Basics of Power System, Electric Machines and Power Electronics

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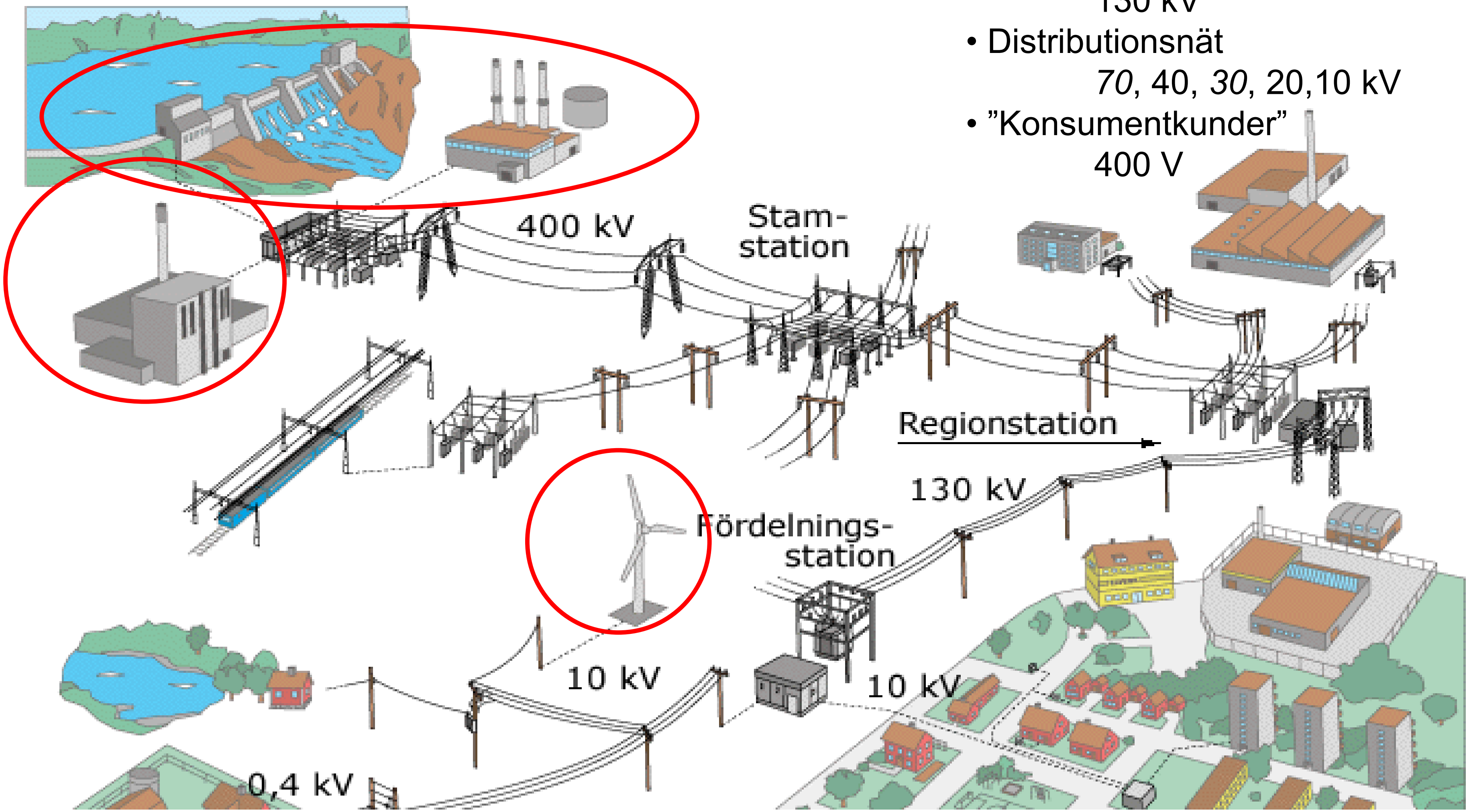
Lecture 201109

Elgenerering

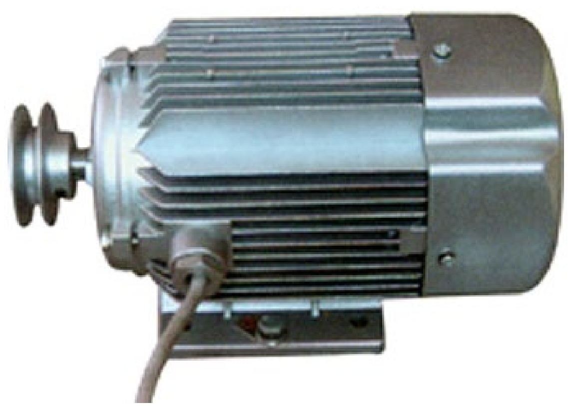
- Transmission
  400, 220 kV
- Regionalnät
  130 kV
- Distributionsnät
  70, 40, *30*, 20,10 kV
- ”Konsumentkunder”
  400 V

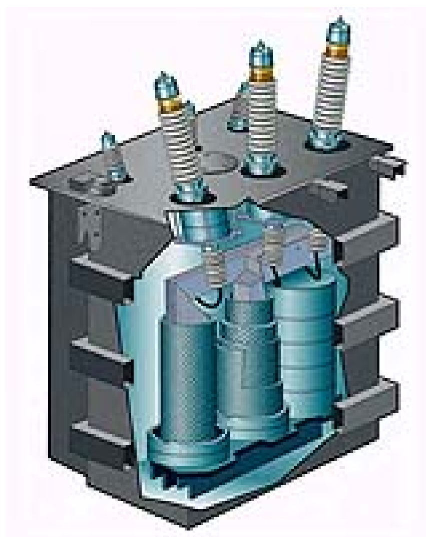


Trefas AC (växelspänning) – Varför ?

De viktigaste faktorerna som har format elsystemets uppbyggnad idag.

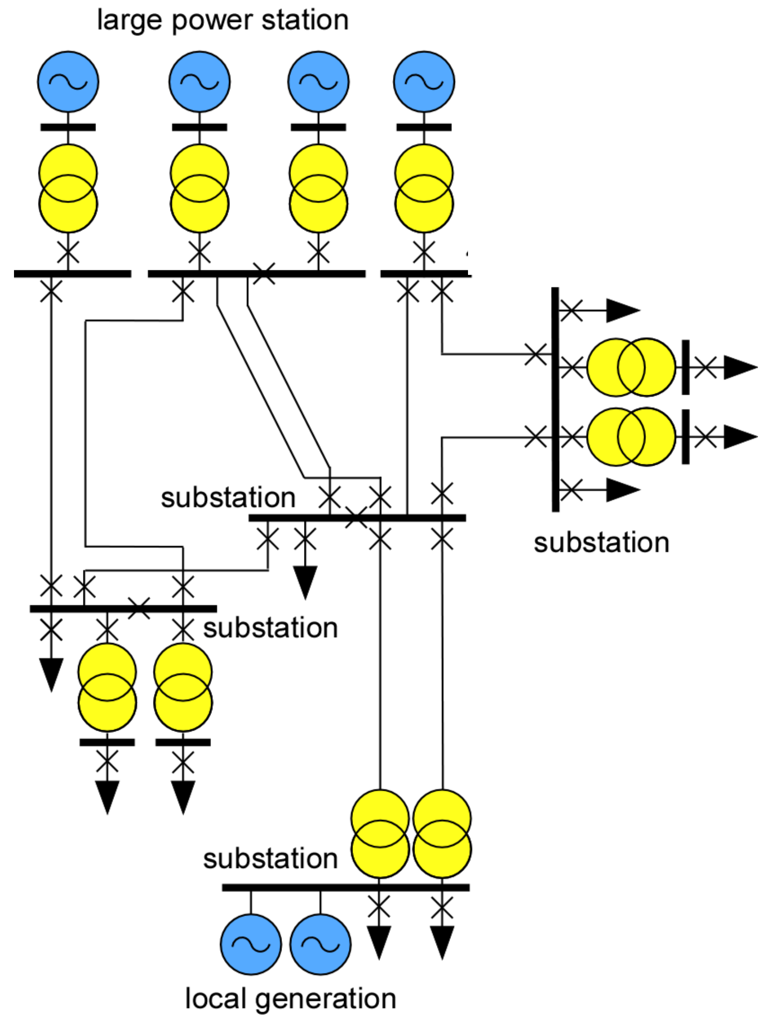
- Transformatorn (fungerar endast för AC)
- Robust och billig motor (med roterande flöde)
- 3-fas effektiv överföring





Beteckningar + enlinjeschema

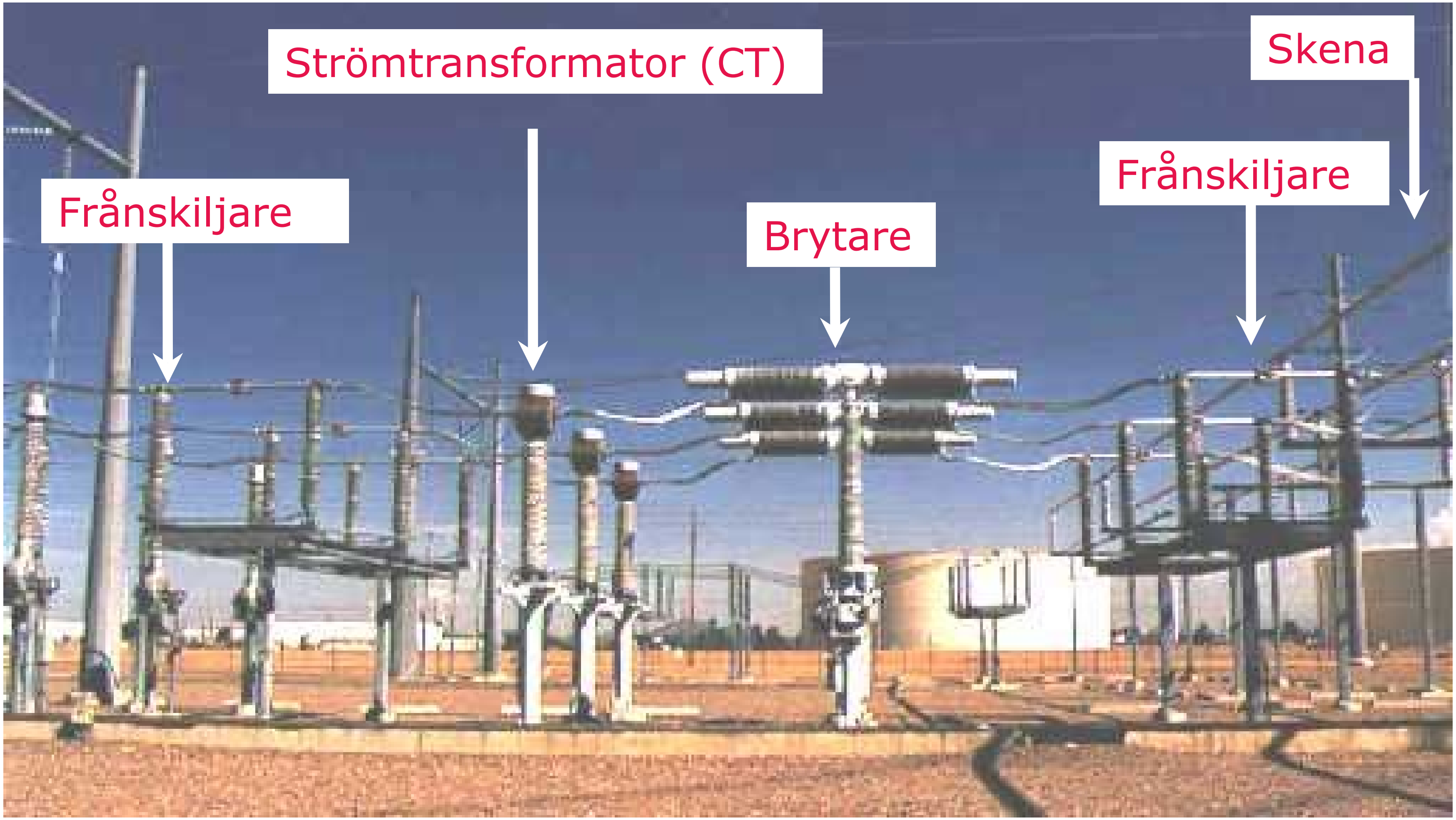
Exempel



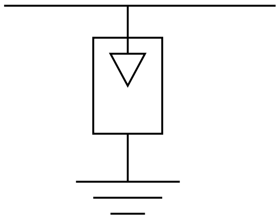
Enlinjeschema
representerar tre faser.

- Genereringsenhet
- Transformator
- Station, skena
- Brytare
- Linje
- Last

Komponenter i ställverket



Ventilavledare (överspänningsskydd)



130 kV ledningar, med och utan topplina

Topplina: För att blixten skall slå där

400 kV-skenor, 400-130 kV transformator

Transformatorer

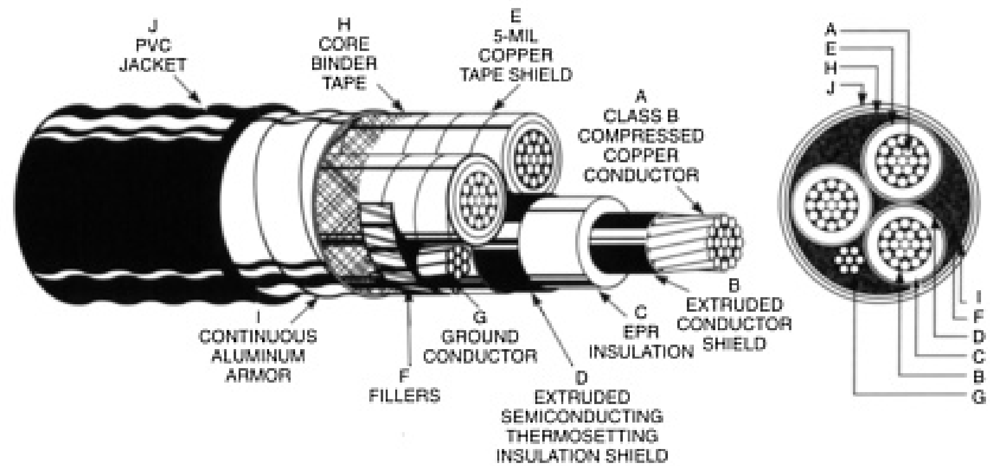
130 kV till 30 kV

www.wikimedia.org

10 kV till 400 V

Kablar

I stället för luftledningar i tättbefolkade områden (städer)



Problem vid längre energitransporter: En kabel är en kondensator och det blir mycket reaktiv effektproduktion

Högspänd likström, HVDC

- 1000 – 3000 MW
- Långa kablar (t.ex hav)
- Hög verkningsgrad
- Utmärkt styrbarhet
- Dyrt med ac/dc/ac-omvandling

Photo:www.abb.com

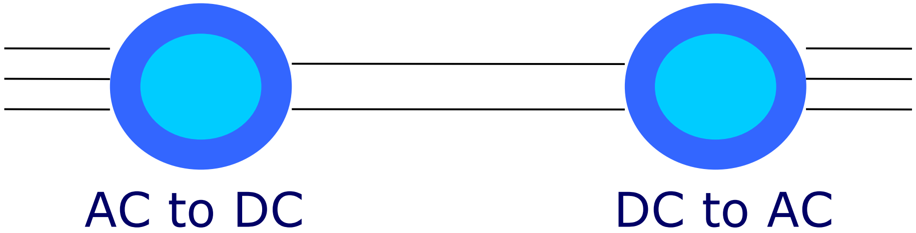
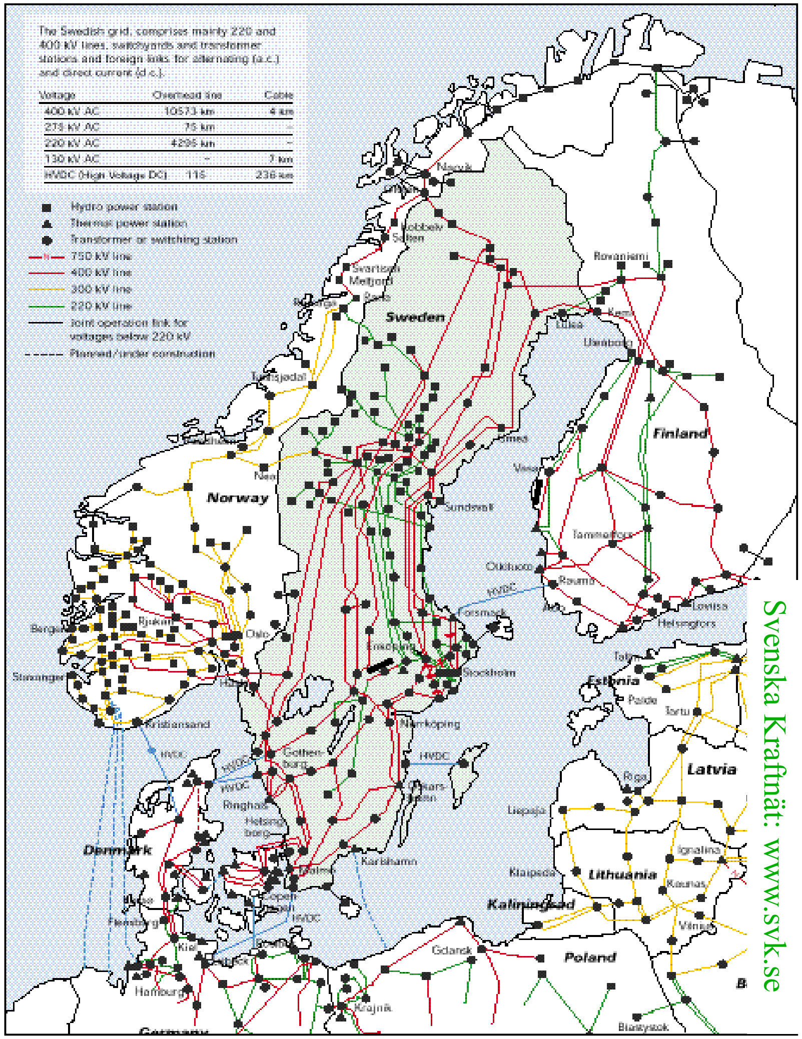


ABB:s största order någonsin

- HVDC till vindfarm i Nordsjön
- 900 MW
- 135 km i sjön & land
- Fyra år från order till drift

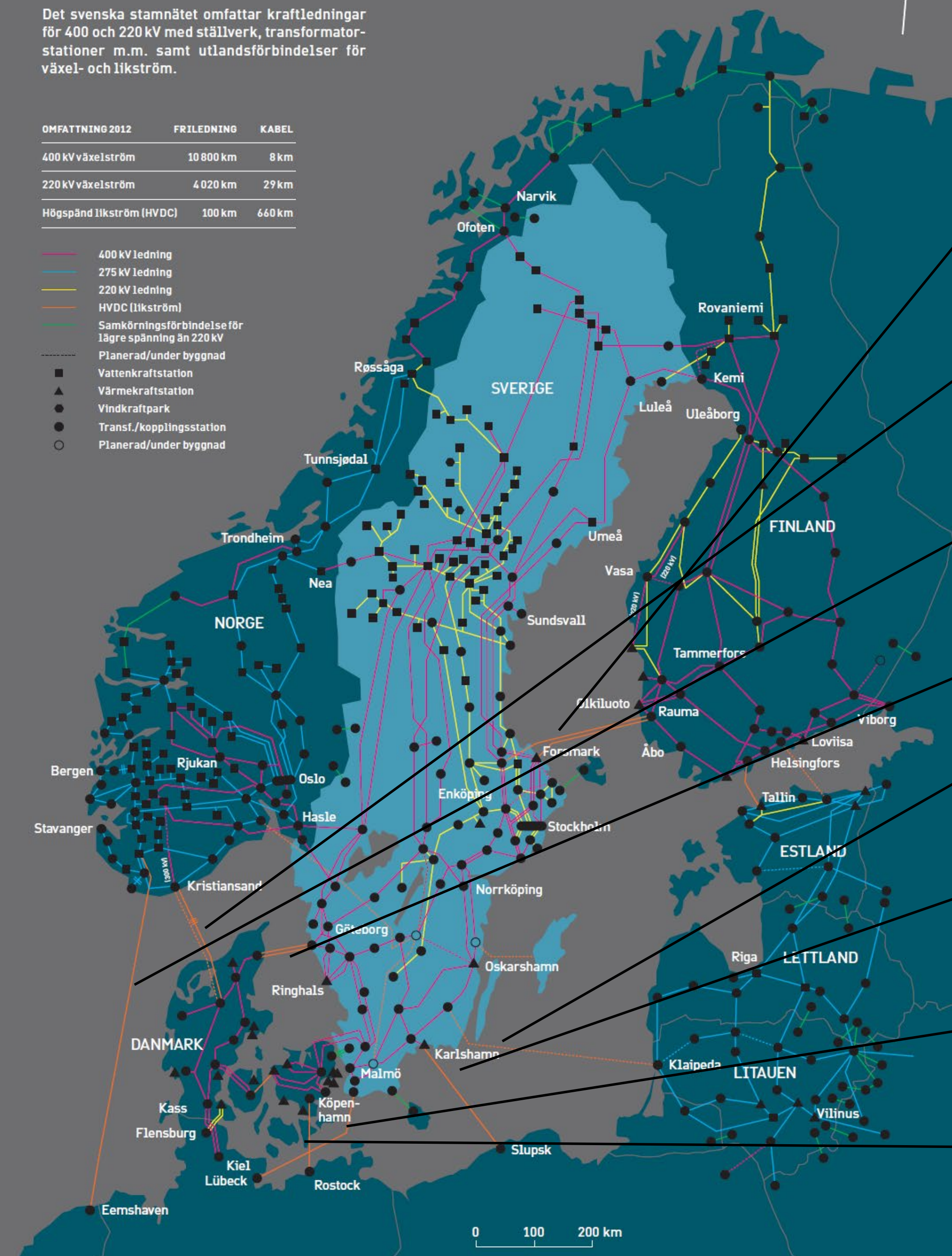
(normalt för luftledning 7-10 år)

