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Power Supplies for Particle Accelerators

Carlos A. Martins

ESS – Accelerator Division – Power Converters Section Leader

www.europeanspallationsource.se

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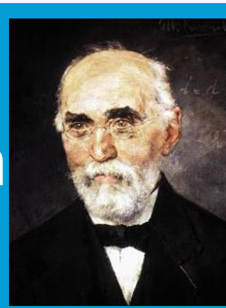
Principle of particle acceleration



Hendrik Lorentz (1853-1928)

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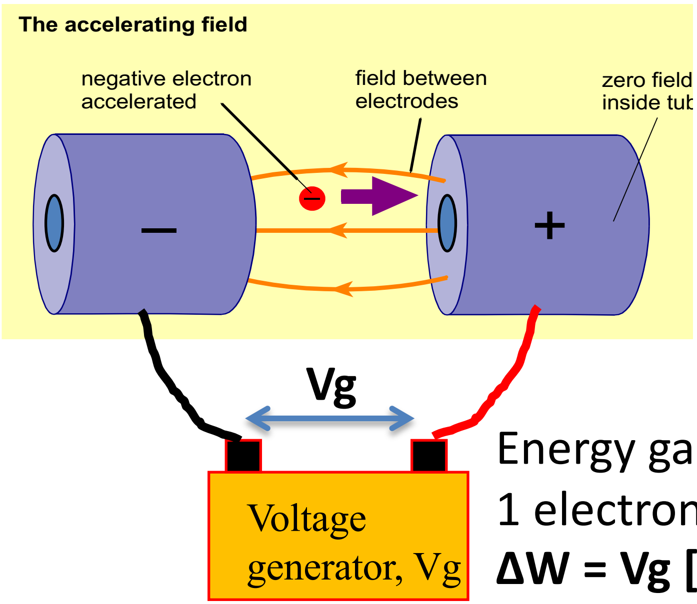
1st term of Lorentz equation

$$\boxed{\vec{F} = q\vec{E}} + q(\vec{v}\ x\ \vec{B})$$

linear acceleration



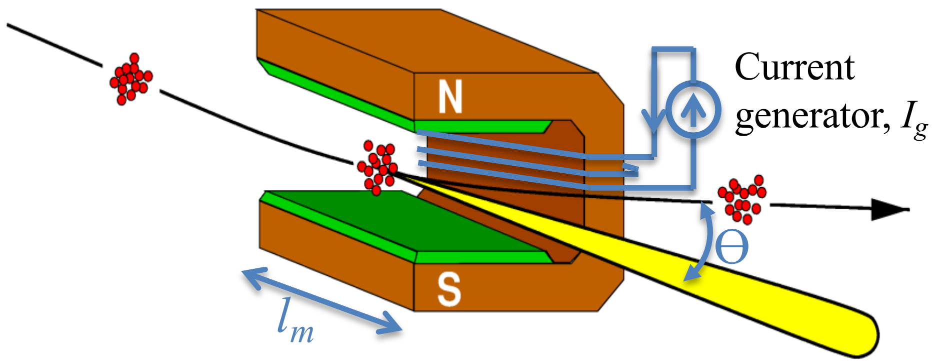
Energy gain, for 1 electron:

ΔW = Vg [eV]

2nd term of Lorentz equation

$$\vec{F} = q\vec{E} + \boxed{q(\vec{v}\ x\ \vec{B})}$$

Centripetal acceleration



Energy gain, for 1 electron:

ΔW = 0

Linear Acceleration:
Method 2: AC / RF accelerator

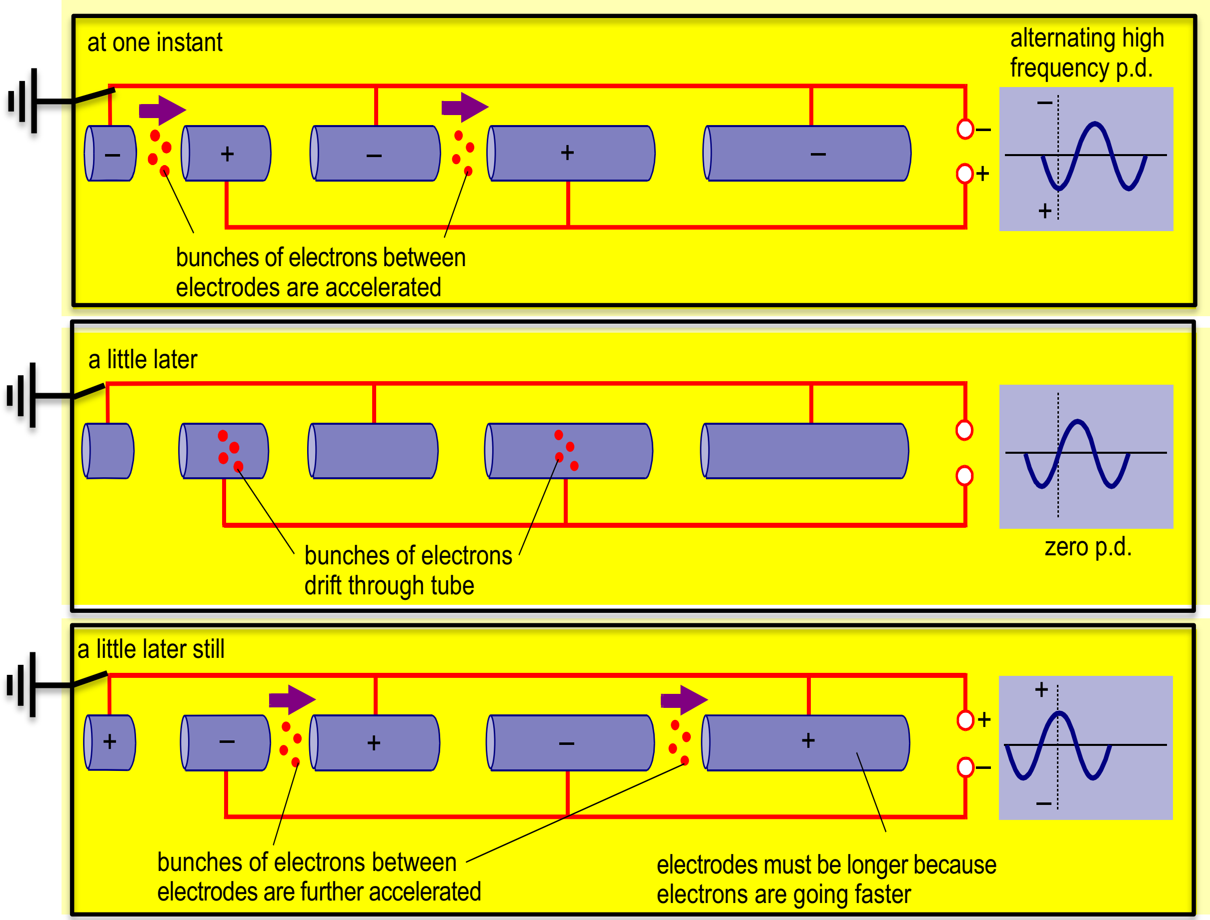
1st term of Lorentz equation

$$\boxed{\vec{F} = q\vec{E}} + q(\vec{v} \; x \; \vec{B})$$

linear acceleration

Principle:

- An AC voltage is applied between multiple electrodes by a single generator, creating electrical fields to accelerate the particles;
- For high efficiency and compactness, the AC voltage must be generated by a RF (Radio Frequency) amplifier;
- Power Supplies are required to power these RF amplifiers;



Linear Acceleration: General architecture of a RF source - Schematics and main components

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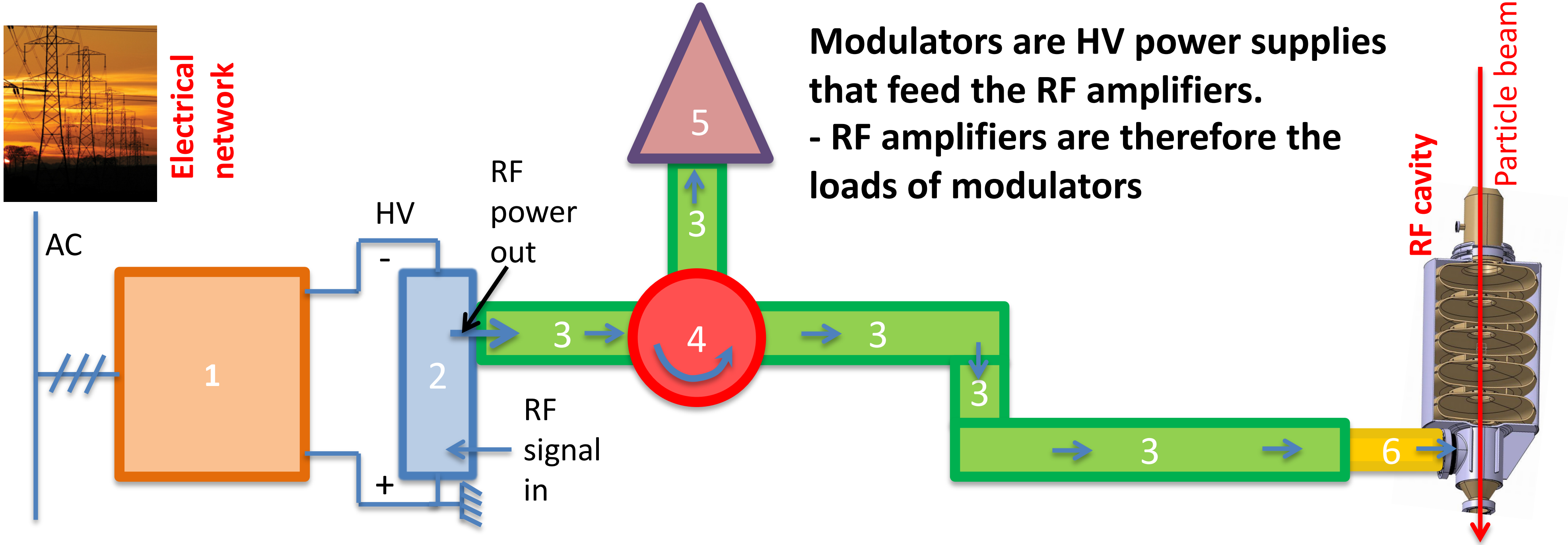


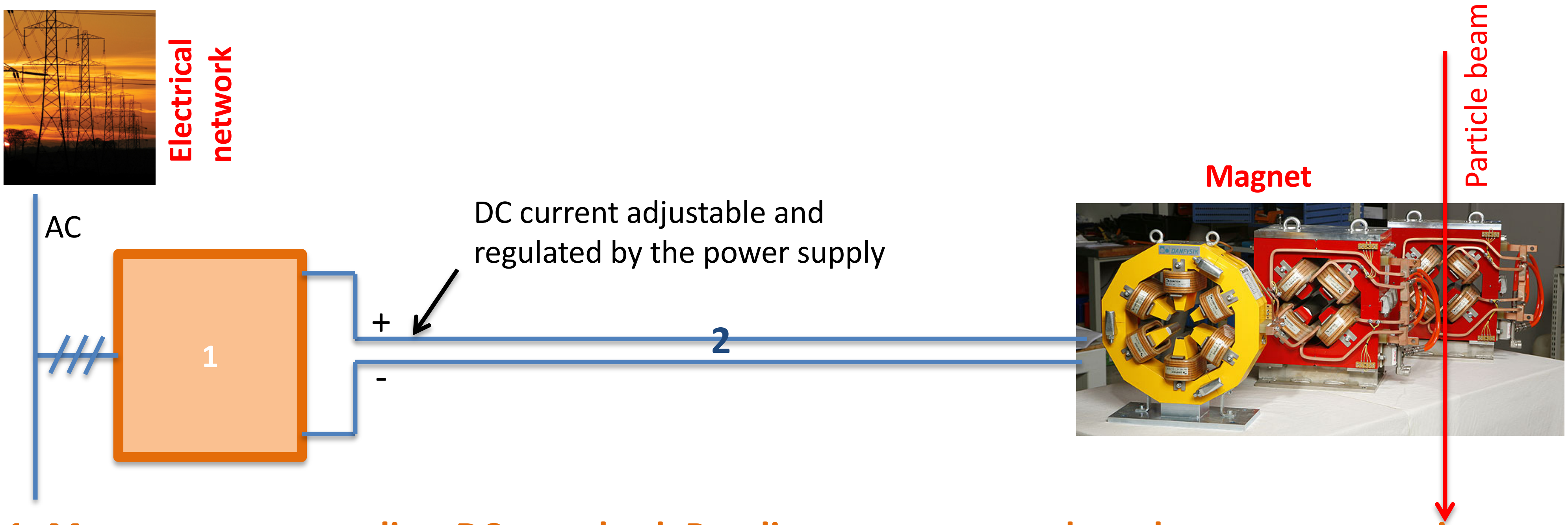
Modulators are HV power supplies that feed the RF amplifiers.
- RF amplifiers are therefore the loads of modulators

