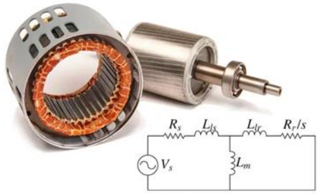
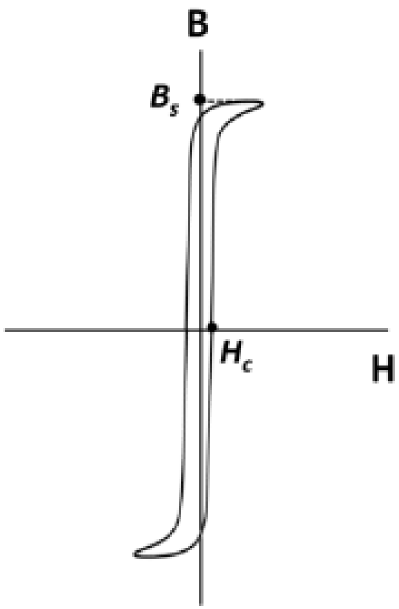


Reminders: magnetic materials

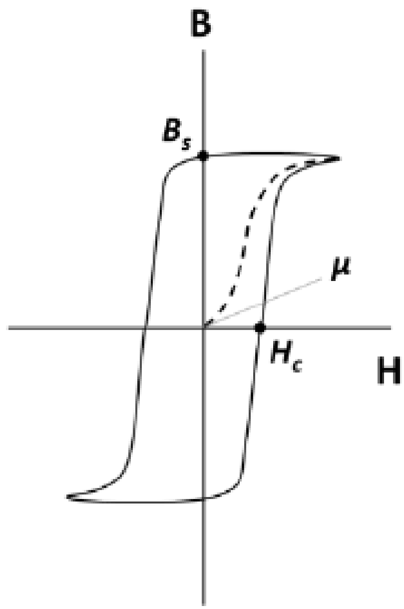
- The shape of the hysteresis loop varies according to the magnetic material

Soft magnetic material

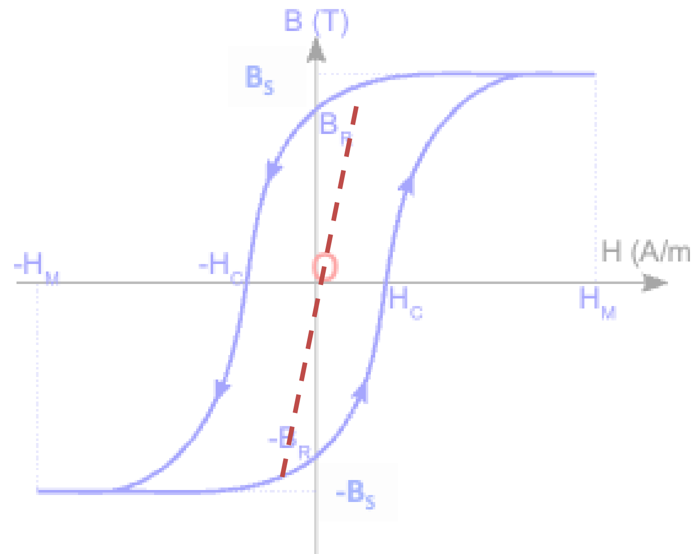


$B_S = 1.5 – 2T$
$B_R < 1T$
$H_C = 1\text{-}10$ A/m

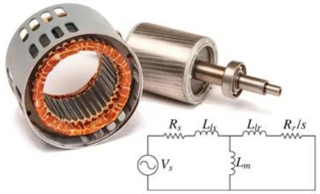
Hard magnetic material



B_R - 1T
$H_C = 10^3$ A/m



Linear approximation outside the saturation region: $B=\mu H$



Magnetic circuits

- Linear homogeneous magnetic circuits:

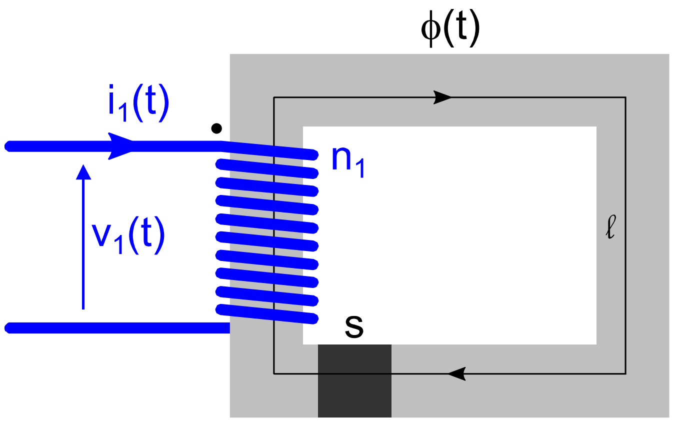
- Materials and geometry are chosen to concentrate flux density as much as possible, thus creating the strongest possible induction => limitation of both mass and size/volume

- Homogeneous = a single magnetic material

- Homogeneous = constant cross section

- Linear = outside the saturation regime

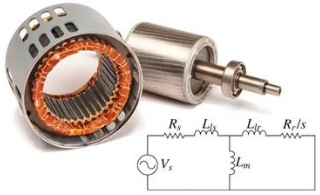
- ℓ (schematic) = mean field line



$$\oint \overrightarrow{H}.\overrightarrow{d\ell} = n.I$$

$$H.\ell = n.I$$

- The nI quantity is also called magnetomotive force



Magnetic circuits

- Hopkinson's relation:

- In a linear homogeneous magnetic circuit, the material exhibits a constant permeability

$$\mu = \mu_0 \mu_r$$

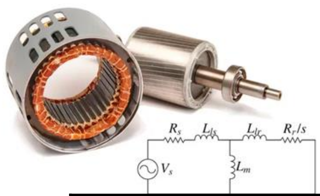
- Therefore: $\mathbf{B} = \mu H$

- We have shown previously that $\Phi = B.S$

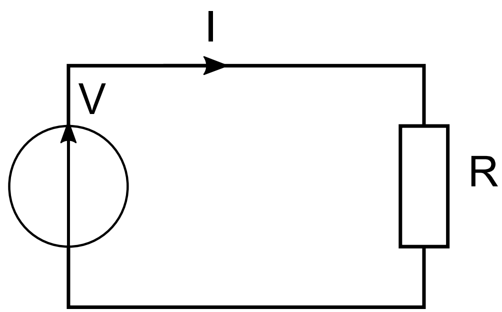
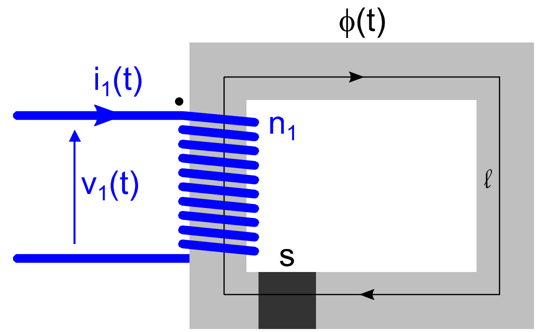
- By considering the Ampere's theorem as well, it can be shown that:

$NI = \Re\Phi$ **Hopkinson's relation**, with the reluctance $\Re = \dfrac{\ell}{\mu S}$ (in H^{-1})

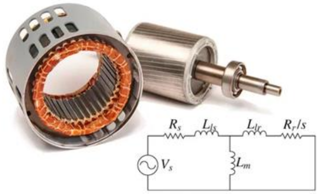
- The reluctance is the opposition that a ferromagnetic material produces to the establishment of a magnetic field



Magnetic circuits: analogy with electrical circuits

Electrical circuit	Magnetic circuit
	
Electromotive force in V : V	Magnetomotive force in A.tr : ε = n.I
Electrical current in A : I	Magnetic flux in Wb : Φ
Electrical resistance in Ω : R $R = \rho \times \frac{\ell}{S}$ • Electrical resistivity in Ω.m : ρ • Conductor length in m : ℓ • Conductor cross section in m² : s	Magnetic reluctance: $\mathfrak{R}$ $\mathcal{R} = \frac{1}{\mu_0 \times \mu_R} \times \frac{\ell}{S}$ • Magnetic permeability in H/m : µ • Circuit length in m : ℓ • Circuit cross section in m² : s
Ohm's law: $V = R.I$	**Hopkinson's law**: $n.I = \mathcal{R}.\Phi$
Electrical field in V/m : E	Excitation magnetic field in A/m : H
Current density in A.m⁻² : $J = \frac{I}{s} = \sigma.E$	Induction magnetic field in T: $B = \frac{\Phi}{s} = \mu.H$

POLYTECH ORLÉANS



Magnetic circuits

- Lenz's law and Faraday's law:

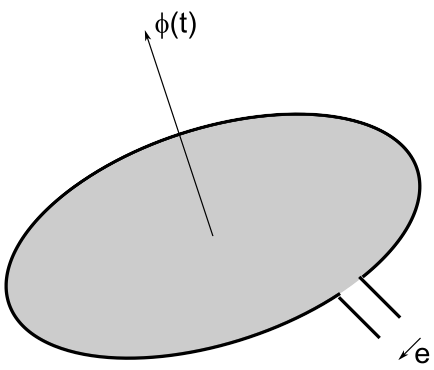
- Lenz's law (qualitative law): Induced currents and fields oppose the causes that gave rise to them

=> The induced field and current oppose the change in flux through the circuit

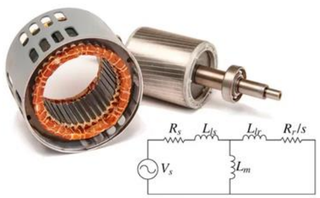
- Faraday's law (quantitative law): Any flux variation produces an induced electromotive force across a circuit

=> For a coil, an electromotive force is produced across each turn of the winding

$$e(t) = -\frac{d\phi(t)}{dt}$$ (receptor convention)



For n turns: $$e(t) = -n \times \frac{d\phi(t)}{dt}$$

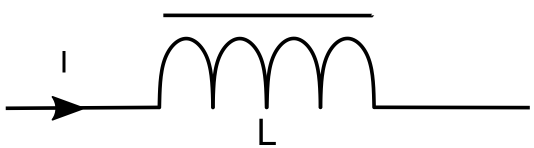


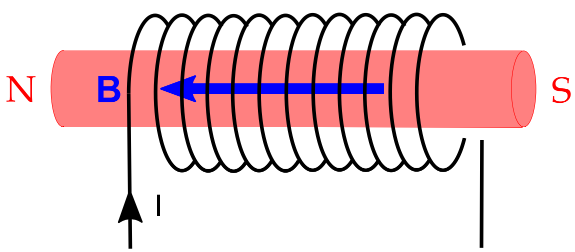
Magnetic circuits

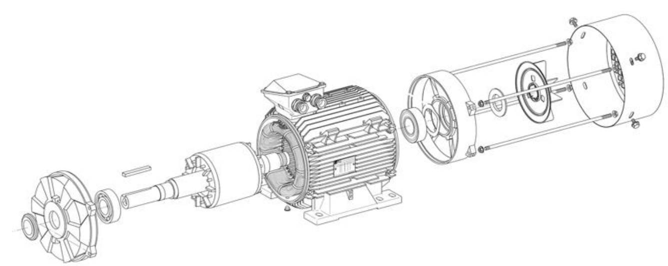
- <u>The iron-core coil:</u>

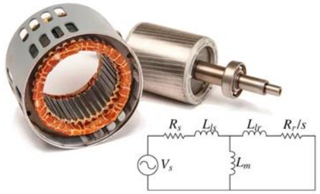
  - A winding of copper wire wrapped on a magnetic circuit of ferromagnetic material forms an iron-core coil

    => transformers, electromagnets, motors









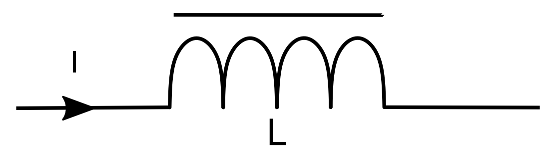
Magnetic circuits

- The iron-core coil:

- Consider an iron-core coil with N turns

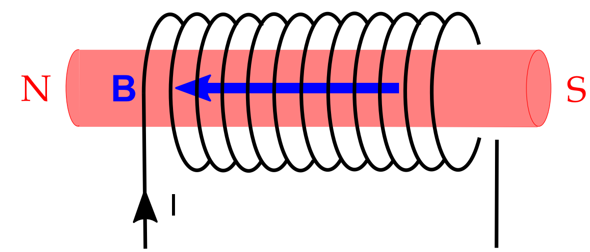
=> Each turn is crossed by the flux ϕ created in the material => Total flux $\phi_T = N\phi$

- By considering both Hopkinson's relation and Faraday's law:



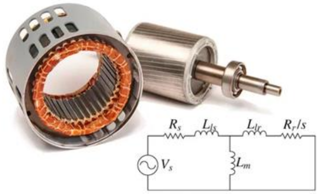
$$\boldsymbol{Ni = \Re\Phi} \qquad \boldsymbol{e(t) = -\frac{d\phi_T(t)}{dt} = -N\frac{d\phi(t)}{dt}}$$

- We introduce the inductance L such that: $\phi_T = Li$



- With L (in H): $L = \dfrac{N^2}{\Re} = \dfrac{N^2\mu S}{\ell}$

- We retrieve the expression: $\boldsymbol{e(t) = -L\frac{di(t)}{dt}}$

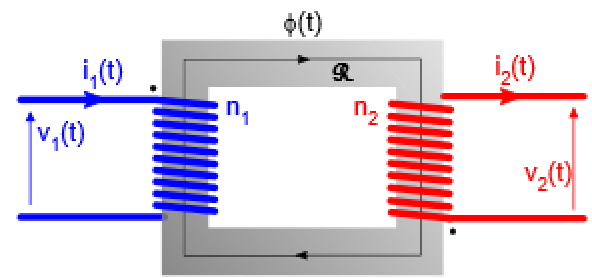


Magnetic circuits

- Mutual inductance: (case of the homogeneous linear magnetic circuit)

  - Mutual inductance occurs when the magnetic circuit has at least two windings

  => Each current has an influence on the flux flowing in the circuit.