Nordel



- Kopplar samman Sverige, Norge, Finland samt Själland växel-strömsmässigt
- HVDC-länkar finns till Ryssland, Gotland, Polen, Holland och Tyskland
- 400 kV högsta spännign
- 1600 MW största enskilda produktionsenhet

- •**Transmission** 400, 220 kV
- **Regionalnät** 130 kV
- **Distributionsnät** *70*, 40, *30*, 20,10 kV
- **Kunder** 400 V (Industri 10-130 kV)



Power: 550 MW, 800 MW
Energy: 11,5 TWh

Power: 250, 440, 700 MW,
Energy: 12 TWh

Power: 700 MW,
Energy: 6 TWh

Power: 600 MW,
Energy: 5 TWh

Power: 700 MW,
Energy: 6 TWh

Power: 600 MW,
Energy: 5 TWh

Power: 600 MW,
Energy: 5 TWh

Power: 600 MW,
Energy: 5 TWh

Σ=51 TWh

Σ =6500 MW

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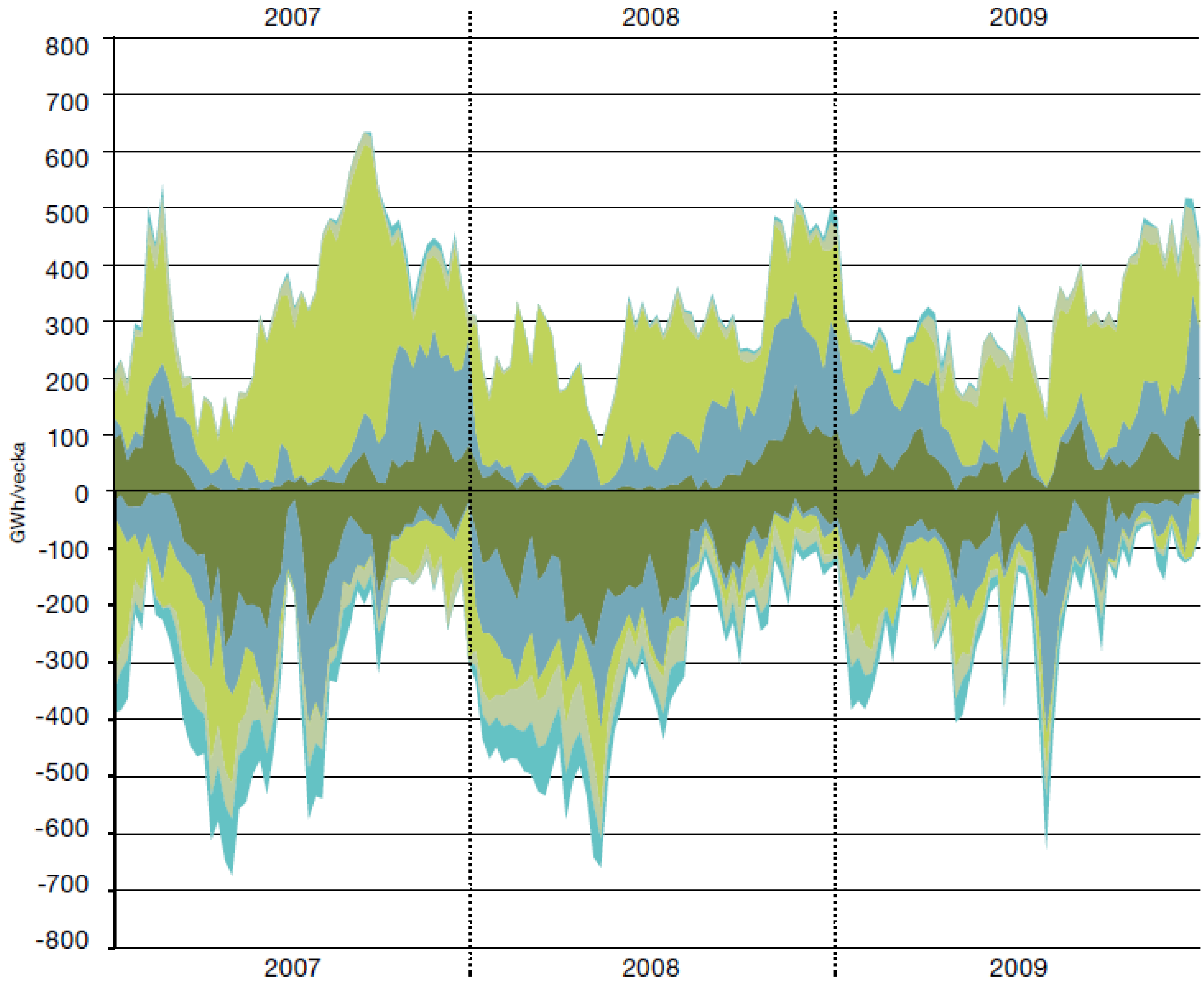
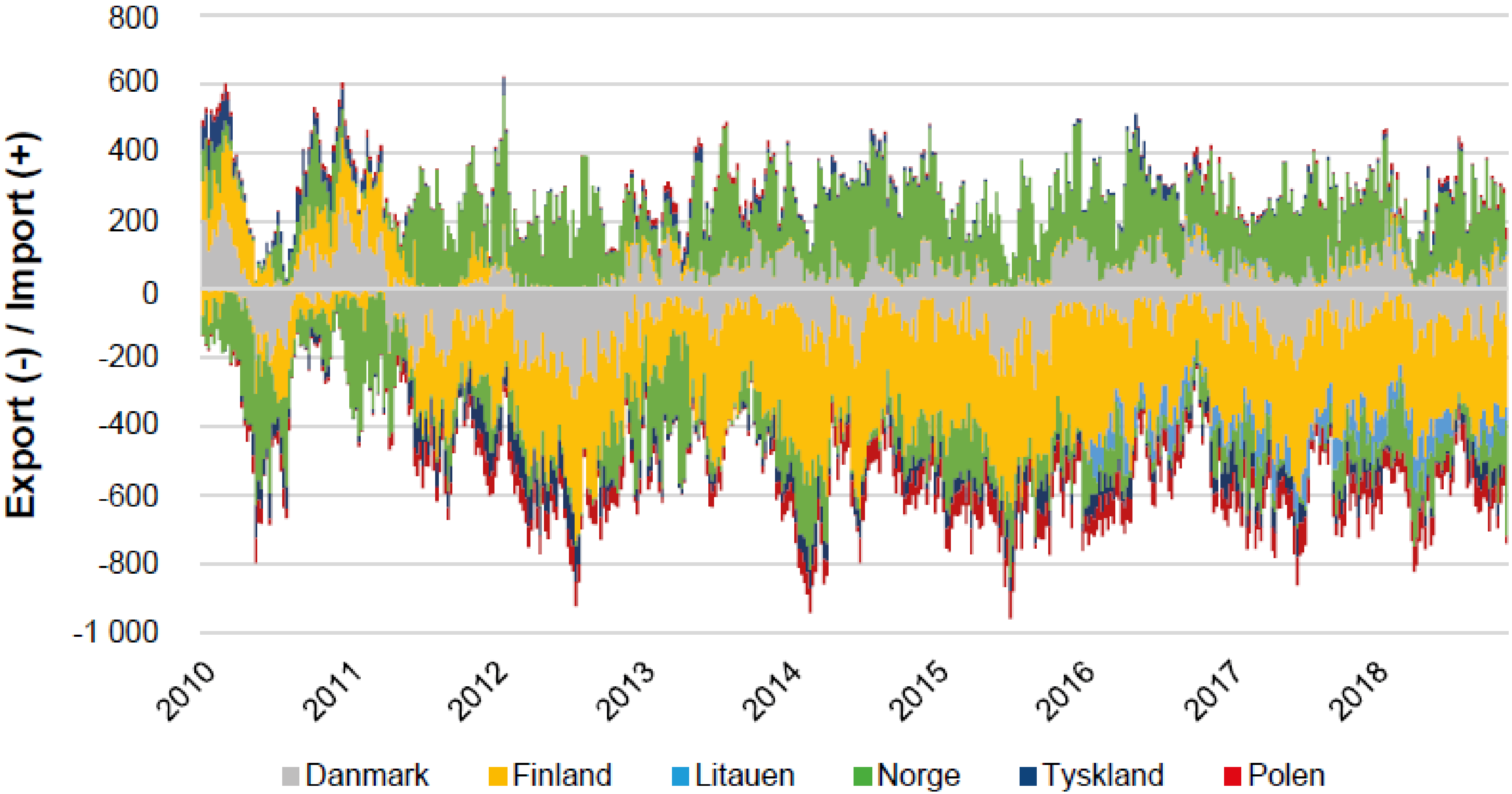
Figur 25 Sveriges elimport (+) och elexport (-), januari 2007 – december 2009



Källa: Svensk Energi, Energimyndighetens bearbetning.



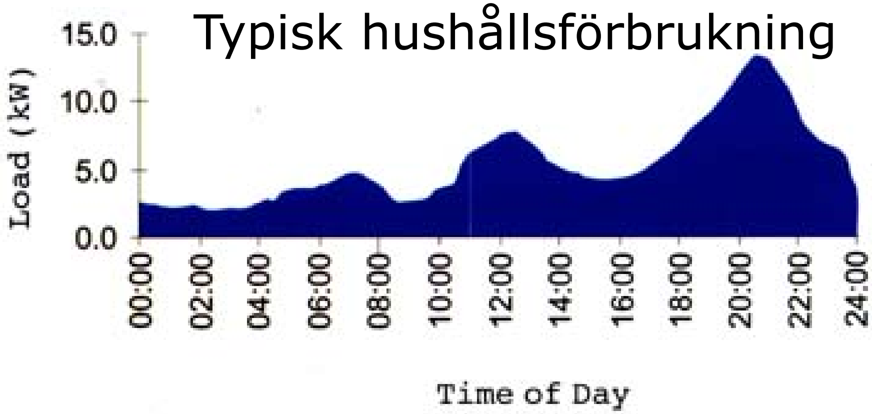
Figur 9 Sveriges elhandel med andra länder 2010–2019, GWh/vecka.

Källa: Veckostatistik Kraftläget, Svensk Energi.

Förbrukning

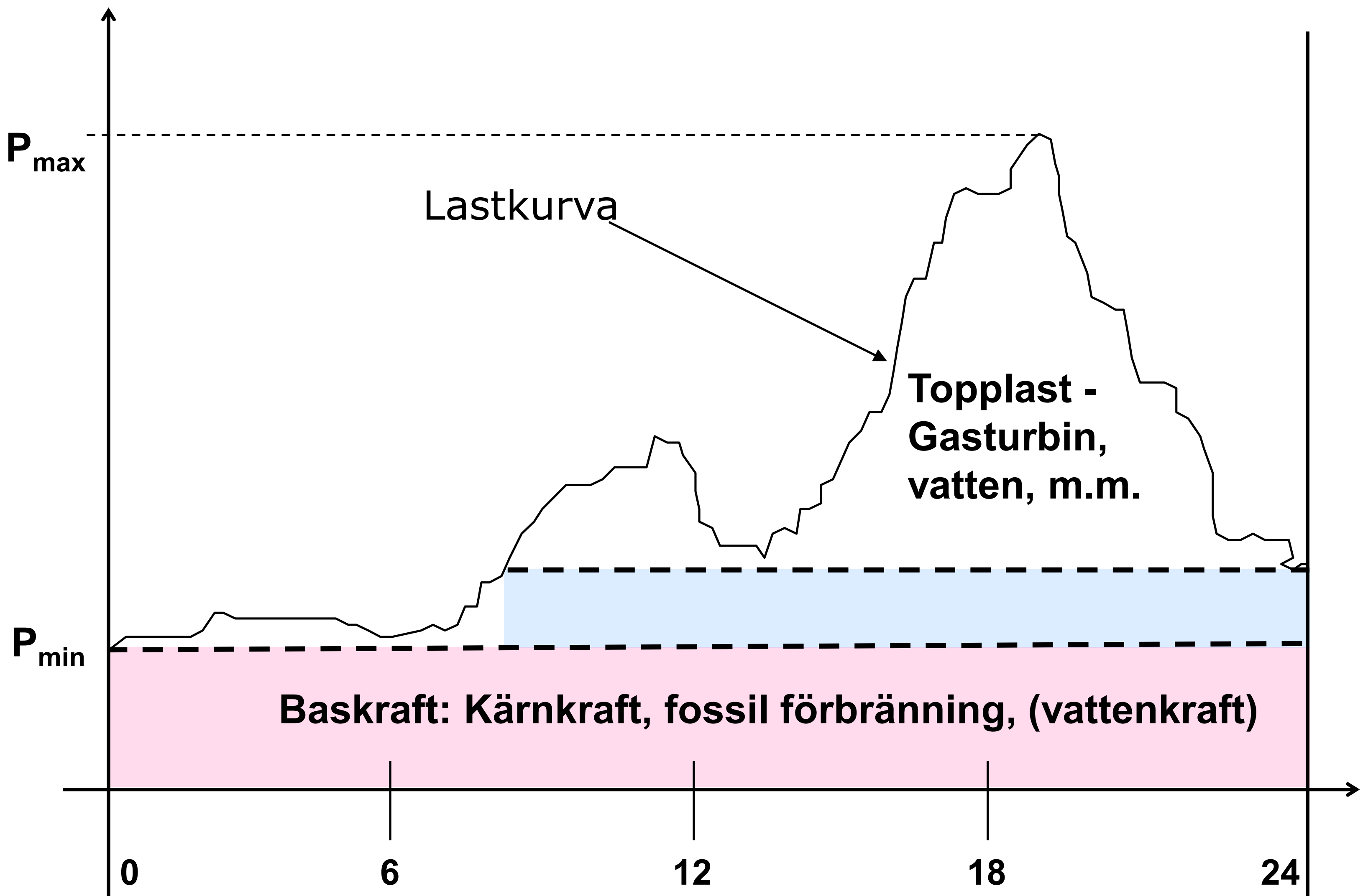
El kan inte lagras. Omvanling till andra energikällor för lagring medför förluster. Alltså behöver vi känna förbrukningen för att planera produktionen

Typisk hushållsförbrukning

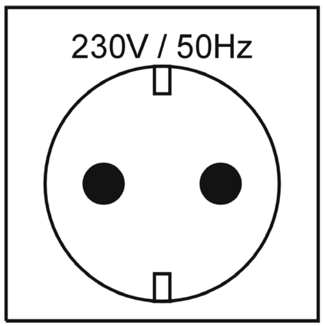


Vintertid högre elkonsumtion i nordliga länder, tvärtom i varma länder

Produktionsplanering



Elkvalité (Power quality)



- Spänning överhuvdtaget
- Spänningsnivå (+6 → -10 %) normalt ±2.5 %
- Spänningsfluktuationer = flicker (Pst)
- Övertoner
- Transienter
- Obalans mellan faserna

Spänningshållning

Spänningen i elnätet styrs från synkrongeneratorerna.

Höjs för långa transporter med hjälp av transformatorer.

För lokal spänningshållning finns lindningsomkopplingar,

vidare finns kondensatorbatterier för spänningshållning på högspänningen.

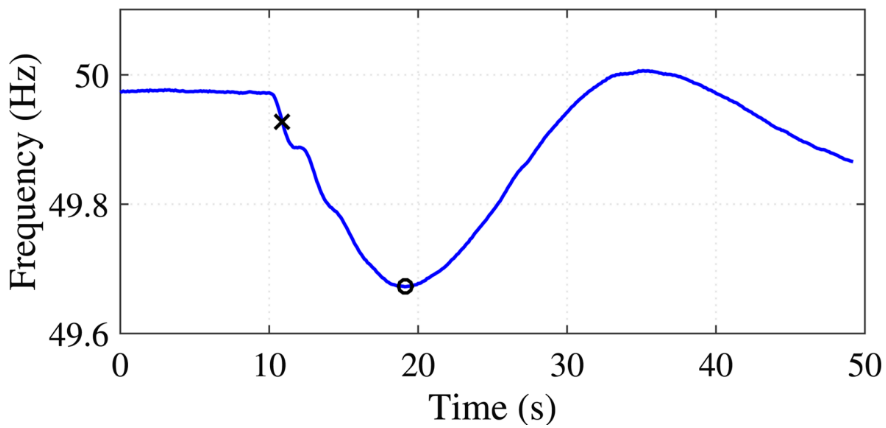
Frequency Control

- Tmek-Tel=J*dw/dt

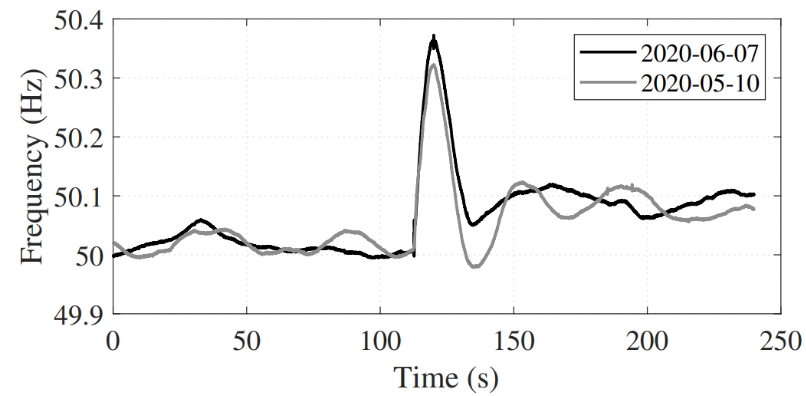
- Tmek = mechanical torque of the turbine
- Tel = electrical braking torque from the generator
- J = Inertia of the rotation machines
- w = speed of the generator
  = frequency of the electric voltage
- dw/dt=change in speed over time

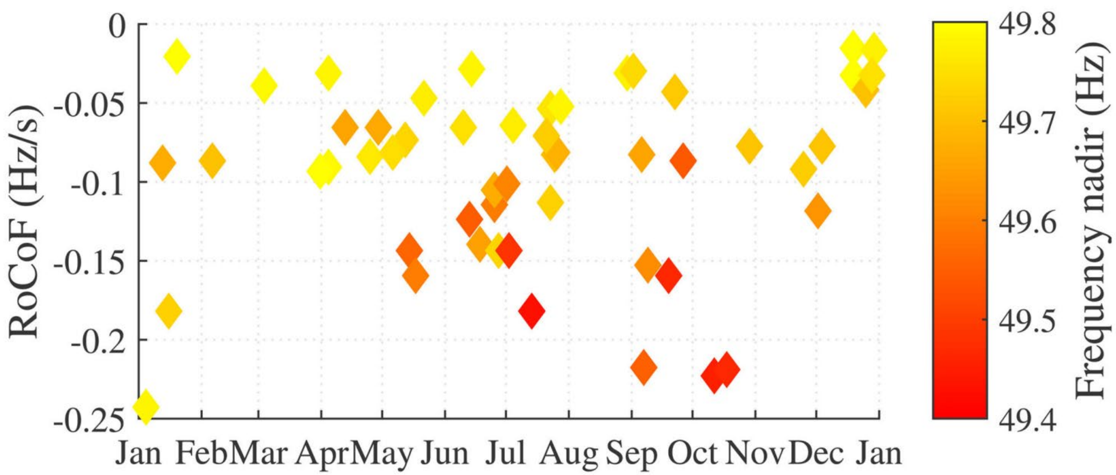
Large interferents (FFR Fast Frequency Reserve+FCR-D Frequency Containment Reserve-disturbance)

