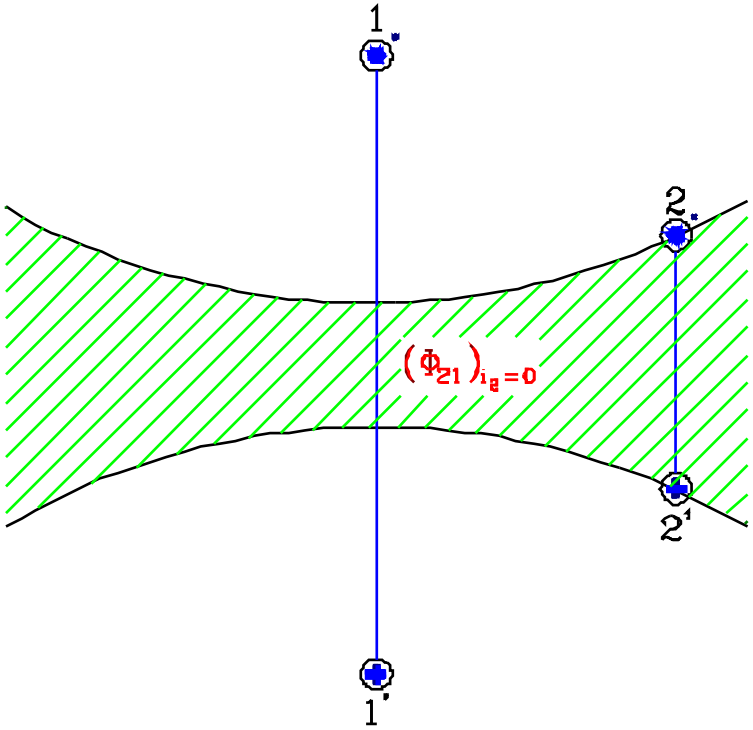
Il vient :

$$M = \frac{N_2}{N_1} k_1 L_1$$

$$ou \quad k_1 = \frac{N_1}{N_2} \frac{M}{L_1}$$

Bobines à spires confondues, couplées dans l'air

Couplage de deux circuits



$$k_2 = \frac{(\Phi_{12})_{i_1=0}}{(\Phi_2)_{i_1=0}}$$

$$M = \frac{N_1}{N_2} k_2 L_2$$

$$ou \quad k_2 = \frac{N_2}{N_1} \frac{M}{L_2}$$

$$k = \sqrt{k_1 k_2} = \frac{M}{\sqrt{L_1 L_2}}$$

Bobines à spires confondues, couplées dans l'air

Schéma équivalent "physique"

$$\Psi_1 = (1-k_1)L_1 i_1 + (k_1 L_1 i_1 + M i_2)$$
$$= N_1 (\phi_{dl})_{i_2=0} + N_1 \phi_C$$

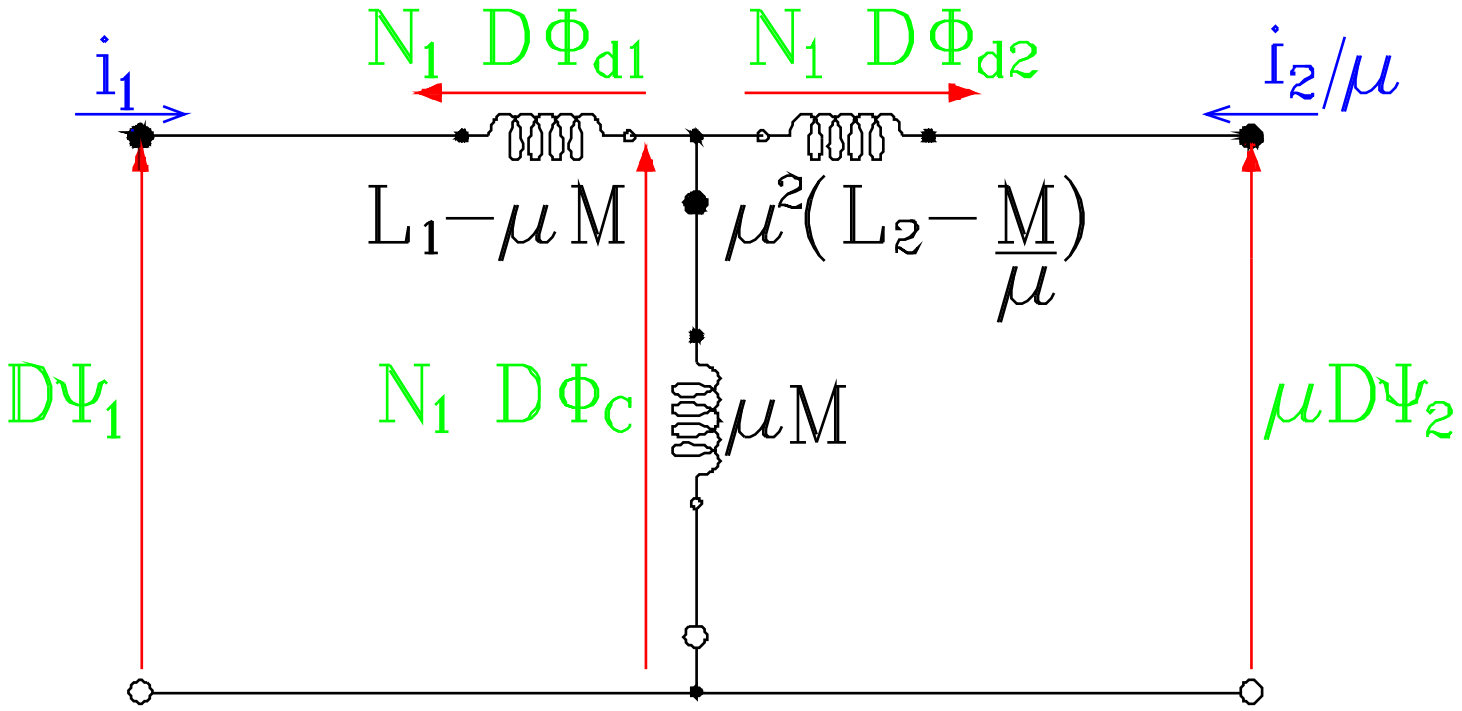
$$\Psi_2 = (1-k_2)L_2 i_2 + (k_2 L_2 i_2 + M i_1)$$
$$= N_2 (\varphi_{d2})_{i_1=0} + N_2 \varphi_C$$

$$\psi_1 = (L_1 - \mu M_1)\, i_1 + \mu M \left(i_1 + \frac{i_2}{\mu} \right)$$

$$\mu \psi_2 = \mu^2 \left(L_2 - \frac{M}{\mu} \right) \frac{i_2}{\mu} + \mu M \left(i_1 + \frac{i_2}{\mu} \right)$$

Bobines à spires confondues, couplées dans l'air

Schéma équivalent "physique"

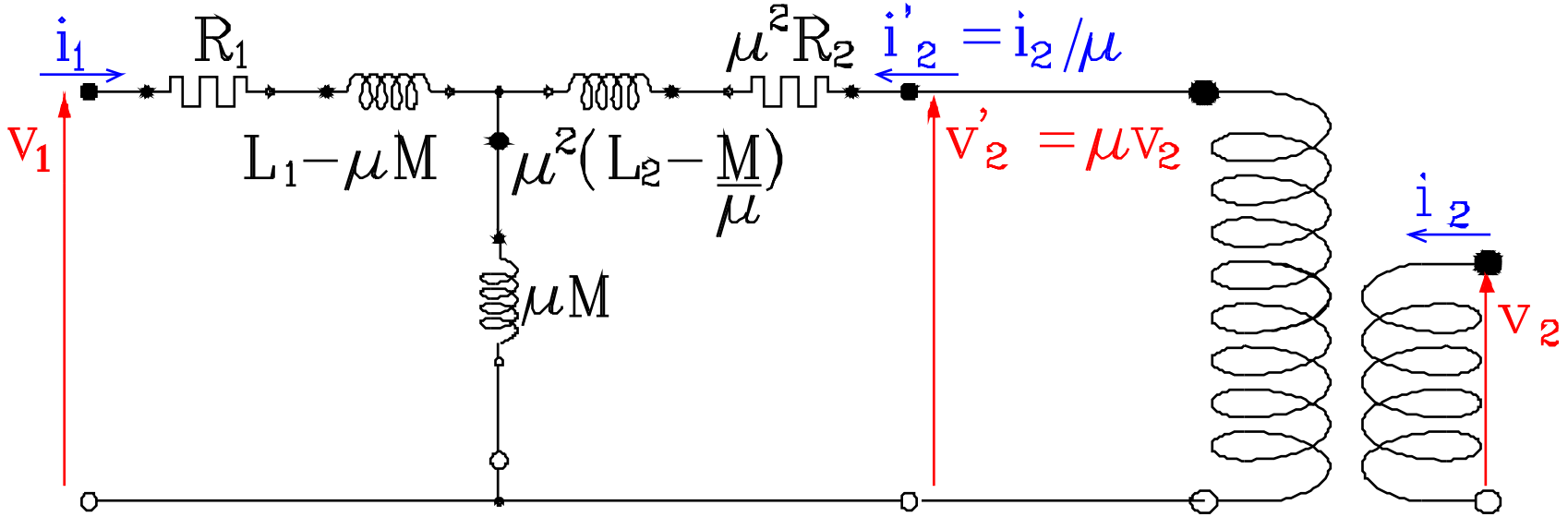


$$\psi_1 = (L_1 - \mu M)\, i_1 + \mu M \left(i_1 + \frac{i_2}{\mu} \right)$$

$$\mu\, \psi_2 = \mu^2 \left(L_2 - \frac{M}{\mu} \right) \frac{i_2}{\mu} + \mu M \left(i_1 + \frac{i_2}{\mu} \right)$$