1- Modulator (HV power supply): DC or pulsed

2- RF amplifier (generator)

3- Waveguides; 4- circulator; 5- RF load; 6- power coupler;

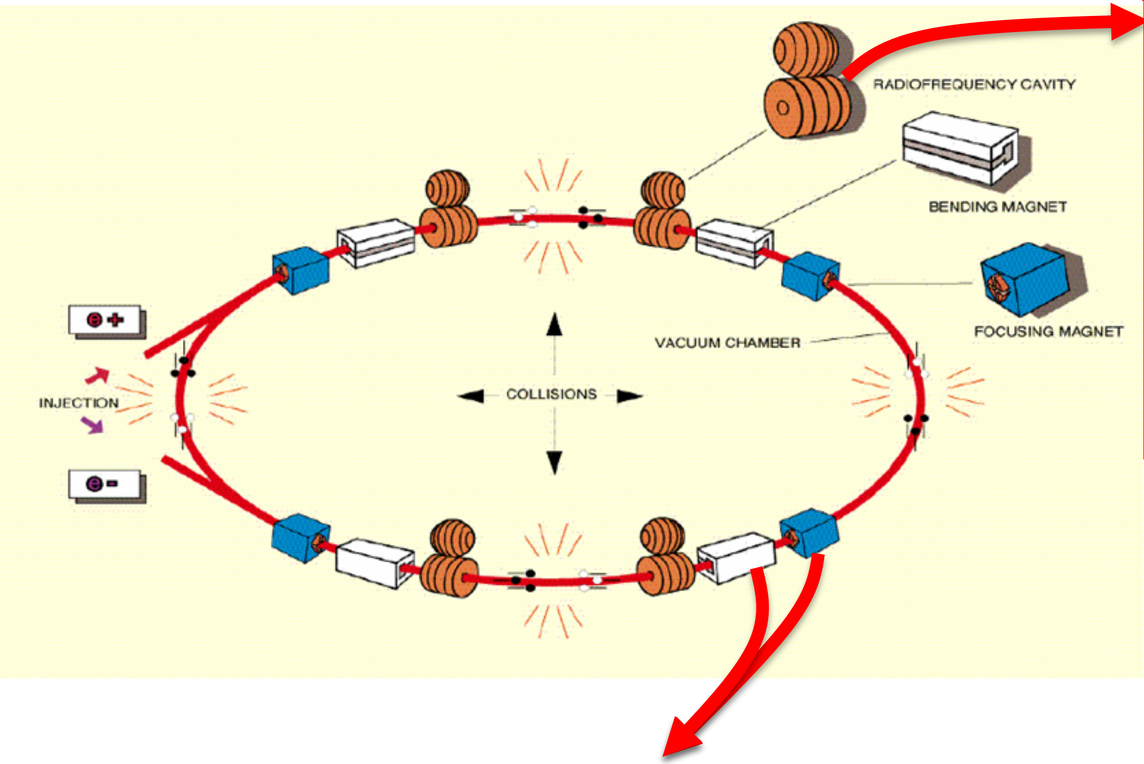
Centripetal Acceleration: Power supply to magnets - Schematics and main components



1- Magnet power supplies: DC or pulsed. Bending magnets; quadrupole magnets; steering corrector magnets

2- DC power cables

Power Supplies in Particle Accelerators: - Typical Requirements



High Voltage power supplies for RF amplifiers:

- High Voltage (20kV to 300kV);
- High Power (100's kW to tens MW, Pulsed or DC);
- High voltage precision (0.2% to 1%);
- Very low short circuit energy;

High Current power supplies for Magnets:

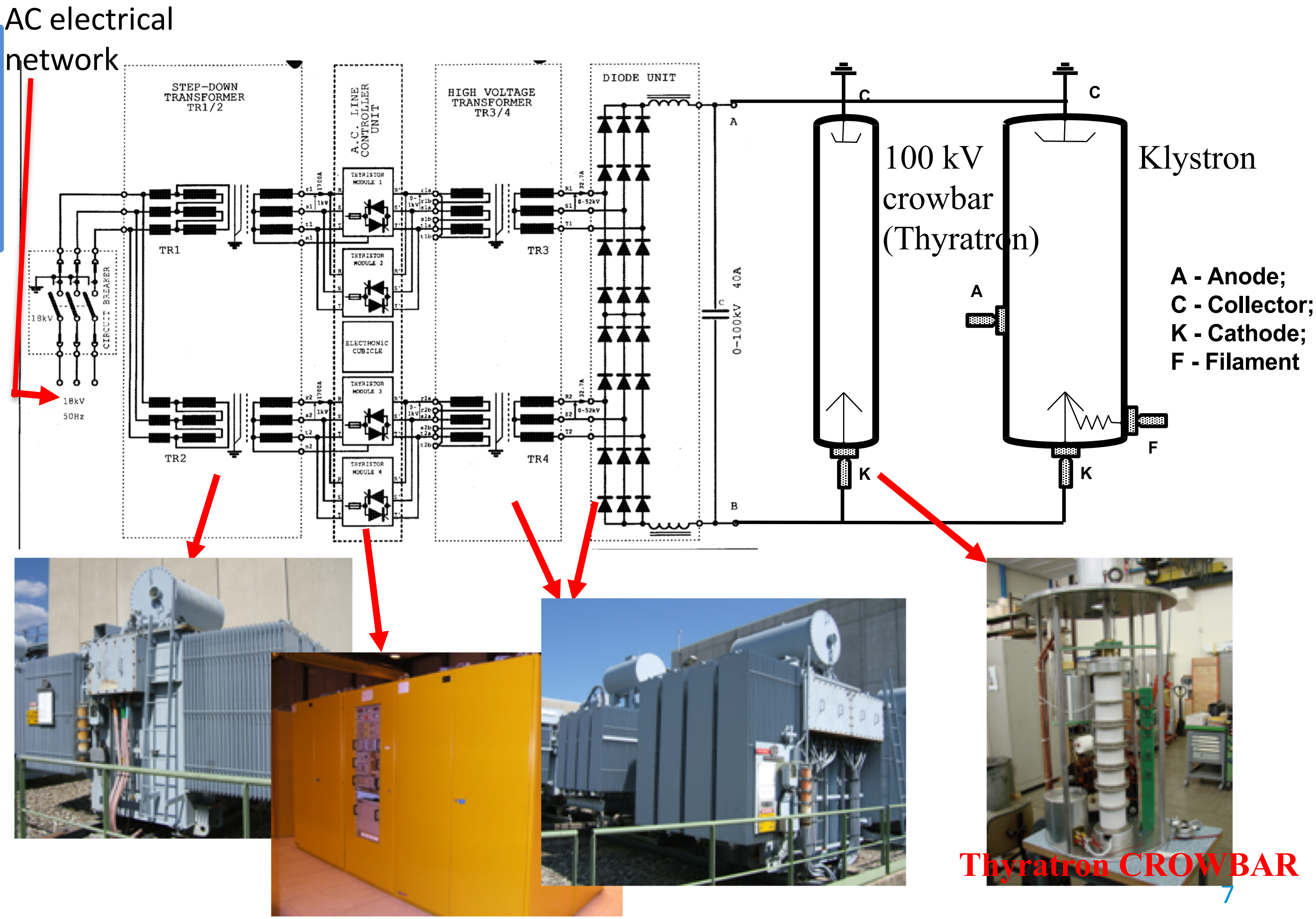
- High Current (from 10's A to ~20kA);
- High Power (10's kW to tens MW, Pulsed or DC);
- High current precision (10ppm to 100ppm);
- Protections for inductive loads;