- Flux created by coil 1 (current i_1) and flowing through coil 2

$$\phi_{1\to 2} = \frac{N_1 i_1}{\Re} \longrightarrow \phi_{T2} = N_2 \phi_{1\to 2}$$

- By analogy with the definition of the inductance: $\phi_{T2} = N_2 \phi_{1\to 2} = M_{12} i_1$

- With M (in H): $M_{12} = \dfrac{N_1 N_2}{\Re}$ $\longrightarrow$ $\boldsymbol{e_2(t) = -M_{12}\dfrac{di_1(t)}{dt}}$

- Voltage across winding k among n other windings: mutual inductances + self-inductance

$$-e_k(t) = M_{1k}\frac{di_1(t)}{dt} + M_{2k}\frac{di_2(t)}{dt} + \cdots + M_{nk}\frac{di_n(t)}{dt} + L\frac{di_k(t)}{dt}$$

Magnetic circuits

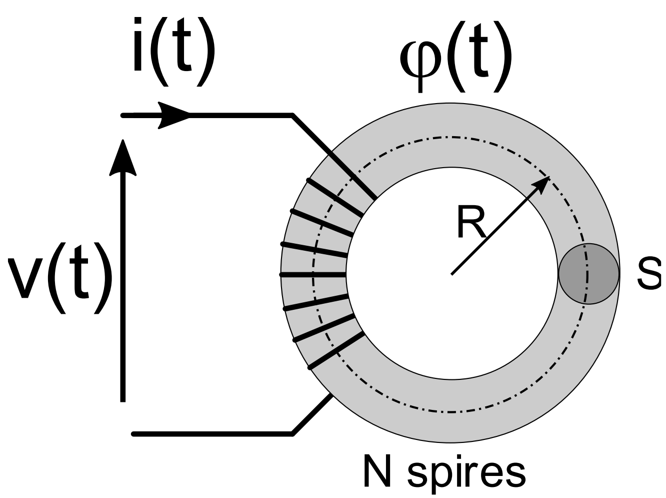
- Boucherot's formula : Ideal coil (no losses)

- The winding is subjected to a sinusoidal voltage

$$v(t) = V\sqrt{2}.\cos(\omega t)$$

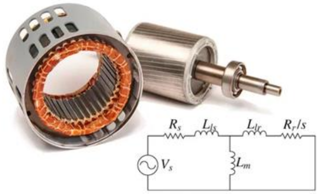
=> Assumption of forced flux

$$\frac{d\varphi(t)}{dt} = \frac{V\sqrt{2}}{N}.\cos(\omega t)$$



$$\varphi(t) = \frac{V\sqrt{2}}{N}.\int_0^t \cos(\omega t).dt$$

$$\varphi(t) = \frac{V\sqrt{2}}{N\omega}.\sin(\omega t) + \varphi(0)$$

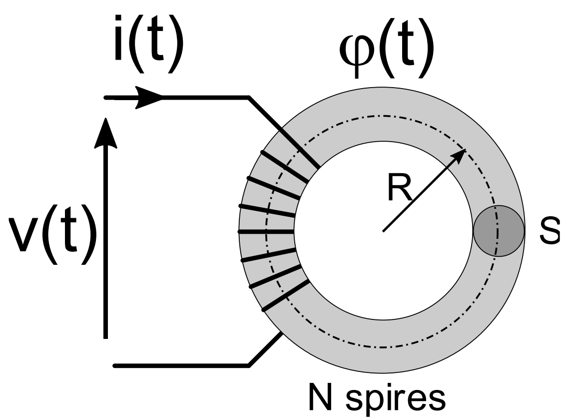


Magnetic circuits

- Boucherot's formula : Ideal coil (no losses)

- $\phi(0)=0$: no permanent magnet, no remanent flux, no second DC winding).

$$\varphi(t) = \frac{V\sqrt{2}}{N\omega}.\sin(\omega t) + \varphi(0)$$



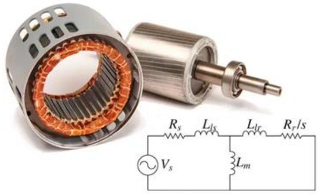
$$\varphi(t) = \frac{V\sqrt{2}}{N\omega}.\sin(\omega t)$$

$$\boldsymbol{\varphi(t) = \frac{V\sqrt{2}}{N\omega}.\cos(\omega t - \pi/2)}$$

- The flux lags the voltage

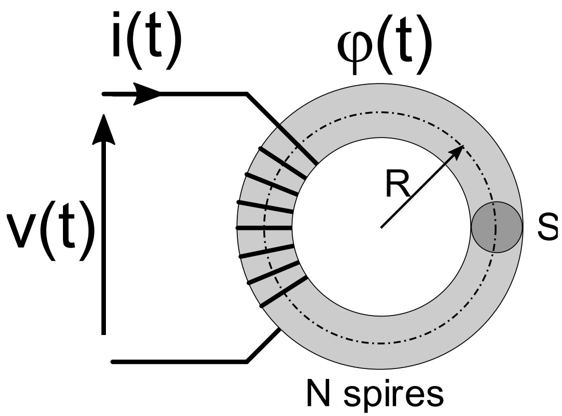
- The relation $N\phi=Li$ (Hopkinson's law) gives the current

$$i(t) = \frac{V\sqrt{2}}{L\omega}.\cos(\omega t - \pi/2)$$



Magnetic circuits

- Boucherot's formula : Ideal coil (no losses)



$$\begin{cases} \varphi(t) = \dfrac{V\sqrt{2}}{N\omega}.cos(\omega t - \pi/_2) \\ \varphi(t) = \Phi_M.cos(\omega t - \pi/_2) \end{cases}$$

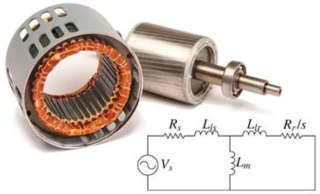
$$\frac{V\sqrt{2}}{N\omega} = \Phi_M$$

$$V = \frac{N.\omega.\Phi_M}{\sqrt{2}}$$

$$V = \frac{N.(2.\pi.f).S.B_M}{\sqrt{2}}$$

$$V = \frac{2.\pi}{\sqrt{2}}.S.N.B_M.f$$

$$\boldsymbol{V = 4,44.S.N.B_M.f}$$

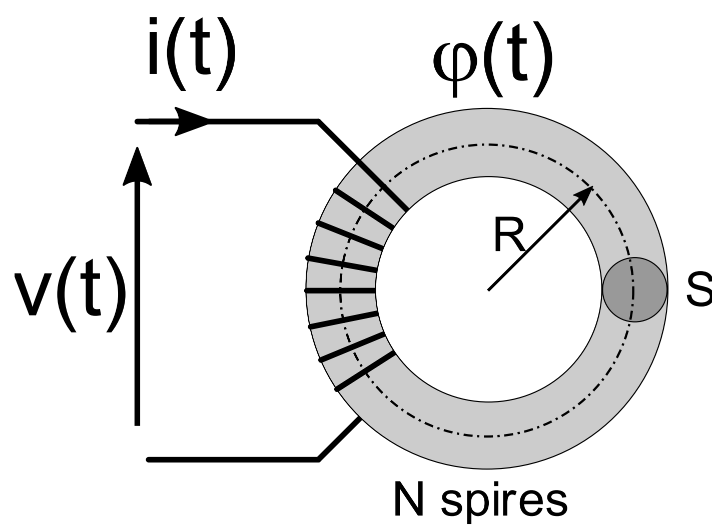


Magnetic circuits

- Boucherot's formula : Ideal coil (no losses)

$$V = 4,44.S.N.B_M.f$$

If the flux ϕ of a coil is due to the current **i** flowing through it (Hopkinson's law), its maximum value ϕ_M depends only on the RMS value of the voltage **V** (at constant frequency).

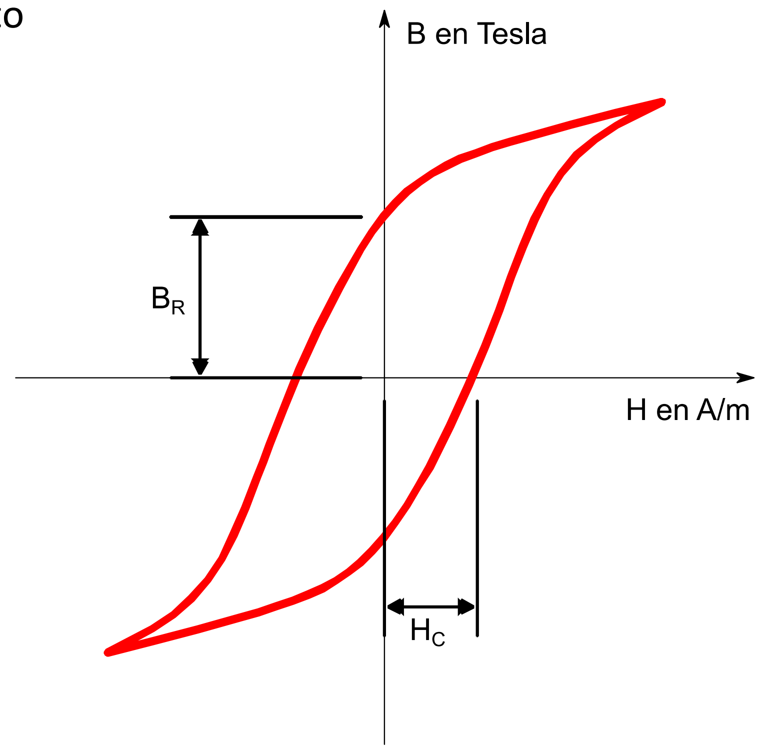


The voltage imposes a flux and the winding draws the current accordingly

Magnetic circuits

- Defects of the iron-core coil: hysteresis losses

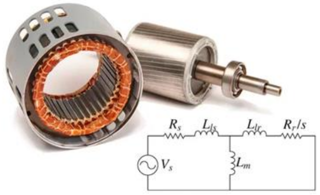
- Hysteresis losses correspond to the power required to magnetize and demagnetize the material over its hysteresis loop.



- Empirical formula:

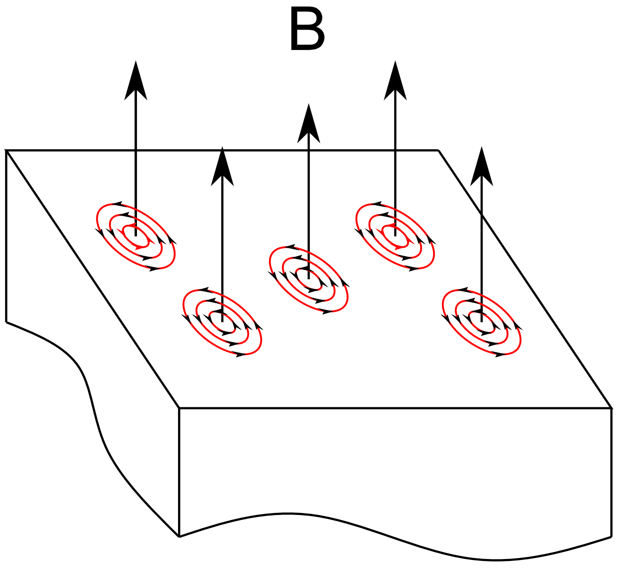
$$P_H = K_H\, l\, S\, f\, B_{max}^n$$

- K_H is a material-related constant
- n is the Steinmetz coefficient (around 1.8)
- l is the mean field line, f the frequency, B_{max} the maximum induction field



Magnetic circuits

- <u>Defects of the iron-core coil</u>: Eddy currents



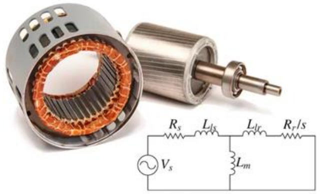
- Currents induced in the magnetic material in which they flow freely

- These currents cause losses in the form of power dissipated by Joule effect

- Empirical formula: $P_E = K_E \, l \, S \, f^2 \, B_{max}^2$

- K_E is a material-related constant
- d is the thickness of the foil in the case of a laminated material
- l is the mean field line, f the frequency, B_{max} the maximum induction field