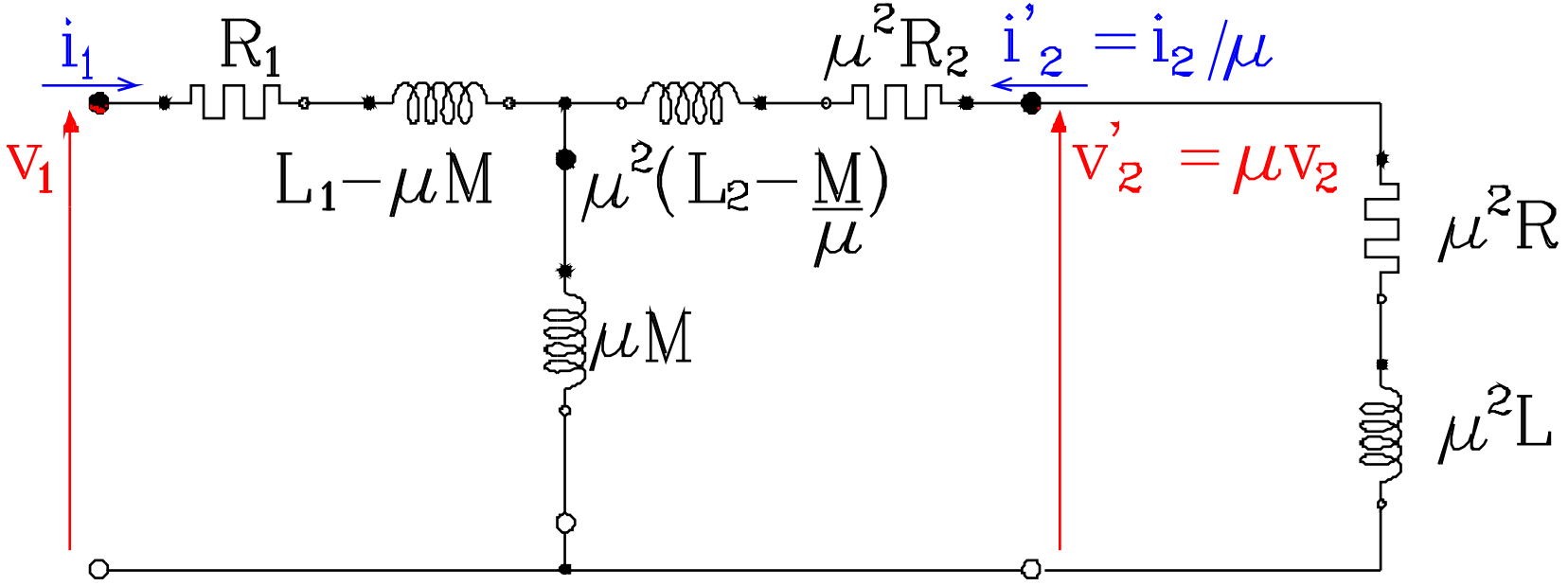
Bobines à spires confondues, couplées dans l'air

Schéma équivalent "physique" complet



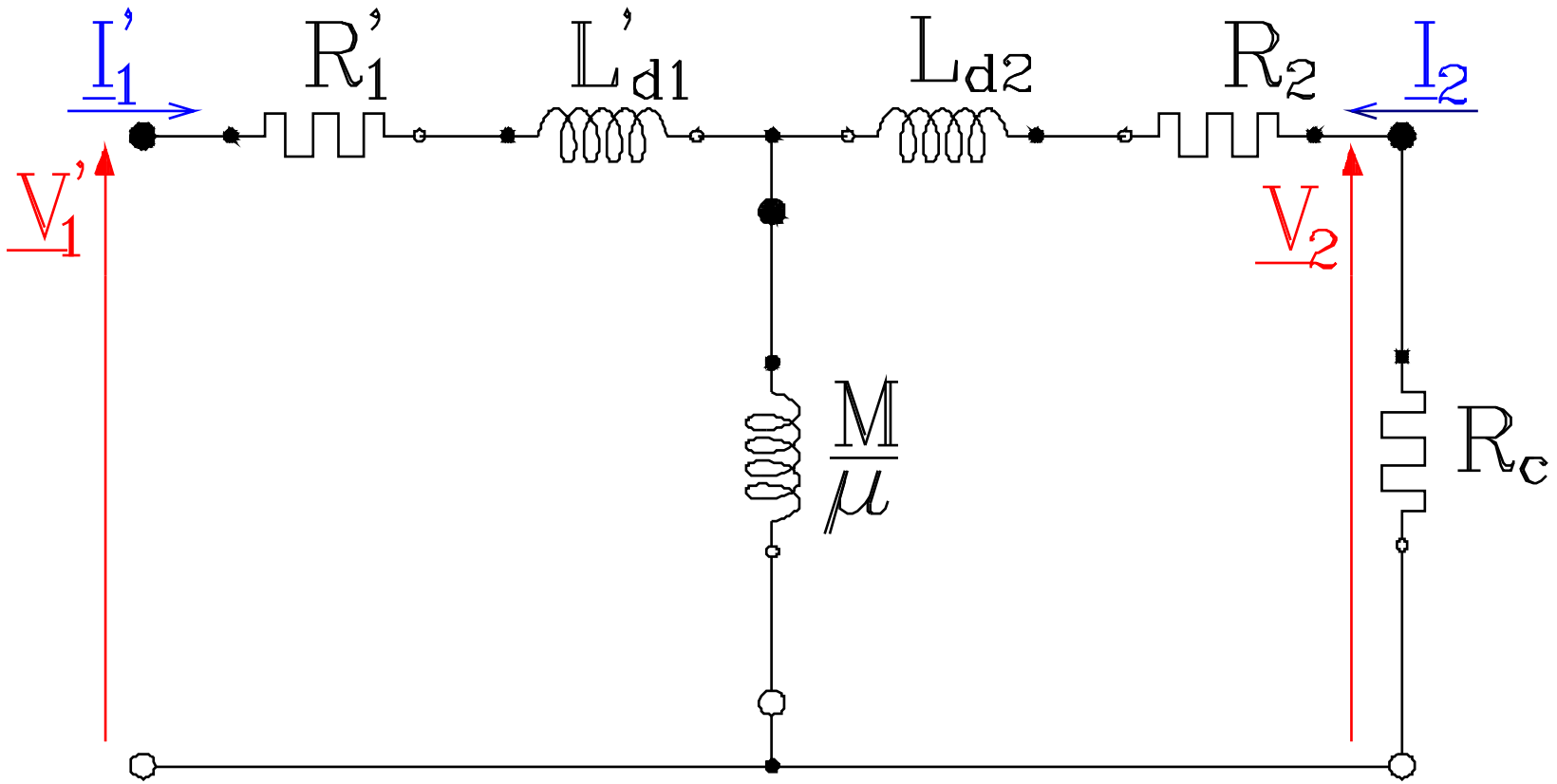
Bobines à spires confondues, couplées dans l'air

Schéma équivalent "vu du primaire"



