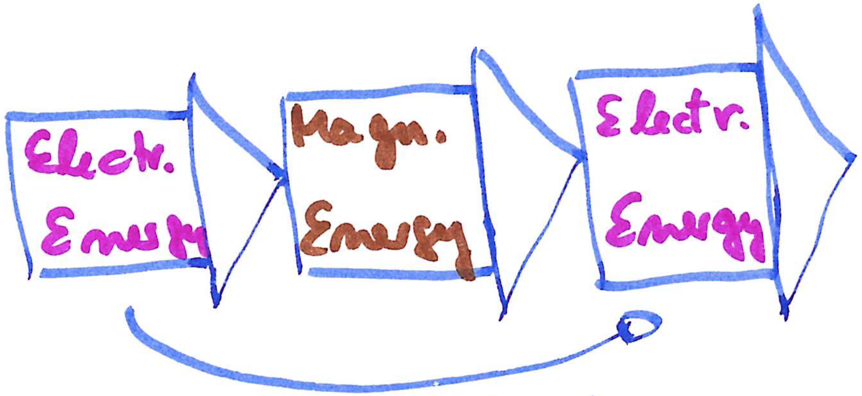
8th January 2020, Rezekne

①

# Electrical Machinery

## The Transformer (Tr.)




no wired connection

⇒ our high standard of living depends high on electrical energy everywhere

②

⇒ electrical power supply depends high on transformers. Electrical power supply without transformers is not possible (I cannot imagine)

⇒ Picture Voltage levels

⇒ Voltage levels (in Ger.)

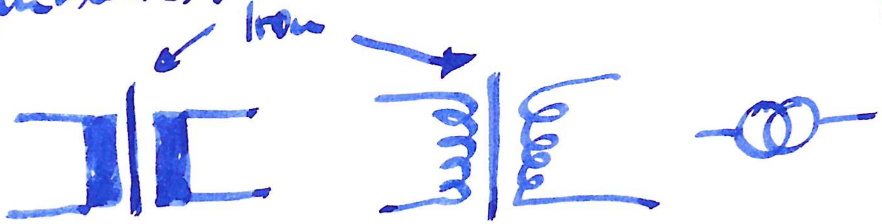
380 kV Highest volt.
110 kV High voltage
20 kV Middle volt.
230/400 V Low voltage

This is not possible without transformer

Transformer → ideal Tr. (1.)
→ real Tr. (2.)

- ideal Transformer
  - ≙ no losses
  - ≙ $\mu_r \to \infty$
  - ≙ no magnetic leakage flux

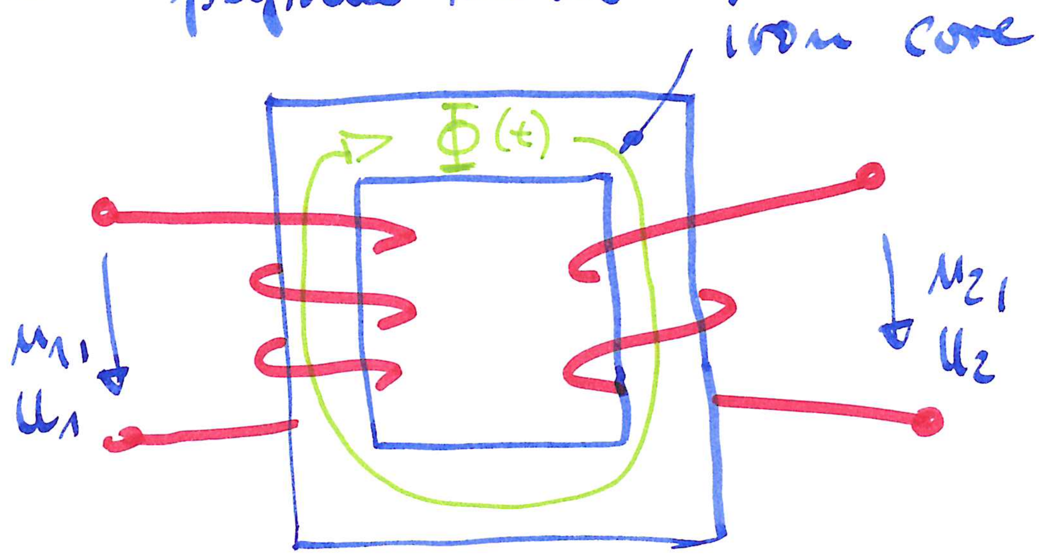
symbols:




4 wire symb. 4 w. s. 2 w. s.



physical model




coil with $N_1$ wind. coil with $N_2$ wind.

We suppose, that inside the iron core is a magnetic flux $\Phi(t) \neq$ const ("God made the flux")

If there is magnetic flux, then at the coils are voltages with the induction law:

$$u_1 = N_1 \cdot \frac{d\Phi}{dt}$$

$$u_2 = N_2 \cdot \frac{d\Phi}{dt}$$

=

$$\frac{u_1}{N_1} = \frac{d\Phi}{dt} = \frac{u_2}{N_2} \; ; \; \frac{u_1}{N_1} = \frac{u_2}{N_2}$$

(1) $$\frac{U_1}{U_2} = \frac{N_1}{N_2} = ü = t$$

Voltage transforming law of an ideal

$t$ : transmission ratio



ideal Tr. → no losses ⇒ $P_1 = P_2$ ⇒

$$U_1 \cdot I_1 = U_2 I_2$$

$$\frac{I_2}{I_1} = \frac{U_1}{U_2} = t$$

(2) $$\frac{I_2}{I_1} = \frac{N_1}{N_2} = t$$

Current transforming law of an ideal Tr.

