Renewable Energy Applications: Photovoltaic and Wind Energy Conversion Systems (WECS)

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Antoni Arias

Outline

1. Renewable Energy Perspectives
2. Solar Photovoltaic (PV)
3. Wind Generation
4. Power Electronics

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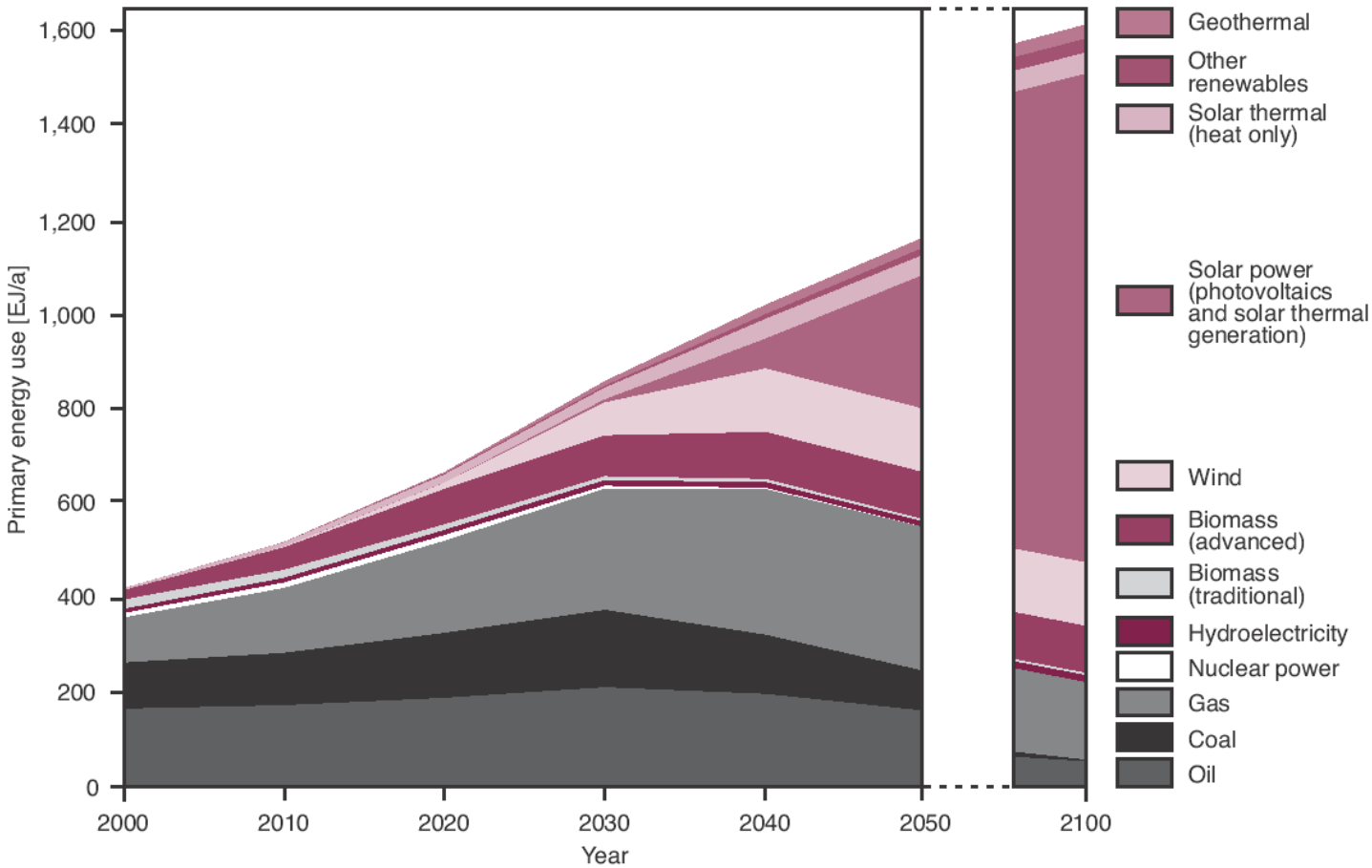
1. Renewable Energy Perspectives

Primary Energy Use



Estimation of primary energy

Source: German Advisory Council on Global Change 2003, WBGU

Energy Sources

- There will be a decrease in the use of power sources based on fossil fuels (especially coal and oil) and also nuclear.
- On the other hand, it is expected an increase in the use of the renewable energy, mainly photovoltaic, wind and waves.
- In the long term, the photovoltaic generation will be the key to cover power demand. Great changes in the photovoltaic cell technology are expected that will increase the ratio efficiency/cost.