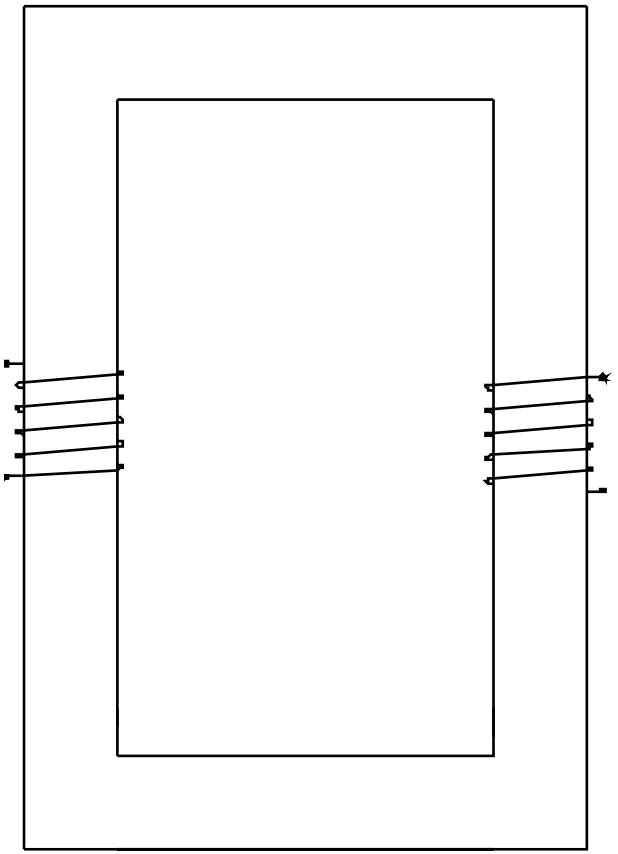
Bobines à spires confondues, couplées dans l'air

Schéma équivalent "vu du secondaire"



Bobines à spires confondues, couplées dans l'air

Transformateurs sans dispersion



Flux et tensions

$$\frac{\psi_1}{\psi_2} = \frac{N_1}{N_2} \quad et \quad \frac{v_1}{v_2} = \frac{N_1}{N_2} = \mu$$

F.m.m. et courants

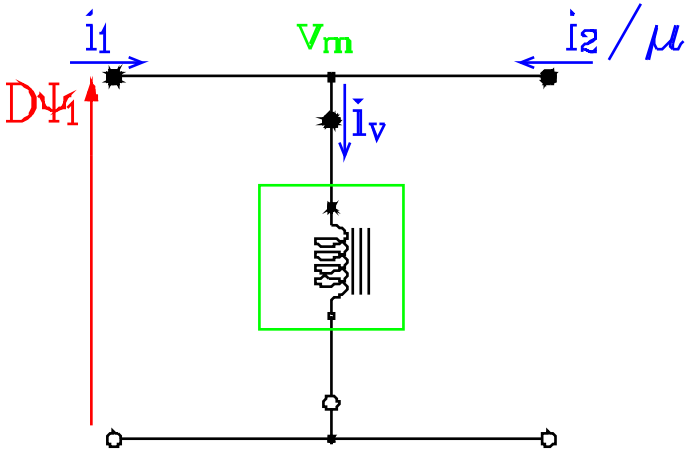
$$N_1\, i_1 + N_2\, i_2 = \oint_l H\, dl$$

$$\oint_l H\, dl = N_1\, i_v$$

$$i_1 + \frac{i_2}{\mu} = i_v$$

Transformateurs à noyau magnétique

Transformateurs sans dispersion

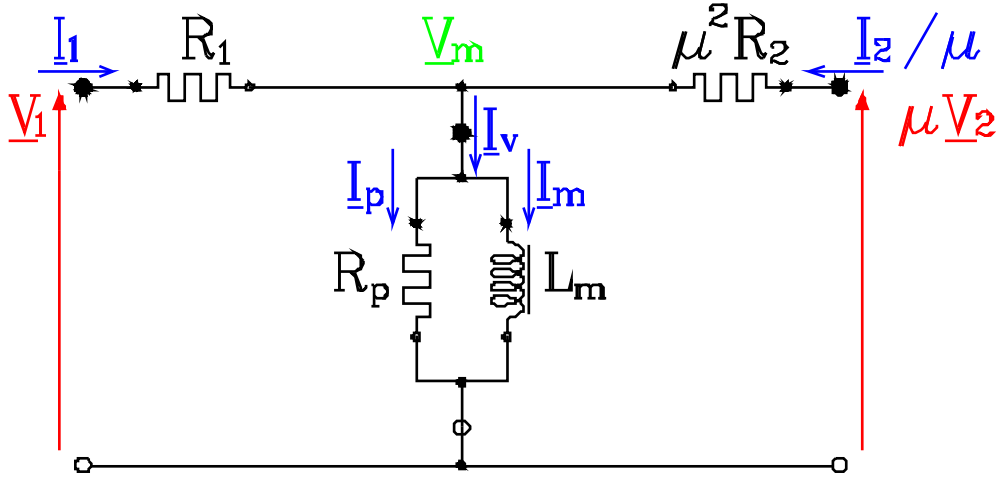


Flux et tensions

$$\frac{\psi_1}{\psi_2} = \frac{N_1}{N_2} \quad et \quad \frac{v_1}{v_2} = \frac{N_1}{N_2} = \mu$$