(1) * (2) ⇒ $$\frac{U_1}{U_2} \cdot \frac{I_2}{I_1} = t^2$$

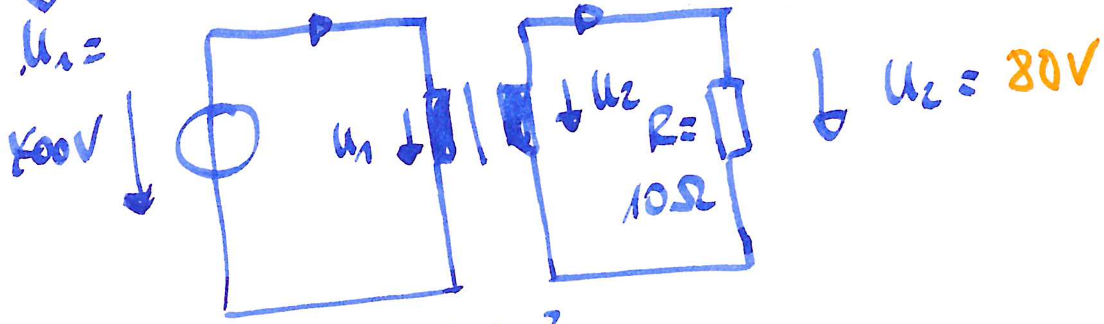
$$\frac{U_1 / I_1}{U_2 / I_2} = \frac{Z_1}{Z_2} = t^2$$ (3)

Impedance transmission of an ideal Tr.

# Exemples

**1**

$I_1 = ? = 1.6\,A \quad I_2 = ? = 8\,A$



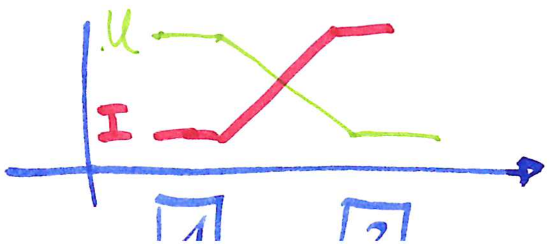

$10 : 2$

$\Rightarrow t = 5$

$$\frac{U_1}{U_2} = \frac{N_1}{N_2} = 5 \;;\; \underline{\underline{U_2}} = \frac{U_1}{5} = \underline{\underline{80\,V}}$$

$$I_2 = \frac{U_2}{R} = \frac{80\,V}{10\,\Omega} = 8\,A$$

$$\frac{I_2}{I_1} = t = 5 \;;\; I_1 = \frac{I_2}{5} = 1.6\,A$$

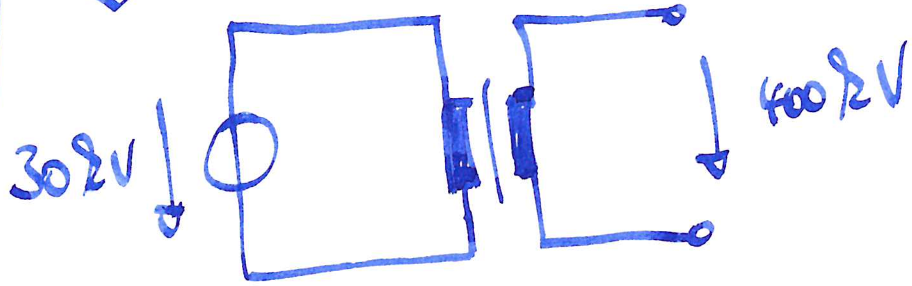





$P_1 = U_1 I_1 = 640\,W$

$P_2 = U_2 I_2 = \sout{10\,W} = 640\,W$

**2**




$500 : N_2 = ?$

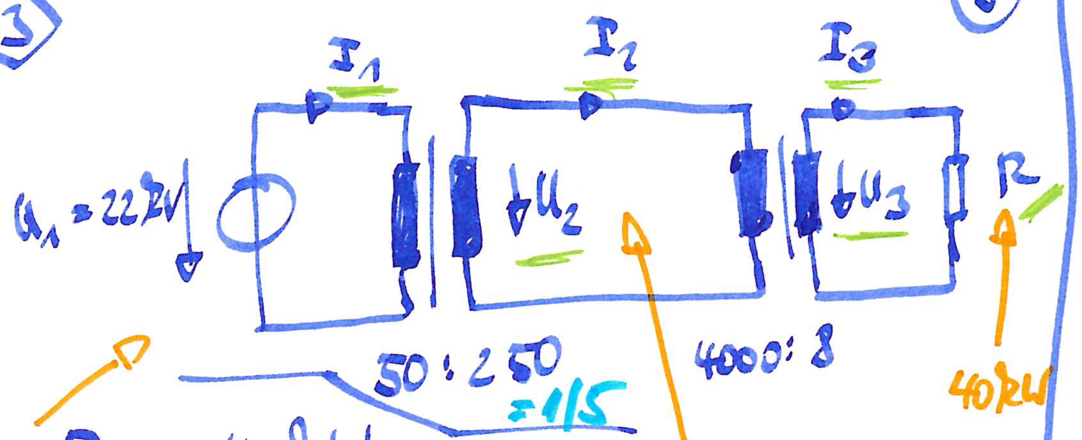
$$\frac{U_1}{U_2} = \frac{N_A}{N_2} \;;\; N_2 = N_1 \frac{U_2}{U_1} = \frac{400\,kV}{30\,kV}$$

$$N_1 \cdot \frac{40}{3} = 13.33$$

$$= 6666.7$$

(3)






40kW $P_R = 40 kW$

~~(bzg $U_3 = 220V$)~~

40 kW

$$I_1 = \frac{P_1}{U_1} = \frac{40 kW}{22 kV} = 1.8 A$$

$$\frac{U_1}{U_2} = \frac{N_1}{N_2} = \frac{50}{250} = \frac{1}{5} \; ; \; U_2 = U_1 \cdot 5 = 110 kV$$

$$\frac{I_2}{I_1} = \frac{1}{5} \; ; \; I_2 = \frac{I_1}{5} = 0.36 A$$

$$I_2 \cdot U_2 = P_2 = P \; ; \; I_2 = \frac{P_2}{U_2} = \frac{40 kVA}{110 kV} = 0.36 A$$