Generation loss

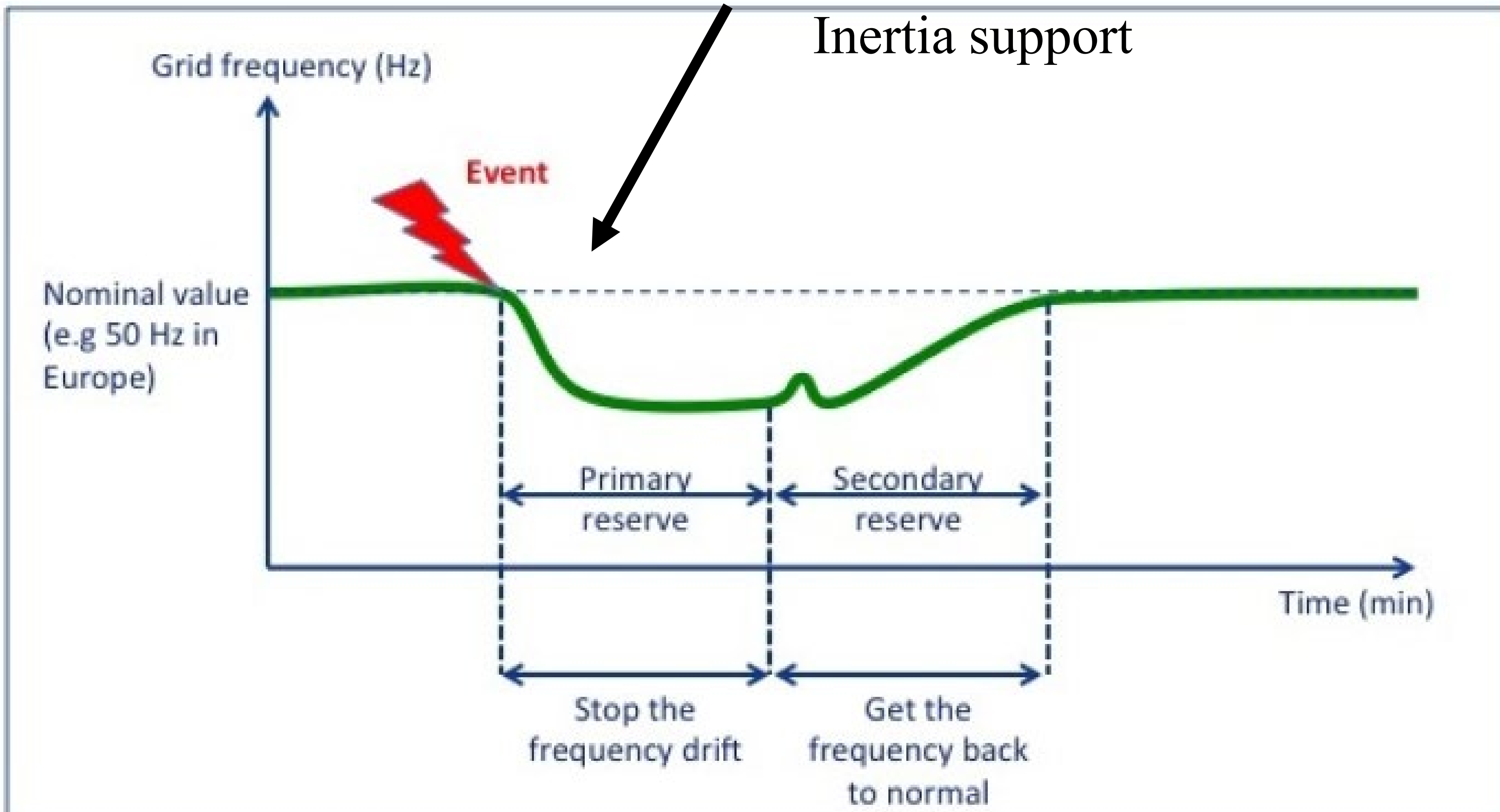


Export suddenly stop/
HVDC go down

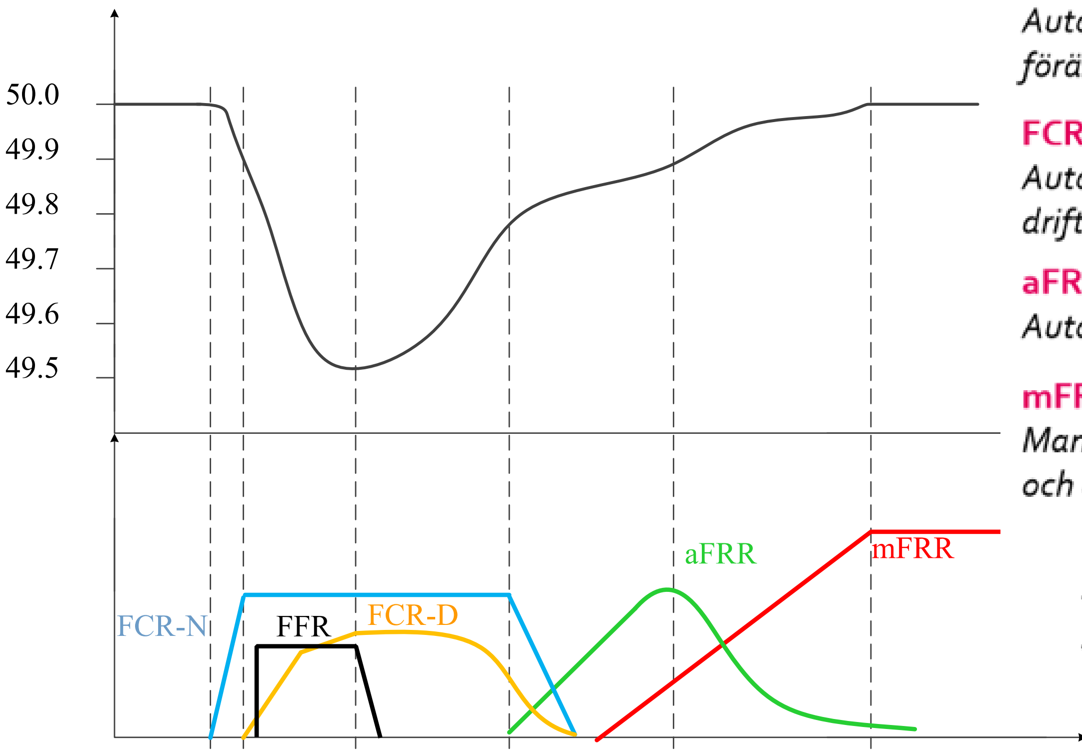




Frequency control with Primary and Secondary control



Introduction Freqency servises



FCR-N = Frequency Containment Reserve – Normal 180 s

Automatisk reserv som stabiliserar frekvensen vid små förändringar i förbrukning eller produktion

FCR-D = Frequency Containment Reserve – Disturbance 30 s

Automatisk reserv som stabiliserar frekvensen vid driftstörningar

aFRR = automatic Frequency Restoration Reserve 120 s

Automatisk reserv som återställer frekvensen till 50 Hz

mFRR = manual Frequency Restoration Reserve 15 m

Manuell reserv som avlastar de automatiska reserverna och återställer frekvensen till 50 Hz

FFR = Fast Frequency Reserve

Ska stötta systemet vid låg svängmassa 2 s

Source: Power Circle

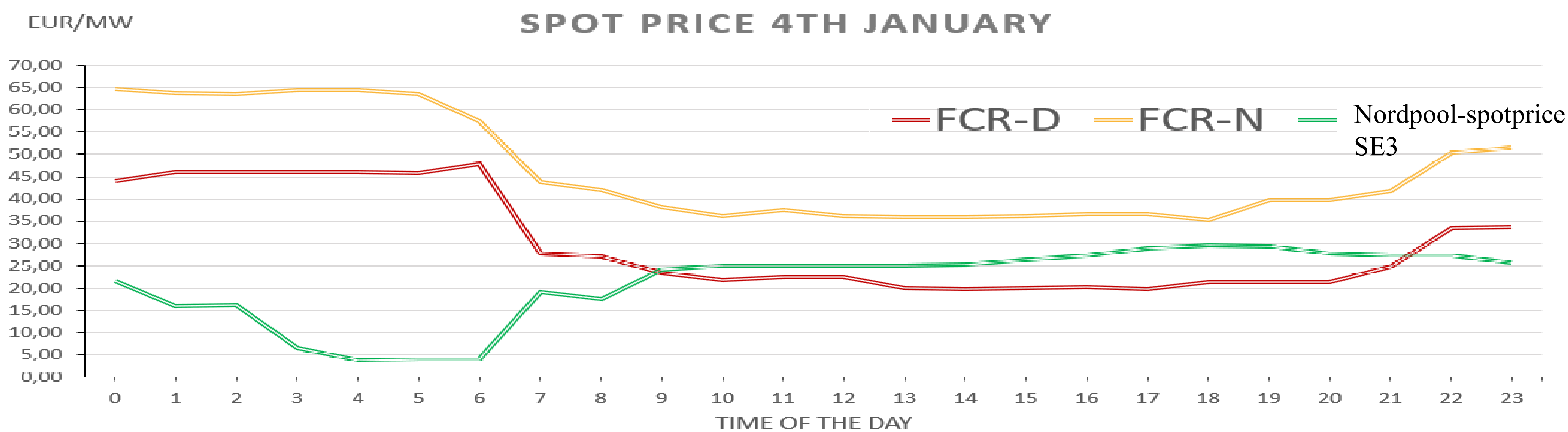
Analytic Market Pricing

FCR-N = Frequency Containment Reserve – Normal 180 s

Automatisk reserv som stabiliserar frekvensen vid små förändringar i förbrukning eller produktion

FCR-D = Frequency Containment Reserve – Disturbance 30 s

Automatisk reserv som stabiliserar frekvensen vid driftstörningar



Sinusoidal Steady State

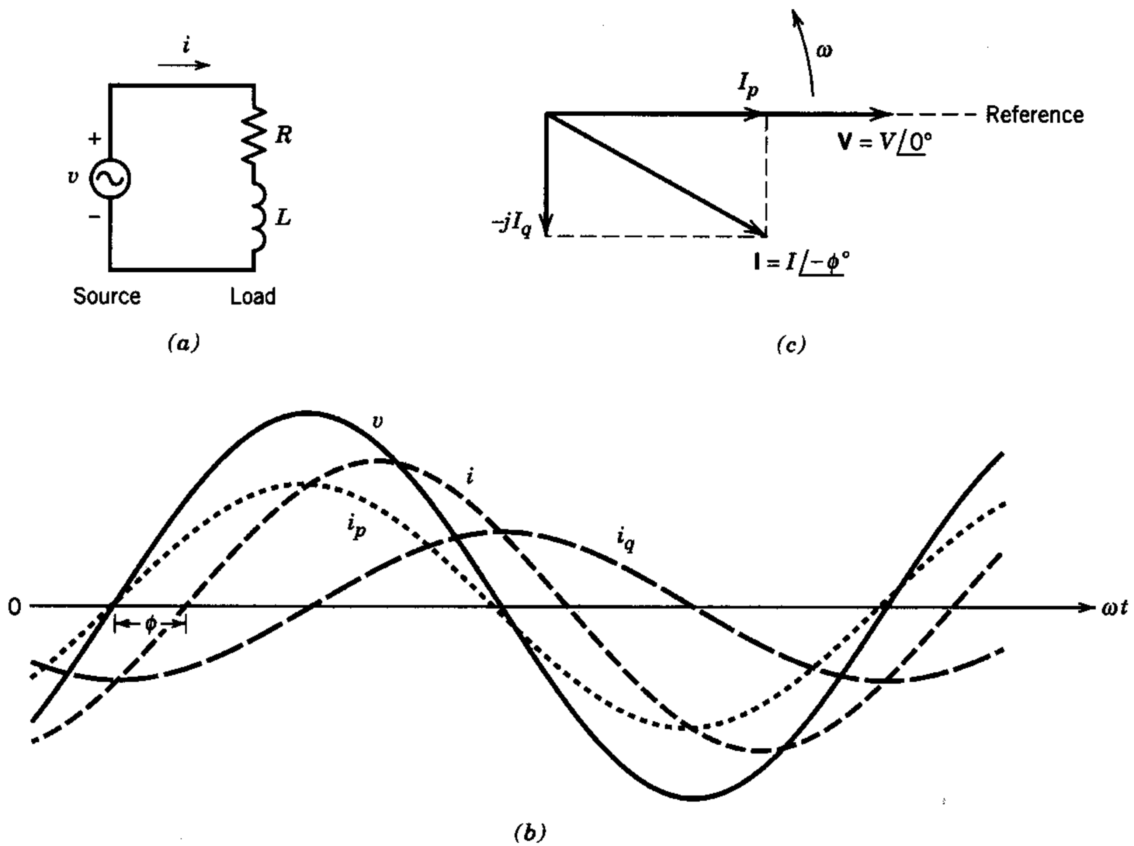
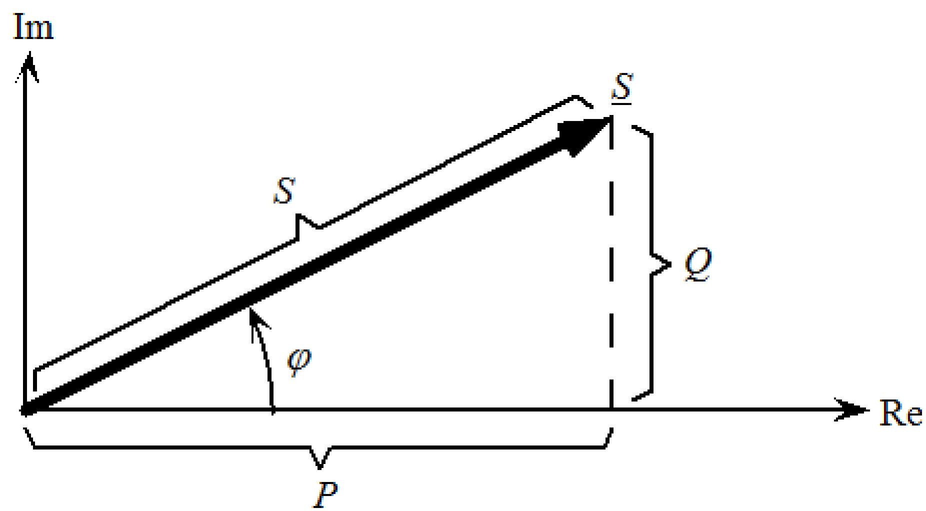


Figure 3-2 Sinusoidal steady state.



P=active, Q=reactive and S=apparent power

$\underline{S} = \underline{U}\,\underline{I}^*$ $\underline{S} = P + \mathrm{j}\,Q$ $P = U I \cos\varphi$

$S^2 = P^2 + Q^2$ $Q = U I \sin\varphi$

Effekt x Tid ger Energi

För att kunna räkna ut hur mycket **energi** en apparat eller lampa använder eller ett kraftverk producerar måste du veta dess **effekt** och hur länge de används.

Effekt mäts i watt (W) och tiden i timmar (h).

Energi är **effekt** multiplicerat med tid och mäts i wattimmar (Wh).

Elpriser anges ofta i kWh där k står för 1000
1000 Wh = 1 kWh

Phasor Representation

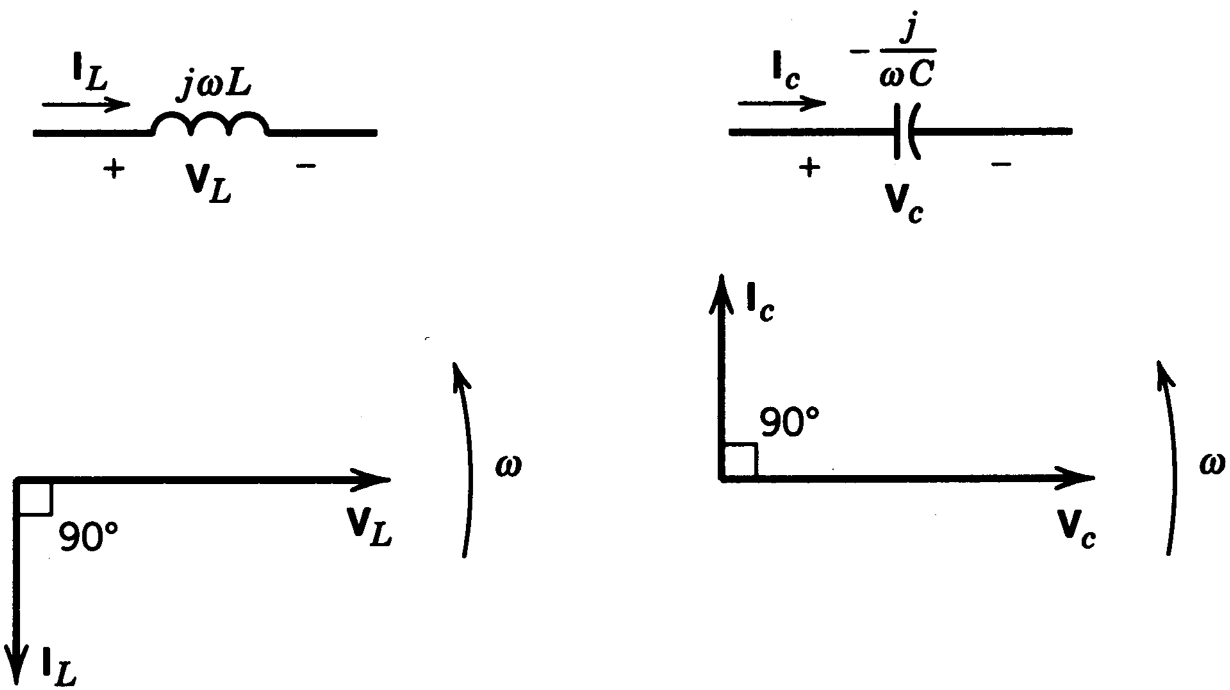
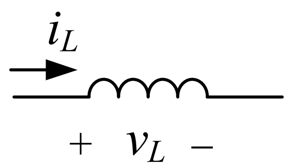


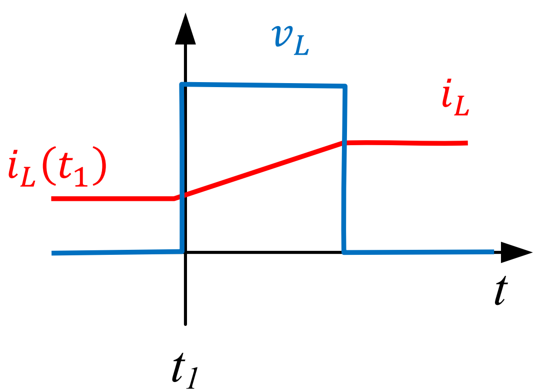
Figure 3-6 Phasor representation.

Inductors

$$v_L = L\frac{di_L}{dt}$$

$$i_L = i_L(t_1) + \frac{1}{L}\int v_L dt$$

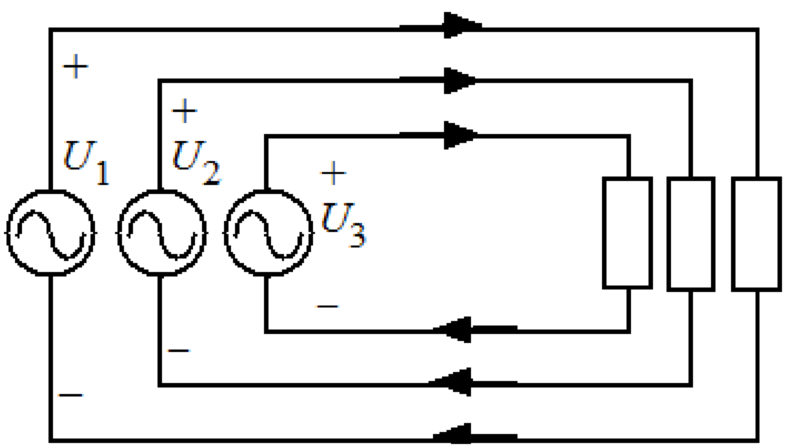


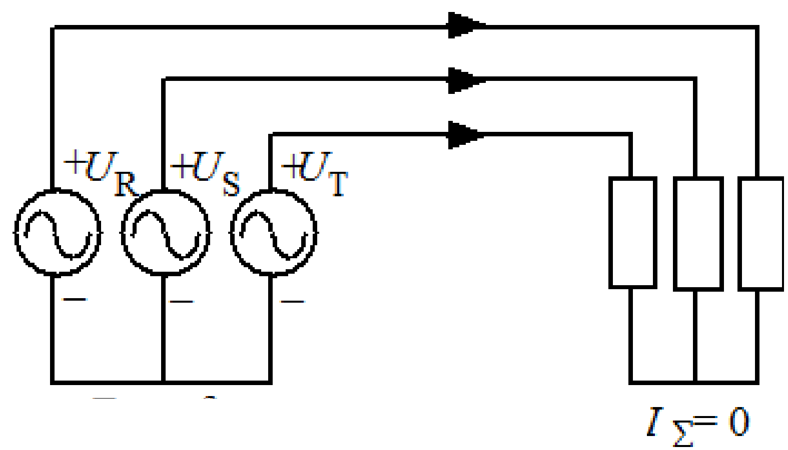


Average and RMS current and voltage?