F.m.m. et courants

$$N_1\, i_1 + N_2\, i_2 = \oint_l H\, dl$$

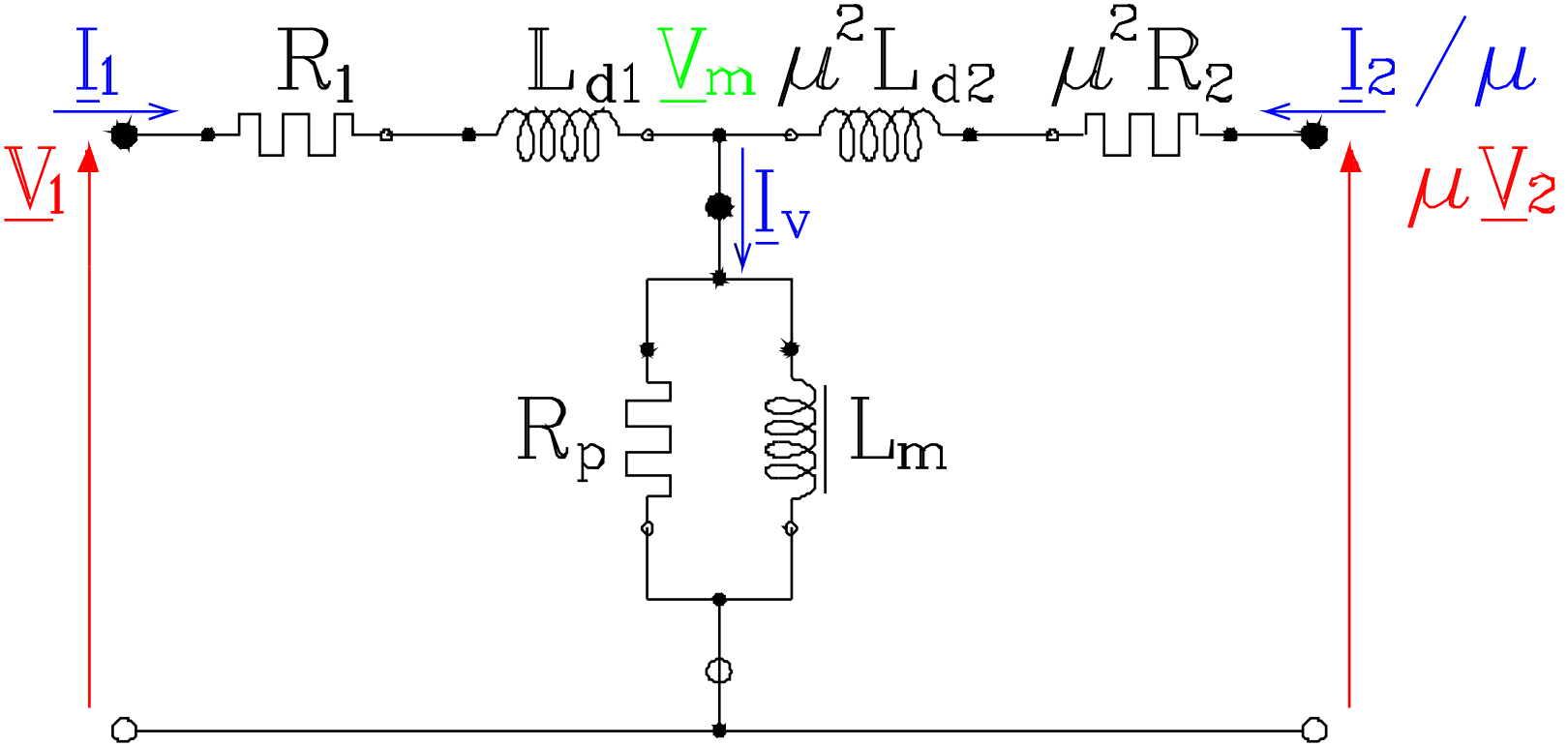


$$\oint_l H\, dl = N_1\, i_v$$

$$i_1 + \frac{i_2}{\mu} = i_v$$

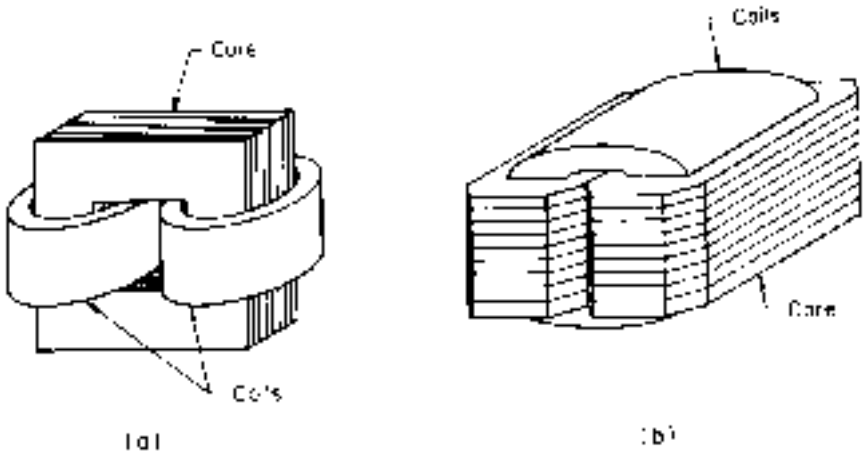
Transformateurs à noyau magnétique

Schéma équivalent



Transformateurs à noyau magnétique

Transformateurs



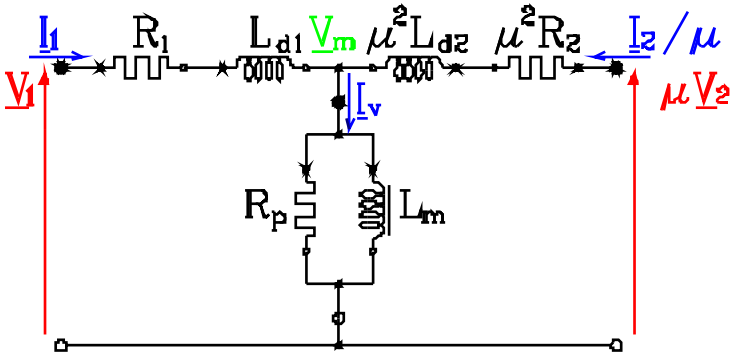
Transformateurs à colonnes

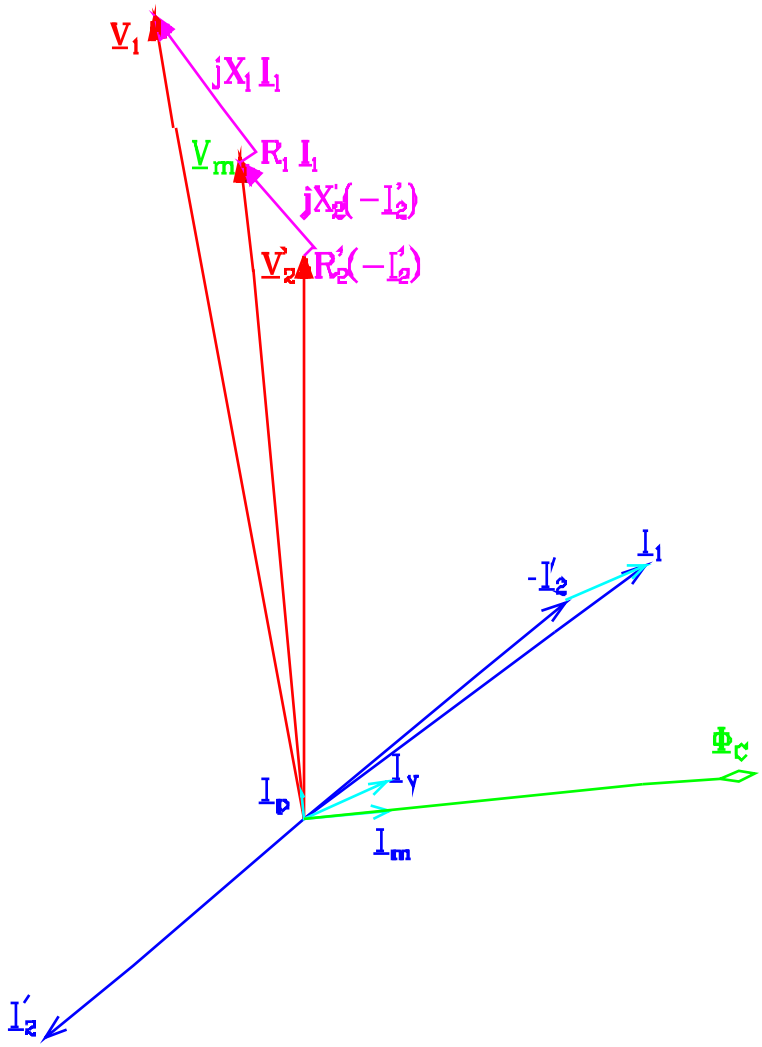
Transformateurs cuirassés

Transformers. (a) Core type with stacked core. (b) Shell type with stacked core. (c) Core type with wound core. (d) Shell type with wound core.