$$\frac{I_3}{I_2} = \frac{4000}{8} = 500 \; ; \; I_3 = 0.36A \cdot 500$$

$$I_3 = 180 A$$

$$P_3 = P = 40 kW = U_3 \cdot I_3$$

$$U_3 = \frac{40 kW}{180 A} = 222 V$$

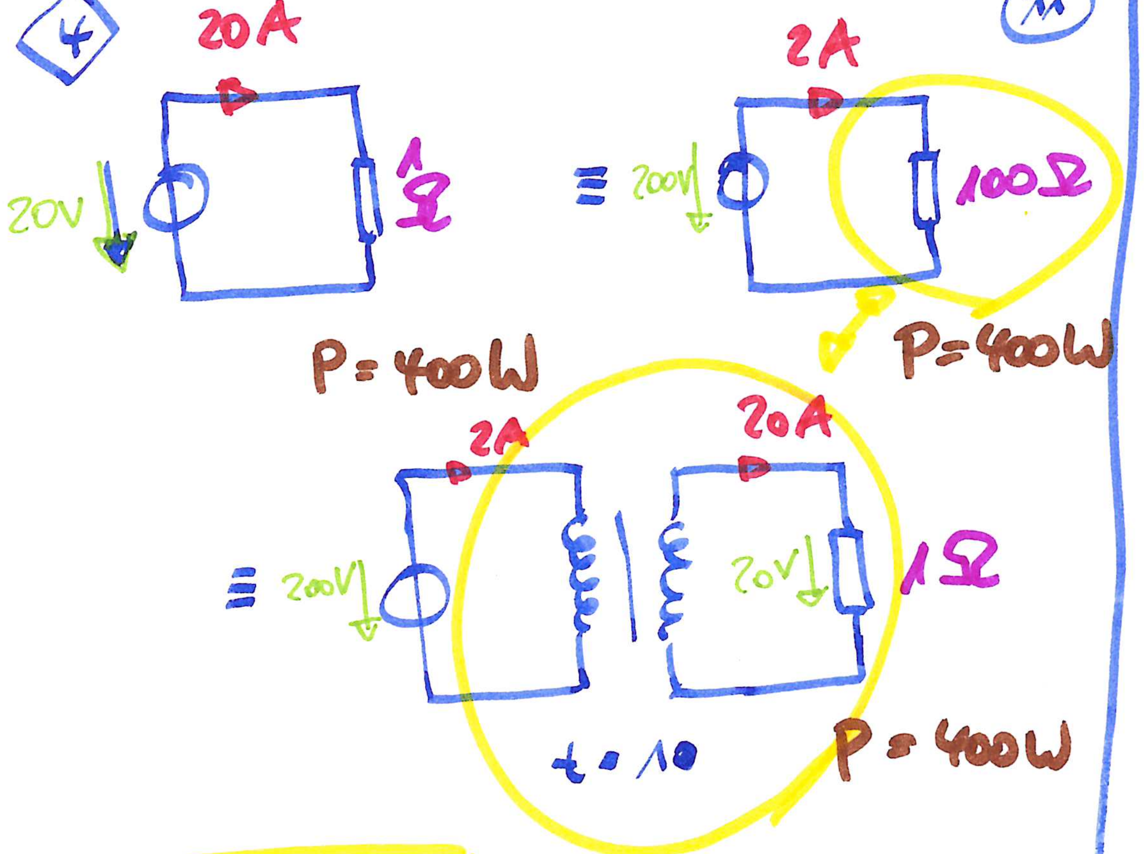
*) $P_R = P_3 = 40 kW$ bzg 220V

$$P = U \cdot I = I^2 \cdot R = \frac{U^2}{R}$$

$$\Rightarrow R = \frac{U^2}{P} = \frac{(220V)^2}{40 kW} = 1.21 \Omega$$

$$P(222V) = \frac{(222V)^2}{1.21 \Omega} =$$

4 11




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

$$Z_1 = Z_2 \cdot t^2$$
$$= 1\Omega \cdot 10^2$$
$$= 100\Omega$$

Example for transforming impedances

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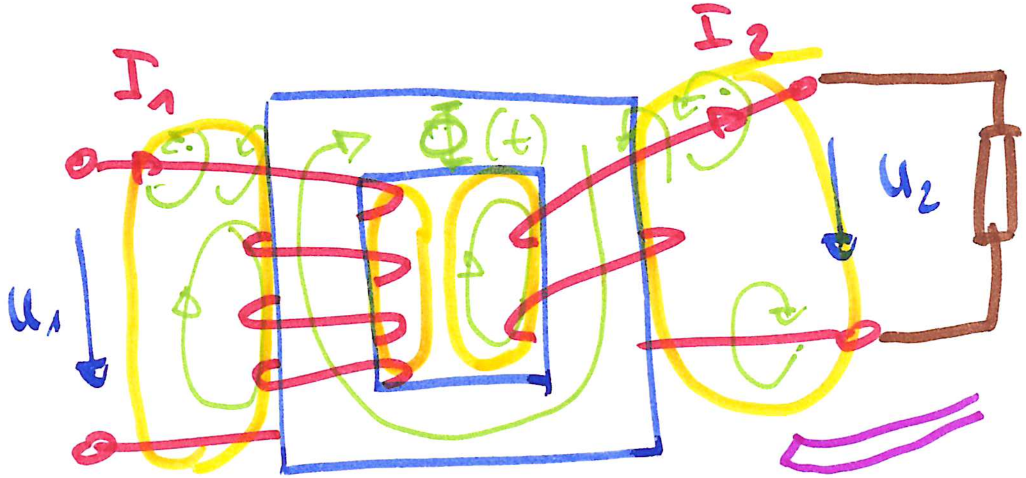
- real transformer
  - has losses ($P = I^2 \cdot R$)
  - has hysteresis
  - leakage flux
  - eddy currents →