Current stiff component

Three one phase system or one three phase system





Three one phase generators

Three loads

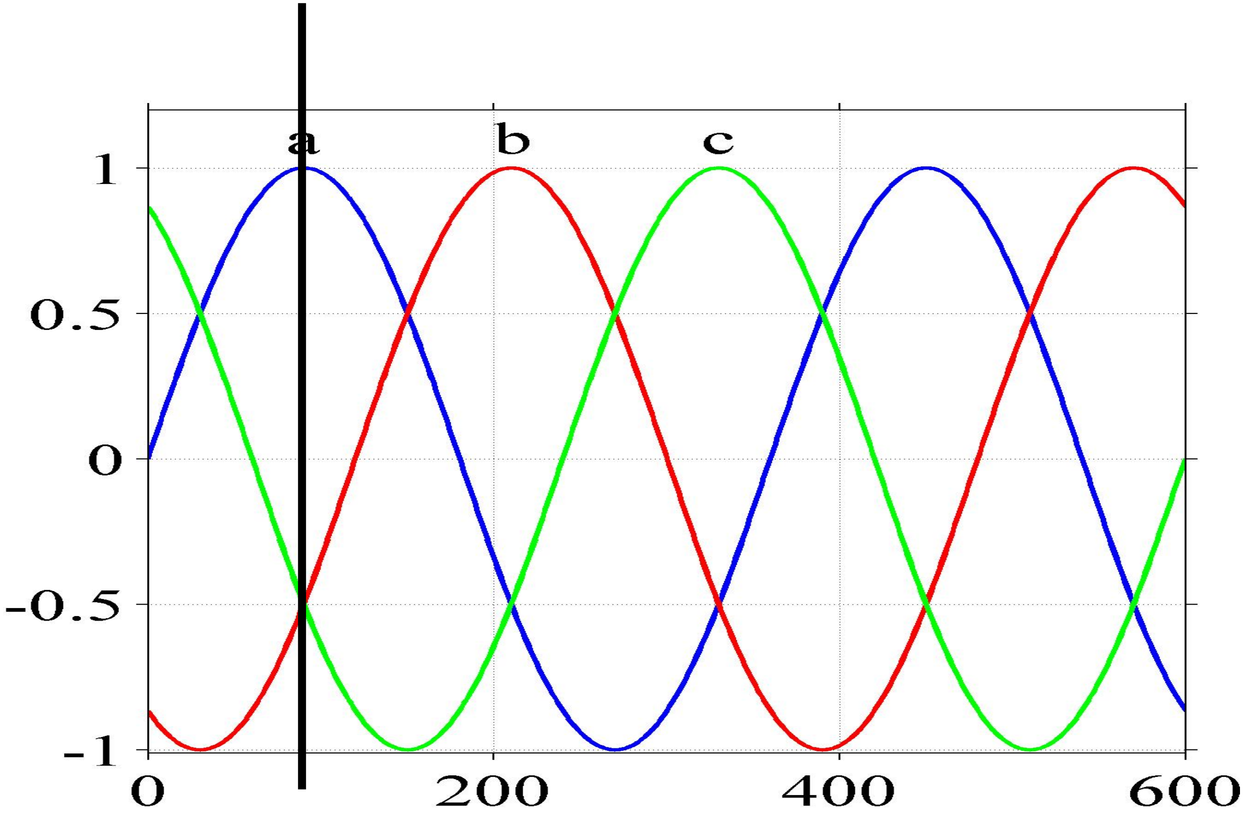
One three phase generators

Half the amount of cabels

Three phase current

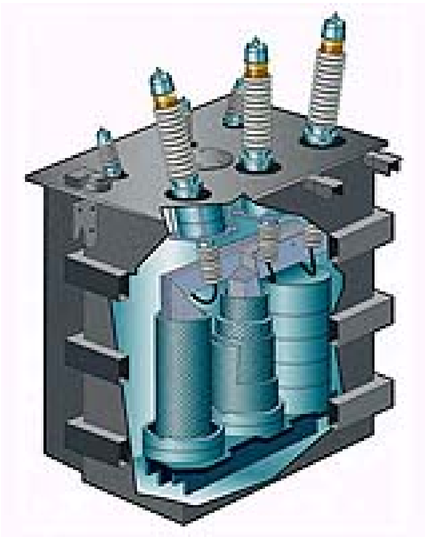
$$i_a(t) = 1$$
$$i_b(t) = -0.5$$
$$i_c(t) = -0.5$$

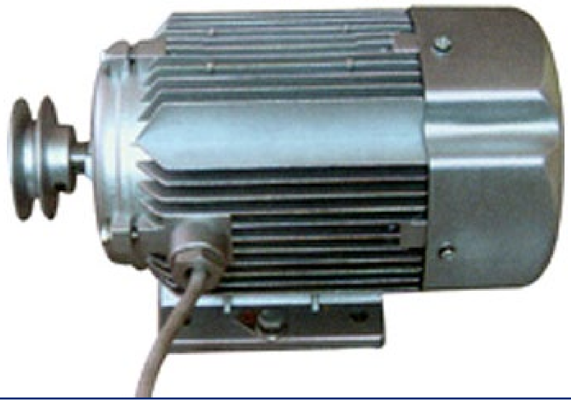
Sum = 0



Three phase AC (voltage) – Way ?

- Transformer (works only for AC)
- Robust and cheap motor (with rotating flux)
- 3-phase transmission
- Lot of energy in rotation machines





Inductors

Inductance Definition

Faraday's Law:

$$e = N\frac{d\Phi}{dt}$$

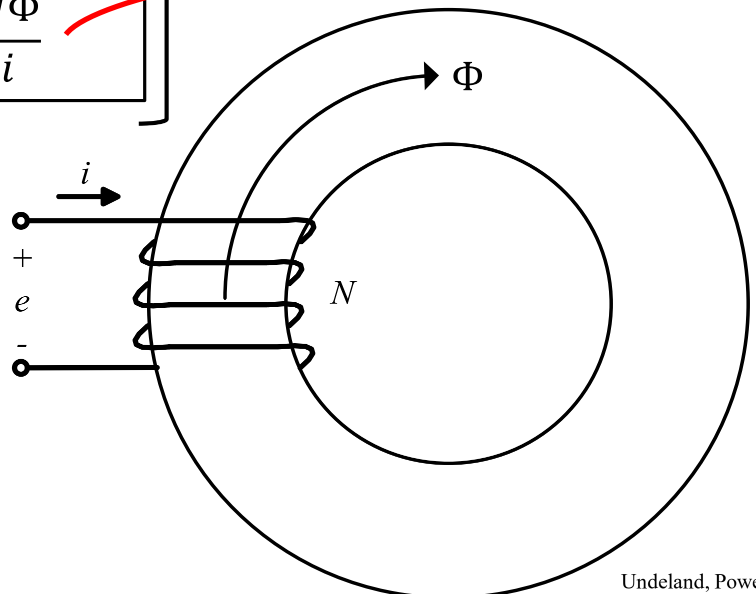
Definition of Inductance:

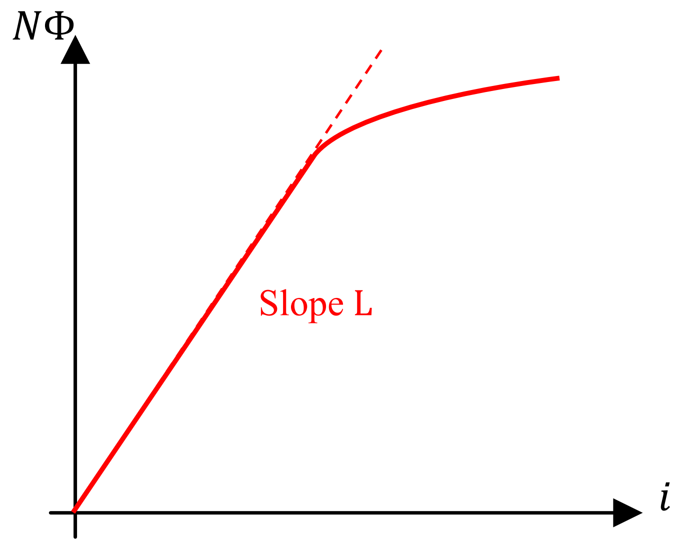
$$L = \frac{N\Phi}{i}$$

$$e = L\frac{di}{dt} + i\frac{dL}{dt} = L\frac{di}{dt}$$

From $\Phi\Re = Ni$ →

$$L = \frac{N}{i}\frac{Ni}{\Re} = \frac{N^2}{\Re}$$





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Ampere's Law

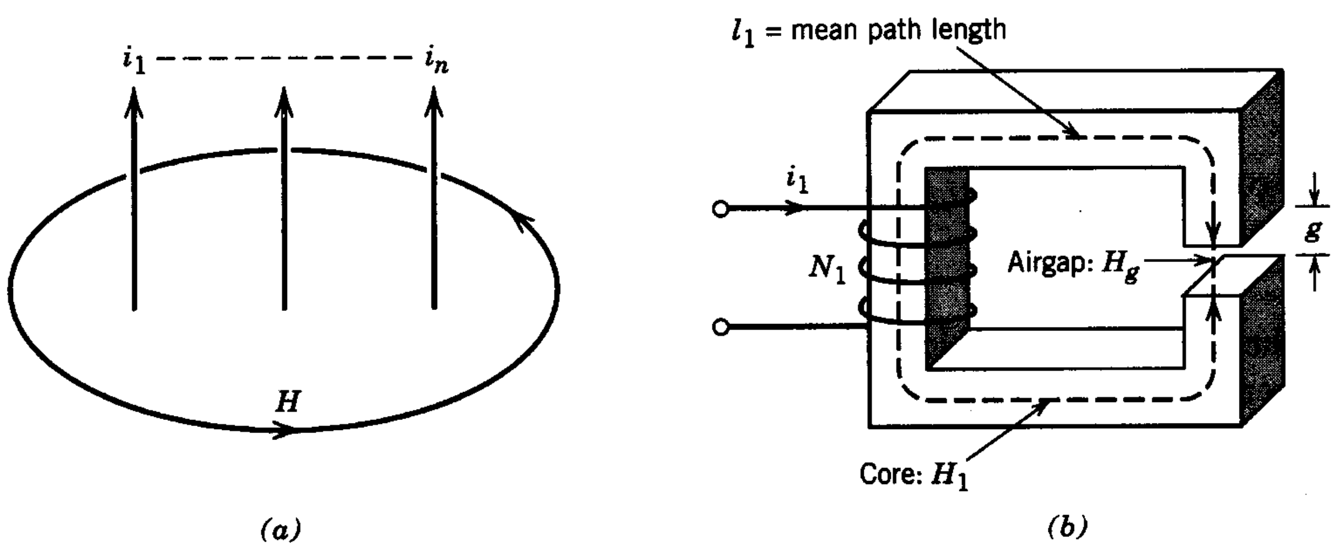


Figure 3-10 (*a*) General formulation of Ampere's law. (*b*) Specific example of Ampere's law in the case of a winding on a magnetic core with an airgap.

- Direction of magnetic field due to currents
- Ampere's Law: Magnetic field along a path

Continuity of Flux Lines

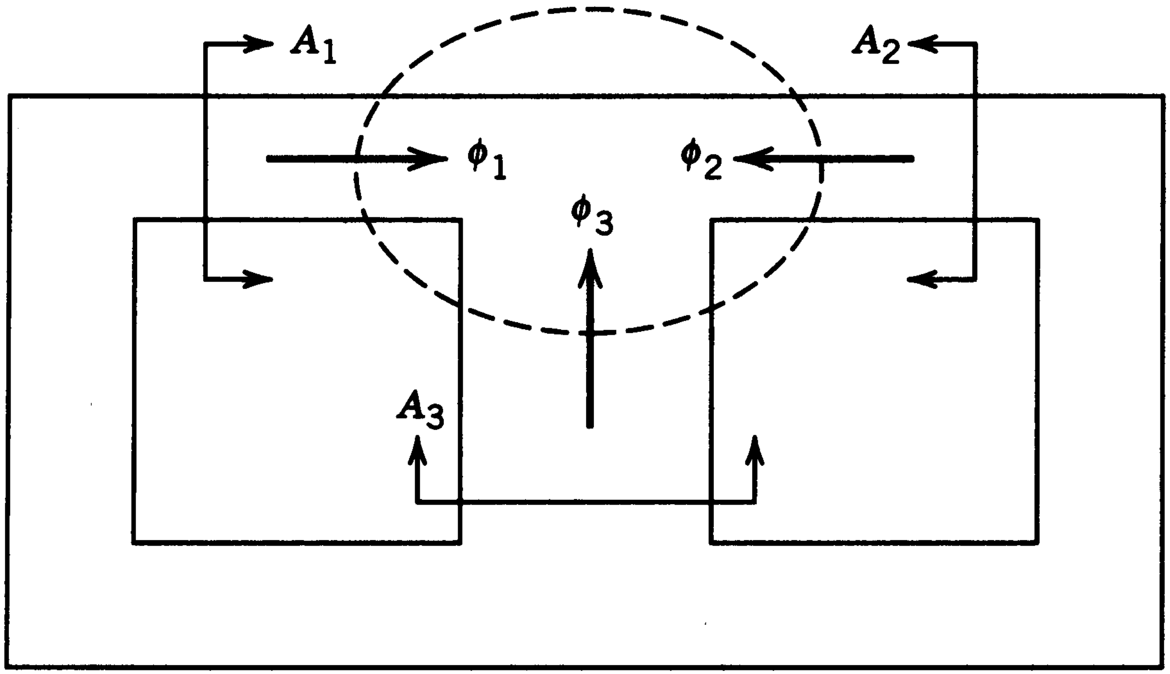


Figure 3-13 Continuity of flux.

$$\phi_1 + \phi_2 + \phi_3 = 0$$

Concept of Magnetic Reluctance

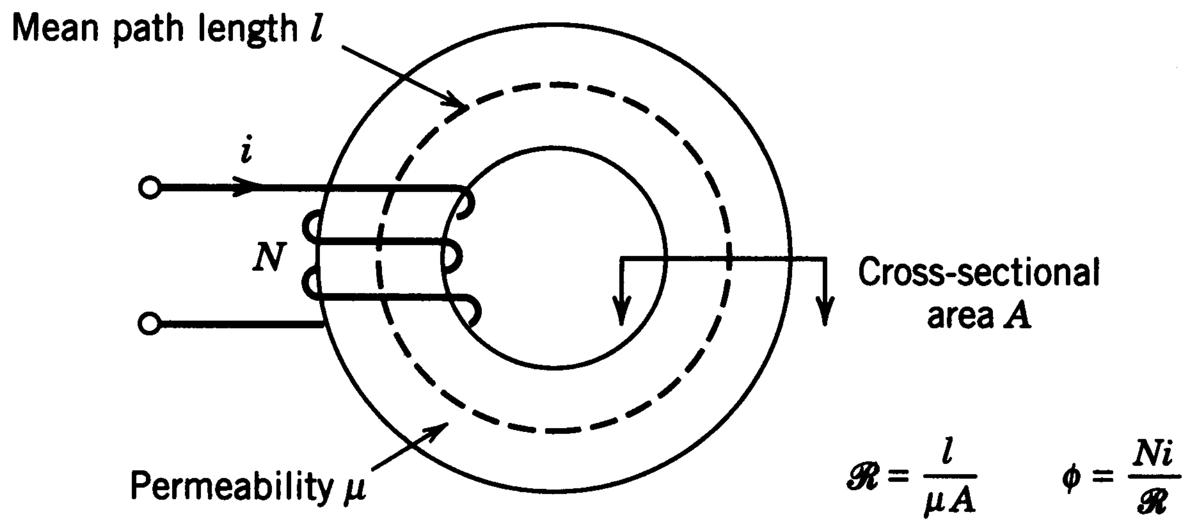
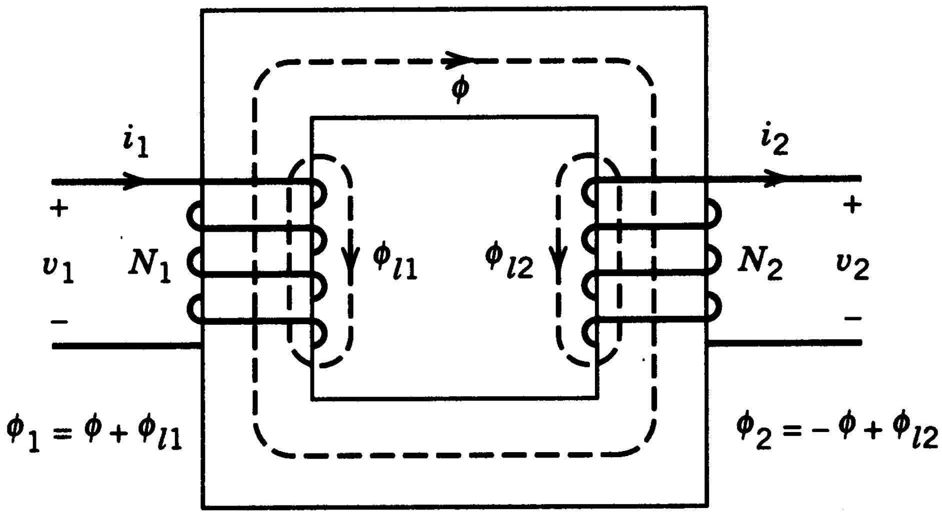


Figure 3-14 Magnetic reluctance.

- Flux is related to ampere-turns by reluctance

Analysis of a Transformer



(a)

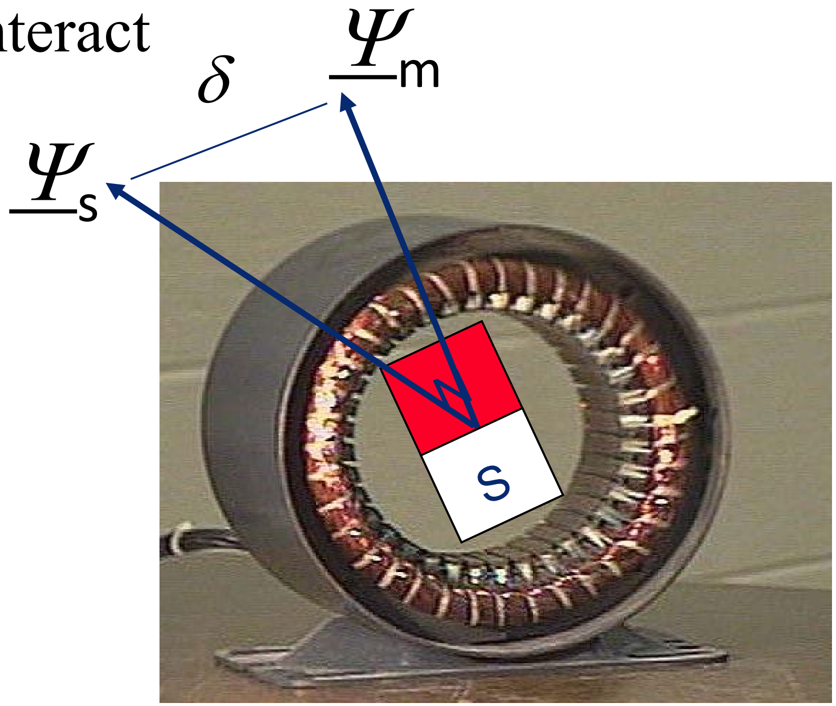
Figure 3-18 (*a*) Cross section of a transformer. (*l*

- u1 like to create a current
- i1 create a flux
- Φ Induce a voltage e1

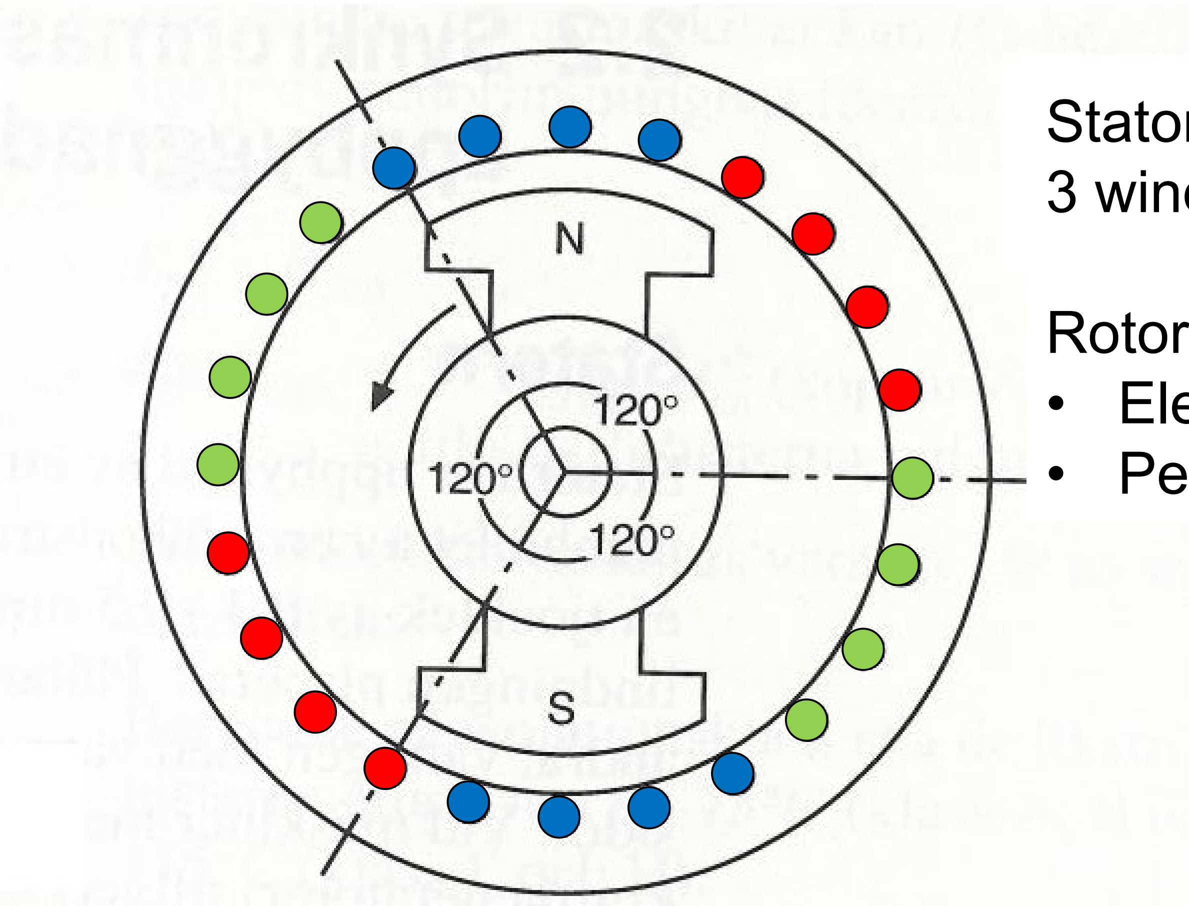
$$u_1 = e_1 = N_1 \frac{d\Phi}{dt}$$
$$u_2 = e_2 = N_2 \frac{d\Phi}{dt}$$
$$\frac{u_2}{N_2} = \frac{u_1}{N_1} \Rightarrow \boxed{\frac{u_1}{u_2} = \frac{N_1}{N_2}}$$