Transformateurs à noyau magnétique

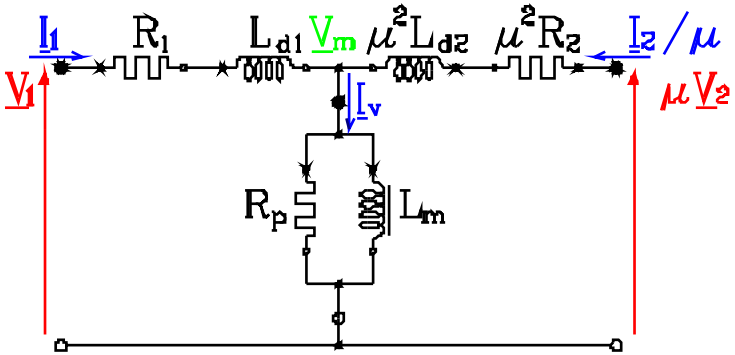
Phaseurs

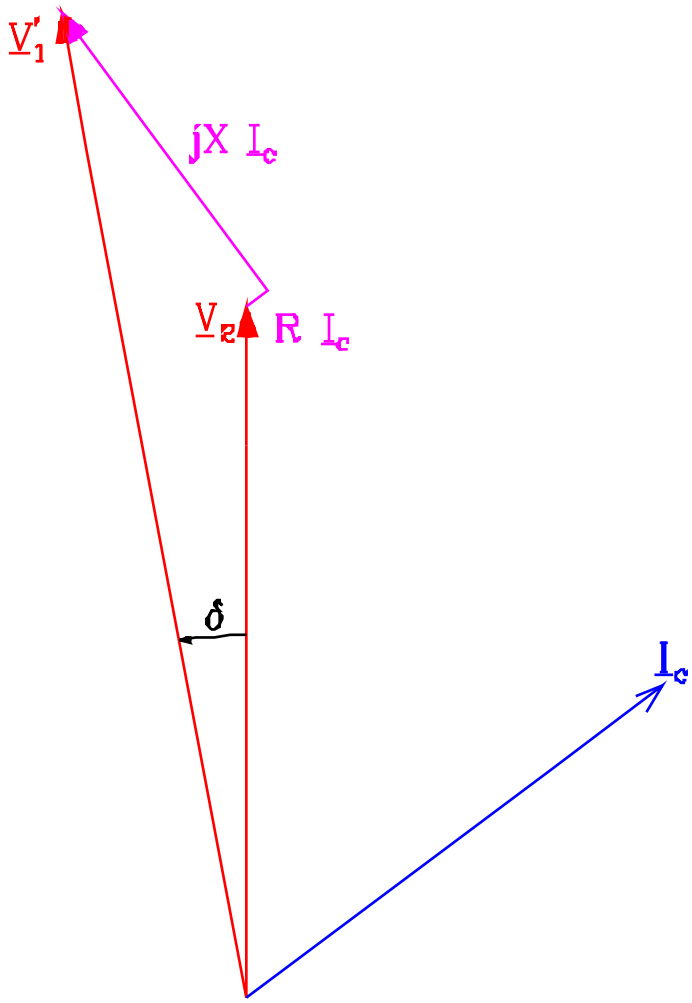




Transformateurs à noyau magnétique

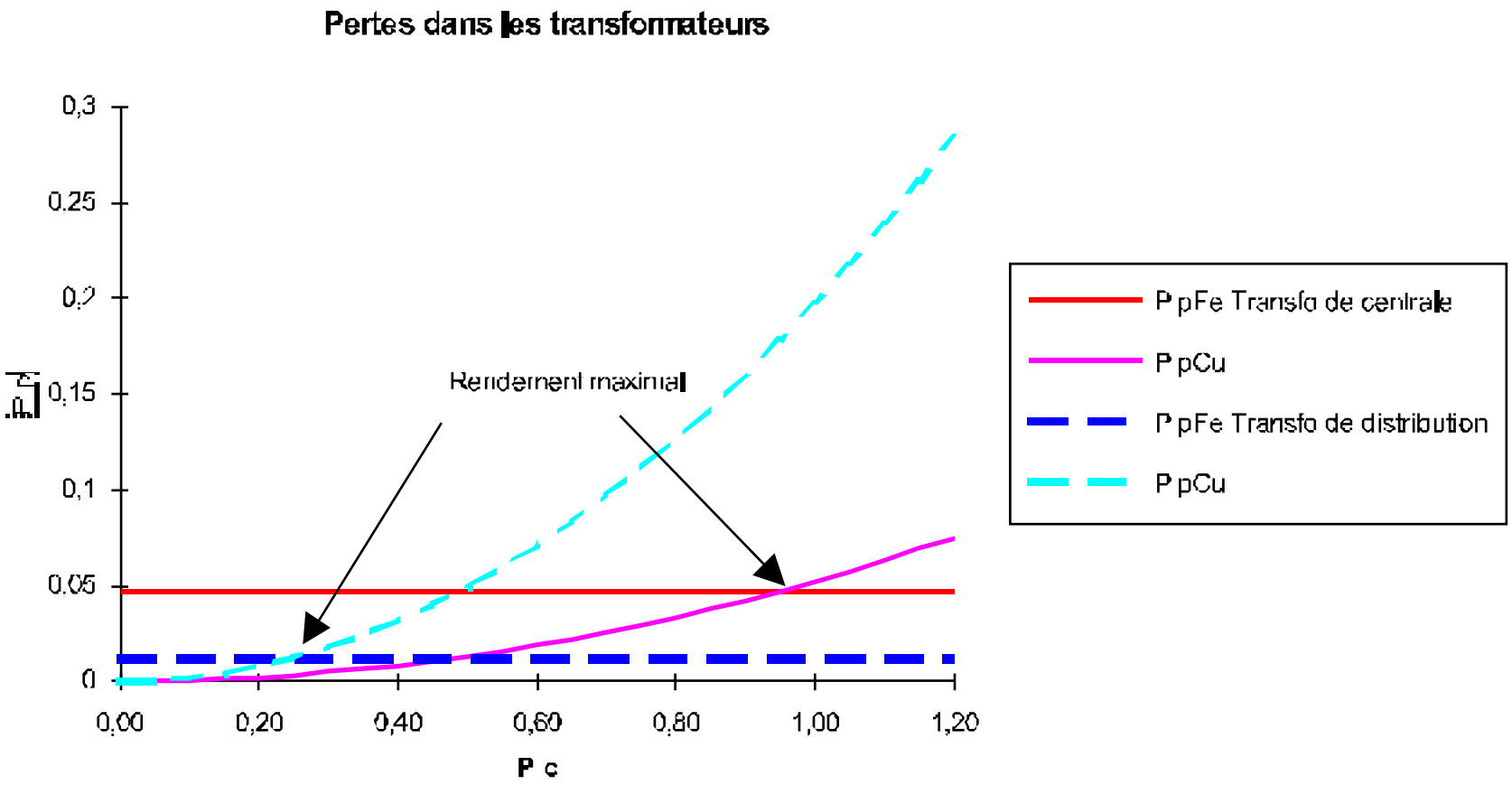
Triangle de KAPP



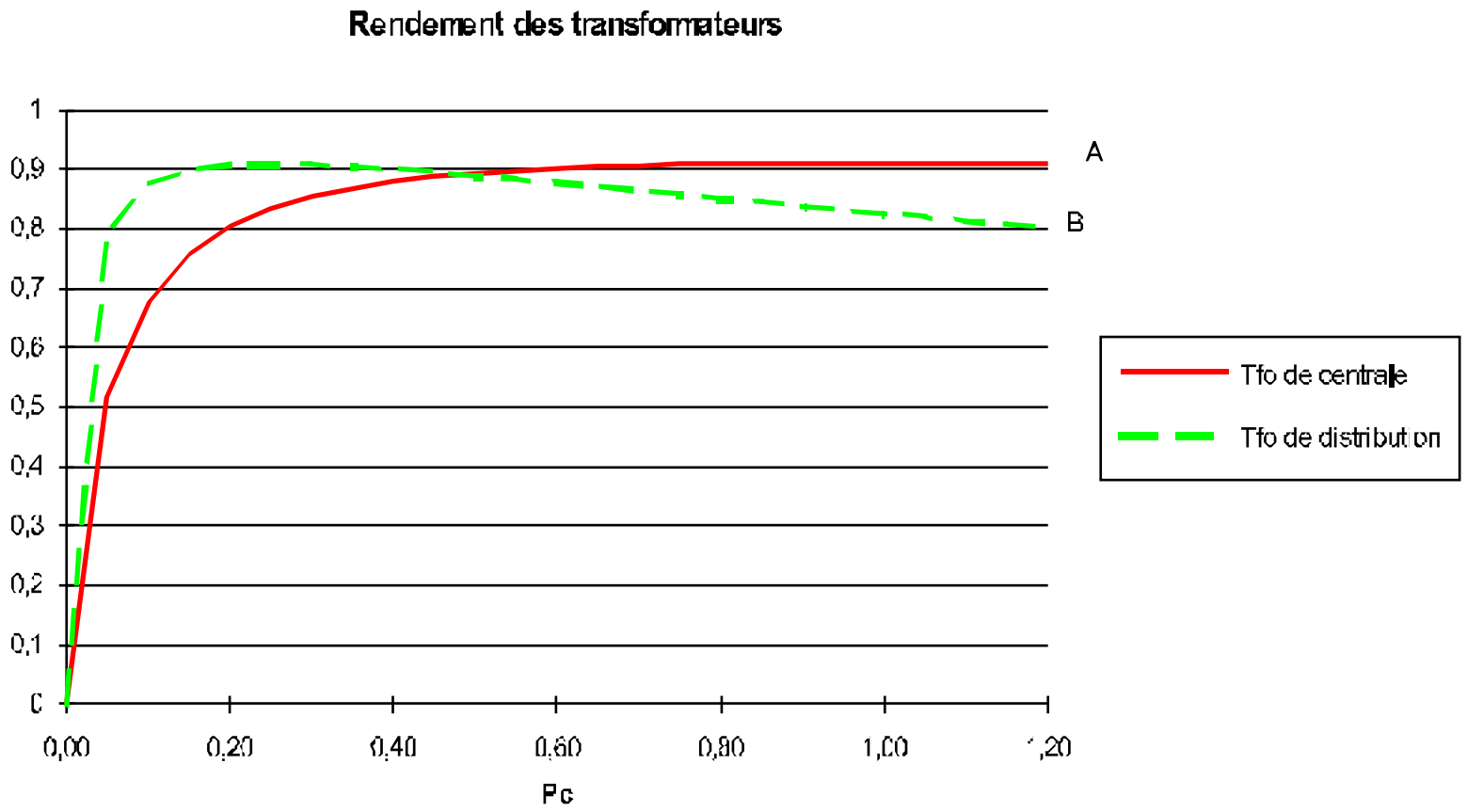


Transformateurs à noyau magnétique

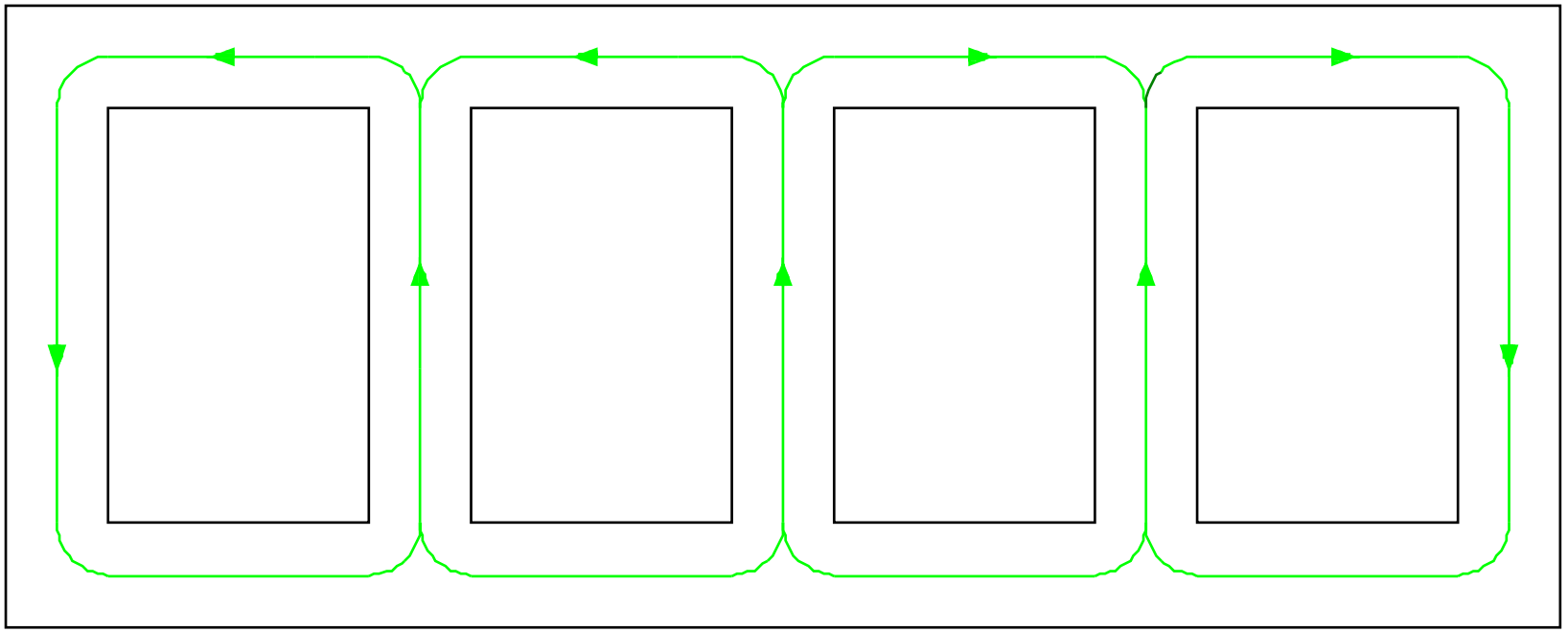