flux: $\Phi = L \cdot I$



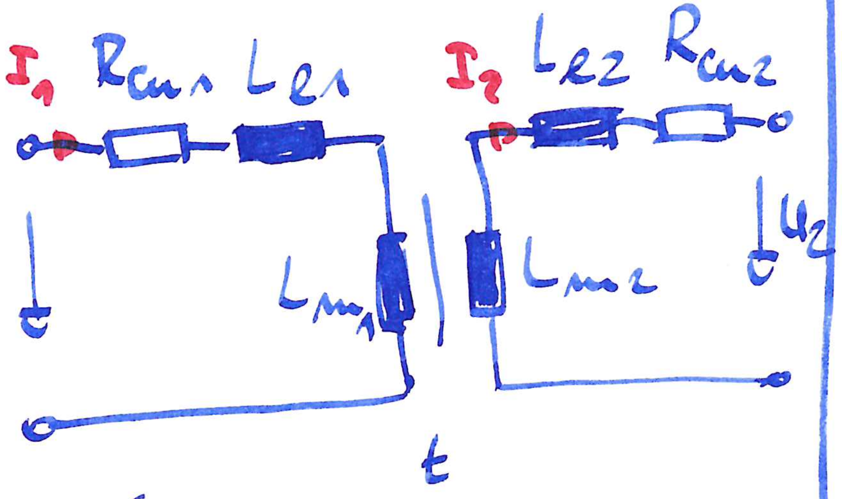

leakage flux $\Phi_e$

(13)

$$L_e = \frac{\Phi_e}{I}$$ : leakage inductance

$\Phi$ in iron $\rightarrow$ $\Phi_m = \Phi_{main}$

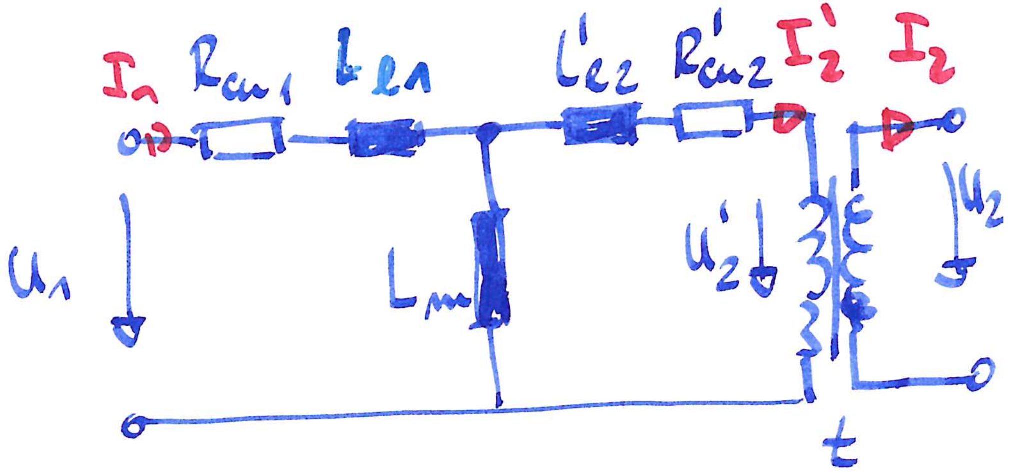
$$L_m = \frac{\Phi_m}{I}$$ : main inductance




↳ electric sub-circuit

(14)

we bring $L_{e2}$ ($L_{m2}$) and $R_{cu2}$ to side no. 1 :




ideal tr.

$$\frac{I_2}{I'_2} = t \quad ; \quad \frac{U'_2}{U_2} = t$$

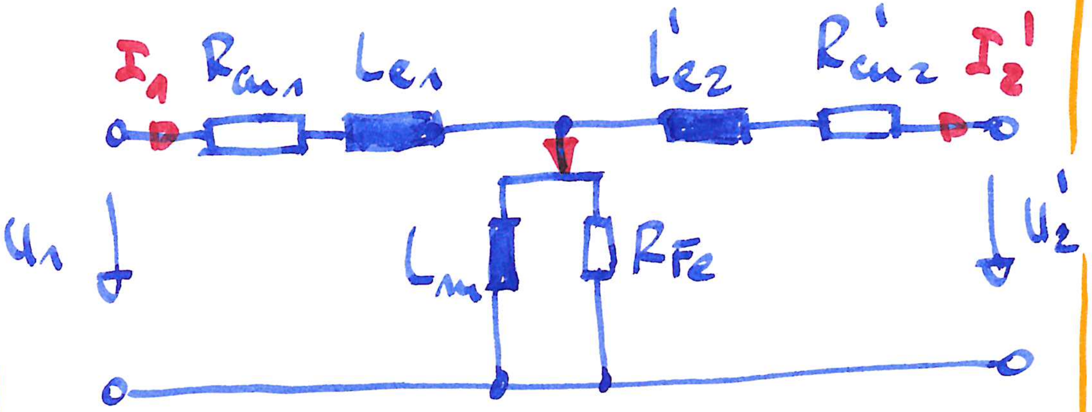
$$I'_2 = \frac{I_2}{t} \quad ; \quad U'_2 = U_2 \cdot t$$

$$L'_{e2} = L_{e2} \cdot t^2$$

$$R'_{cu2} = R_{cu2} \cdot t^2$$

(15)

full electric subcircuit for a transformer:




$R_{Fe}$ : R of iron → hyst. losses
→ eddy current losses

$R_{cu1}, R'_{cu2} \ll R_{Fe}$

$L_{e1}, L'_{e2} \ll L_m$

(16)

→ ideal tr.: $R_{cu1} = R'_{cu2} = 0$

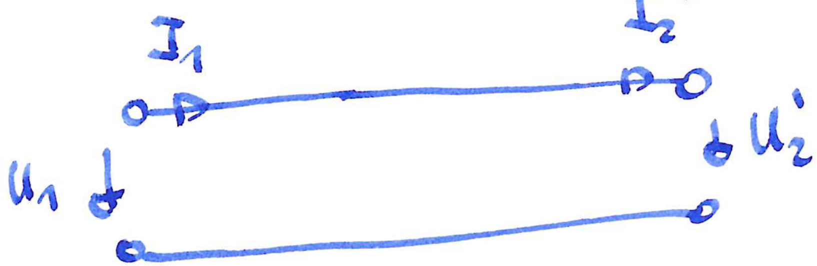
$L_{e1} = L'_{e2} = 0$

$L_m \to \infty$

$R_{Fe} \to \infty$

$\{ Z_m = \omega \cdot L_m \to \infty$

full electric subcircuit for a ideal transformer:



$\Rightarrow I_2' = I_1 = \frac{I_2}{t} \Rightarrow \frac{I_2}{I_1} = t$

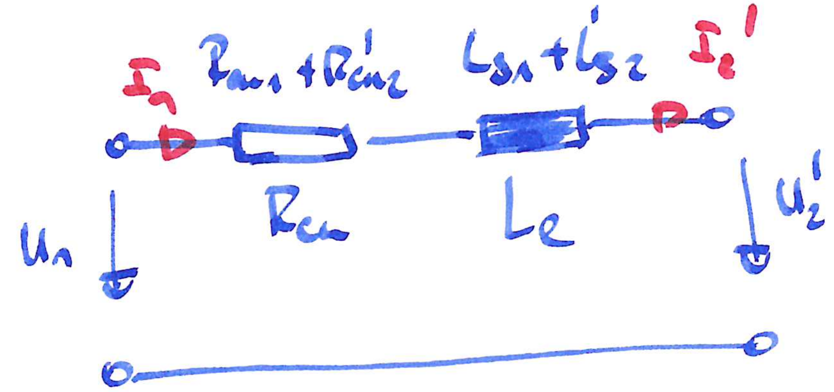
current law of an ideal tr.

$\Rightarrow U_1 = U_2' = U_2 \cdot t \Rightarrow \frac{U_1}{U_2} = t$

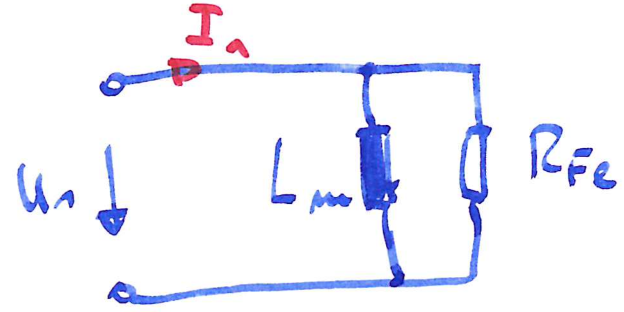
voltage law of an ideal tr.



$\Rightarrow$ a transformer with full load:




$\Rightarrow$ a transformer with no load:

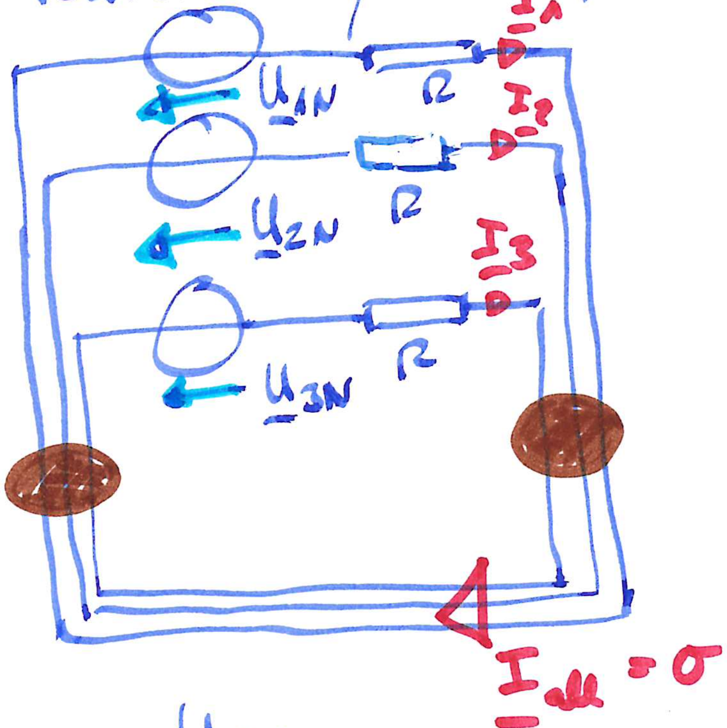


9. Jan 2020 Retzlme ①

# Electrical Machinery

- 3 phase power supply

▷ First reason to use 3 phase p.