- <u>Defects of the iron-core coil</u>: **IRON LOSSES P_F** $\boldsymbol{P_F = P_H + P_E}$



Magnetic circuits

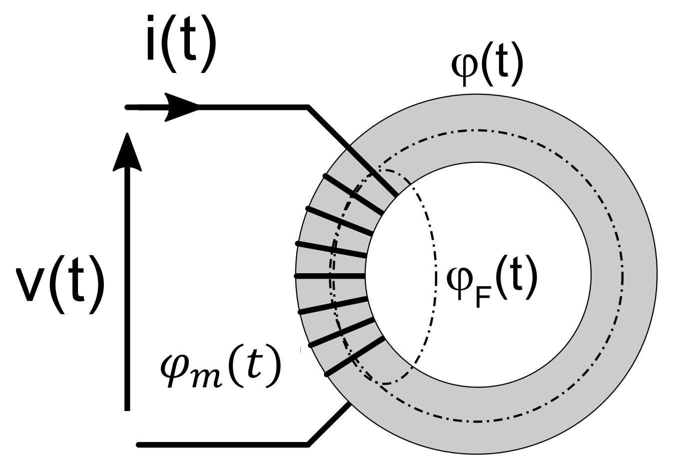
- Defects of the iron-core coil: Leak inductance

- Magnetic materials are never perfect, and never channel all the field lines

=> Part of the magnetic flux propagates in the air via less reluctant paths

=> This corresponds to magnetic leaks (flux outside the magnetic circuit)

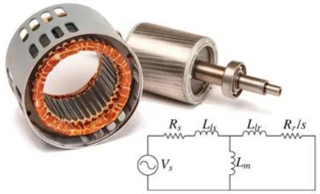
- The magnetic field channeled in the magnetic circuit is called "magnetizing flux"



$$\phi = \phi_m + \phi_f$$

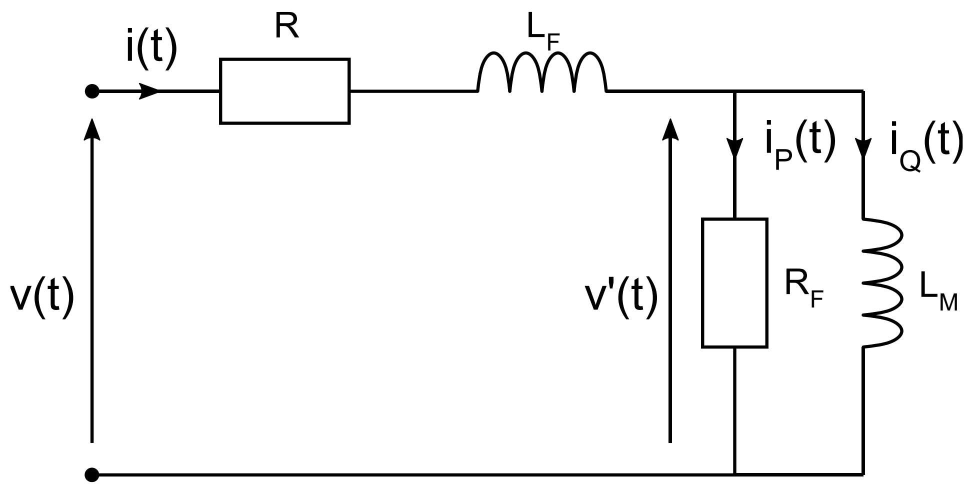
$$v(t) = -N\frac{d\phi}{dt} = -(L_m\frac{di}{dt} + L_f\frac{di}{dt})$$

- L_m is the magnetizing inductance, L_f is the leak inductance

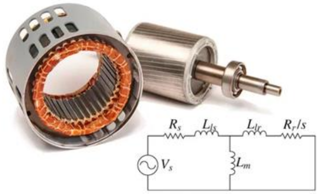


Magnetic circuits

- Linear model of the iron-core coil:



- R is the resistance of the coil N turns
- L_F is the leak inductance, L_M is the magnetizing inductance
- R_F is the resistor modelling the iron losses

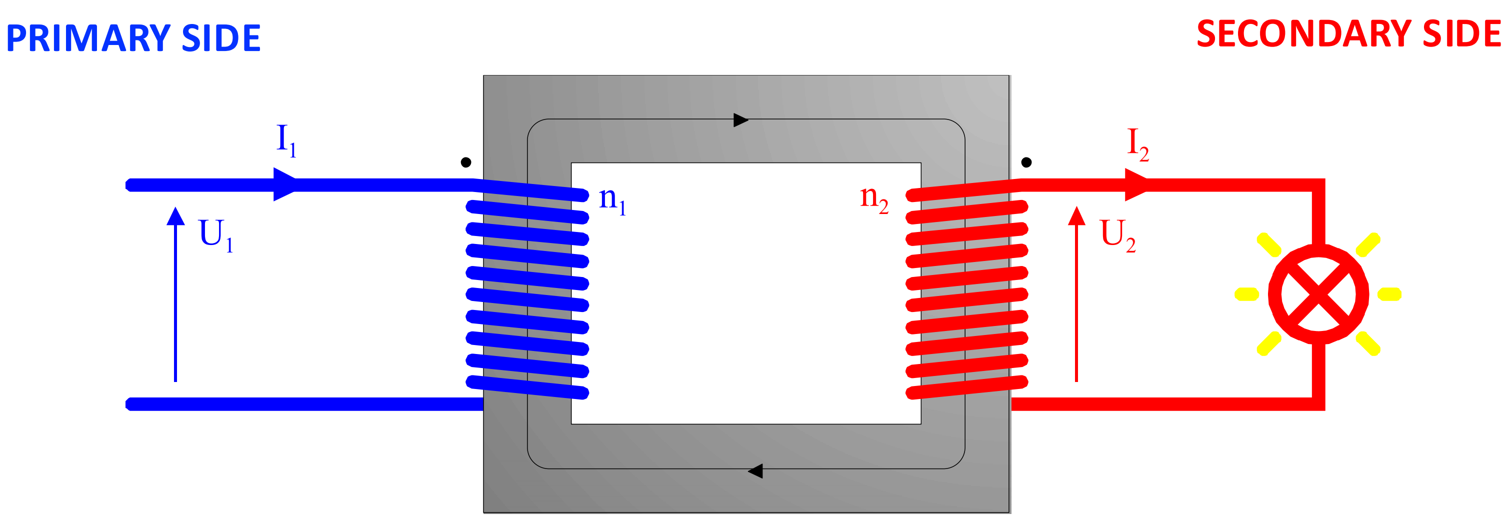


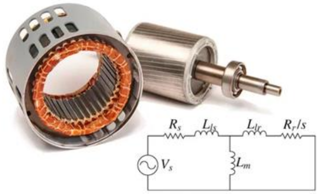
Single-phase transformer

- The transformer enables a change in the RMS value of an AC voltage to be achieved with high efficiency => step-up transformer or step-down transformer

- A single-phase transformer consists of two windings wound on the same magnetic circuit

=> Usually, the two windings have different numbers of turns



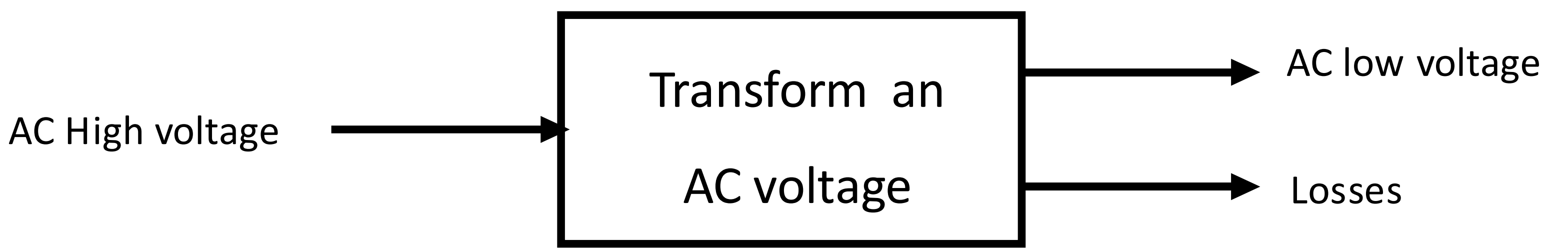


Single-phase transformer

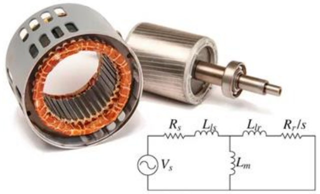
- Functional approach: More precisely, the transformer is a static machine that allows sinusoidal quantities (voltages, currents) to be modified without changing their frequency.

=> **Voltage adaptation**: step-down or step-up transformer

=> **Galvanic insulation**: insulation transformer

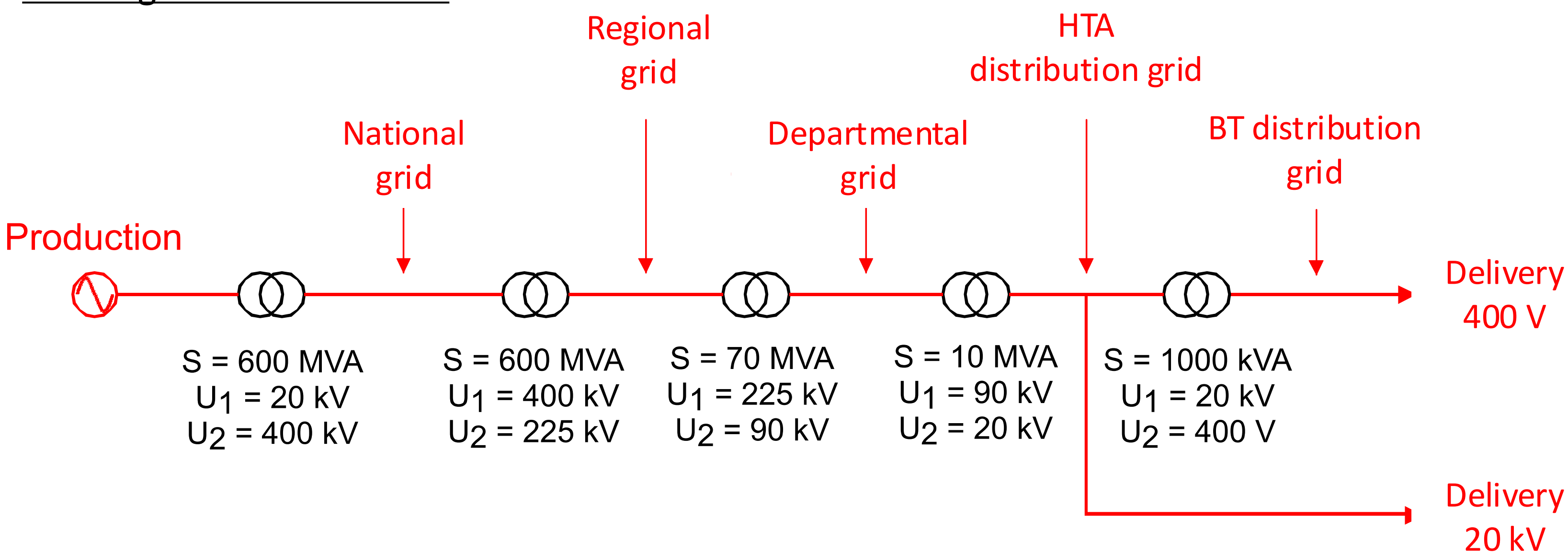


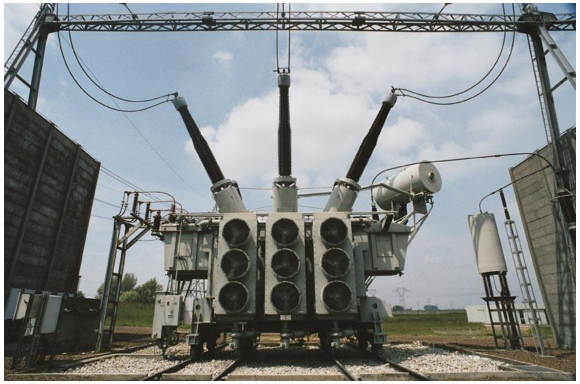
Transformer



Single-phase transformer

- Power grid base structure:



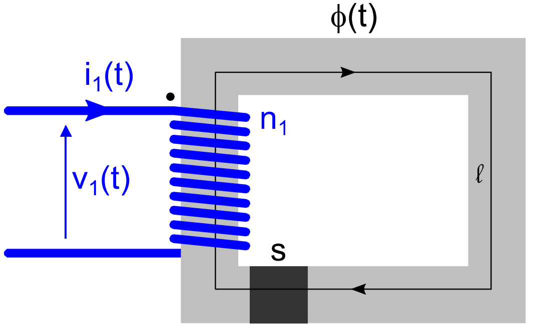


Single-phase transformer

- Principle:

- Hopkinson's relation in the case of a single winding at the primary side:

$$n_1 . i_1 = \mathcal{R} . \Phi$$

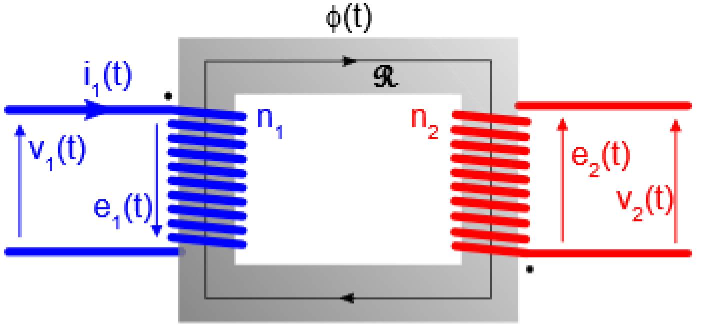


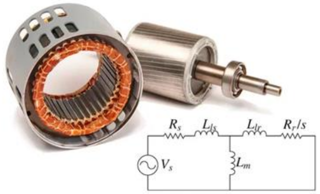
- For two windings and i2 =0 (no load)

$$e_1 = -v_1 = -n_1 \frac{d\varphi}{dt}$$

$$v_1 = n_1 \frac{d\varphi}{dt}$$

$$e_2 = -n_2 \frac{d\varphi}{dt} = v_2$$



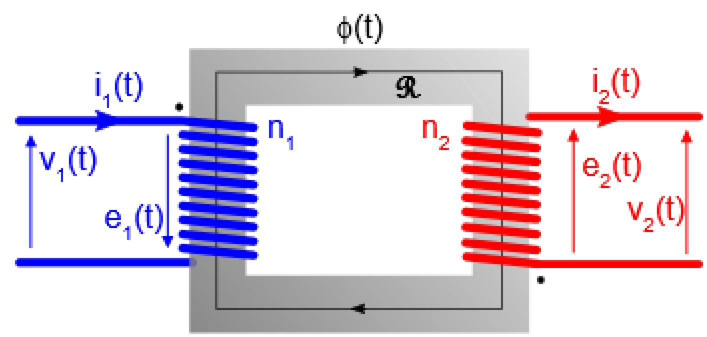


Single-phase transformer

- Principle:

- For two windings and i2 ≠ 0 (presence of a load)

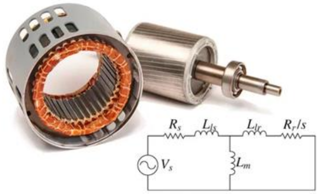
$$n_1.i_1 + n_2.i_2 = \mathcal{R}\phi$$



$$e_1 = -v_1 = -n_1\frac{d\varphi}{dt}$$

$$v_1 = n_1\frac{d\varphi}{dt}$$

$$e_2 = -n_2\frac{d\varphi}{dt} = v_2$$



Single-phase transformer

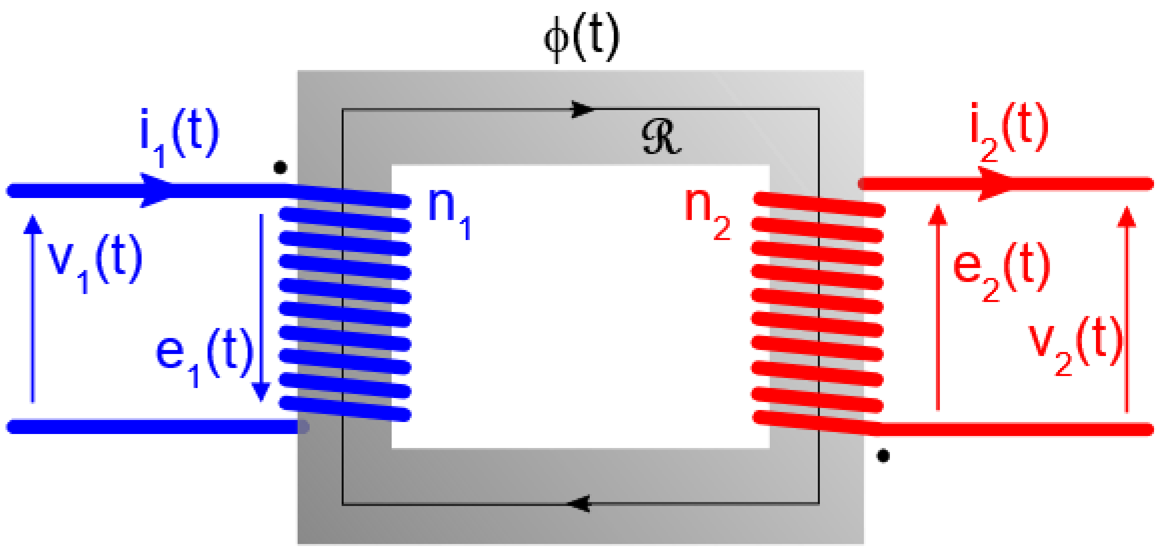
- Principle: receptor convention/generator convention

- Seen from the primary grid, the transformer is a receptor

=> Receptor convention at the primary side

- Seen from the load, the transformer is a generator

=> Generator convention at the secondary side



Single-phase transformer

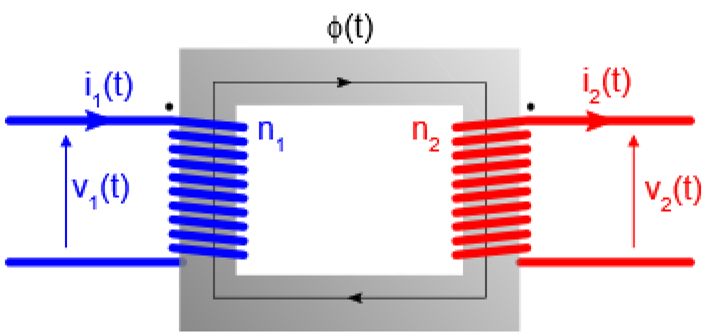
- Principle: homonymous terminals

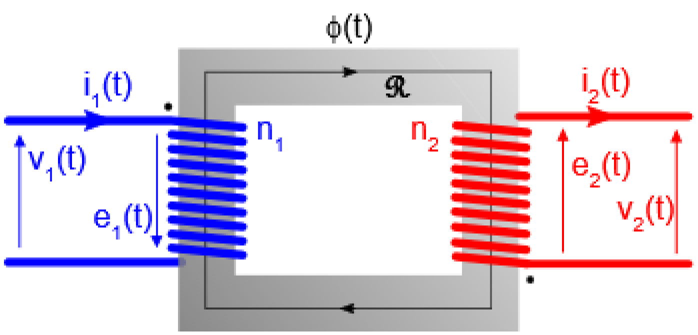
- The winding direction is marked with dots (●). Terminals marked in this way are called “homonymous terminals”. They correspond to points of the same instantaneous polarity.

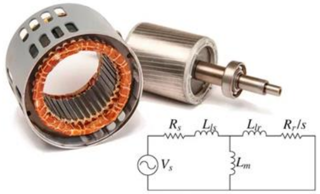
- Sign conventions for magnetic and electrical quantities:

=> A positive current entering through a homonymous terminal creates a positive flux in the magnetic circuit

=> According to Hopkinson's law, the magnetomotive force is preceded by the sign + if the current orientation arrow enters through a homologous terminal, and by the sign - otherwise.





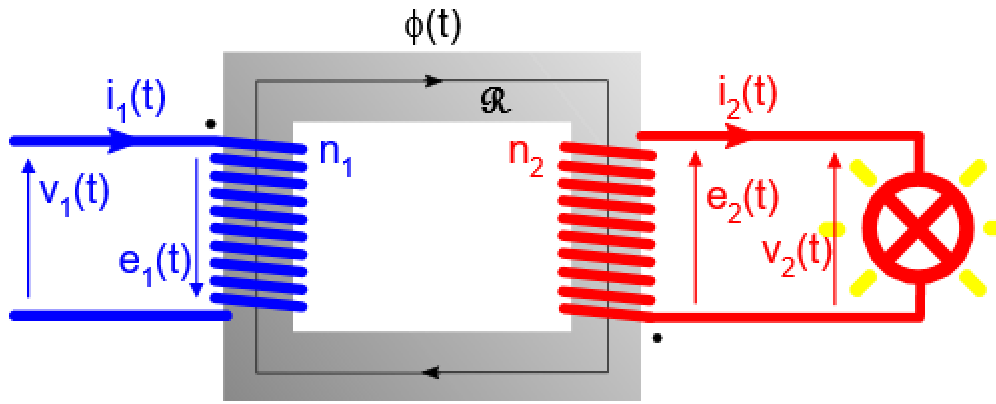


Single-phase transformer

- Principle: the ideal transformer - voltages

- Ideal windings = no voltage drop, no losses

- Ideal magnetic circuit = zero reluctance



$$v_1 = -e_1 = n_1 \frac{d\varphi}{dt}$$

$$v_2 = e_2 = -n_2 \frac{d\varphi}{dt}$$

- The **transformation ratio** is given by:

$$\boldsymbol{m = \frac{n_2}{n_1} = -\frac{v_2}{v_1}}$$

m > 1: Step-up transformer

m < 1: Step-down transformer

Single-phase transformer

- Principle: the ideal transformer - currents

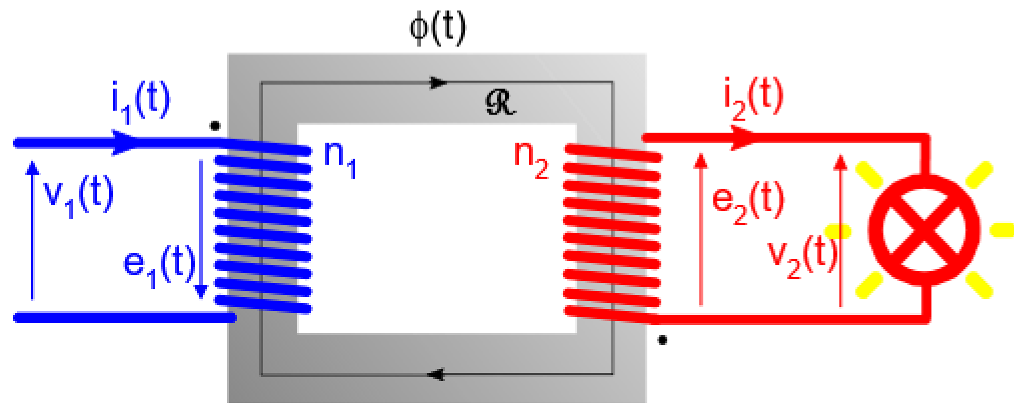
- Ideal windings = no voltage drop, no losses

- Ideal magnetic circuit = zero reluctance

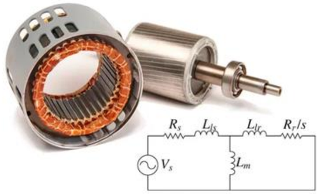
- Hopkinson's relation:

$$n_1.i_1 + n_2.i_2 = \mathcal{R}\phi$$

$$n_1.i_1 + n_2.i_2 = \boldsymbol{\mathcal{R}\phi = 0}$$



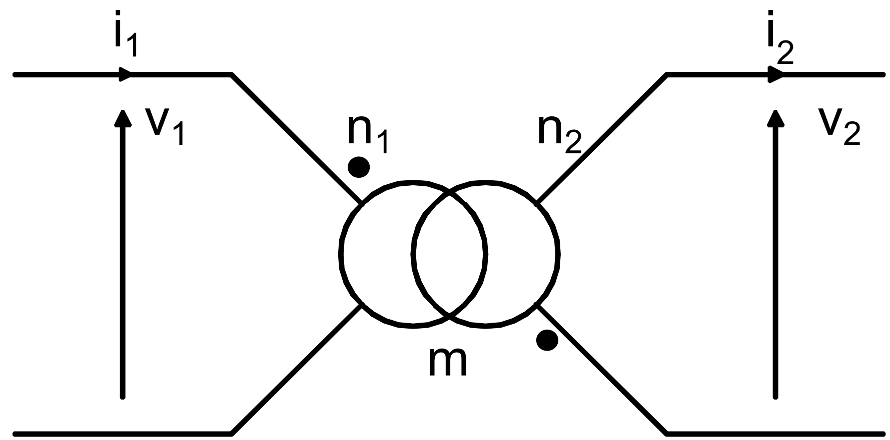
$$\frac{i_2}{i_1} = -\frac{n_1}{n_2} \qquad \frac{i_2}{i_1} = -\frac{1}{m} \qquad i_1 = -m.i_2$$