Synchronous machine

1. Rotating flux in the stator
2. Stationary flow in the rotor (magnets or field winding)
3. 1 + 2 = force, magnetic fluxes interact



Synchronous machine

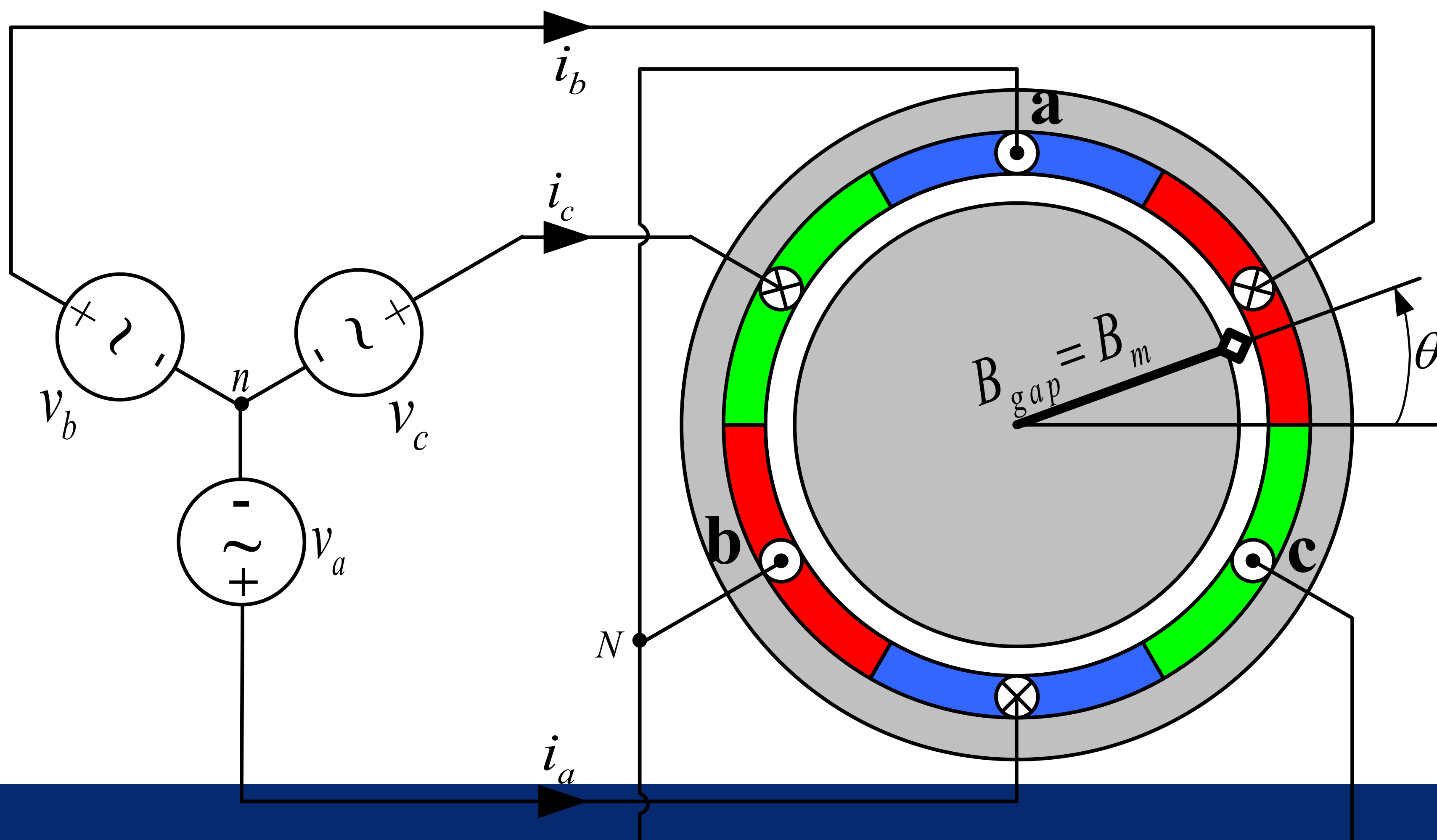


Stator
3 windings (one per phase)

Rotor
- Electric magnetization
- Permanent magnets

Synchronous machine

Rotating flux in the airgap

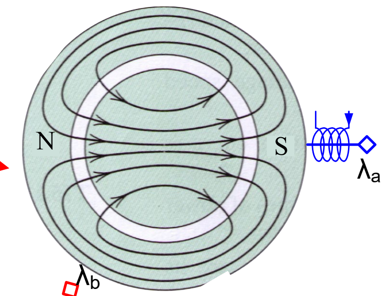


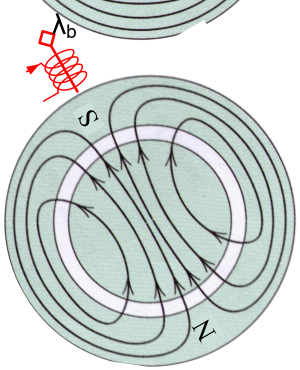
- The stator has three windings offset 120 degrees from each other in the room Each phase current creates a flow in the air gap offset 120 degrees from each other in time

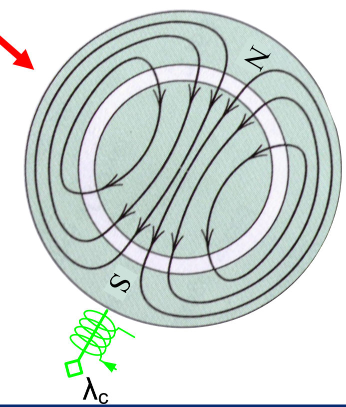
$$B_a(t,\theta) = K i_a(t)\cos(\theta)$$

$$B_b(t,\theta) = K i_b(t)\cos(\theta - 120^\circ)$$

$$B_c(t,\theta) = K i_c(t)\cos(\theta + 120^\circ)$$







- The total flow in the air gap becomes

$$B_{gap}(t,\theta) = B_a(t,\theta) + B_b(t,\theta) + B_c(t,\theta)$$

The flow created by the phase currents, for example for a time

Draws a vector for the sinusoidal flow, the vector shows the position of the maximum value of the flow

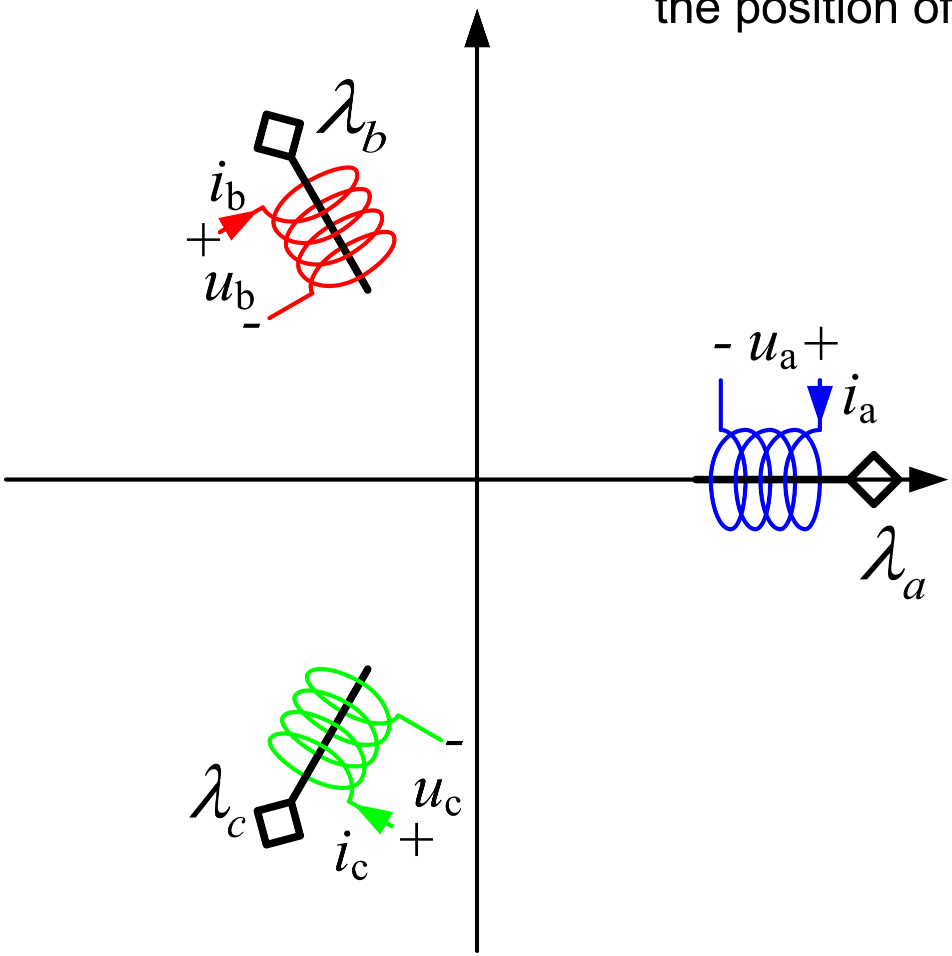
$B_x = K i_x$

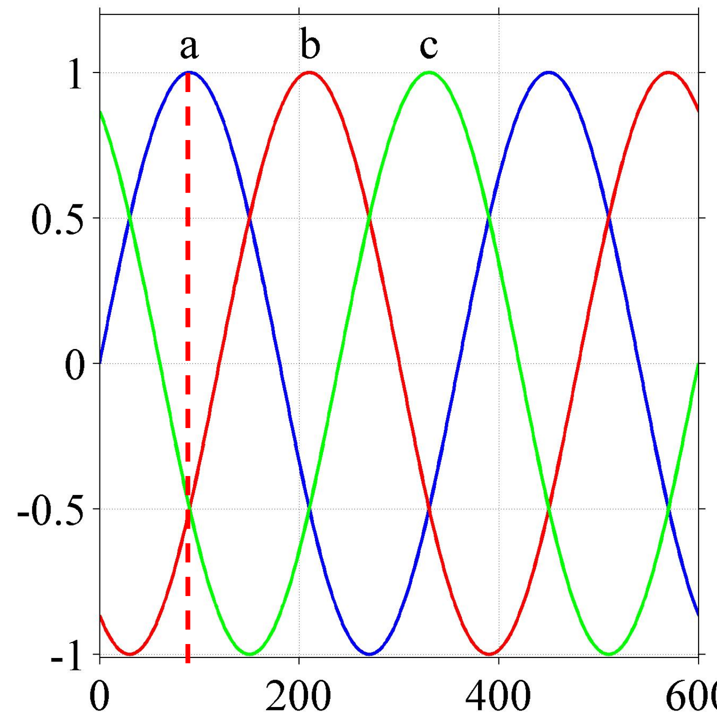
Exempel:

$$i_a(t) = I_m$$

$$i_b(t) = -0.5 I_m$$

$$i_c(t) = -0.5 I_m$$





The flow created by the phase currents, for example for a time

Draws a vector for the sinusoidal flow, the vector shows the position of the maximum value of the flow $B_x = K i_x$

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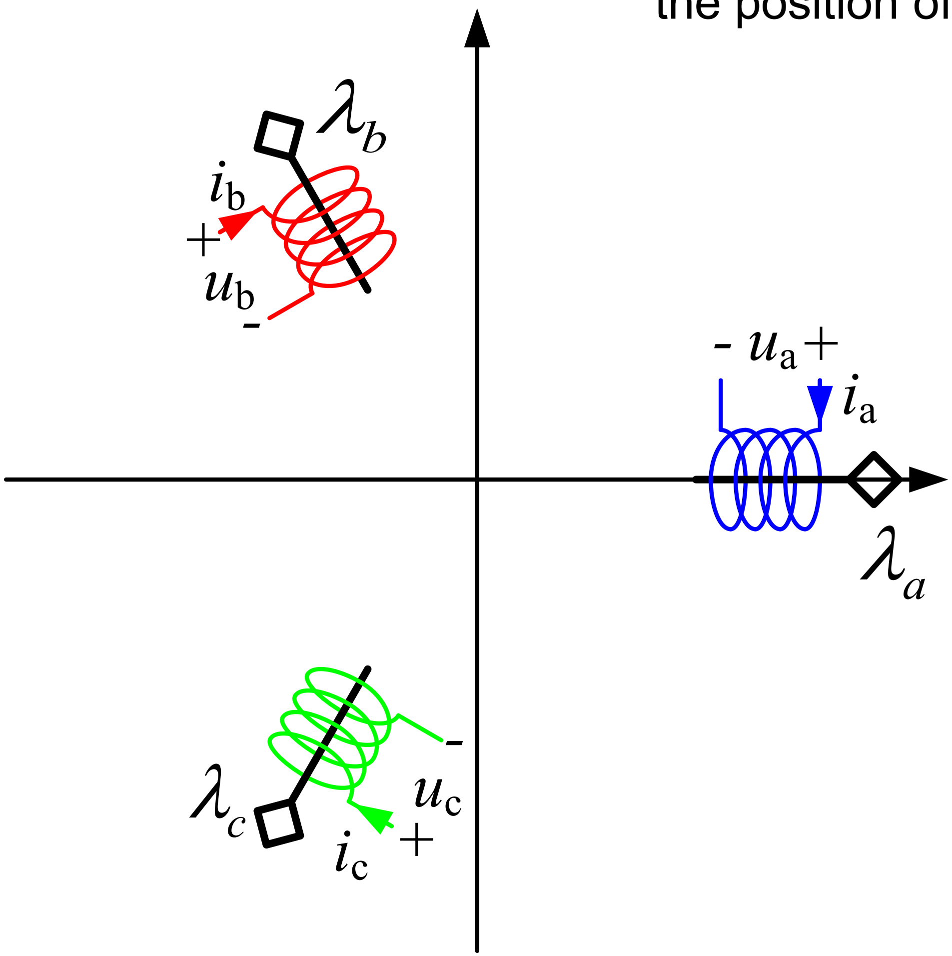

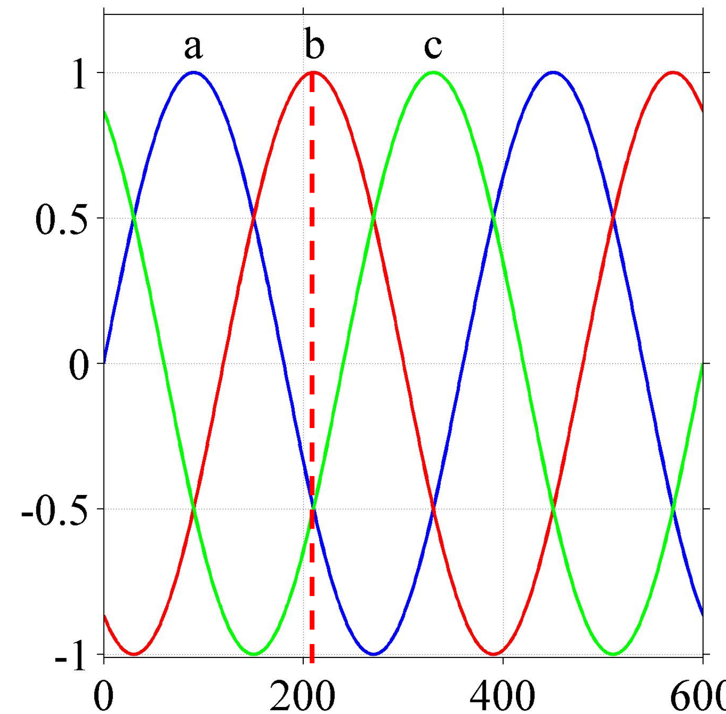

The flow created by the phase currents, for example for a time

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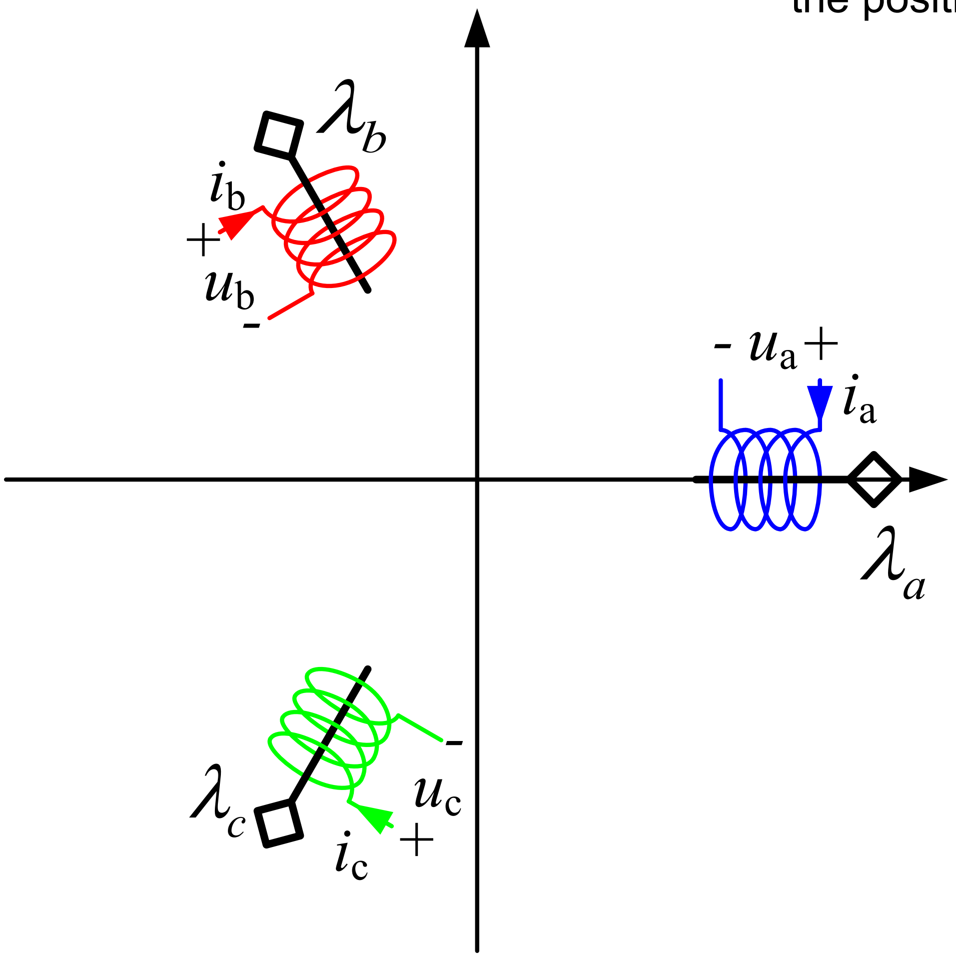