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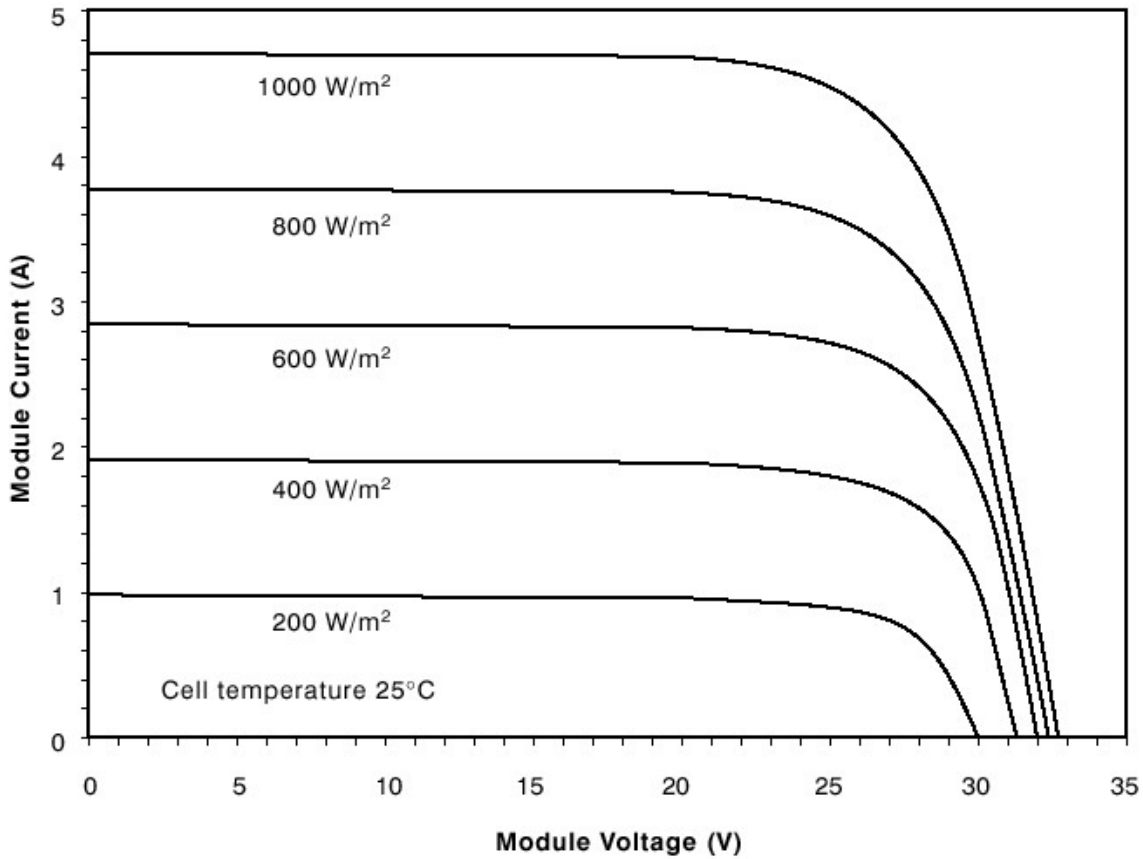