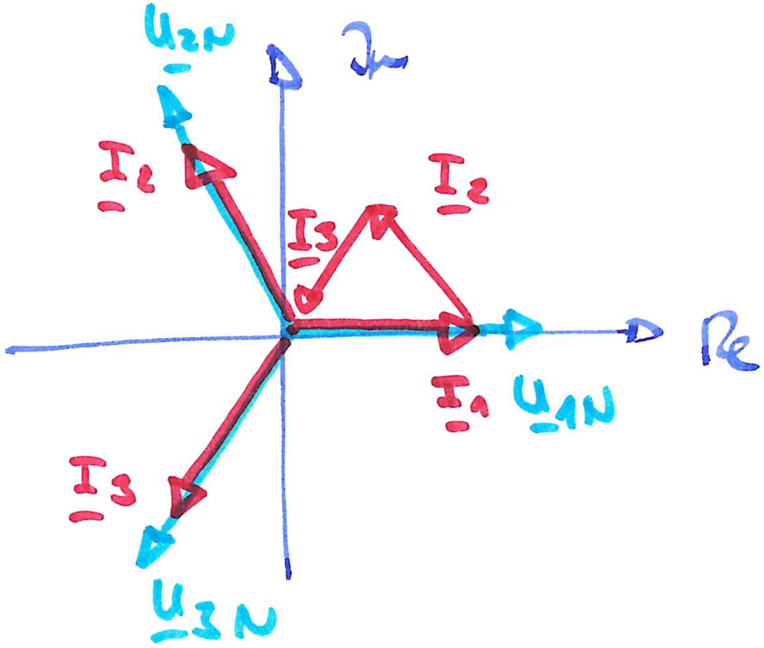



$\underline{U}_{1N} = U_Y$

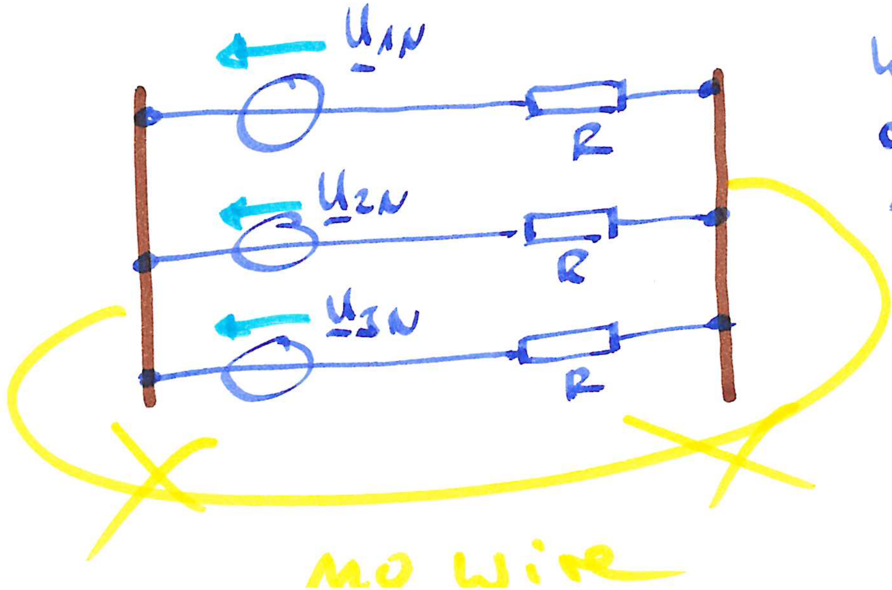
$\underline{U}_{2N} = U_Y \cdot e^{j120°} = U_Y e^{j\frac{2\pi}{3}}$

$\underline{U}_{3N} = U_Y \cdot e^{-j120°} = U_Y e^{-j\frac{2\pi}{3}}$

②




Kirchhoff 1: $\sum_{k=1}^{3} \underline{I}_k = \underline{I}_1 + \underline{I}_2 + \underline{I}_3 = 0$

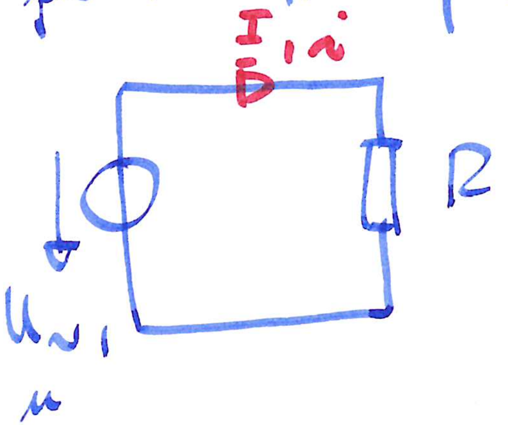



We need only the half of wires/copper/costs

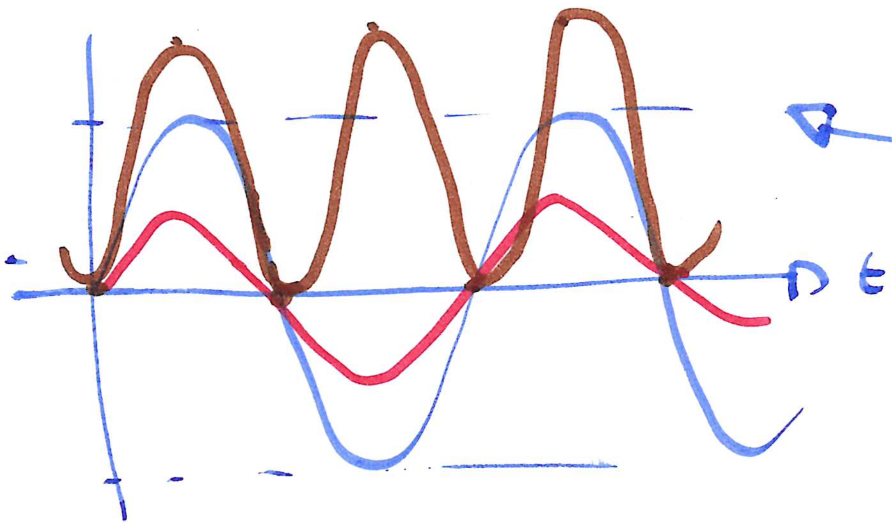
▷ Second reason to use 3 phase power supply (3)

→ we analyze the power

please see power by AC




$p = u \cdot i$




(4) we continue in MATHCAD

figure

the power of a 3 phase load / motor is a constant, it does not depend from the time as the power in a 1 phase system

(5)

• (3 phase) synchronous machine

generator ↙ ↘ motor (SM)

▷ animation

| |
|---|
| 3p motor / generator |
| 1p " / " |

in reality the air volume in the motor / generator is smaller, very small, see more real rotor / stator

▷ E 24 pic 4

▷ rotating field of the stator in case of motor

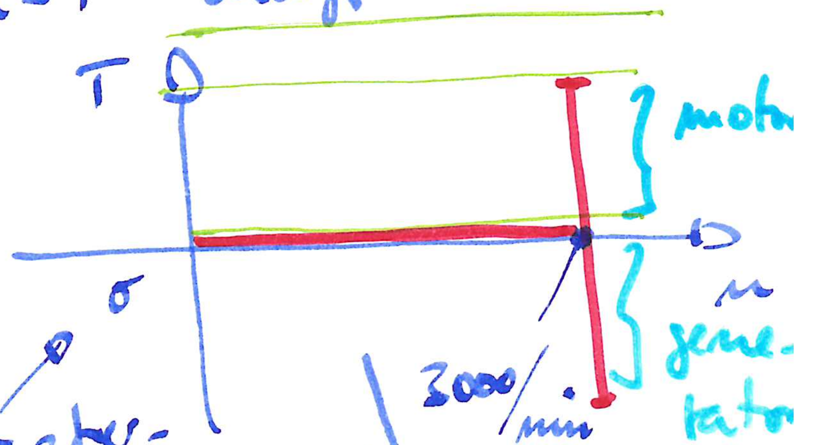
(6)

▷ the stator generates a turning magnetic field (yellow arrow). This yellow arrow acts with the rotor = Permanent Magnet → Electro Magnet.