For All power supplies:

- Low harmonic distortion on the electrical grid;
- High reliability (MTBF's > 50'000 hours);
- Compact;
- Cost effective;

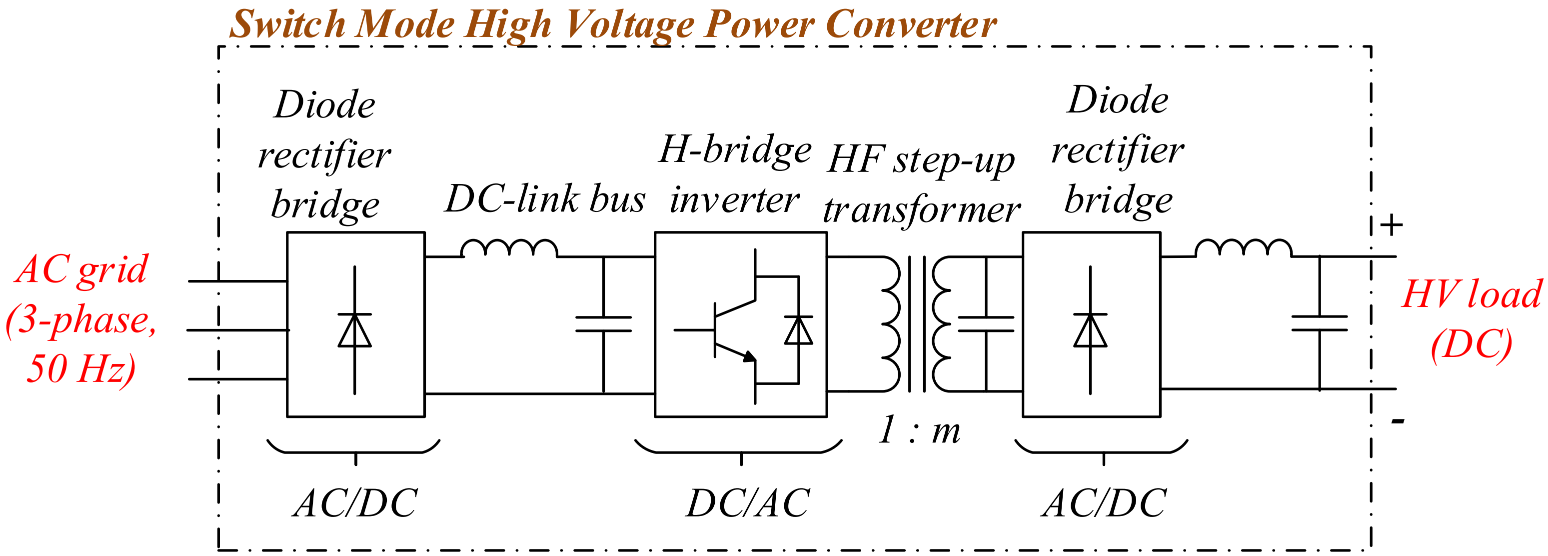
Modulators:
- CW (Continuous Wave) modulators conventional topology

- For high power (> 100's kW), usually need to be custom made;



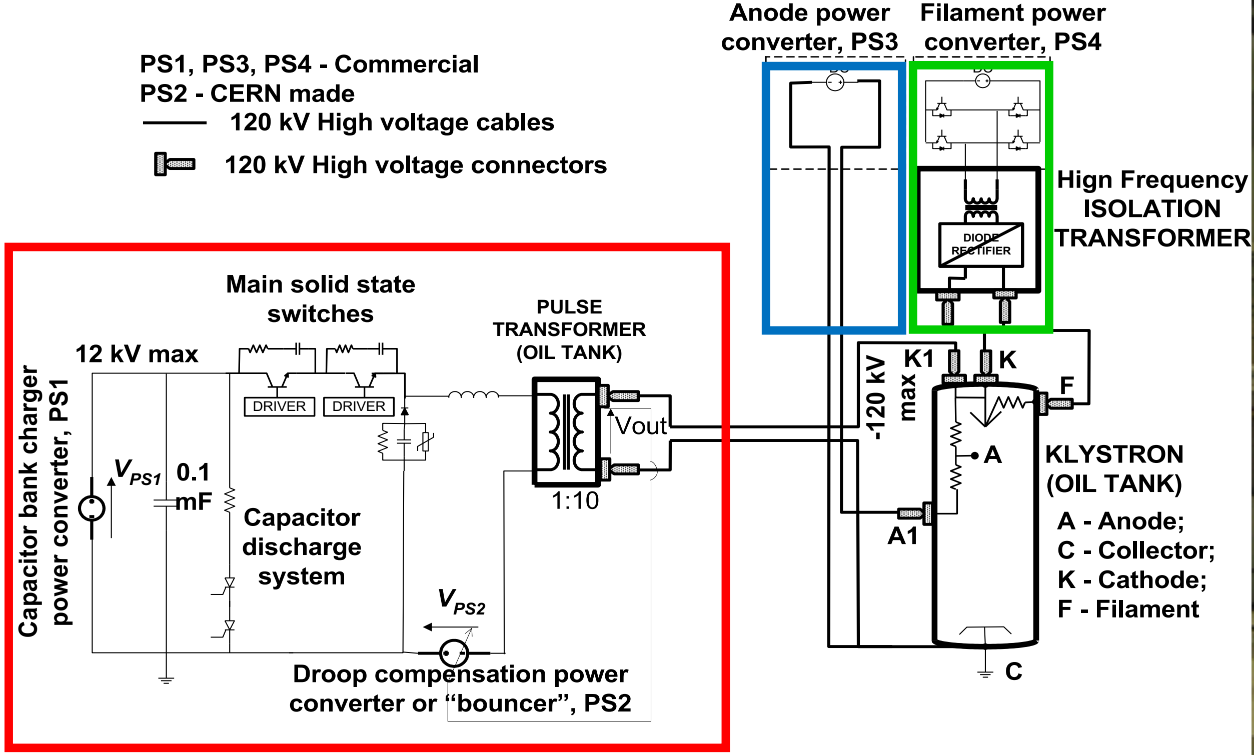
Modulators:
- CW (Continuous Wave) modulators modern switch mode based topology