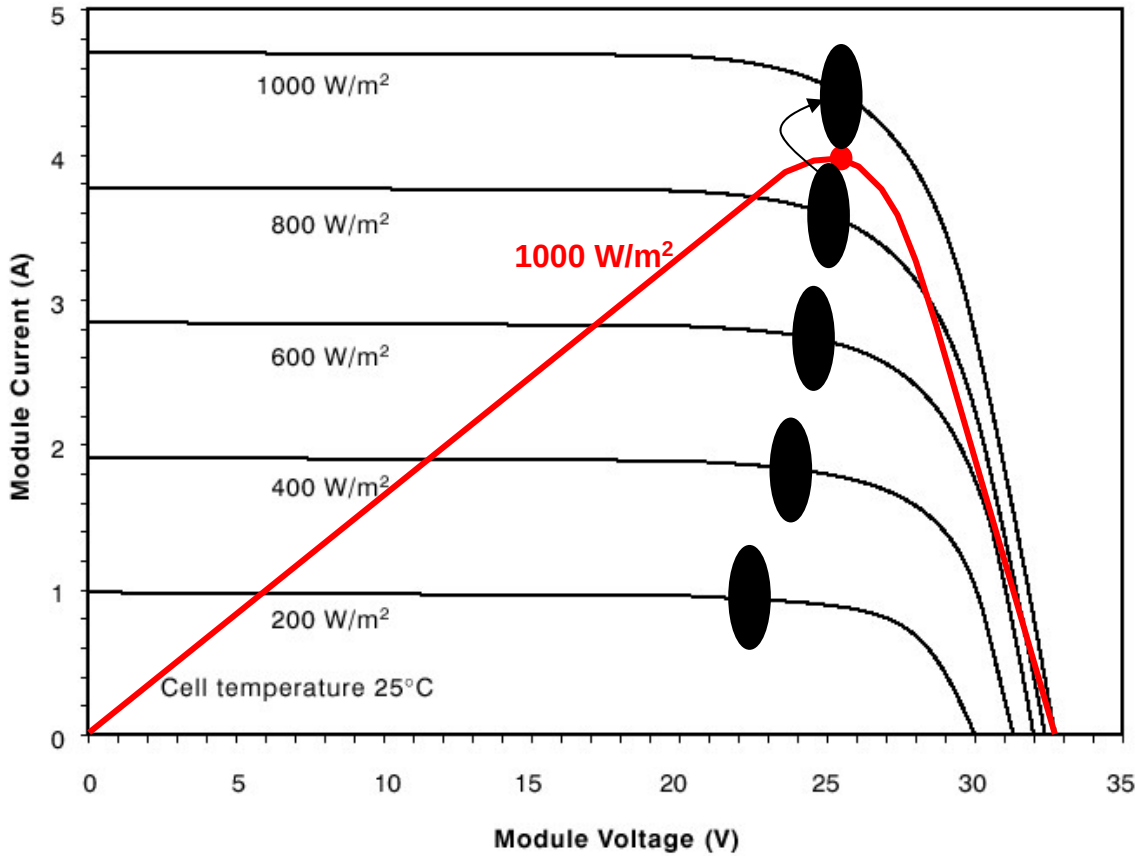
2. Solar Photovoltaic (PV)