Pertes dans les transformateurs



Rendement des transformateurs

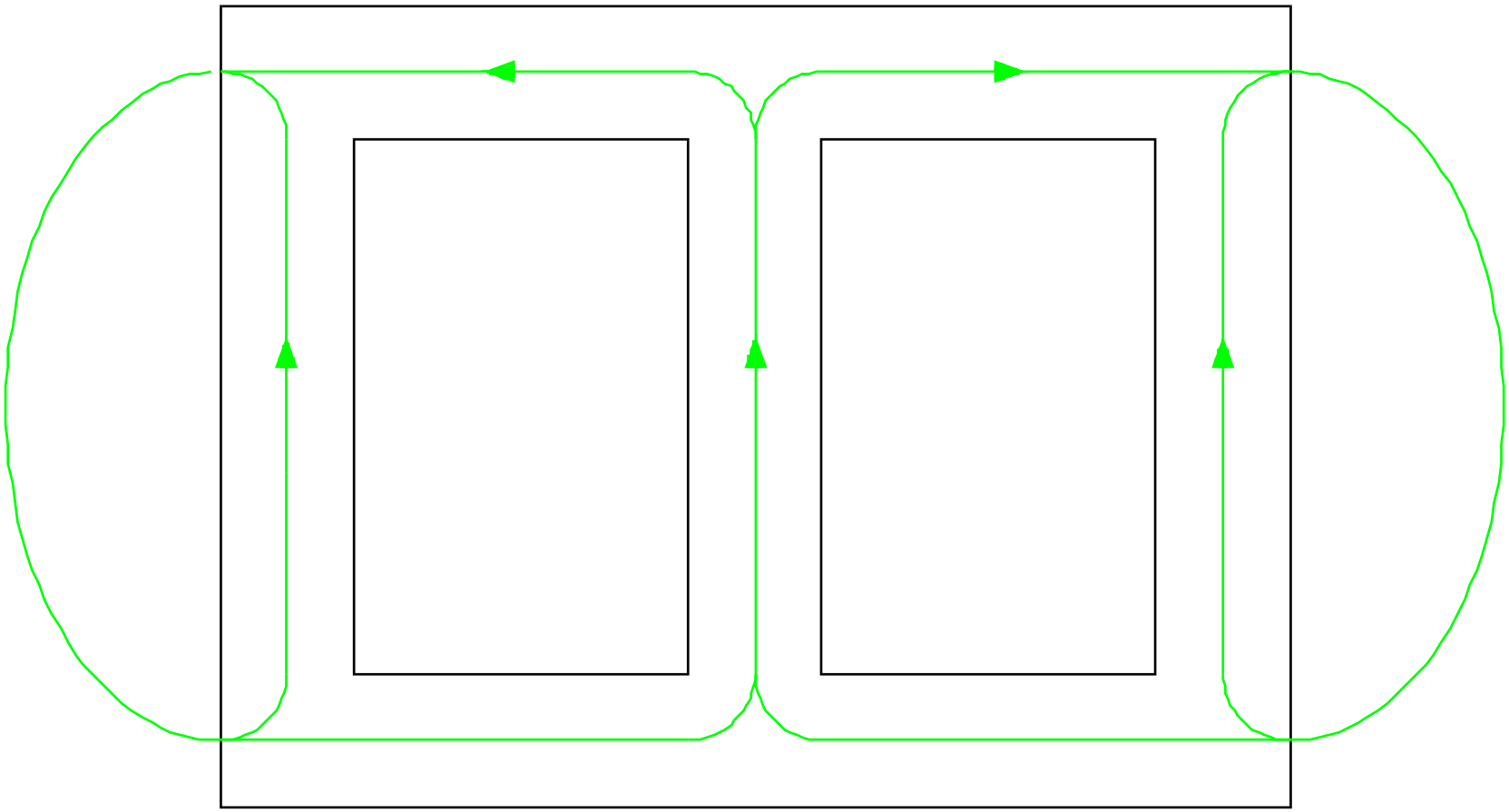


Transformateur à flux libre

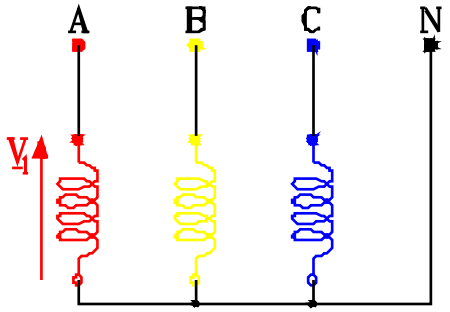


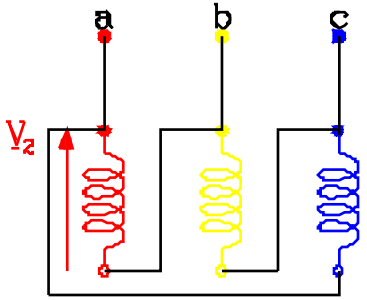
Transformateur à 5 colonnes

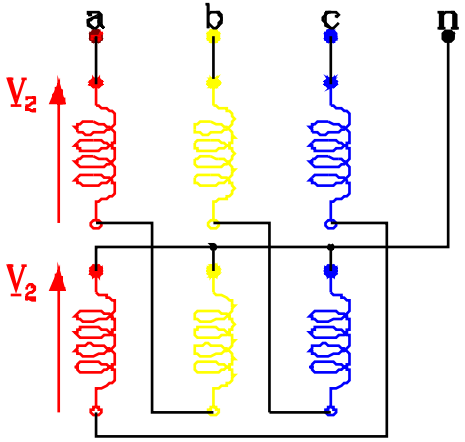
Transformateur à flux forcé