- For low and medium power ranges (up-to ~100kW), can be commercial "of-the-shelf";



Pulsed modulators for klystrons:- Topology based on pulse transformer. Example of CERN Linac4

Simplified schematics



- For long pulses, modulators are generally custom made, independently on rated power;
- For short pulses (< 20µs), can be commercial "of-the-shelf" up-to power levels of ~100kW. Above this limit, must be custom made.

Pulsed modulators for klystrons:
Examples of ESS "of-the-shelf" modulators

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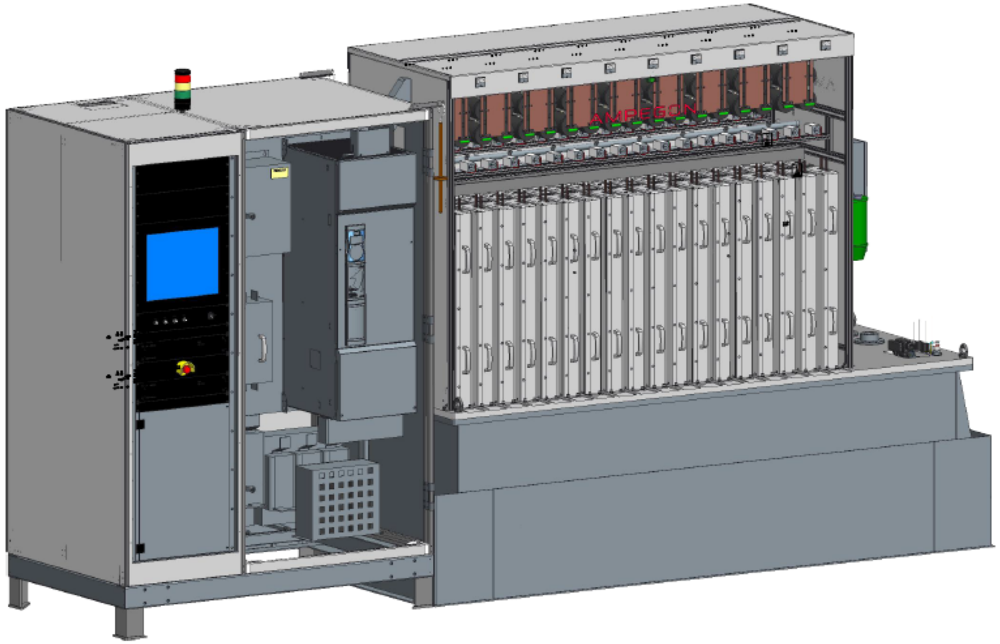
115 kVpk, 25Apk, 2.8ms, 14 Hz

1st ESS/CERN modulator prototype
(able to feed 1 klystron)

115 kVpk, 50Apk, 3.5ms, 14 Hz



2nd ESS modulator prototype
(able to feed 2 klystrons)

Modulators for ESS Accelerator
(SML topology; ESS “build-to-print” design)

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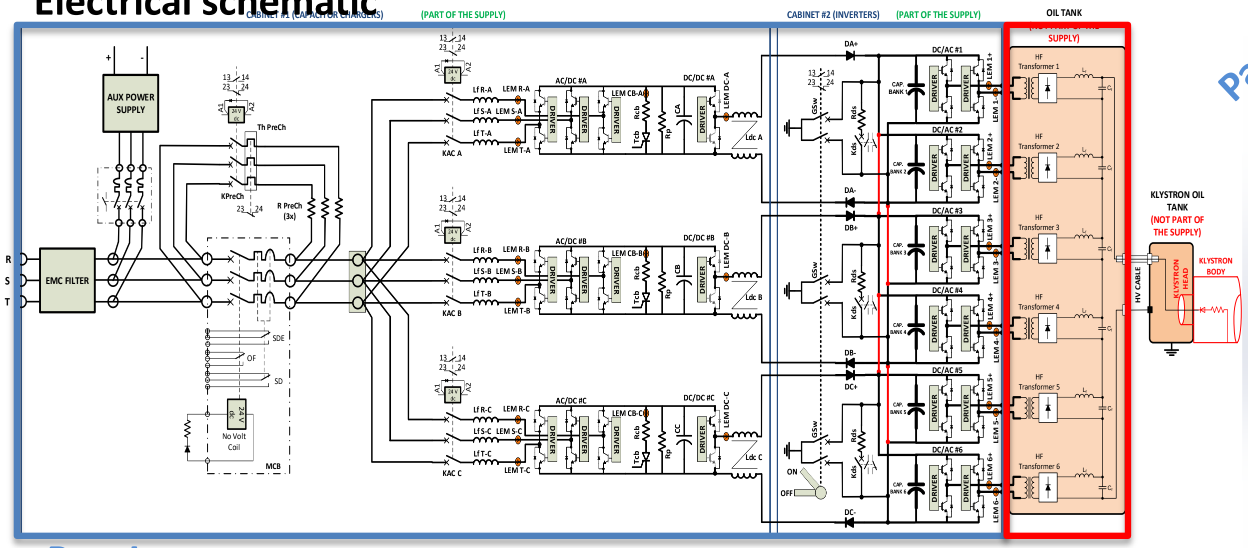
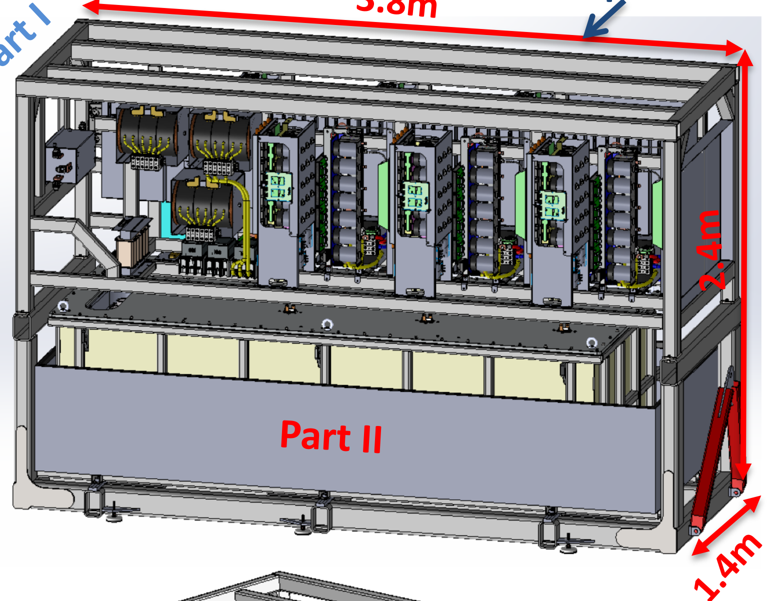
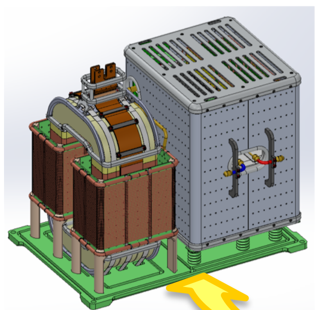
Electrical schematic