$P = \omega \cdot M = \omega \cdot T$ in general

↳ = Torque

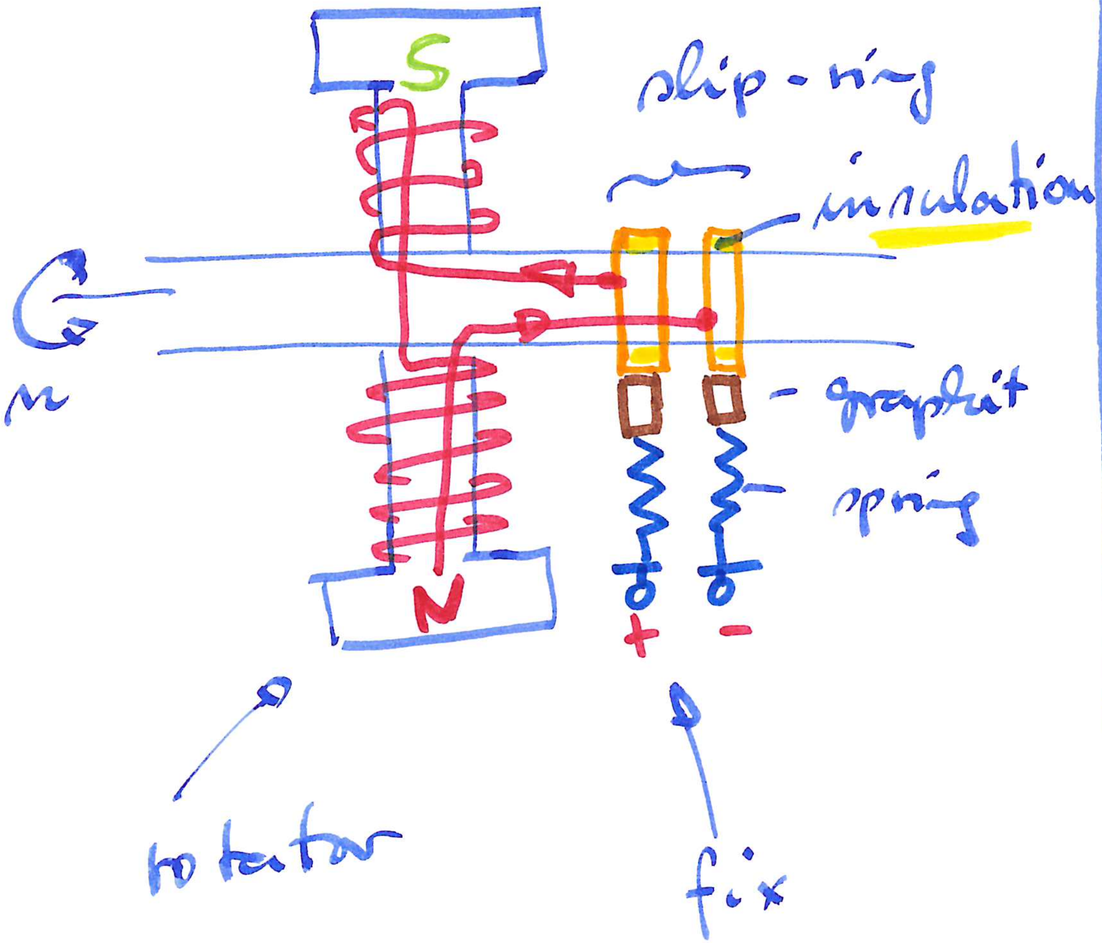
n - T - diagram




Characteristic diagram of ... = 50 Hz

⑦

to bring the current to the turning electro magnet, you need a slip-ring

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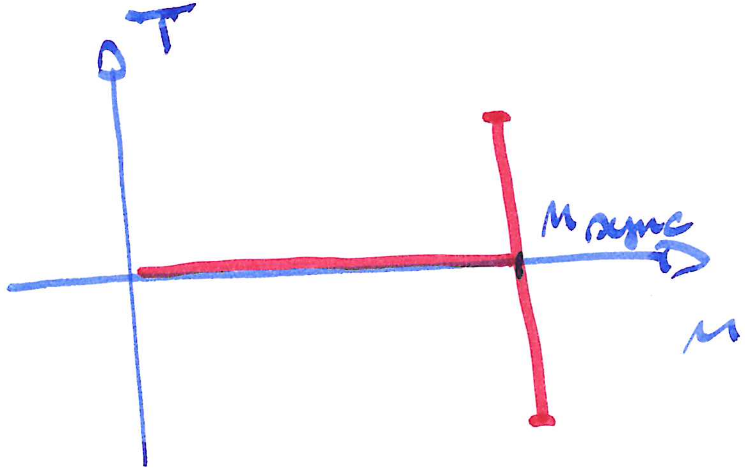
# Electrical Machinery, Rez., 11.01.20 (1)

- Look back: synchronous mach.




$n_{sync} = 3000/min; 1500/min;$

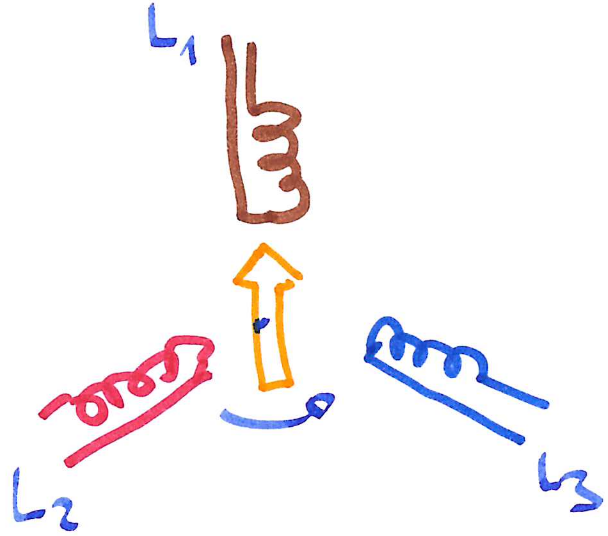
$1000/min; 750/min \ldots$

with $\boxed{n_{sync} = \frac{f}{p}}$ → number of pole pairs

$p \stackrel{!}{=} 20 \Rightarrow n_{sync} = \frac{50}{s \cdot 20} = \frac{5 \cdot 60}{2 \, min}$