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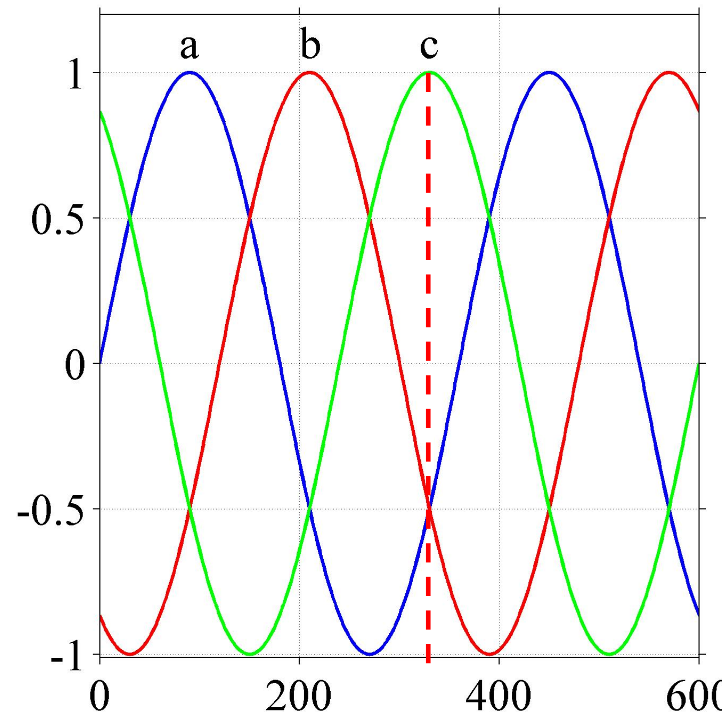
$$i_b(t) = -0.5I_m$$

$$i_c(t) = I_m$$

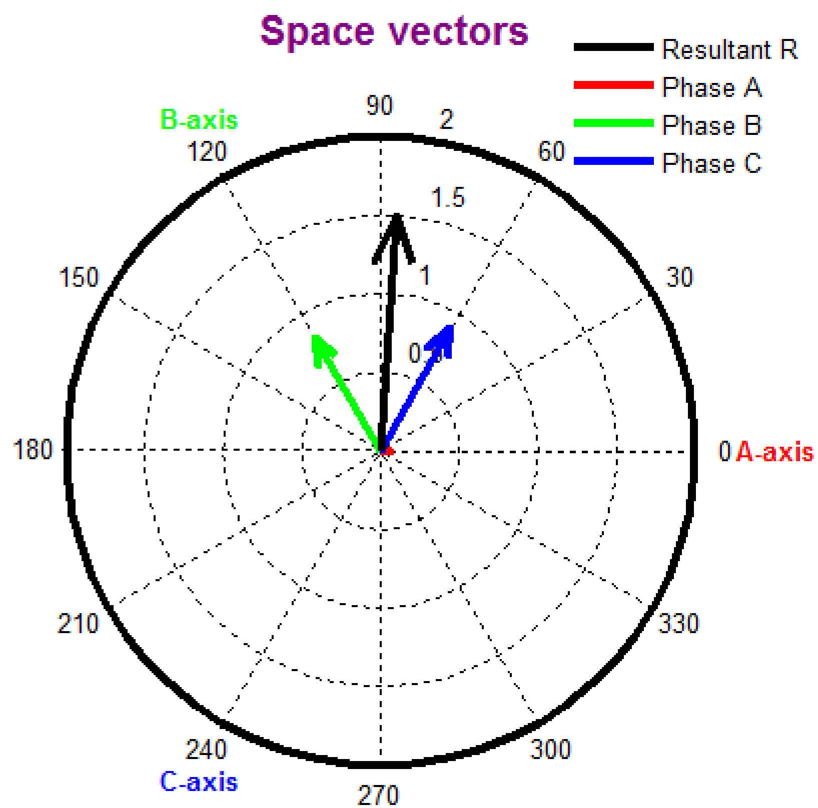


$$B_{gap}(t,\theta) = B_m \quad \text{when} \quad \theta = \omega t$$

- Ie. the flow rotates counterclockwise with constant amplitude and with speed :

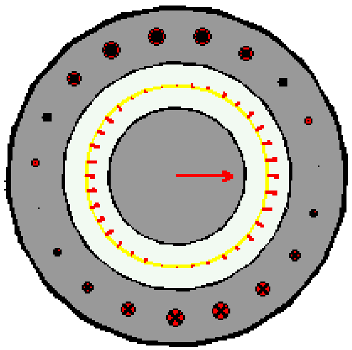
$$\omega = \omega_s$$ ← Synchronous angular velocity

Rotating flux

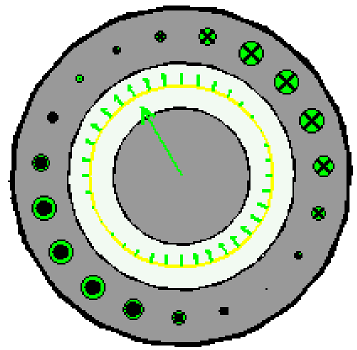


http://people.ece.umn.edu/users/riaz/animations/spacevectors.html

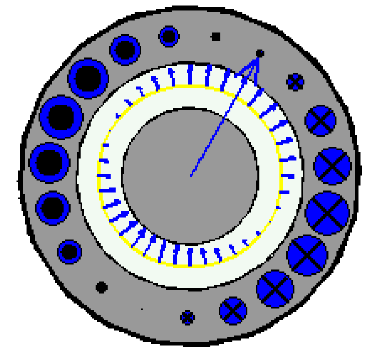
OBS andra färger!!



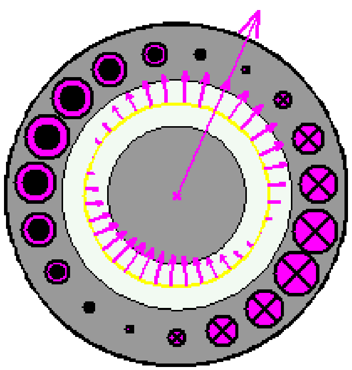
Phase A



Phase B

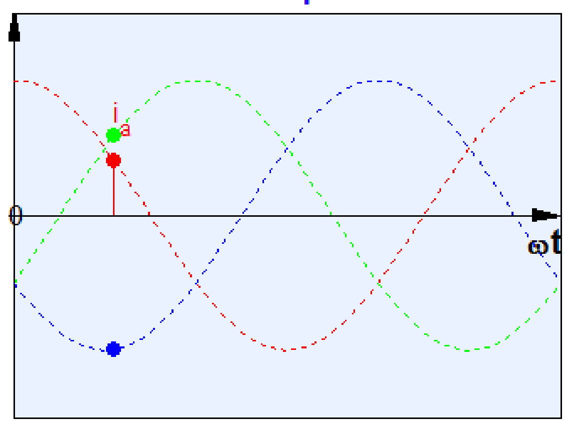


Phase C

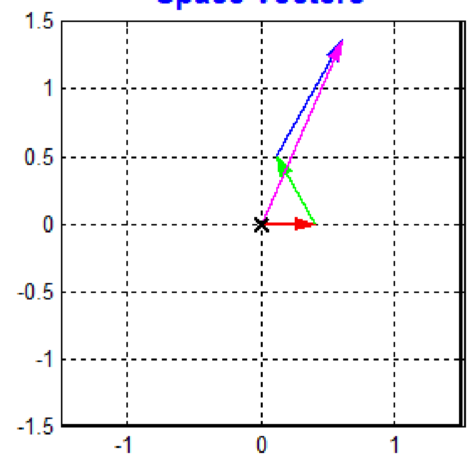


Resultant

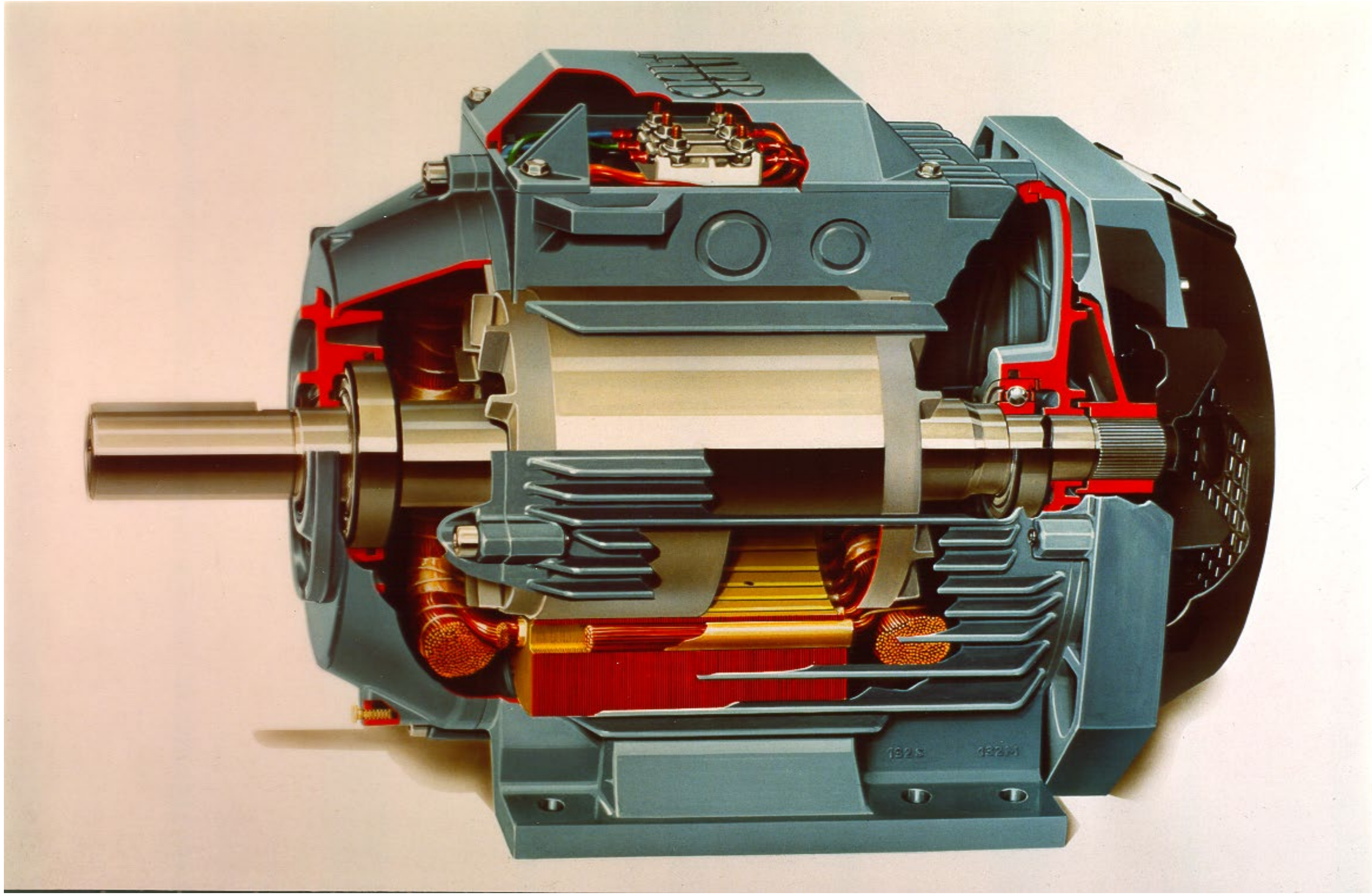
Balanced three-phase currents



Space vectors



Asynkromotor



Components in a motor/generator

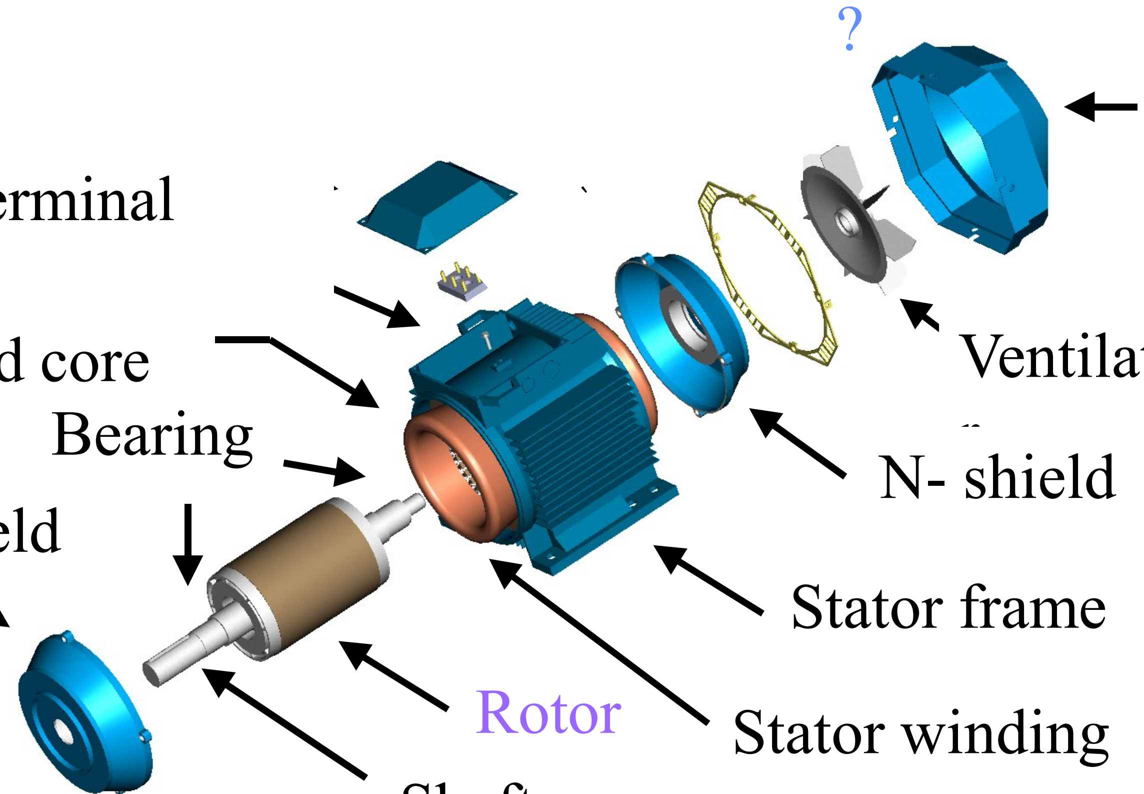
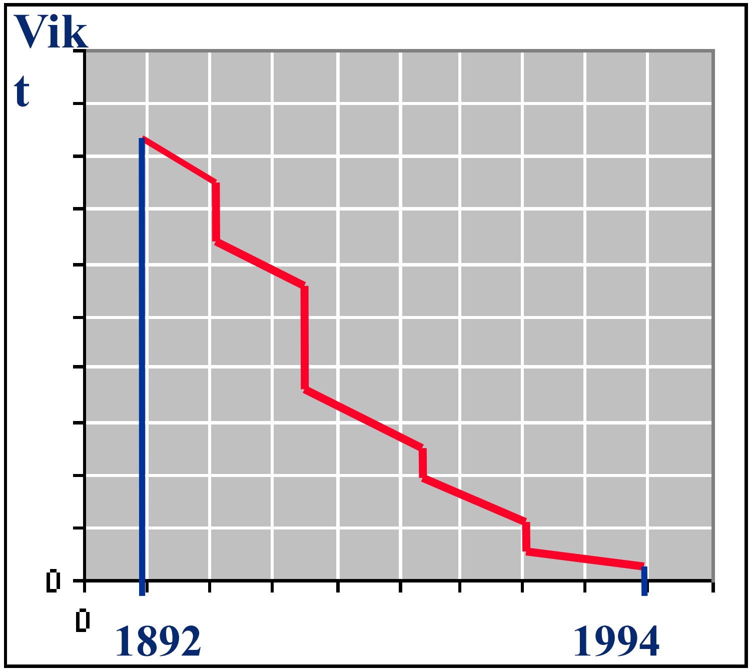


ABB Motors

Grundläggande teori

- När uppfanns asynkronmotorn ?
- Har den ändrat sig sedan dess ?

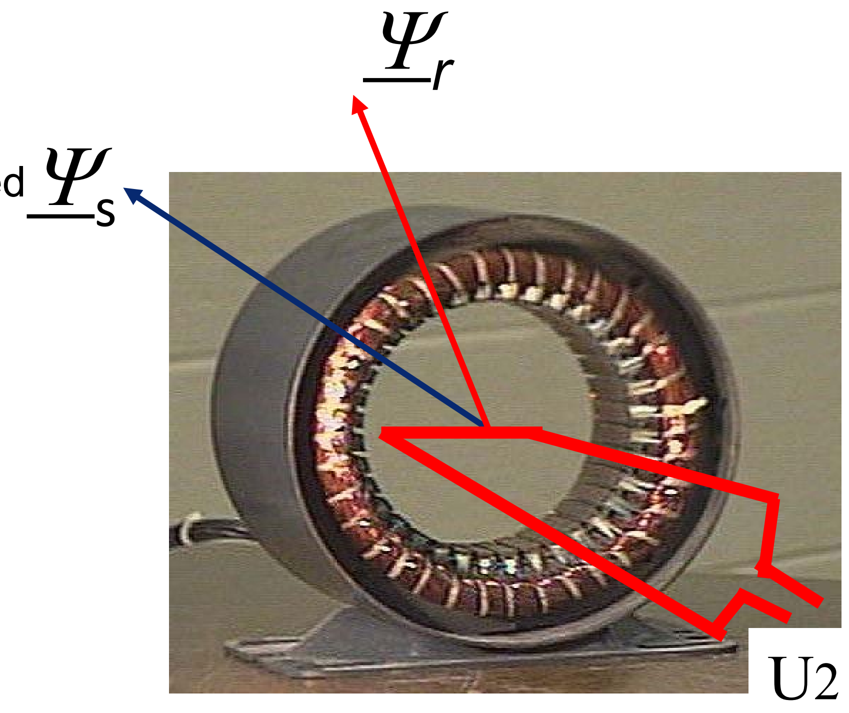


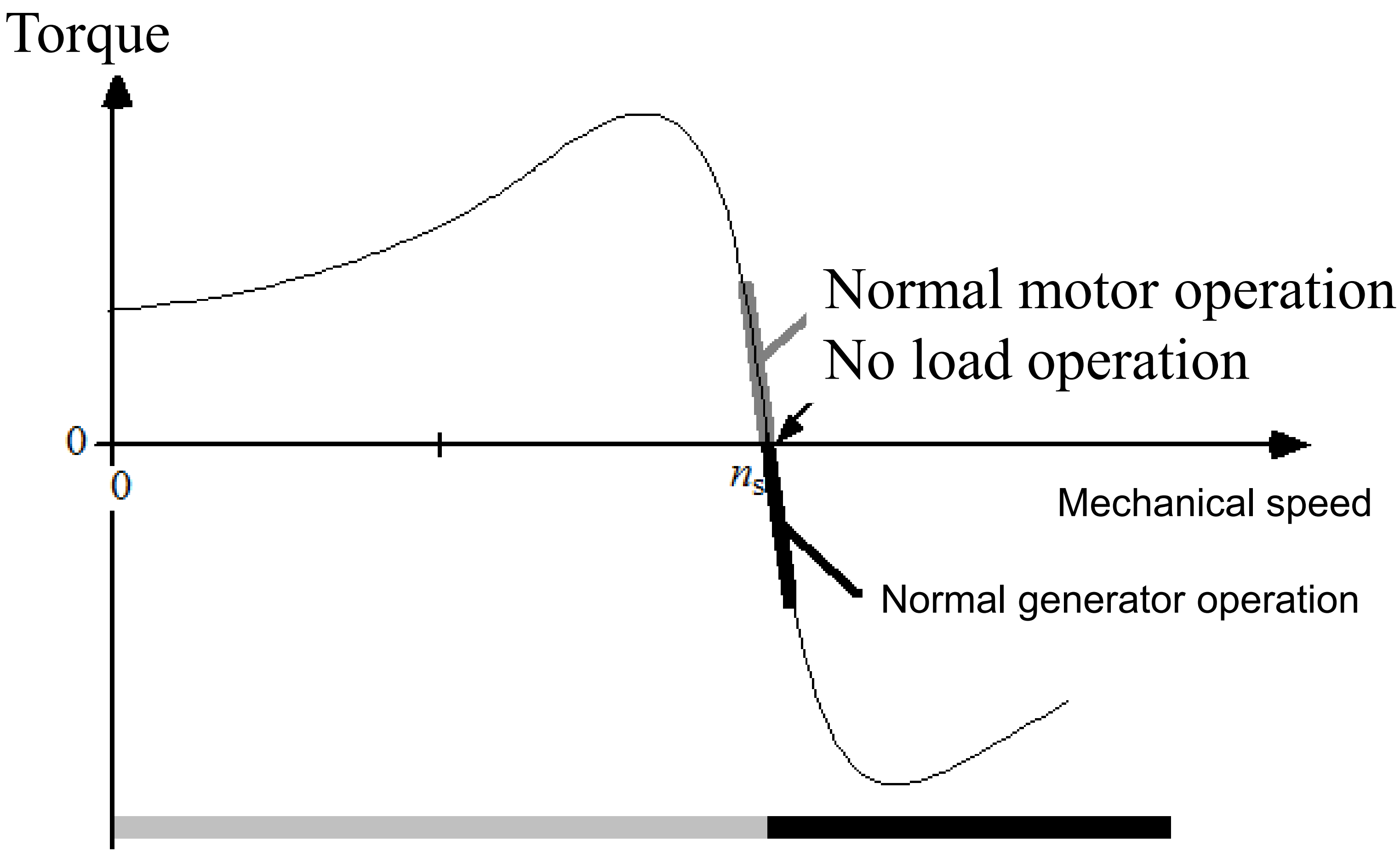
Induction machine

a) Rotating flow as in the stator of the synchronous machine
b) Induced voltage in the rotor, U2 = s * U1,
c) Provides current depending on resistance in rotor I2 = U2 / R2
d) Mechanical rotation of the rotor gives the frequency in rotor current; f1 = f2 + k * n2
e) Flow from the stator goes together with the flow from the rotor
 = magnetic field that cooperates