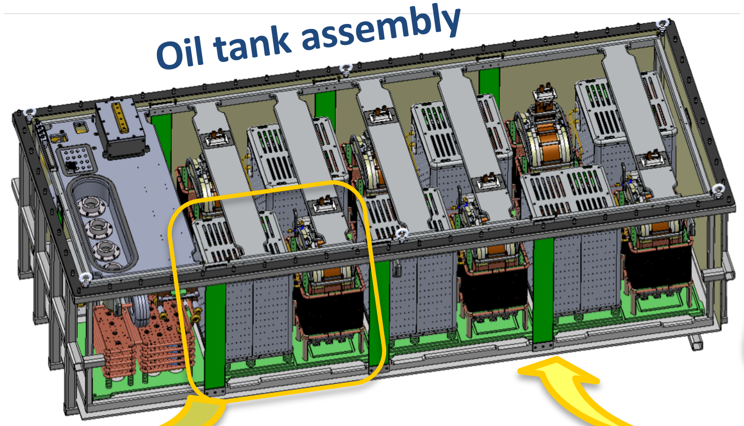


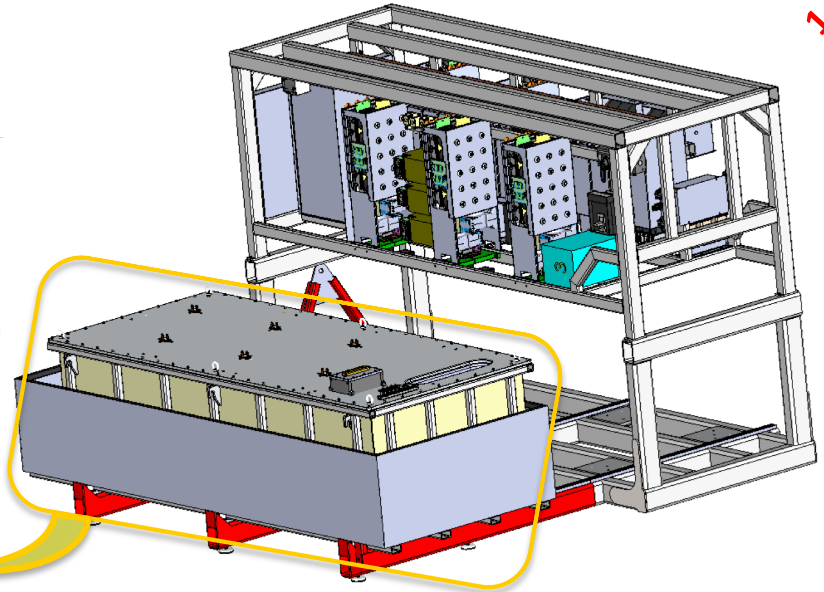
Modulator for ESS Accelerator
(able to feed 4 klystrons)

HV module



Oil tank assembly





Modulators for ESS Accelerator
(SML topology; ESS “build-to-print” design)

115 kVpk, 100Apk, 3.5ms, 14 Hz

Power supplies for magnets
Example3: Commercial "of-the-shelf"

Normal conducting magnets
(dipoles or quadrupoles)

+1000A; +100V

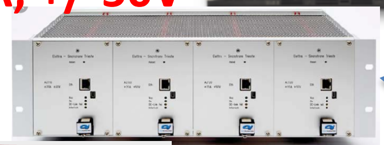
+20kA; +/-10V

Superconducting magnets
(dipoles or quadrupoles)

+200A; +100V

+200A; +50V

+/-20A; +/-50V

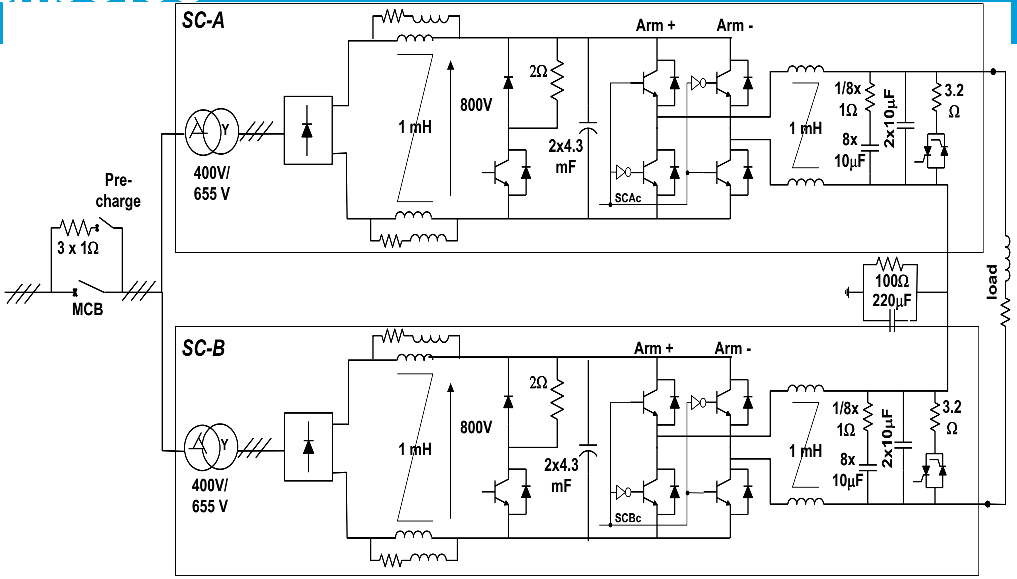


+/-100A; +/-100V

Normal conducting magnets
(steering correctors)