Single-phase transformer

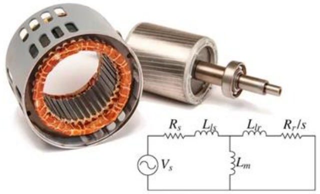
- Principle: the ideal transformer - symbol

$$m = \frac{n_2}{n_1} = -\frac{V_2}{V_1} = -\frac{I_1}{I_2}$$



$$\eta = \frac{P_2}{P_1} = \frac{V_2 . I_2}{V_1 . I_1} = 1$$

- Conservation of power, for the ideal transformer only



Single-phase transformer

- Principle: winding imperfection

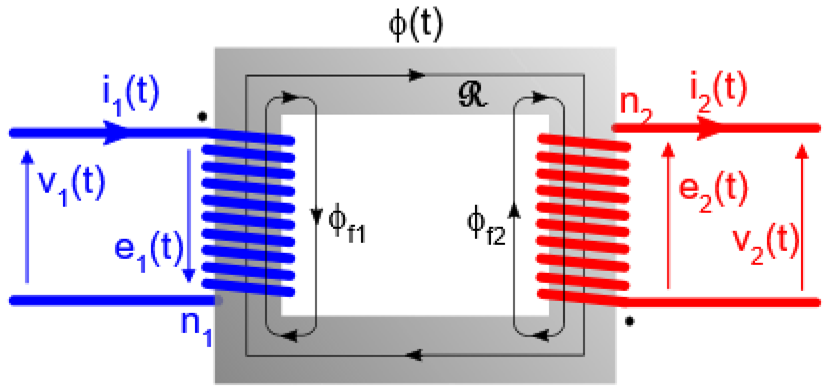
- Joule losses (or copper losses)

$$P_J = r_1.I_1^2 + r_2.I_2^2$$

$$R = \rho.\frac{\ell}{s} \qquad \rho_\Theta = \rho_0(1 + a\Theta)$$

Copper (Cu) : $\rho_0 = 1{,}6.10^{-8}\,\Omega.m$, a = 0,39
Aluminum (Al) : $\rho_0 = 2{,}42.10^{-8}\,\Omega.m$, a = 0,43

$$v_1 = -e_1' + r_1.i_1$$
$$v_2 = e_2' - r_2.i_2$$



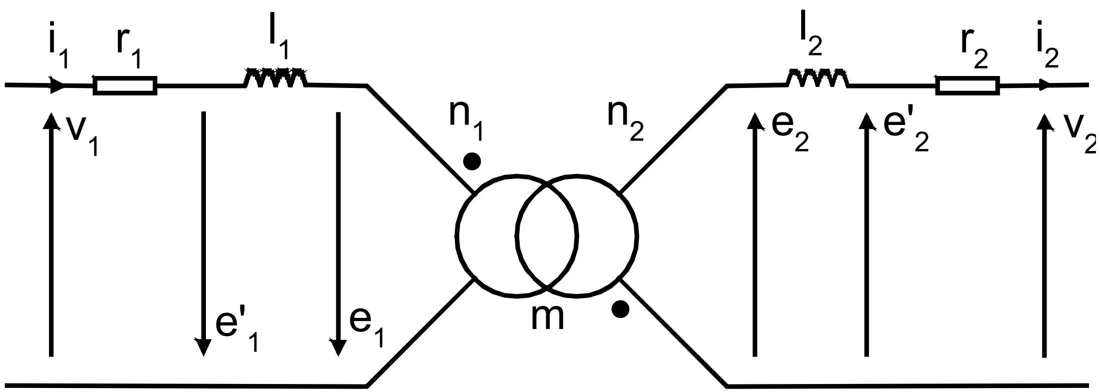
- Magnetic leaks

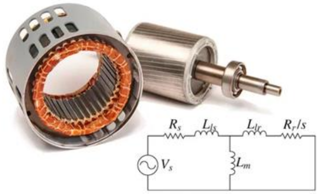
$$\phi_T = \phi_{f1} + \phi_{f2} + \phi$$

$$e_1' = n_1.\frac{d\varphi}{dt} + n_1.\frac{d\varphi_{f1}}{dt}$$

$$e_1' = e_1 + l_1.\frac{di_1}{dt}$$

$$e_2' = e_2 + l_2.\frac{di_2}{dt}$$



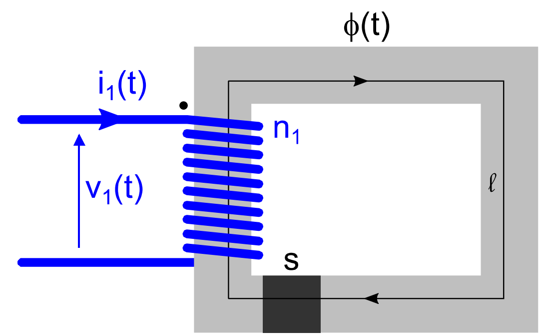


Single-phase transformer

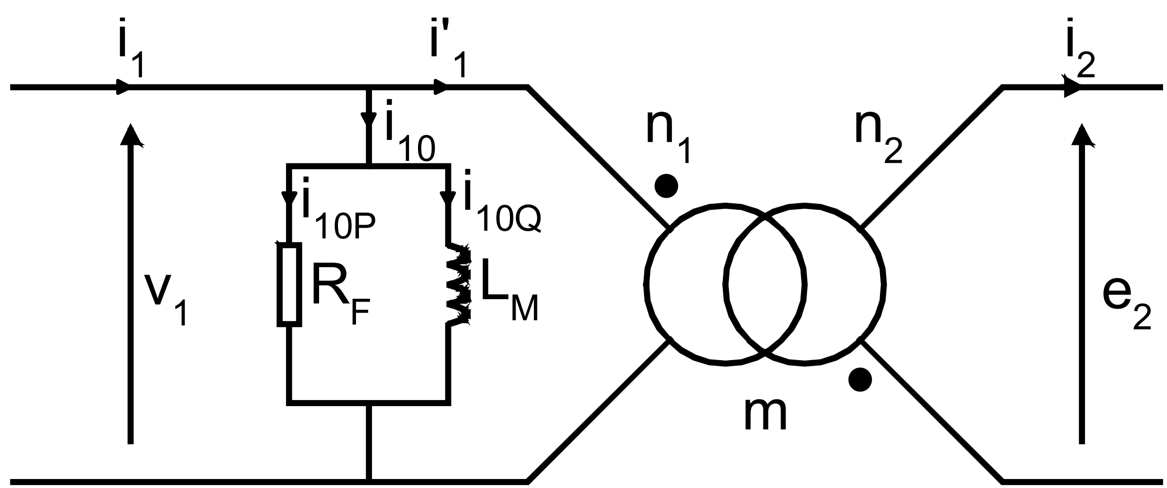
- Principle: magnetic circuit imperfection

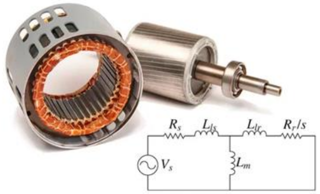
- Finite permeability and non zero reluctance of the magnetic circuit

=> A primary current is consumed at no load



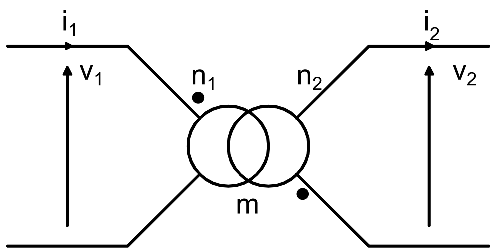
$$\mathcal{R}\phi = n_1 . i_{10}$$

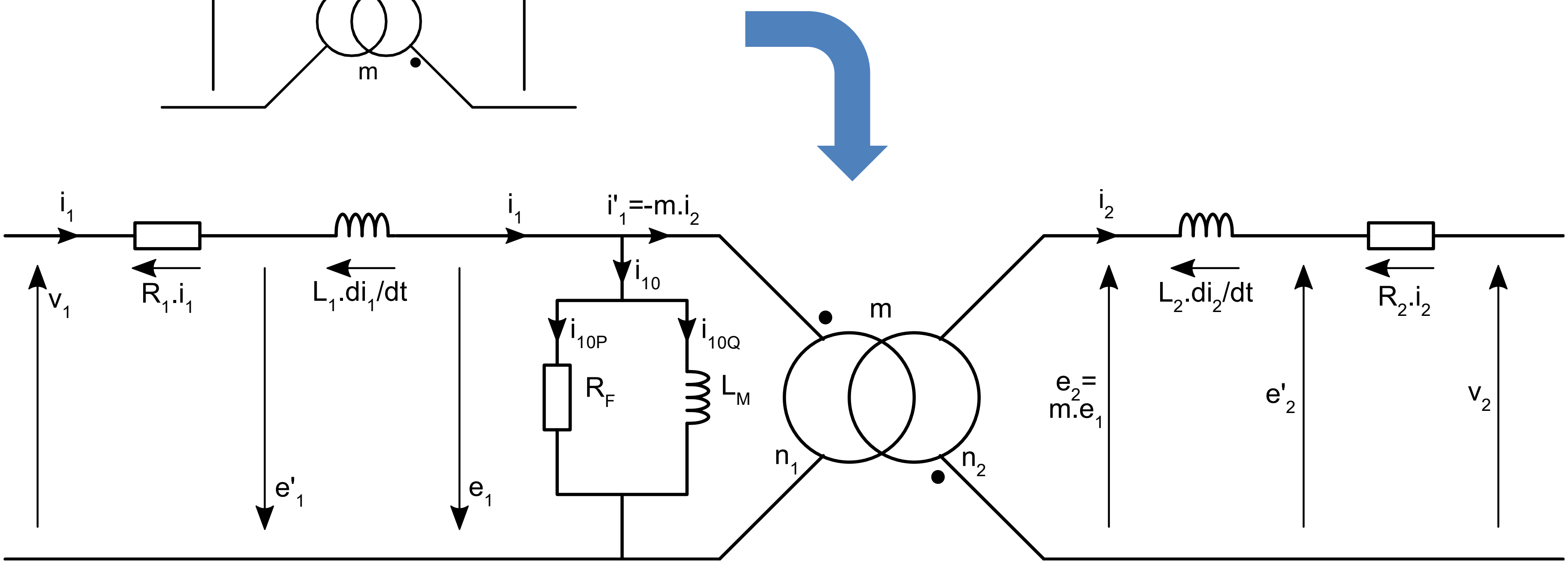




Single-phase transformer

- Equivalent model of the real transformer



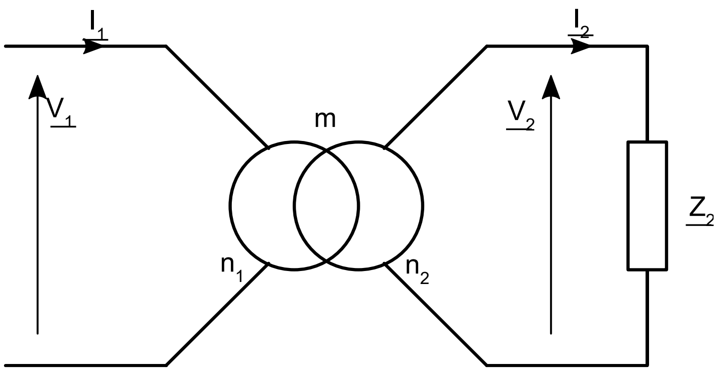


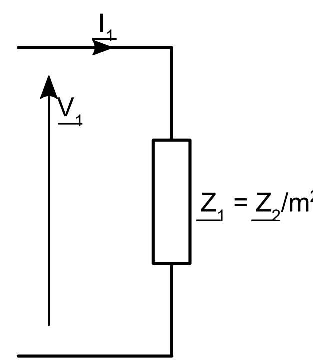
Single-phase transformer

- Equivalent model of the real transformer: Impedance transfer

- A transformer, in which an impedance Z_2 is connected to the secondary side is equivalent to an impedance Z_1 connected to the primary side with:

$$\boldsymbol{Z_1 = \frac{Z_2}{m^2}}$$

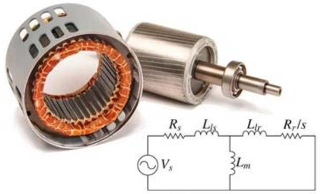




- We remind: $I_1 = m.I_2$ et $V_1 = \frac{V_2}{m}$
- We write: $Z_2 = \frac{V_2}{I_2}$ et $Z_1 = \frac{V_1}{I_1}$

$$Z_1 = \frac{V_1}{I_1} = \frac{V_2/_m}{m.I_2} = \frac{1}{m^2}.\frac{V_2}{I_2} = \frac{Z_2}{m^2}$$