U1 = voltage in stator, U2 = voltage in rotor
R2 = resistance in rotor
f1 = frequency in stator
ns = speed of stator flux=synchronous speed
f2 = frequency in rotor
n2 = mechanical speed
k = constant
s= slip of machine

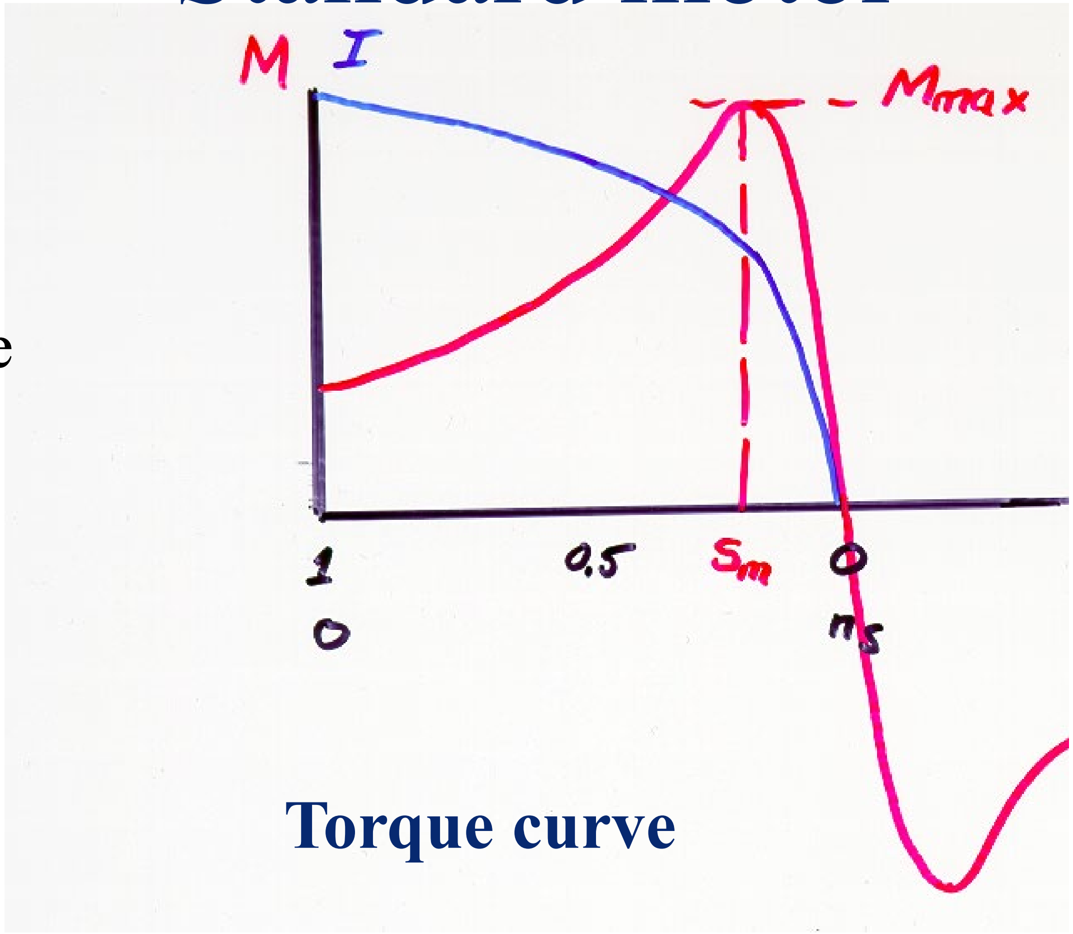
s=(ns-n2)/ns




Torque
Normal motor operation
No load operation
0
0
n_s
Mechanical speed
Normal generator operation

Standard motor

M=Torque
I=Current



Torque curve

LINDNING

HANDLINDNING

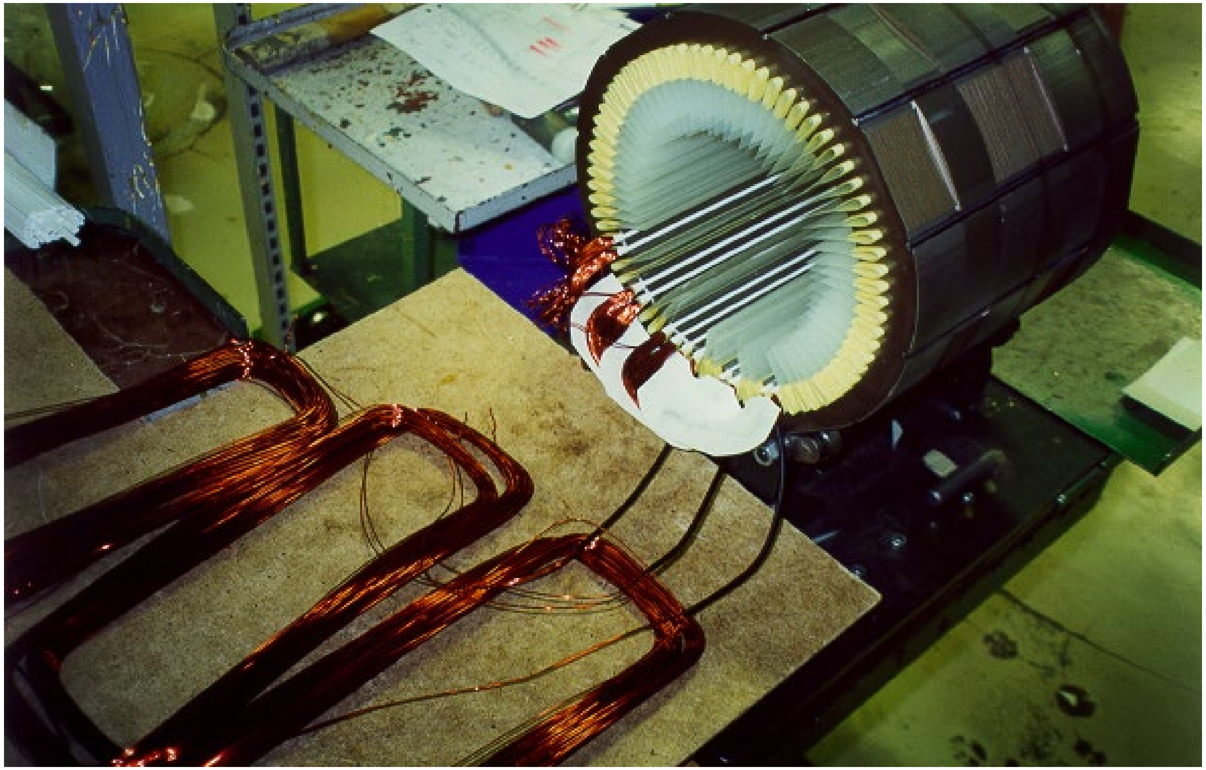


ABB Motors

Standard motors

IEC 34-1

112-132

ABB Motors CE

3~ Motor M2AA 112 M | Cl, F | IP 55 | IEC 34-1

3G AA 112 001-ADA

No.

V	Hz	min^{-1}	kW	A	cos φ
380-420 Δ	50	1435	4,0	8,9	0,80
660-690 Y	50	1435	4,0	5,1	0,80
440-480 Δ	60	1435	4,6	8,6	0,81

6206 2Z/C3 6205 2Z/C3 | 27 Kg

160-250

ABB Motors CE

3 Motor M2AA 200 MLA 4

IEC 200 M/L 55

No

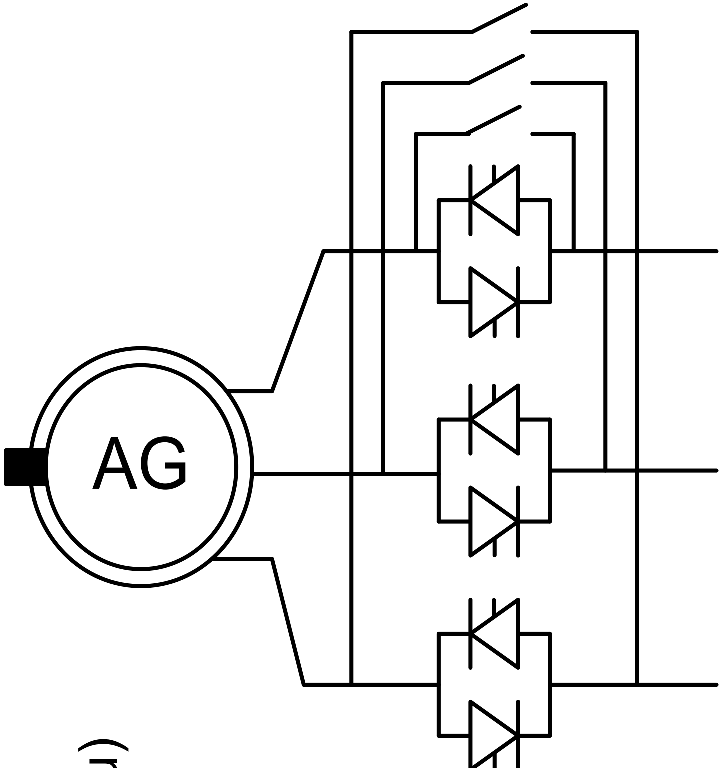
Ins.cl.F | IP 55

V	Hz	kW	r/min	A	cos φ	I_A/I_N	t_E/s
690 Y	50	30	1475	32.5	0.83		
400 △	50	30	1475	56	0.83		
660 Y	50	30	1470	34	0.83		
380 △	50	30	1470	59	0.83		
415 △	50	30	1475	54	0.83		
440 △	60	35	1770	59	0.83		

Prod.code 3GAA 202 001-ADA

6312/C3 6210/C3 | 180 Kg

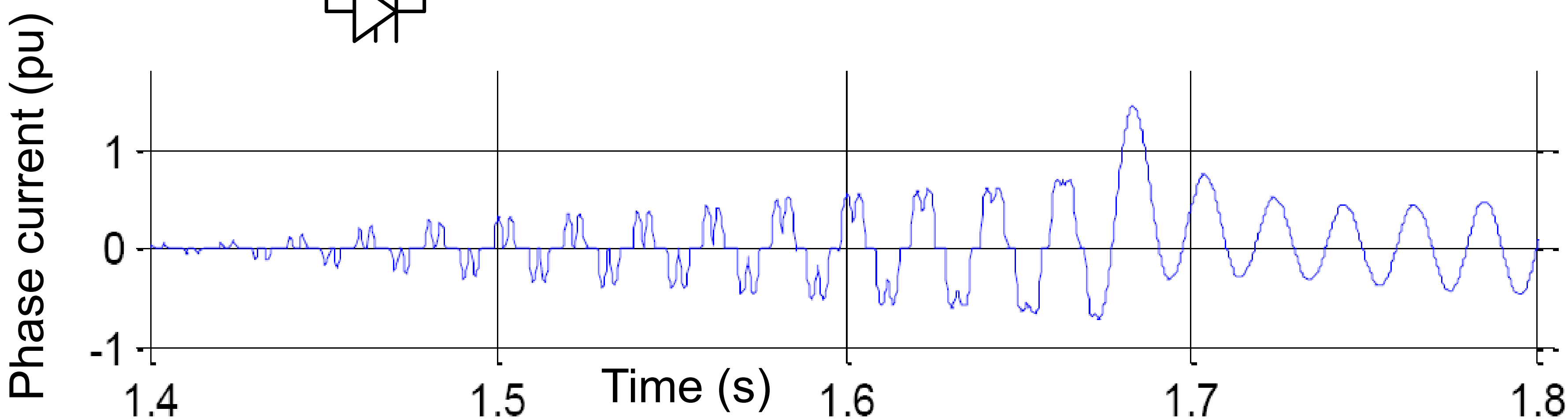
IEC 34-1

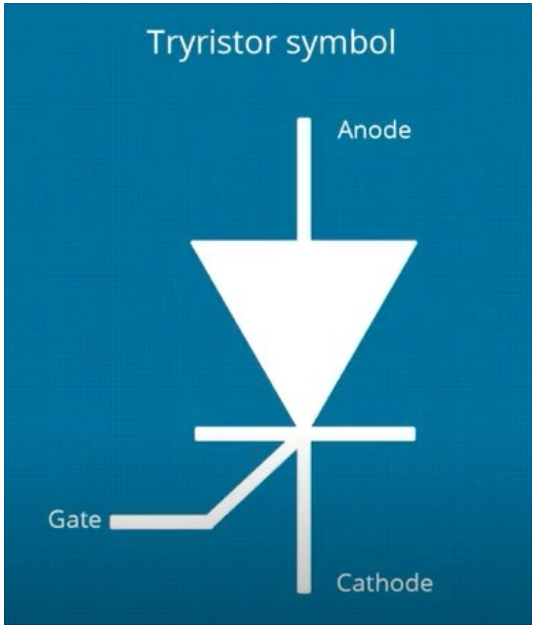


Soft starter

Active during starting/connection of induction generator.

Short circuit after connection

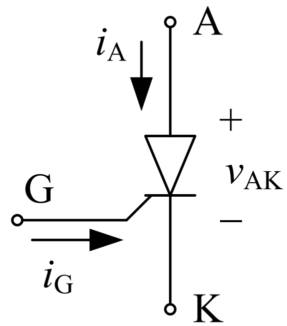


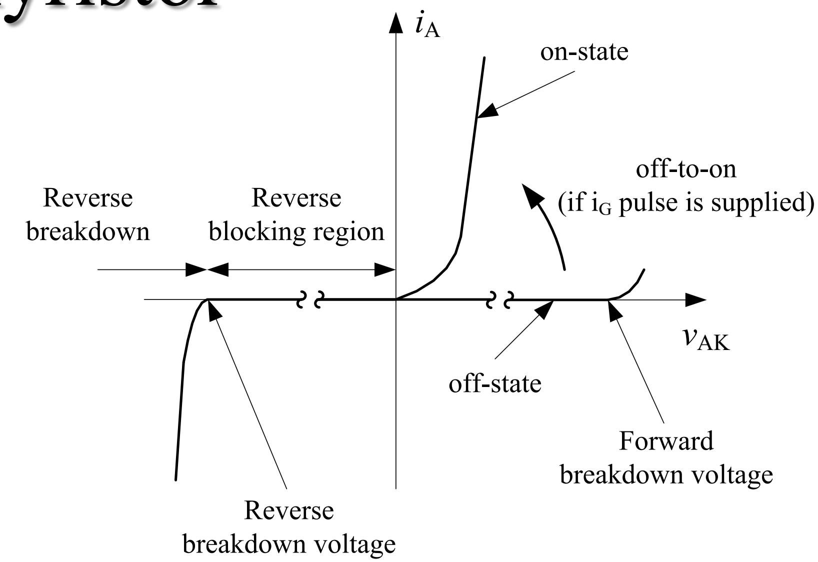


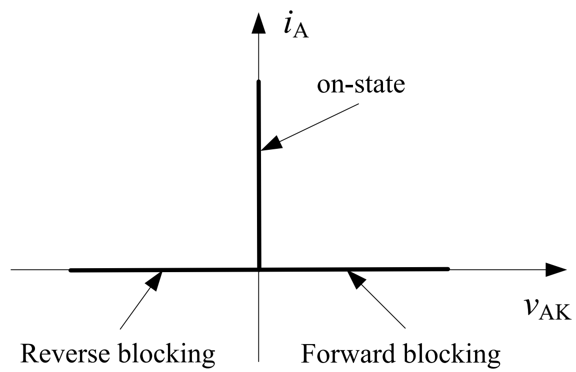
Thyristor

Revers blocking – negative voltage
Forward blocking – no trigging signal
Forward conducting - trigger signal+ positive voltage

The Thyristor





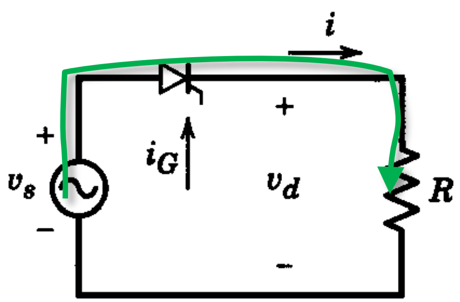


- Basically a diode that can be turned on.
- Does not conduct when forward biased unless a current is applied on the gate terminal

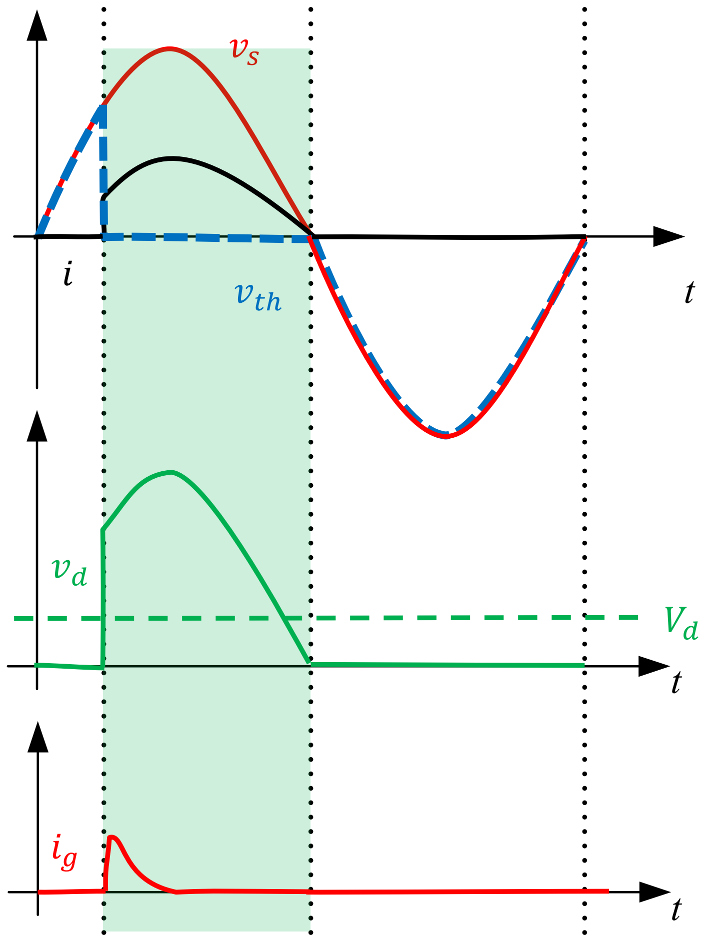
Undeland, Power Electronics
Figure 2-3, page 18

Simple Thyristor Circuits

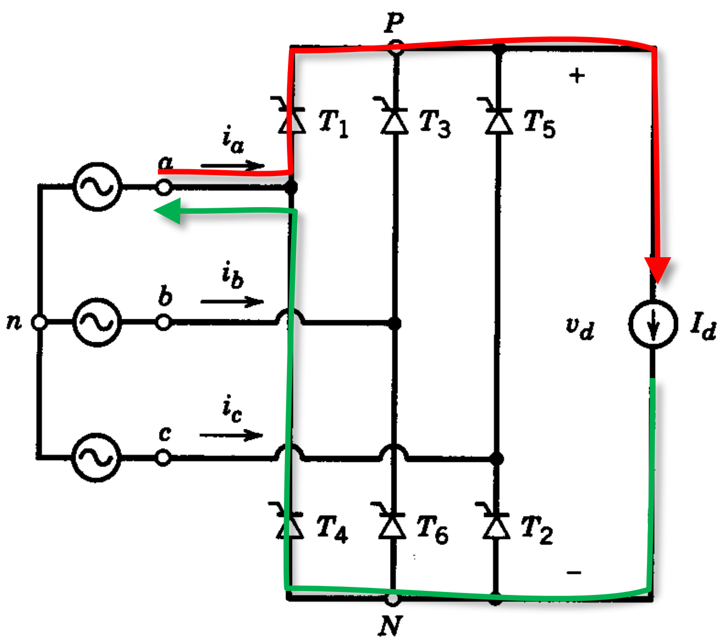
- The thyristor can be described as a diode that you can turn on
- The current keeps on flowing until it reaches zero where the thyristor turns off