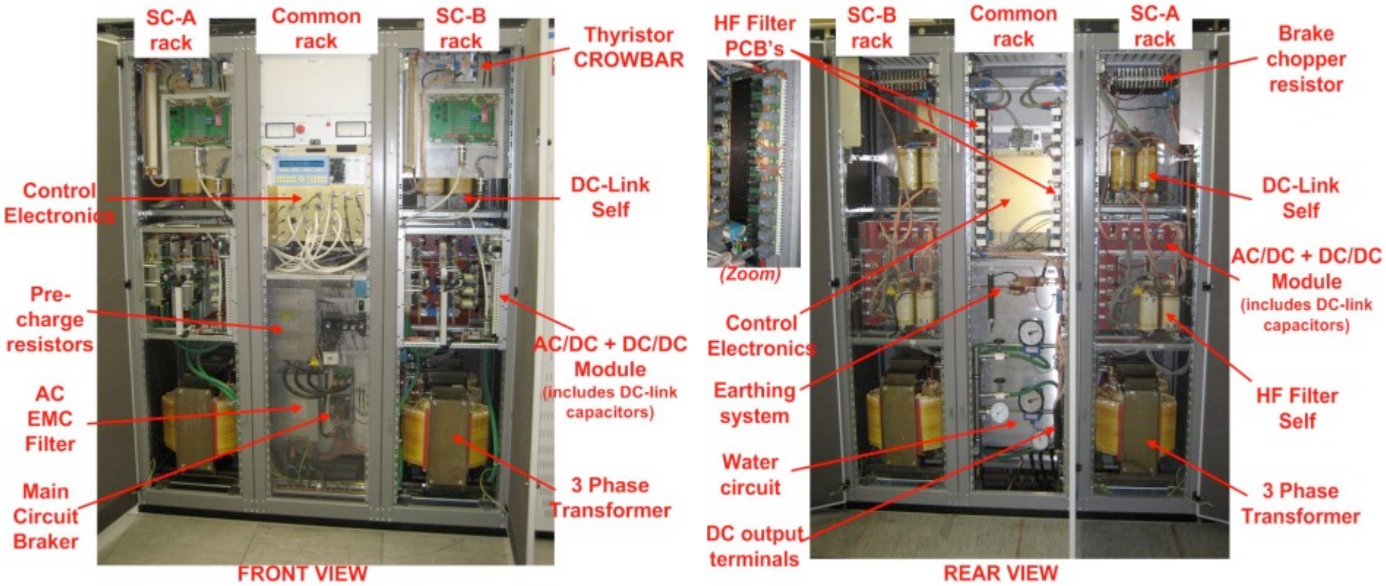
Power supplies for magnets

Example 1: steering/correction magnets of CERN Proton Synchrotron; similar for ESS dogleg bending dipoles



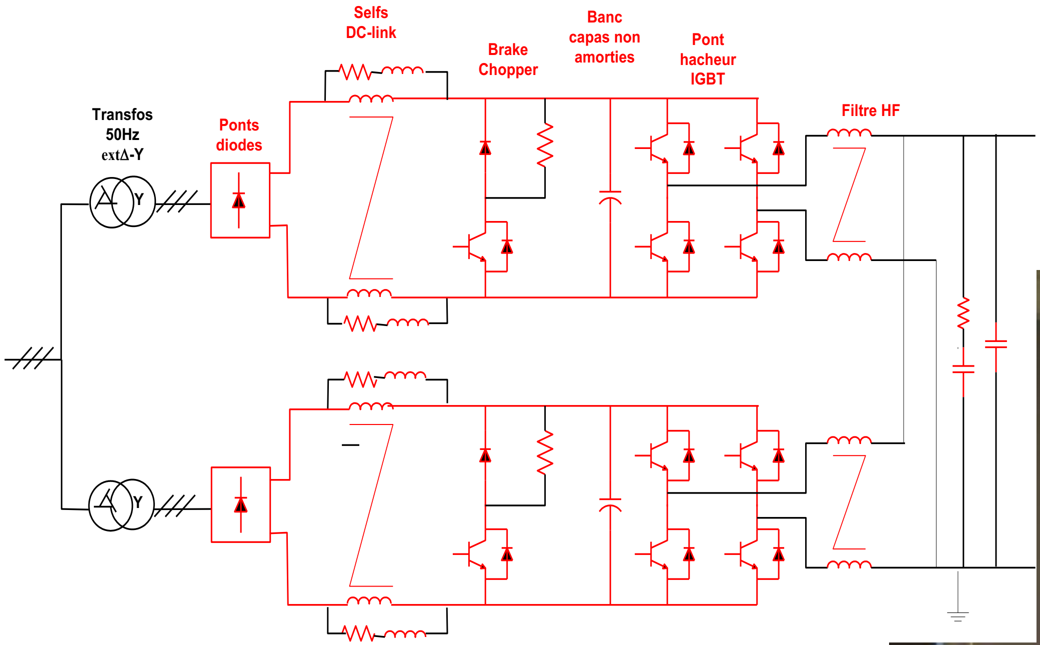
4-Quadrant

(+/-1200V, +/-250A)



Total size: 1800 mm (width) x 800 mm (depth) x 2400 mm (height)

Power supplies for magnets
Example 2: correction magnets of CERN Proton Synchrotron;



4-Quadrant, (+/-600V, +/-1600A)