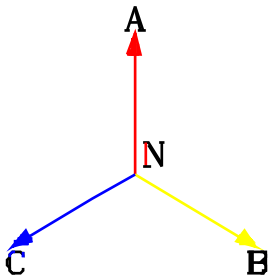


Couplages

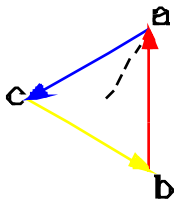




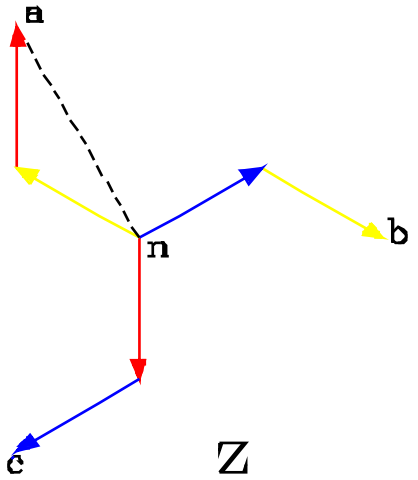




Y

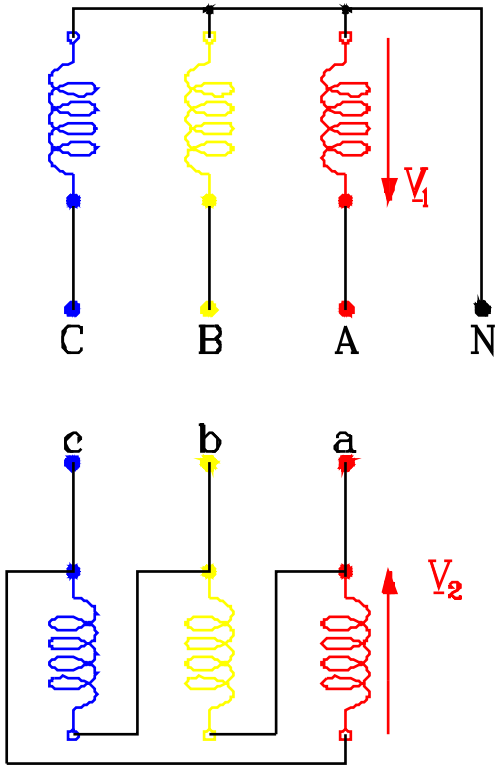


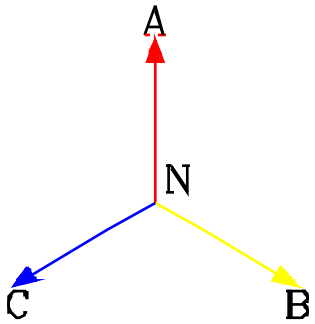
d



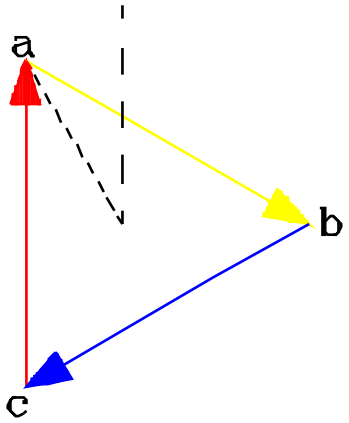
z

Trois unités indépendantes



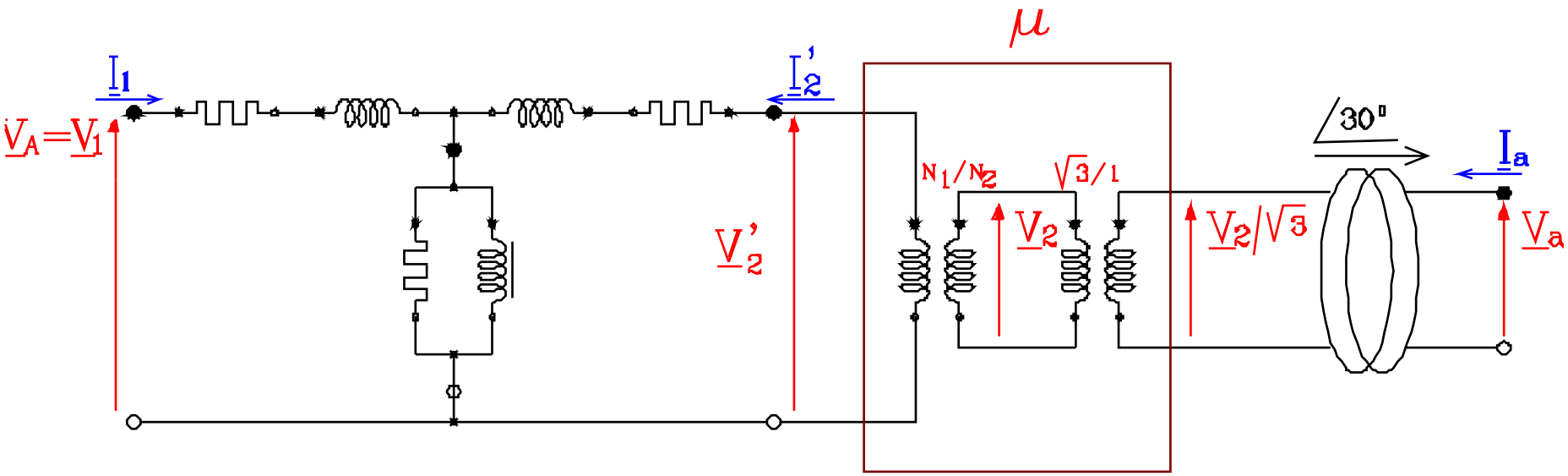