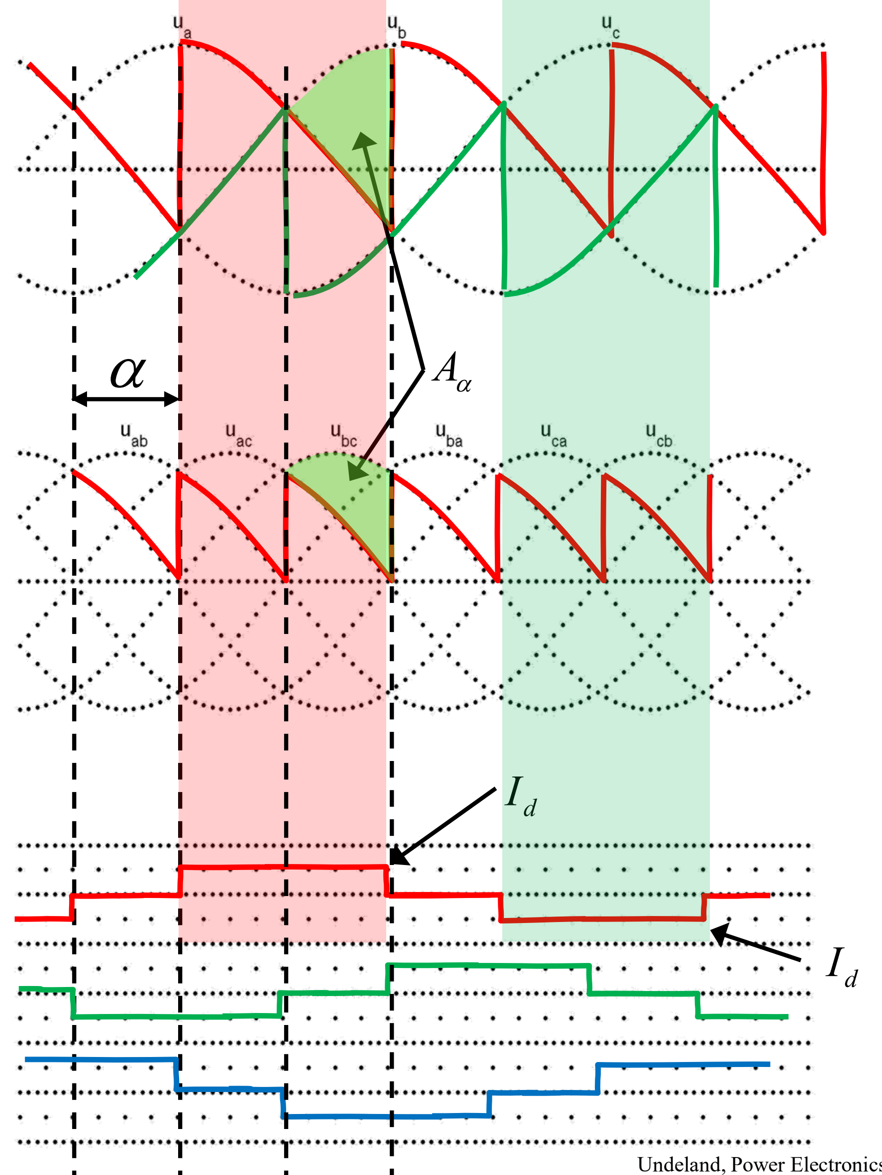


Undeland, Power Electronics
Figure 6-2, page 123



Three-Phase Thyristor Rectifier Delay α=60°

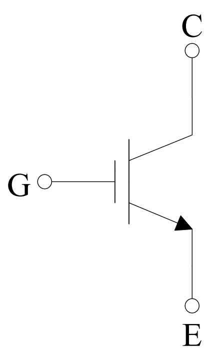




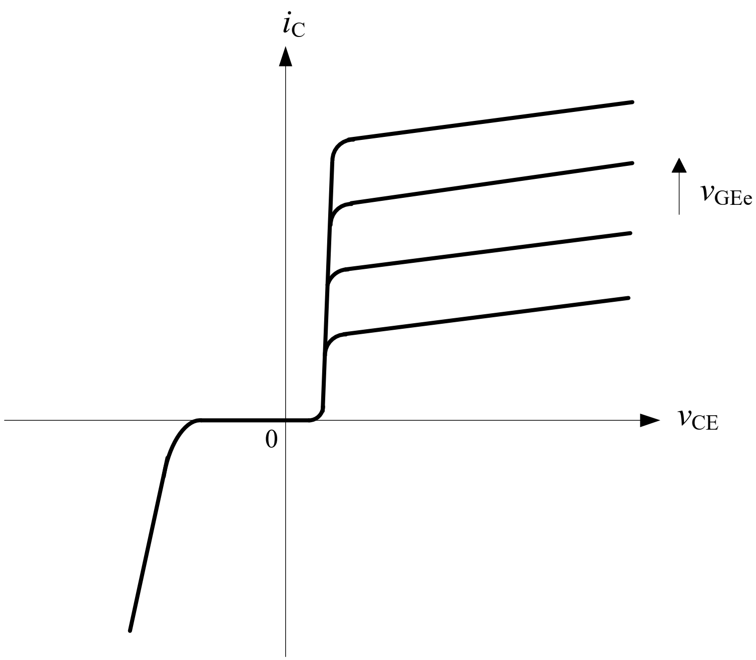
Undeland, Power Electronics
Figure 6-20, page 139

The IGBT

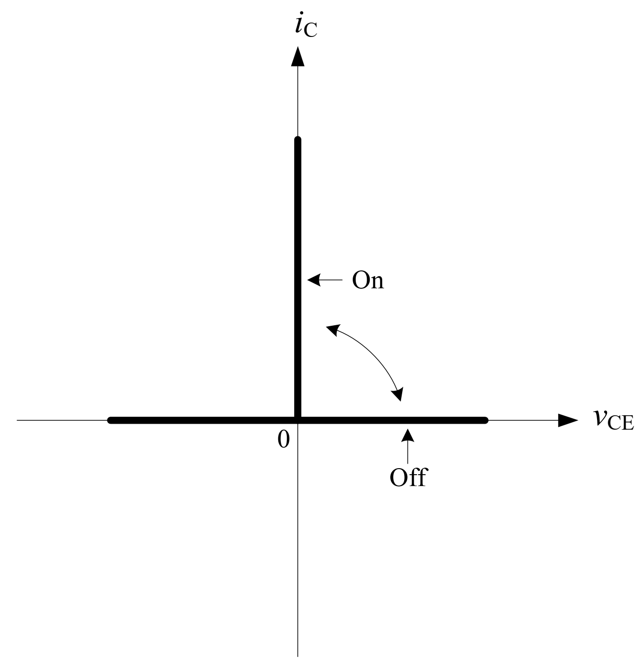
- A bipolar junction transistor with an insulated gate that facilitates the control of the component



symbol



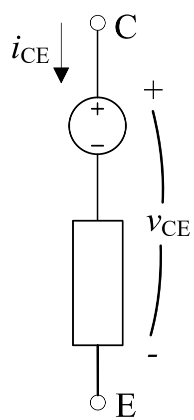
iv characteristics



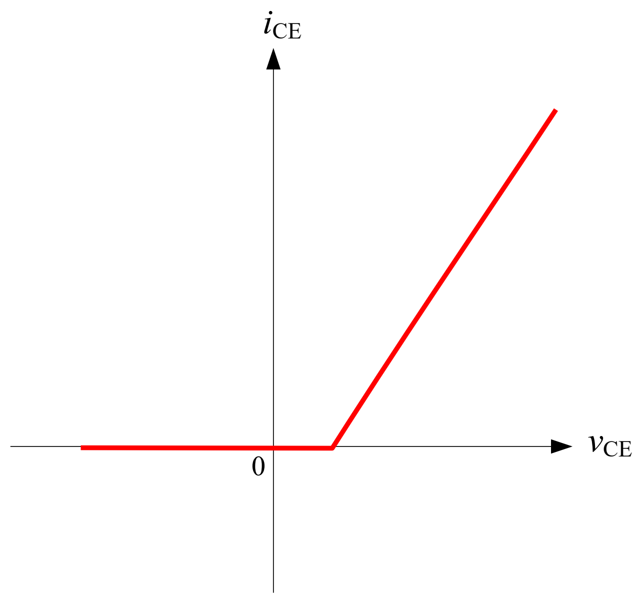
idealized characteristics

The IGBT

- A bipolar junction transistor with an insulated gate that facilitates the control of the component

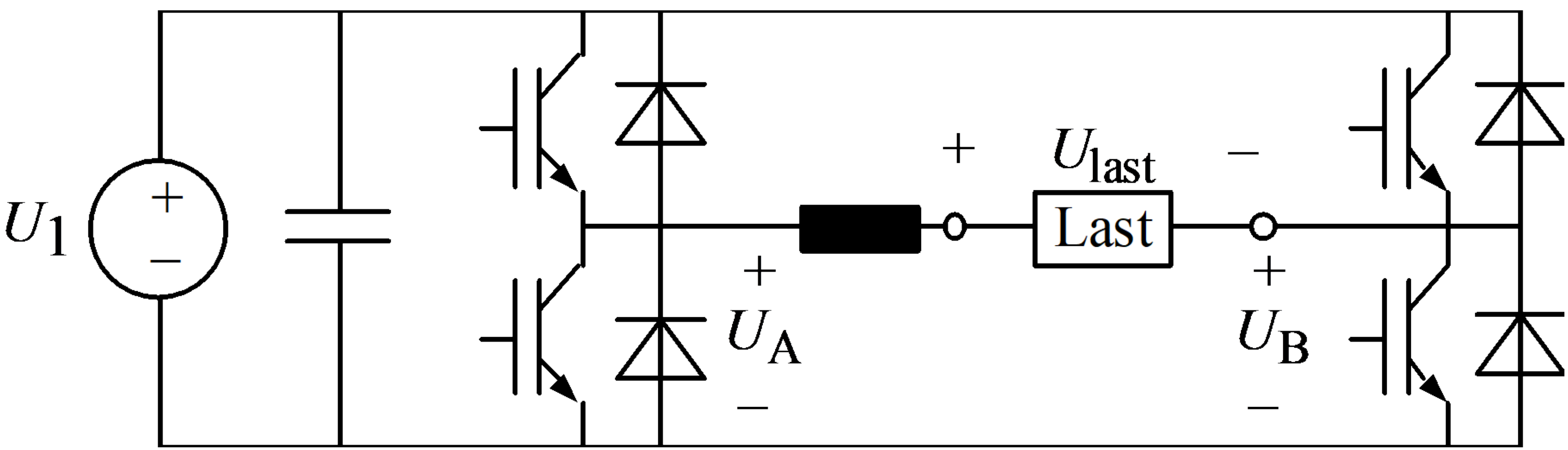


Equivalent circuit when conducting

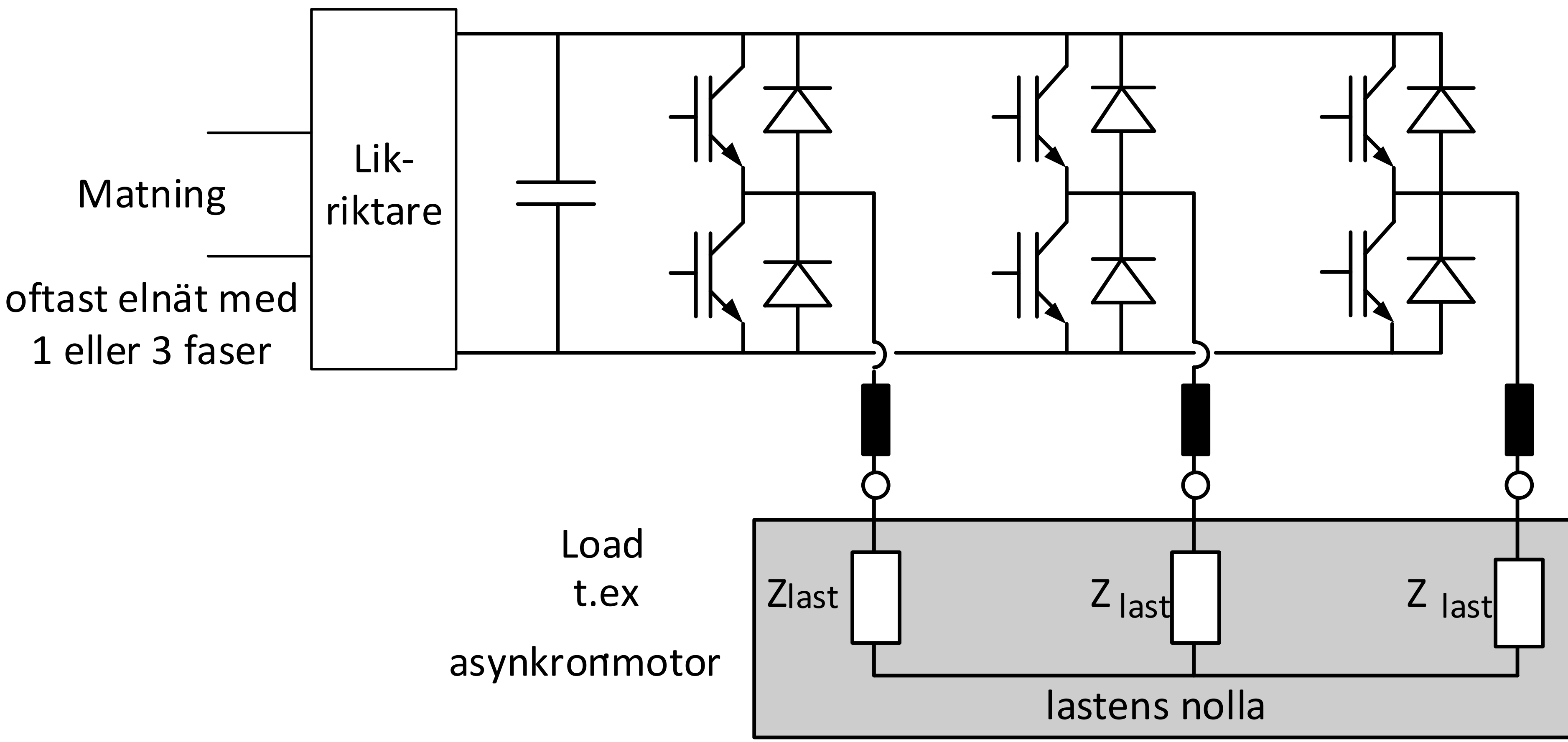


Simplified *i*-*v* characteristics

From dc- to ac-voltage



Three phase inverter

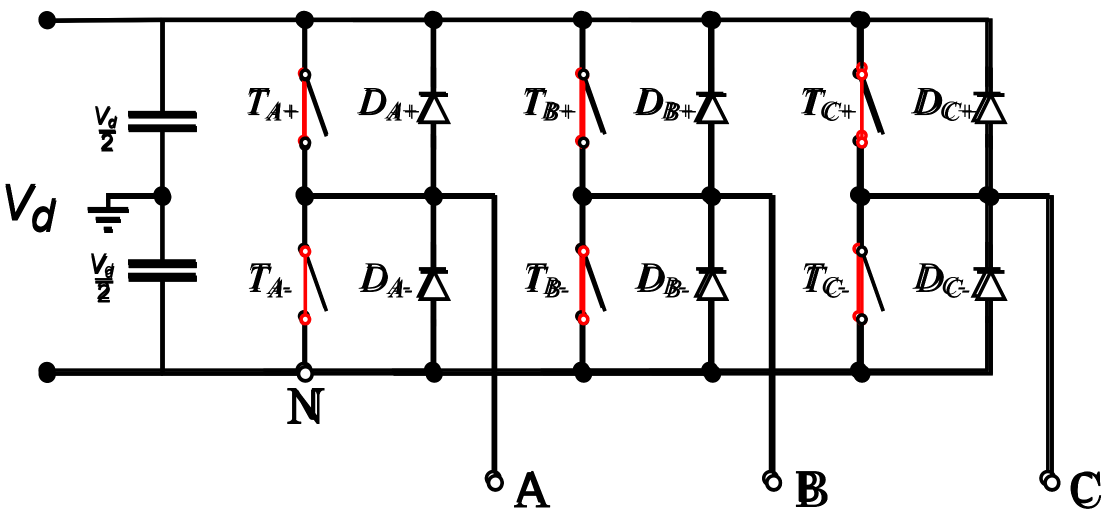


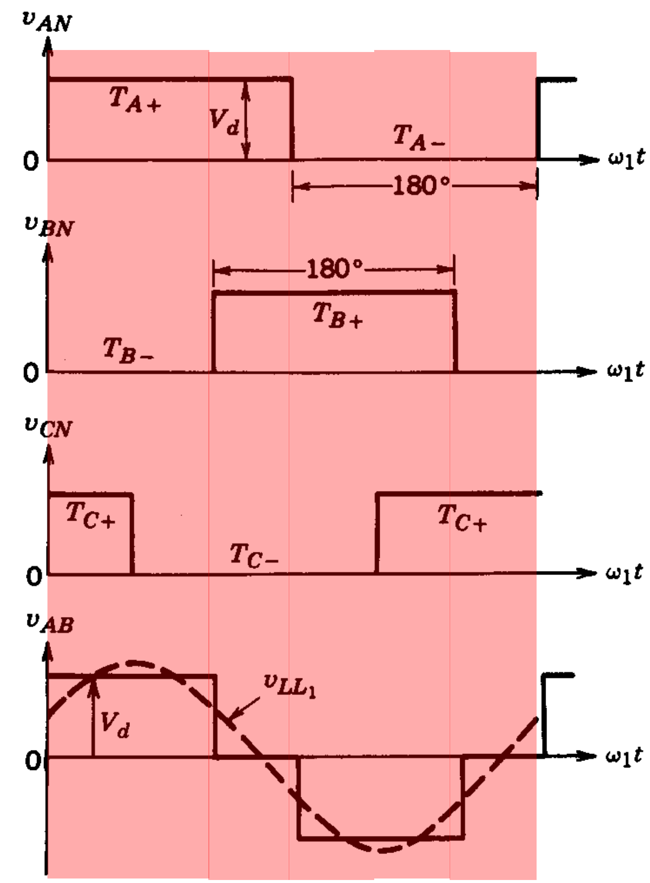
http://people.ece.umn.edu/users/riaz/animations/inverter3phase.html

Three-Phase Inverter

Square Wave Mode

$$v_{AB} = v_{AN} - v_{BN}$$





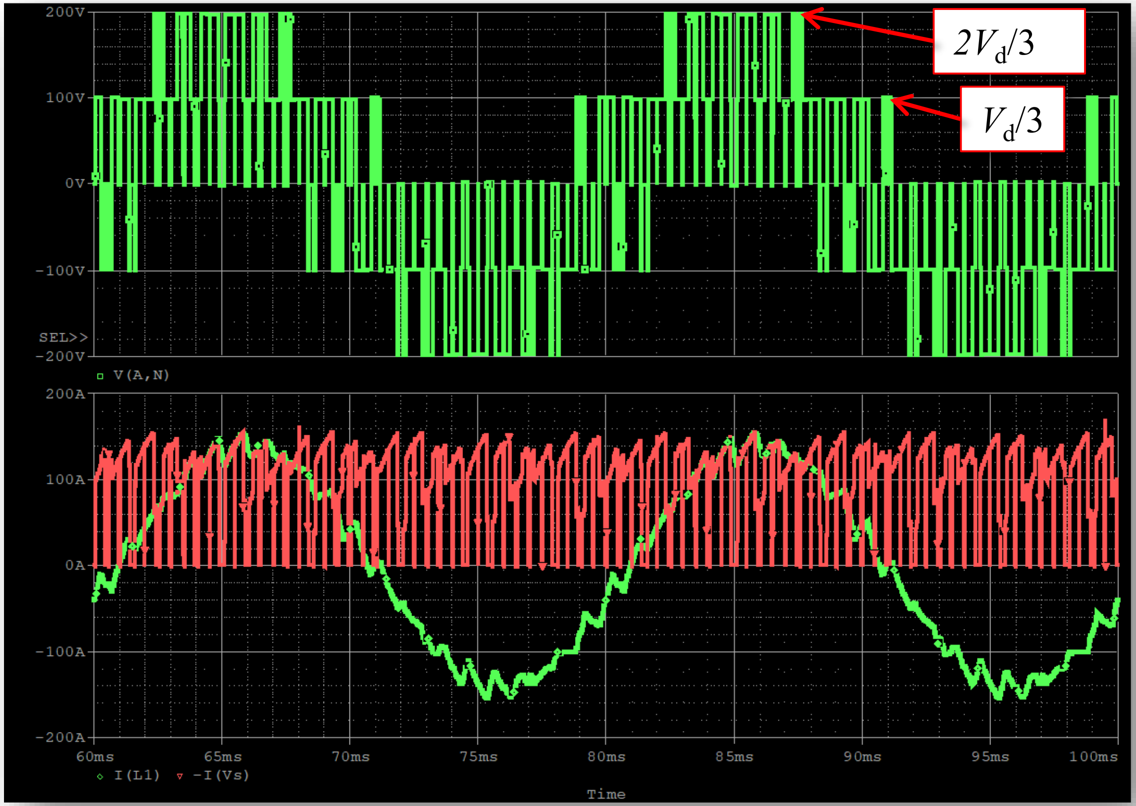
Ex: Show which switch is on at various time intervals

Undeland, Power Electronics
Figure 8-24, page 230

Three-Phase Inverter
PWM Operation With RL-Load

- If an RL-load is applied the source current will become positive and an active power will be consumed.

$$v_{An} = \frac{2}{3} v_{AN} - \frac{1}{3}(v_{BN} + v_{CN})$$



Diode rectifier

Diodes

AC/DC-rectifier

Used together with synchronous generators