Classical grid compensator topology

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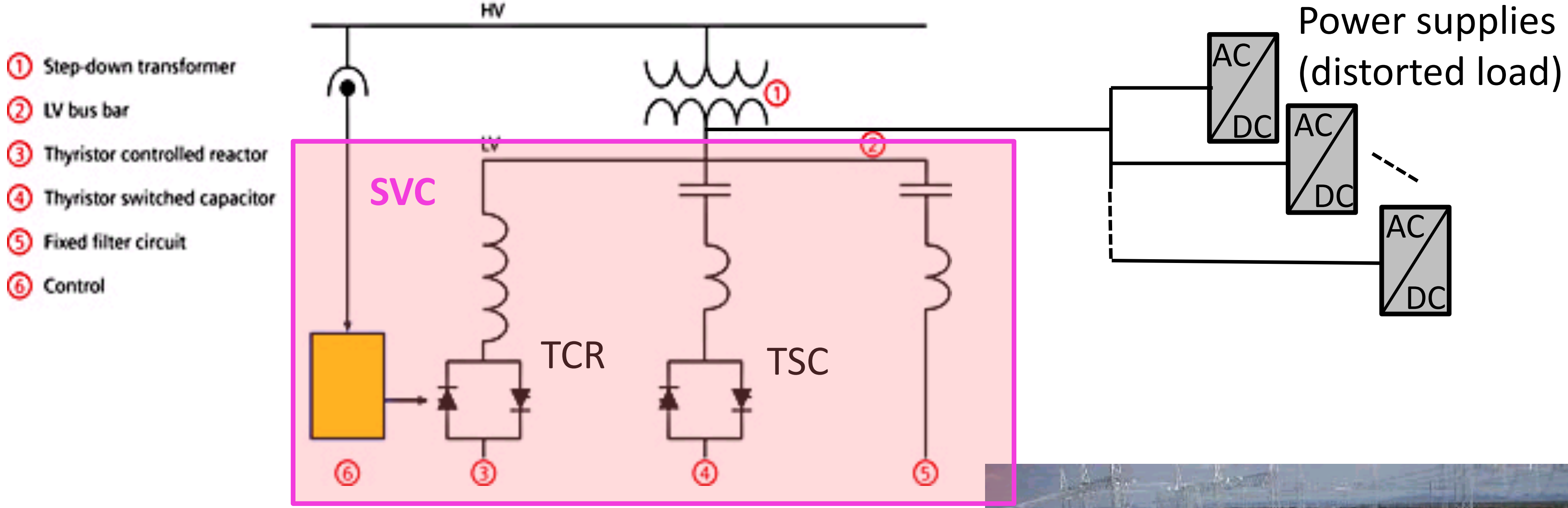
Centralized compensation scheme



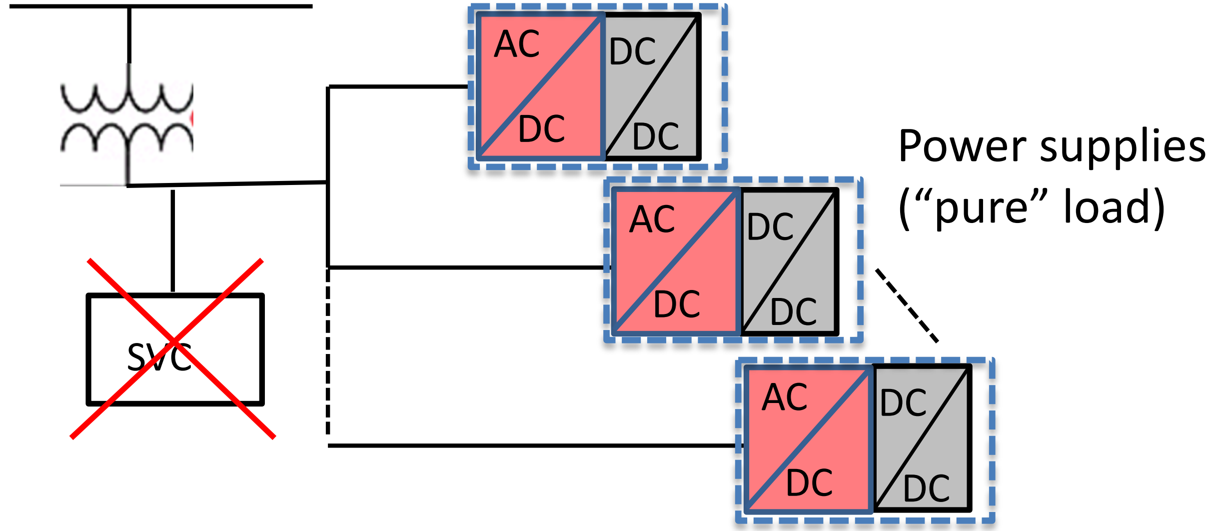
Static VAR Compensators (SVC's):

- Reactive power compensation;
- Voltage stabilization of the common LV or MV grid busbar (flicker mitigation);
- Current harmonic filtering (compliance with Energy Quality standards)

Bulky and expensive solution

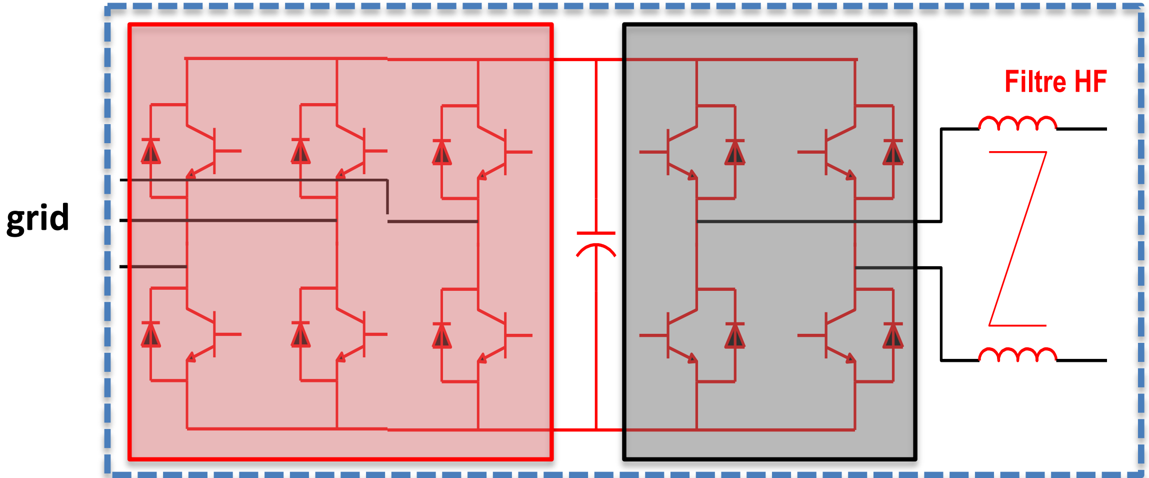
Grid Friendly Power Supply Topologies using Active Front End’s (AFE’s) AC/DC

Integrating compensation functionalities in the Power Supply structure



Example:

- ESS klystron modulators’ AC grid front end stage



AC/DC: Active Front End   DC/DC: IGBT H bridge

- Unitary power factor;
- Nearly zero harmonic distortion (sinusoidal current absorption)
- Energy recovery to the grid, if required