(2)

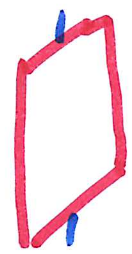
- Asynchronous motor or induction motor




$L_1, L_2, L_3$: 3 phase power supply

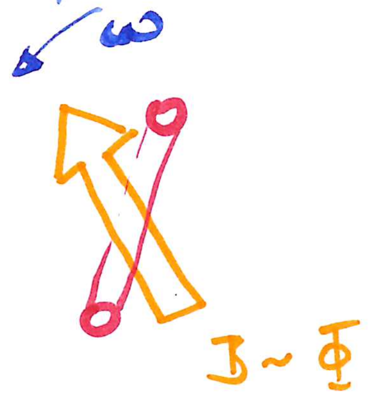
$n_{sync}$

rotating magnetic field = stator field = $3 \sim \Phi$



copper winding

We bring the copper winding into ③
the stator field (in 2D)




 $M_S = M_{sync}$

 $M_W = M_{winding}$

1. moment: $M_{sync}$ = const
$M_W = 0$
⇒ $f(i_W) = M_S$
⇒ big $i_W$
⇒ force between
$\Phi \cdot i_W = F = F_1$

④ 2. moment: $M_S$ = const
$M_W = M_{W2}$
⇒ $f(i_W) = M_S - M_W$
$< M_S$
⇒ smaller $i_{W2}$
⇒ force between
$\Phi \cdot i_{W2} = F_2 < F_1$
⇒ the winding follows the rotating field
⇒ the speed of the rotor is increasing

⇒ the winding begins to turn

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3. moment: $n_s$ = const

$n_w = n_s$

$\Rightarrow f(i_w) = 0 \quad \left(\frac{d\Phi}{dt} = 0\right)$

$\Rightarrow i_{w3} = 0$

$\Rightarrow F_3 = T_3 = 0$

$\Rightarrow n_w$ gets smaller

$n_w = n_s - \varepsilon$

4. moment: $n_s$ = const

$n_w$ = little bit smaller than $n_s$ ~~tan~~

but $\neq n_s$

$\Rightarrow i_w > 0$

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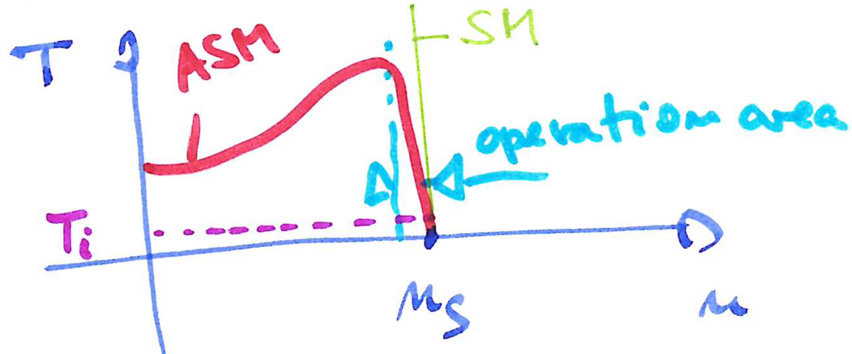
Characteristic diagram T-n of an induction motor




$T_i$: internal torque

ASM are mostly used as motors and not as gener.

ASM is the most used motor in industry, ... (in 3 phase s.)

Real composition:

See in internet: rotor induct. motor

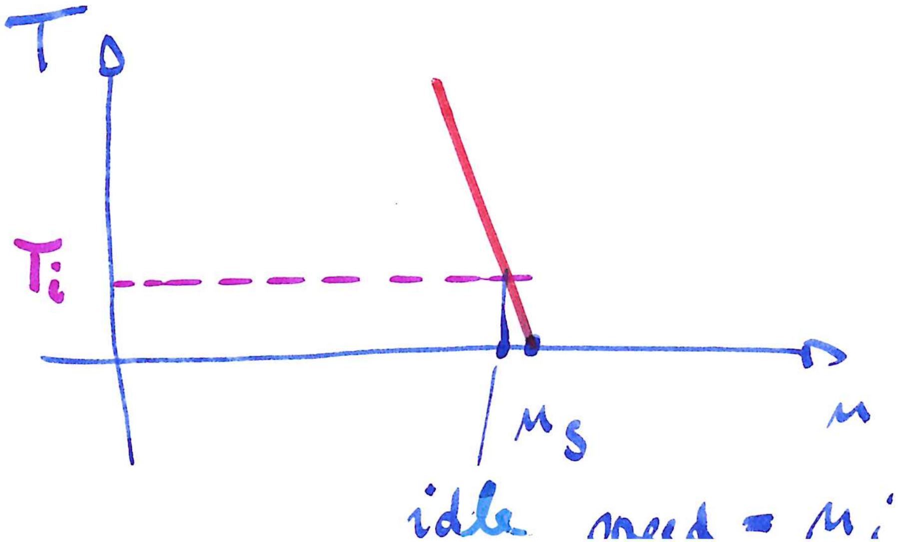
(7)

You find rotors

- without slip rings, squirrel-cage motor, short circuit motor — mostly used
- with slip rings (3 pieces)

each motor has internal load:

- torque of the ventilation
- torque of the friction of the ball bearing




(8)

for example: $n_S = 3000/\text{min}$

$n_i = 2800/\text{min}$

$n_S = 1500/\text{min}$

$n_i = 1480/\text{min}$

p = 2

Animation SM, ASM

www:.klemmkasten.de

9

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- DC - machine
  - animation
    look our website
  - script
    look our website