Y



d

Schéma équivalent



Indice horaire

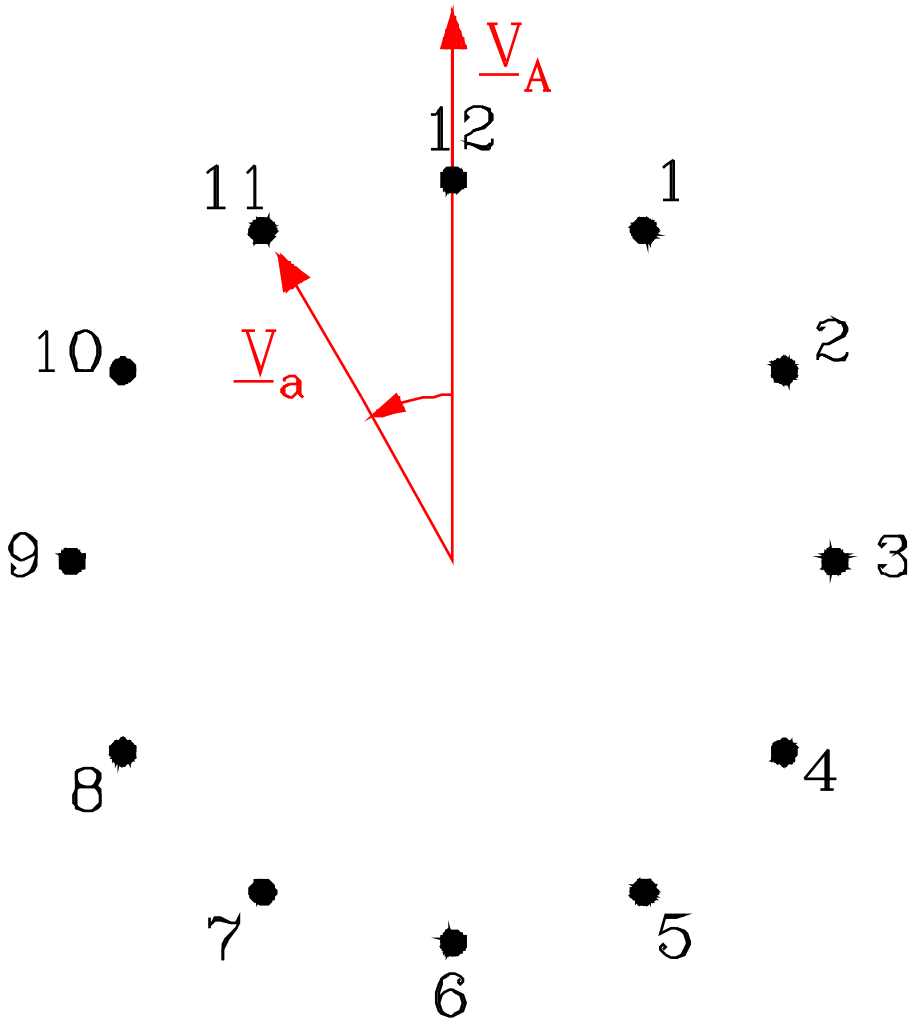
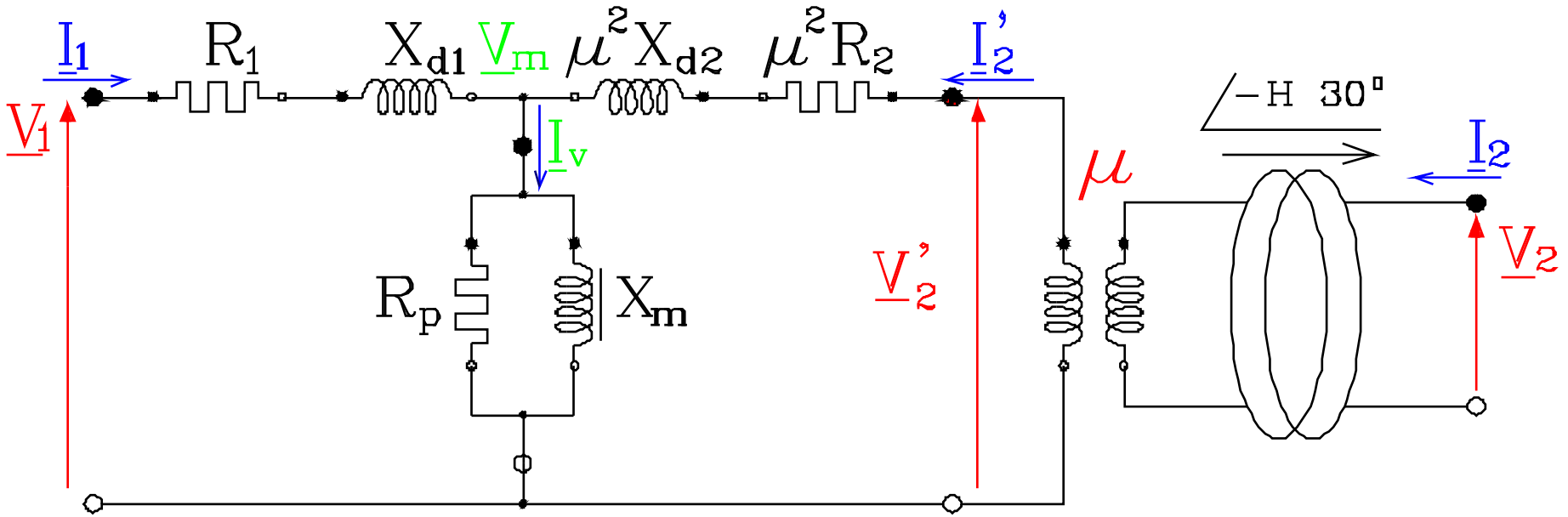
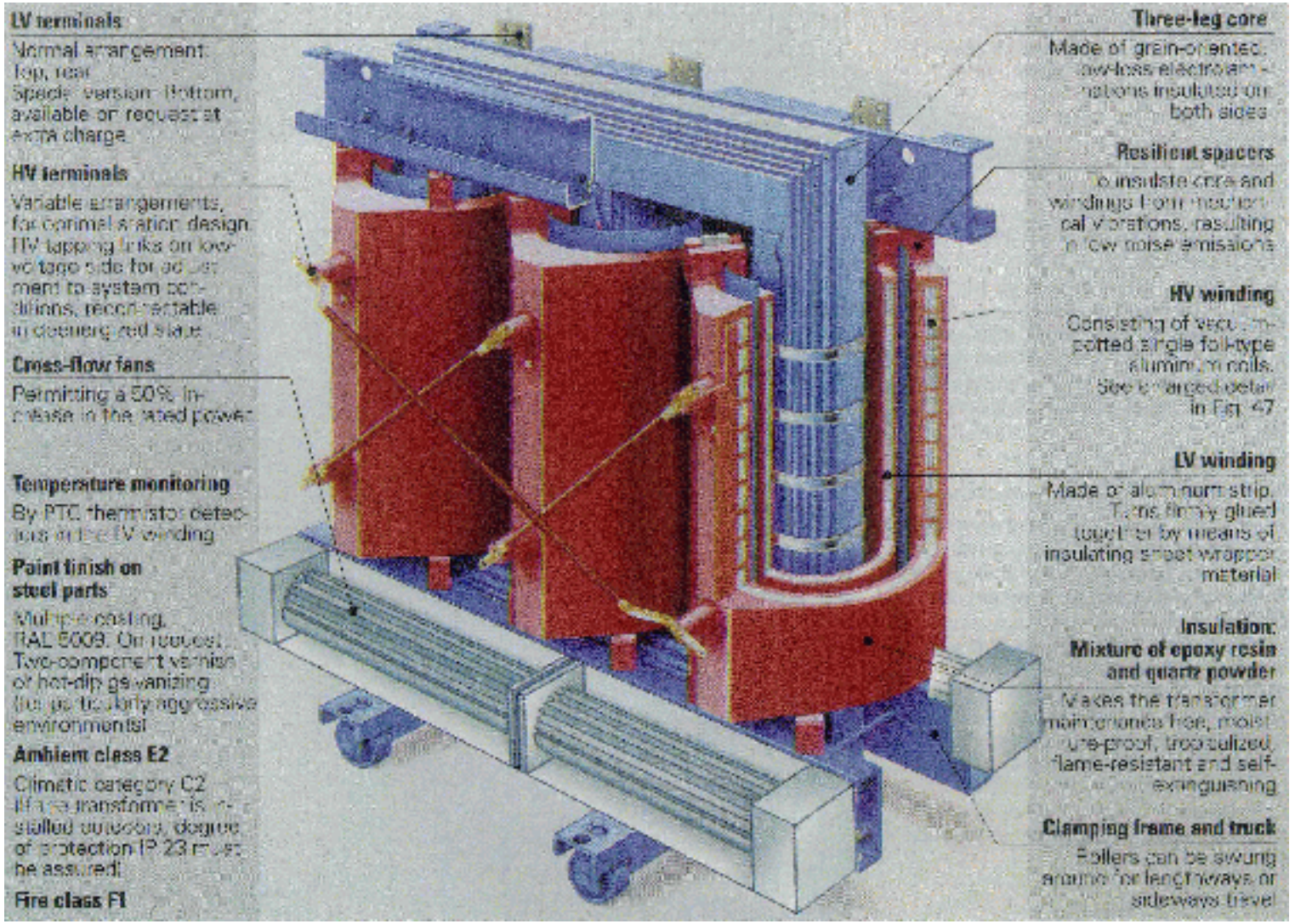


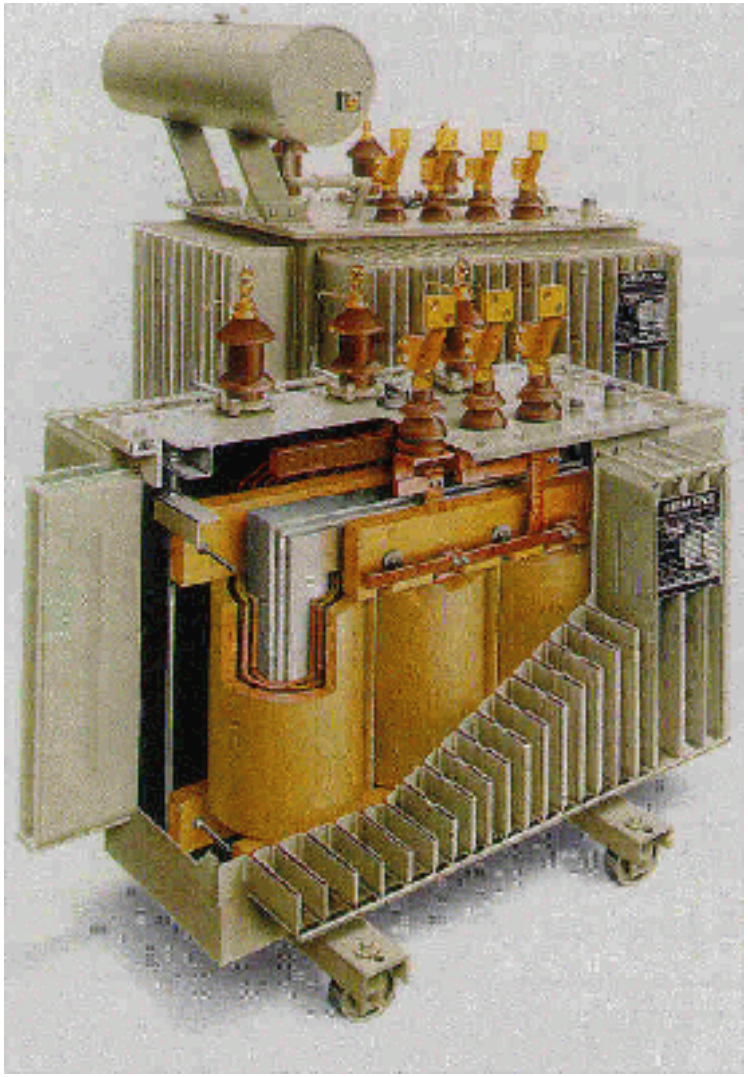
Schéma équivalent



Transformateur de distribution



Transformateur de distribution



Transport d'un transformateur de 300 MVA