$$Z_1 = \frac{Z_2}{m^2}$$

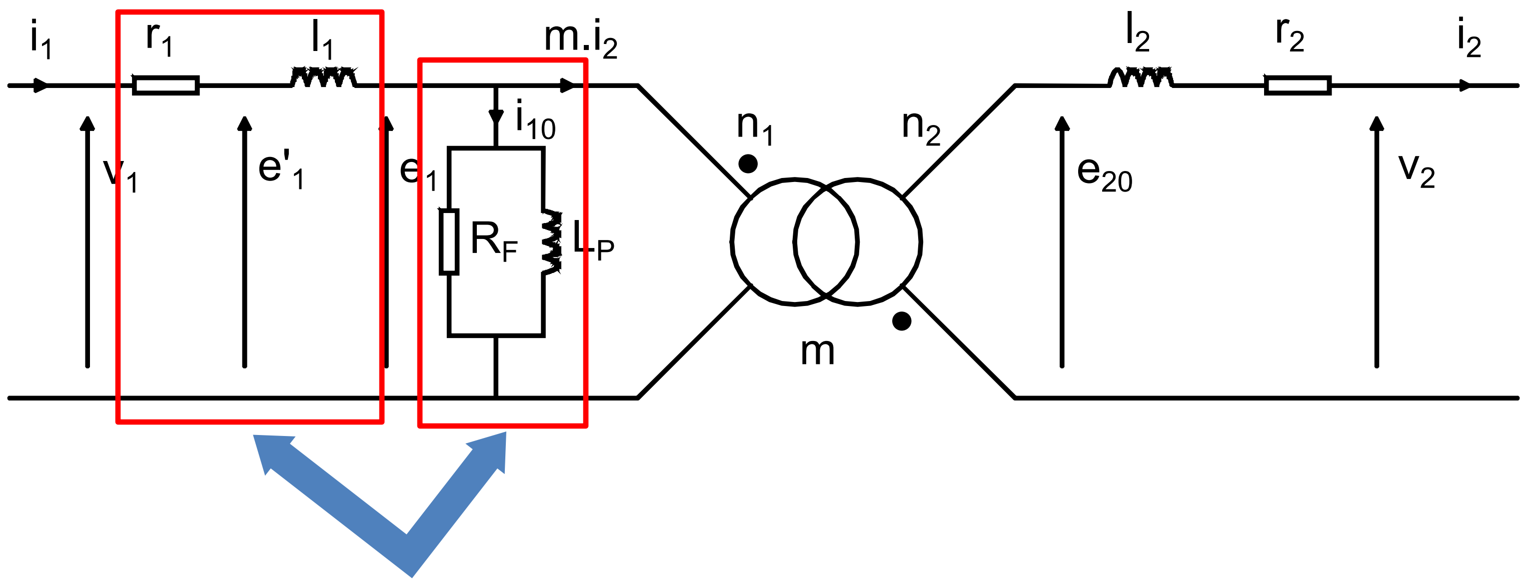


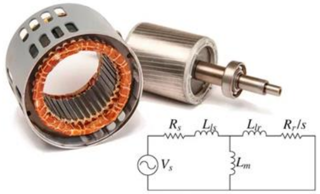
Single-phase transformer

- Equivalent model of the real transformer: Kapp's assumption

- The voltage drop across R_1 and L_1 is small compared to the voltages e_1 and V_1

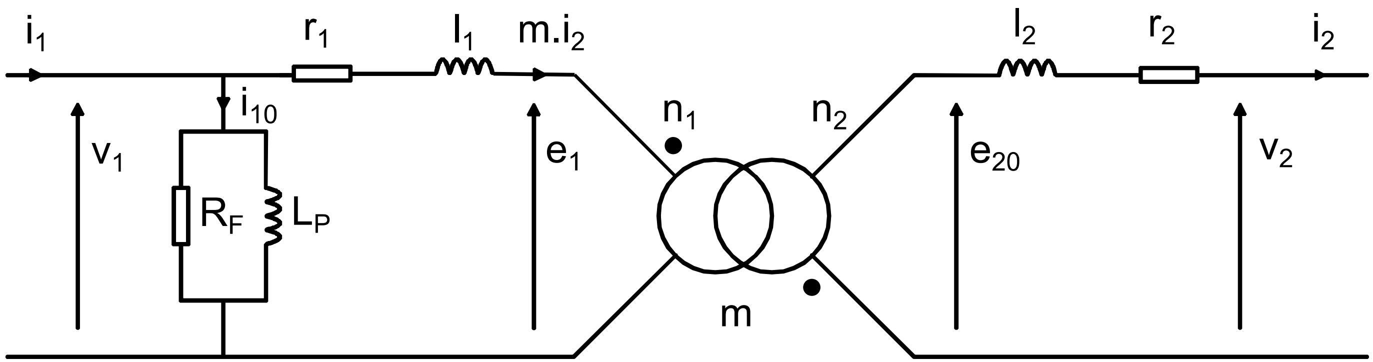
=> R_1/L_1 and R_F/L_p can be swapped





Single-phase transformer

- Equivalent model of the real transformer: Kapp's assumption

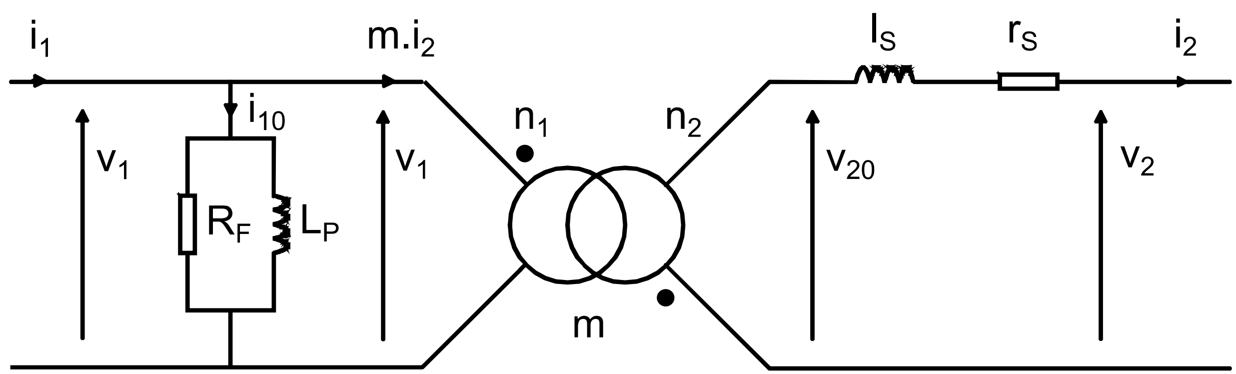


- Kapp's equivalent secondary model (R_1 and L_1 are transferred to the secondary side)

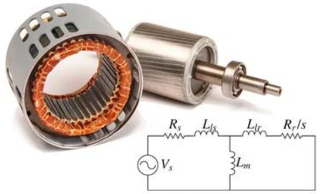
$$r_S = r_2 + m^2 . r_1$$

$$l_S = l_2 + m^2 . l_1$$

$$m = \frac{n_2}{n_1} = \frac{V_{20}}{V_1} \cong \frac{I_1}{I_2}$$



$$\underline{V_2} = -m.\underline{V_1} + R_s.\underline{I_2} + jX_s.\underline{I_2}$$



Single-phase transformer

- Equivalent model of the real transformer: Kapp's assumption

- Kapp's equivalent primary model (R_2 and L_2 are transferred to the primary side)

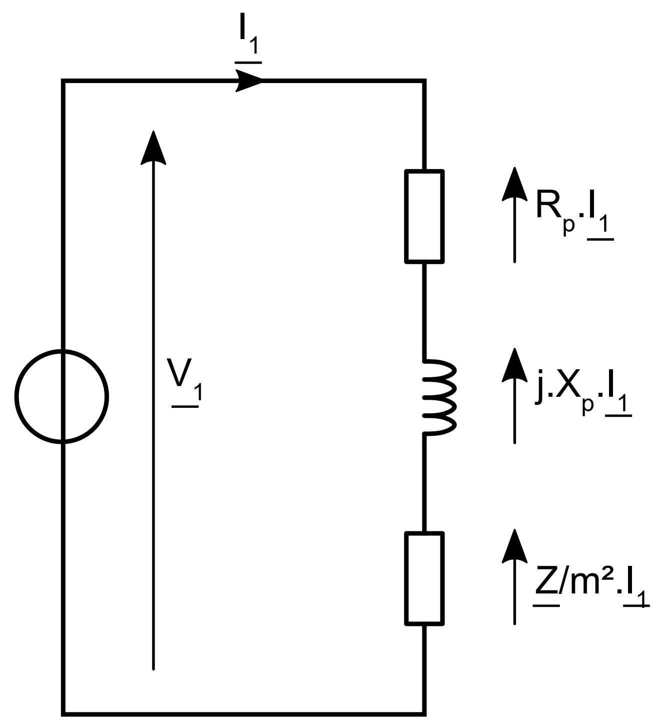
$R_P = R_1 + \frac{R_2}{m^2}$: total winding resistance transferred to the primary side

$X_P = X_1 + \frac{X_2}{m^2}$: total winding reactance transferred to the primary side

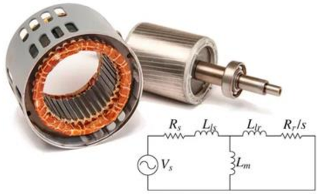
$\underline{Z_P} = R_p + jX_p$: total winding impedance transferred to the primary side

$\frac{\underline{Z}}{m^2}$: secondary side load transferred to the primary side.

$$\underline{V_1} = \frac{\underline{Z}}{m^2}.\underline{I_1} + \underline{Z_P}.\underline{I_1}$$



(this model will be useful for the induction motor)



Single-phase transformer

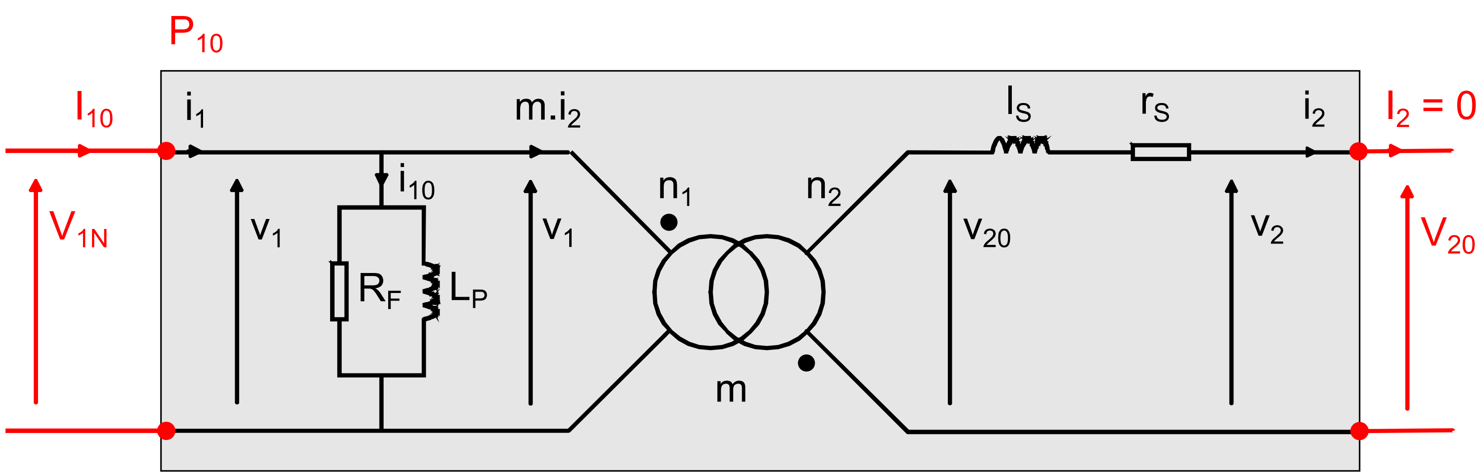
- Determining the elements of the Kapp secondary equivalent model:

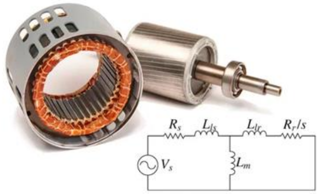
- Test at no load:

- conditions: Transformer supplied at rated voltage (V_{1N}) + open secondary side ($I_2 = 0$)

- Measured quantities: V_{1N}, I_{10}, V_{20}, P_{10} (iron losses) and Q_{10}

$$R_F = \frac{V_{1N}^2}{P_{10}} \qquad X_P = L_P.\omega = \frac{V_{1N}^2}{Q_{10}} \text{ with } Q_{10} = \sqrt{(V_{1N}.I_{10})^2 - P_{10}^2} \qquad m = \frac{V_{20}}{V_1}$$





Single-phase transformer

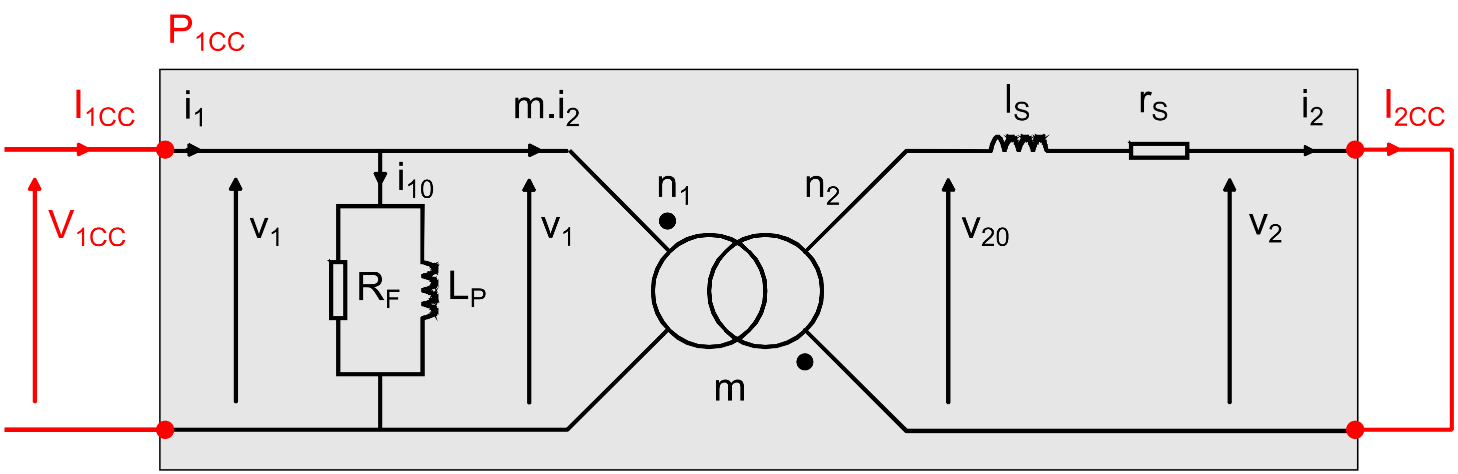
- Determining the elements of the Kapp secondary equivalent model:

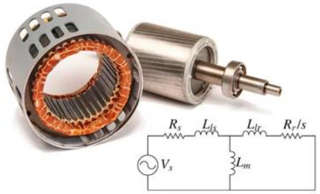
- Short-circuit test: (short circuit at the secondary side)

- conditions: Transformer supplied at reduced voltage (V_{1CC}) + rated secondary side current ($I_{2CC} = I_{2N}$)

- Measured quantities: V_{1CC}, I_{1CC}, I_{2CC}, P_{1CC} (Joule losses) and Q_{1CC}

$$\boldsymbol{R_S = \frac{P_{1CC}}{I_{2CC}^2}} \qquad \boldsymbol{X_S = L_S.\omega = \frac{Q_{1CC}}{I_{2CC}^2}} \quad \text{with } Q_{1CC} = \sqrt{(V_{1CC}.I_{1CC})^2 - P_{1CC}^2}$$

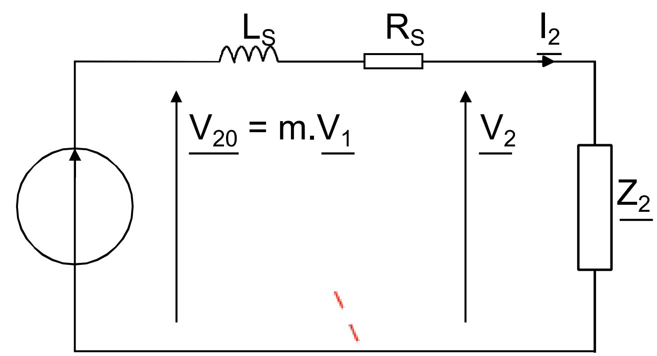




Single-phase transformer

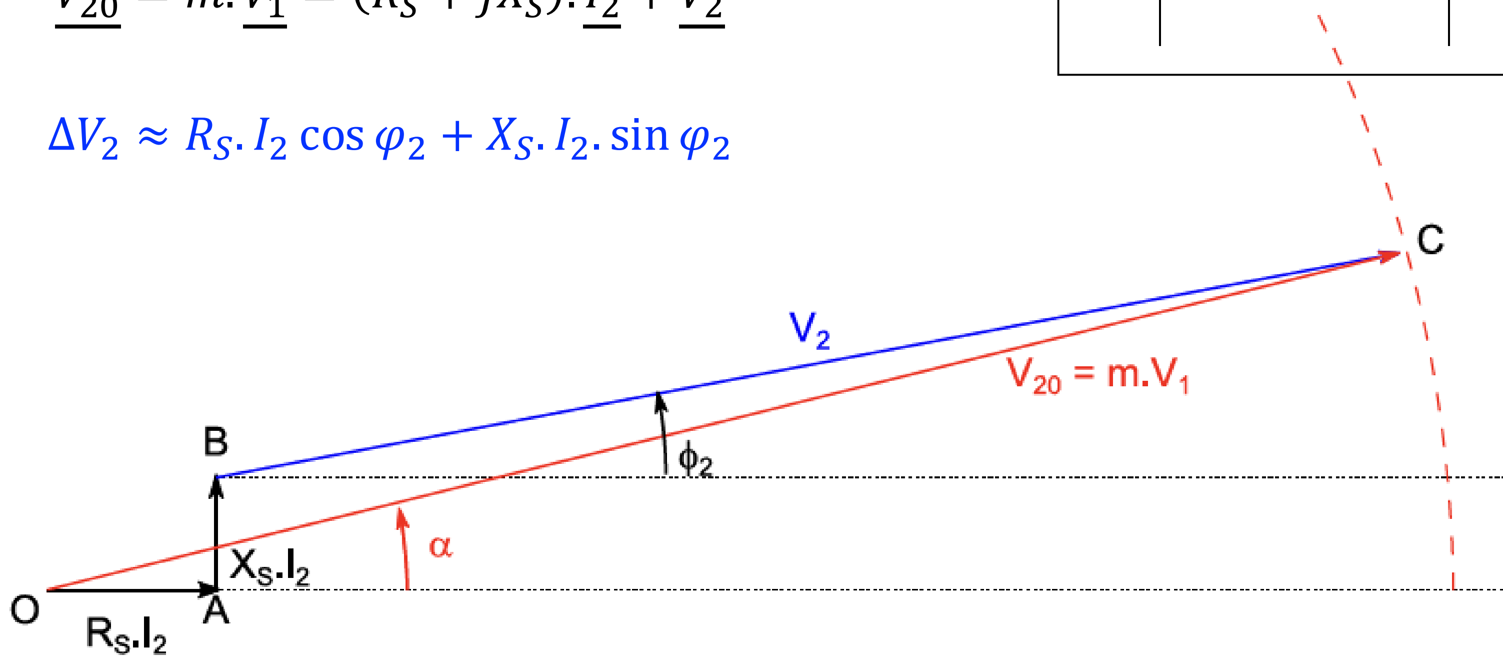
- Voltage drop at the secondary side of the transformer:

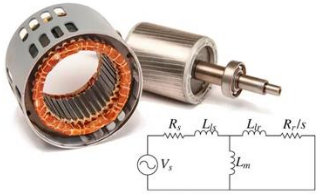
- Kapp's triangle: case of the inductive load ($\phi_2 > 0$)



$$\underline{V_{20}} = m.\underline{V_1} = (R_S + jX_S).\underline{I_2} + \underline{V_2}$$

$$\Delta V_2 \approx R_S.I_2 \cos\varphi_2 + X_S.I_2.\sin\varphi_2$$

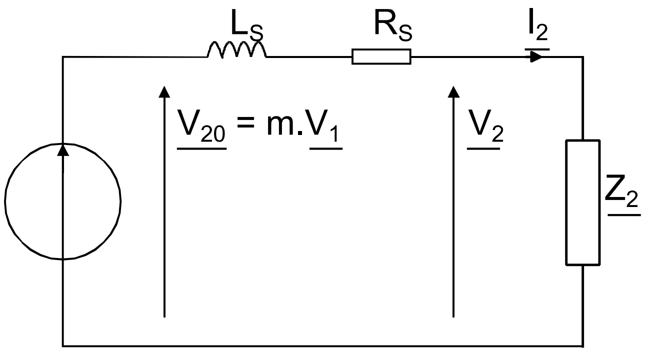




Single-phase transformer

- Efficiency:

$$\eta = \frac{V_2 . I_2 . \cos\varphi_2}{V_2 . I_2 . \cos\varphi_2 + R_S . I_2^2 + P_F}$$



- P_F is obtained from the test at no load (P_{10})

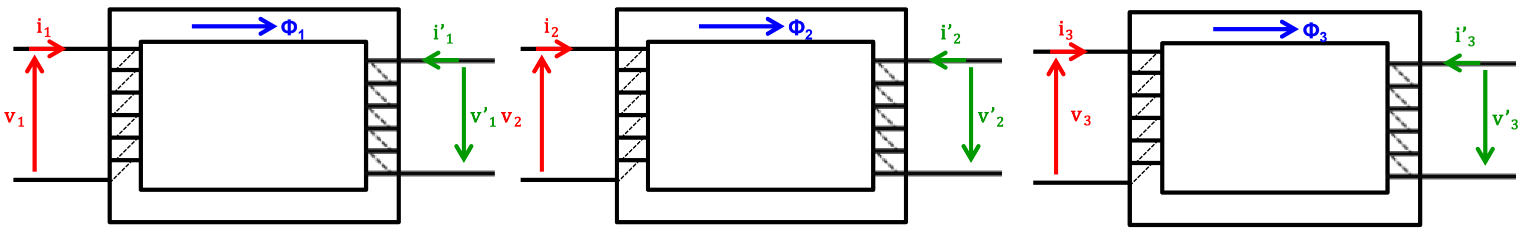
- Optimum current obtained from
$$\eta = \frac{V_2 . \cos\varphi_2}{V_2 . \cos\varphi_2 + R_S . I_2 + \frac{P_{Fer}}{I_2}}$$

- The maximum efficiency is given for $R_S . I_{2Opt} = \frac{P_{Fer}}{I_{2Opt}}$ and $I_{2Opt} = \sqrt{\frac{P_{Fer}}{R_S}}$

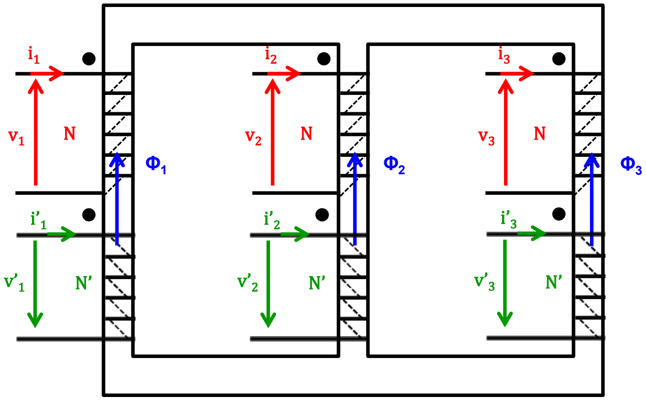
Three-phase transformer

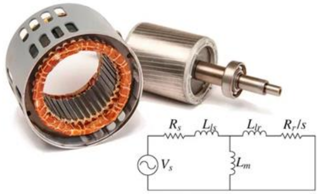
- Construction and connection:

- At first glance, the three-phase transformer can be considered as the combination of 3 single-phase transformers



- Or it can be integrated on a single magnetic circuit comprising 3 columns, each carrying the primary winding and the secondary winding





Three-phase transformer

- <u>Construction and connection</u>:

- Both the primary and the secondary sides of the transformer need to be connected (delta or Y)

- The nature of these couplings is designated by letters, using upper case letters for the high voltage side and lower case letters for the secondary side

1st letter (upper case): connection on H.T. side

- **Y: «** star »

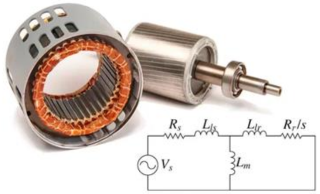
- **D** or **Δ:** delta

2nd letter (lower case): coupling on B.T. side

- y: star

- **d:** delta

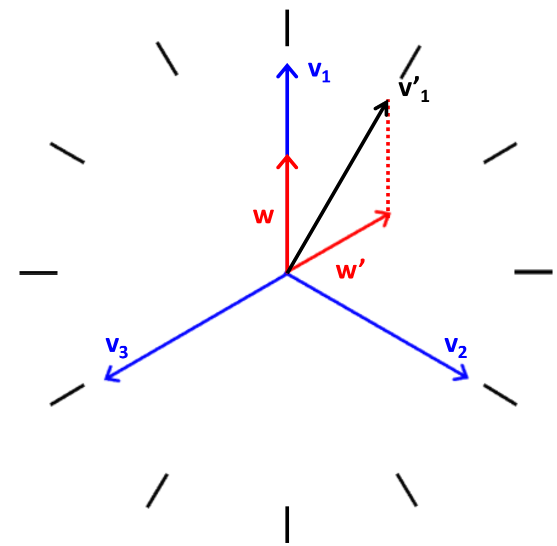
Add letter “ N ou **n”** if neutral is out.



Three-phase transformer

- Hourly index: Phase shift angle between primary and secondary voltages expressed in hours

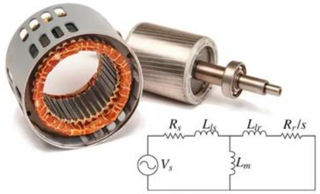
- Marked from 0 to 11, each hour angle is always a multiple of 30°:
=> 0 for 0
=> 1 for 30
=> 2 for 60°, and
=> 6 for 180
=> ...



- That's why a specific representation has been chosen:
=> On the same Fresnel diagram, we plot two vectors representing two homologous voltages, one on the primary side, the other on the secondary side.

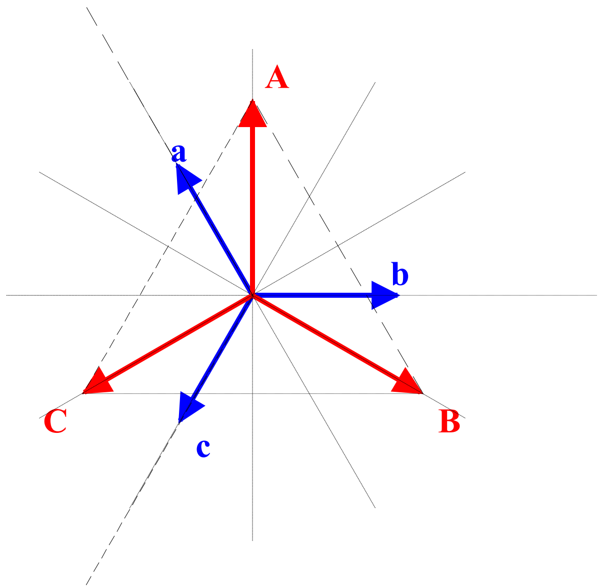
=> The voltage on the primary side is shown vertically, pointing upwards.

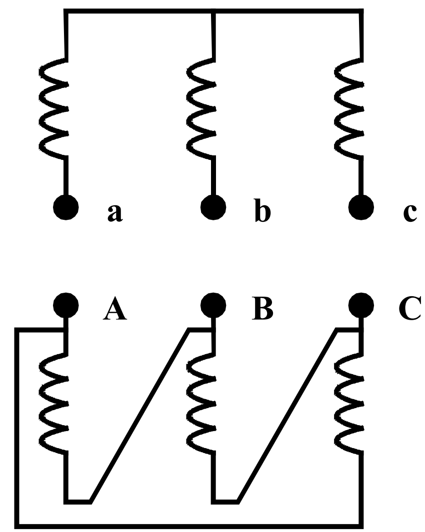
If we consider these two vectors as the two hands of a watch, the time indicated by the watch is by definition the transformer hourly index

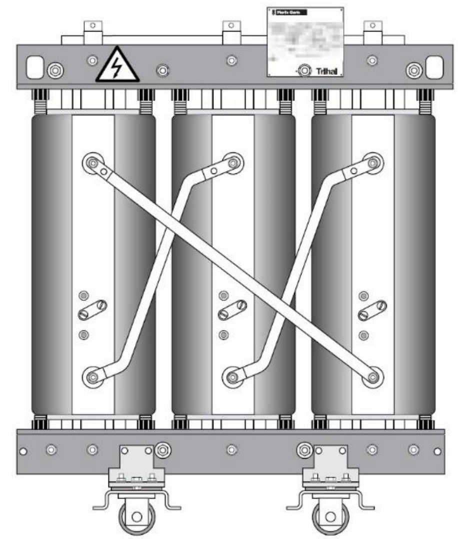


Three-phase transformer

- Example of Dyn 11 connection:



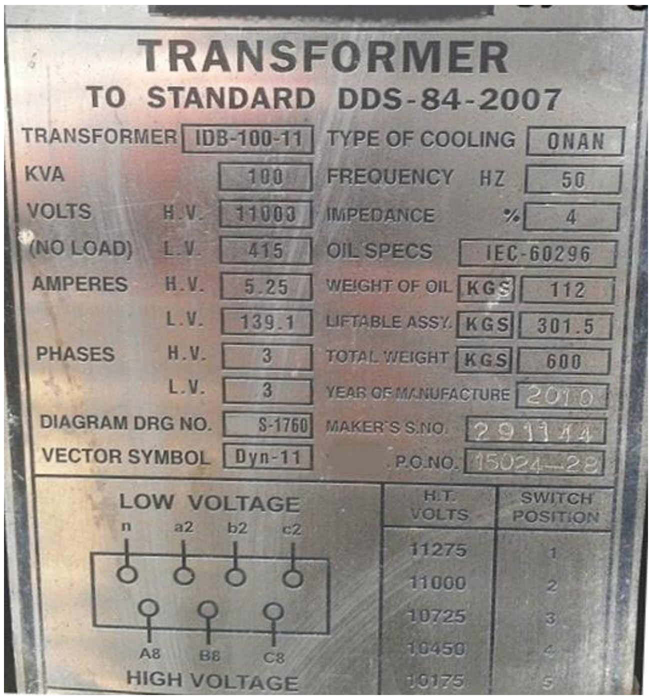


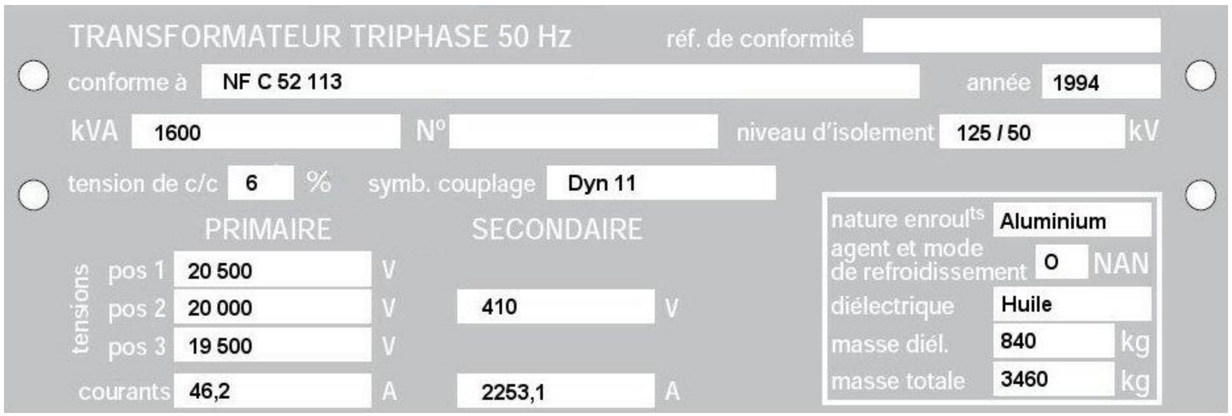


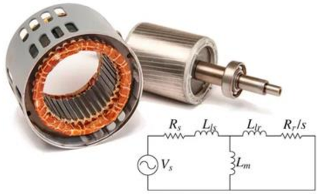
- High-voltage side => delta coupling.
- Low-voltage side => Y connection with neutral out.
- 330° phase shift (11x30) between primary and secondary.

Three-phase transformer

- Transformer name plate: gives all the rating







III - Transformers

Three-phase transformer

- Equivalent model of the real transformer:

- Each transformer column can be modeled separately by a single-phase equivalent diagram at the secondary (see before)

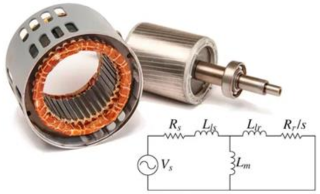
- Each element of the secondary model can be determined by the same tests as those of the single-phase transformer

- Test at no load:

$$\boldsymbol{R_F = \frac{3V_N^2}{P_0}} \qquad \boldsymbol{X_P = L_P.\omega = \frac{3V_N^2}{Q_0}} \quad \text{with } Q_0 = \sqrt{(V_N.I_0)^2 - P_0^2} \qquad \boldsymbol{m = \frac{V'_N}{V_N}}$$

- Short-circuit test: (short circuit at the secondary side)

$$\boldsymbol{R_S = \frac{P_{CC}}{3I'^2_{CC}}} \qquad \boldsymbol{X_S = L_S.\omega = \frac{Q_{CC}}{3I'^2_{CC}}} \quad \text{with } Q_{CC} = \sqrt{(V_{CC}.I_{CC})^2 - P_{CC}^2}$$



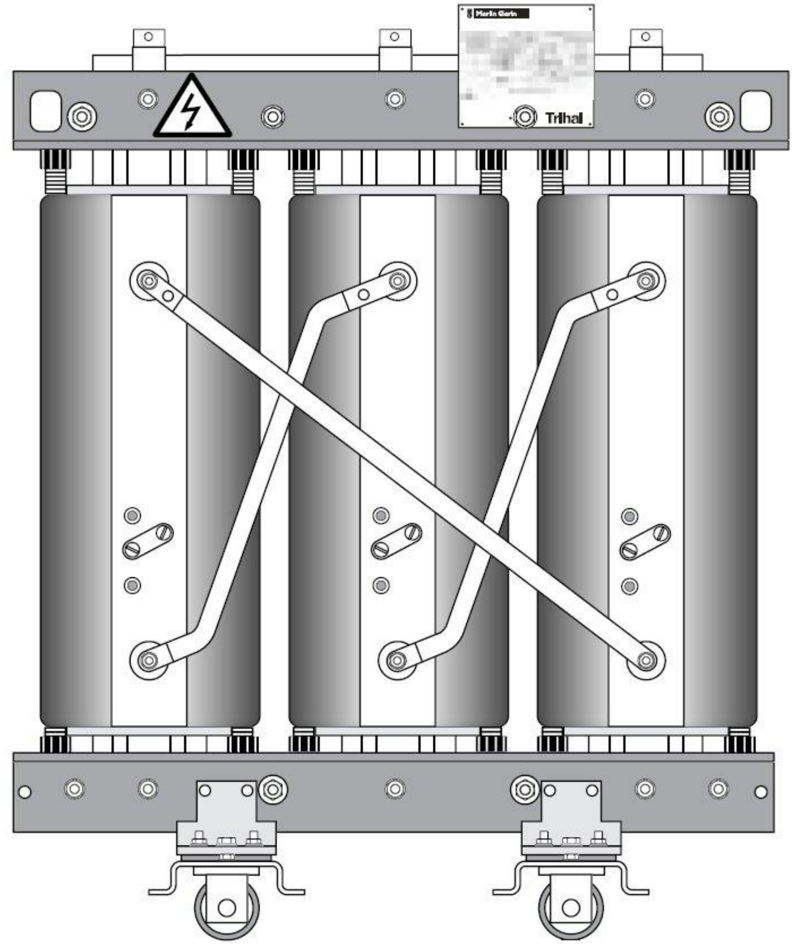
Three-phase transformer

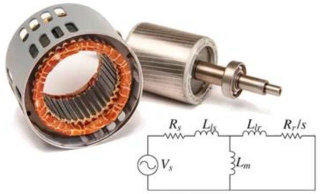
- <u>HTA/BT distribution transformers</u>: Dry transformer

- Active parts coated in protective resins (often epoxies) and mounted on a support frame in the open air.

- Good ventilation of the device and the room is required

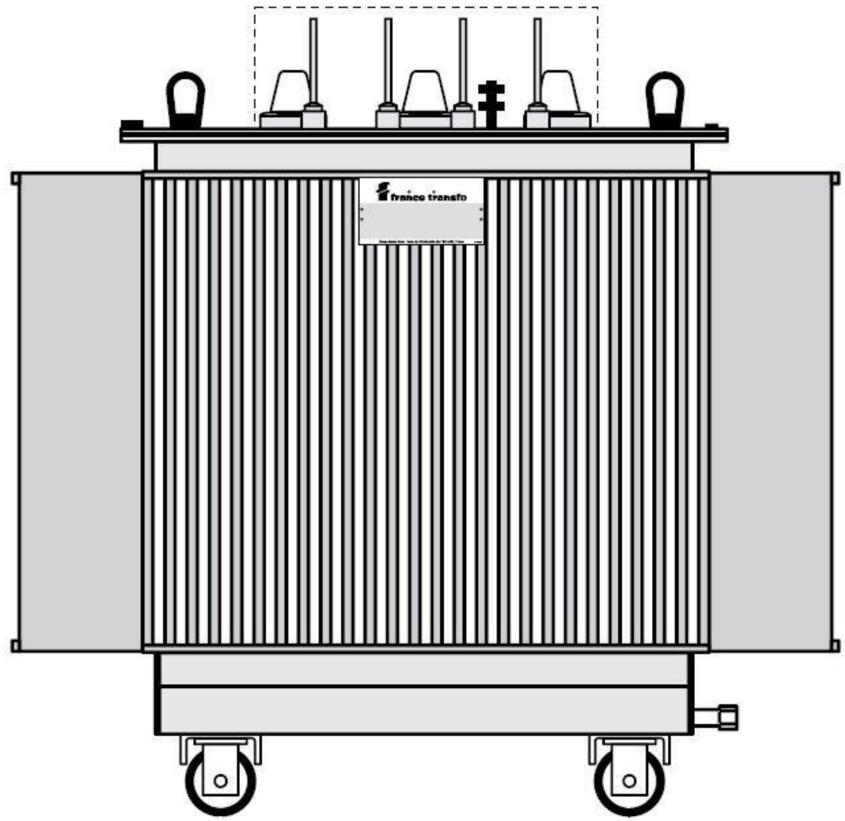
- Dust removal from ambient air recommended





Three-phase transformer

- HTA/BT distribution transformers: Immersed transformer



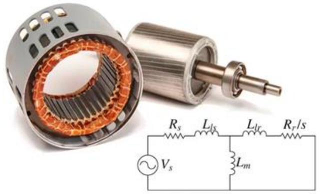
- Sealed with Total/Integral filling

- Hermetically sealed transformer

- Flexible tank

- Flexible tank

- Accordion-folded walls to absorb changes in dielectric volume as it heats up



Three-phase transformer

- HTA/BT distribution transformers: Dry and Immersed transformers

Transformateur de type enrobé sous enveloppe

Transformateur 400 kVA avec accessoires de protection