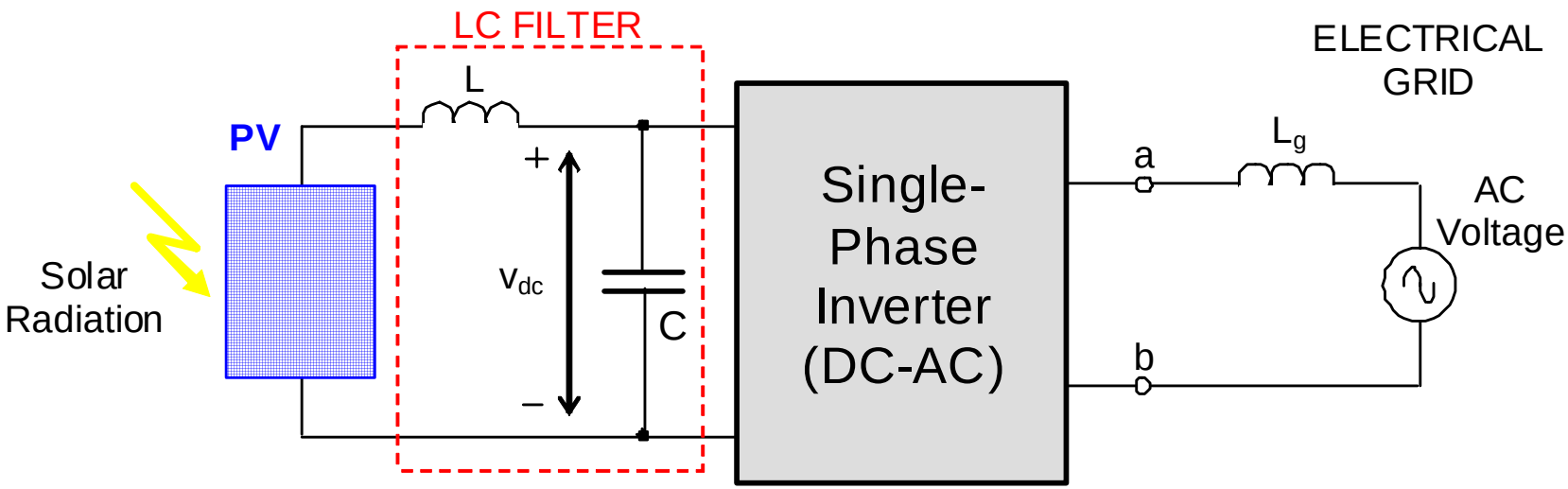


Maximum Power Point Tracking (MPPT)

Power (W)

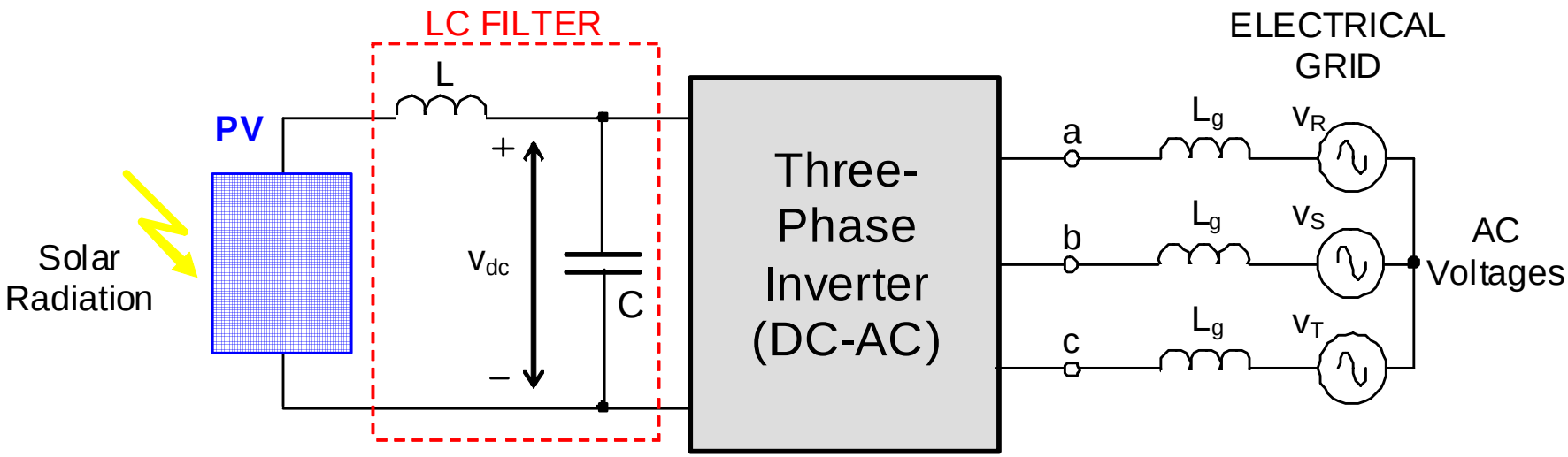


Single-Phase PV System



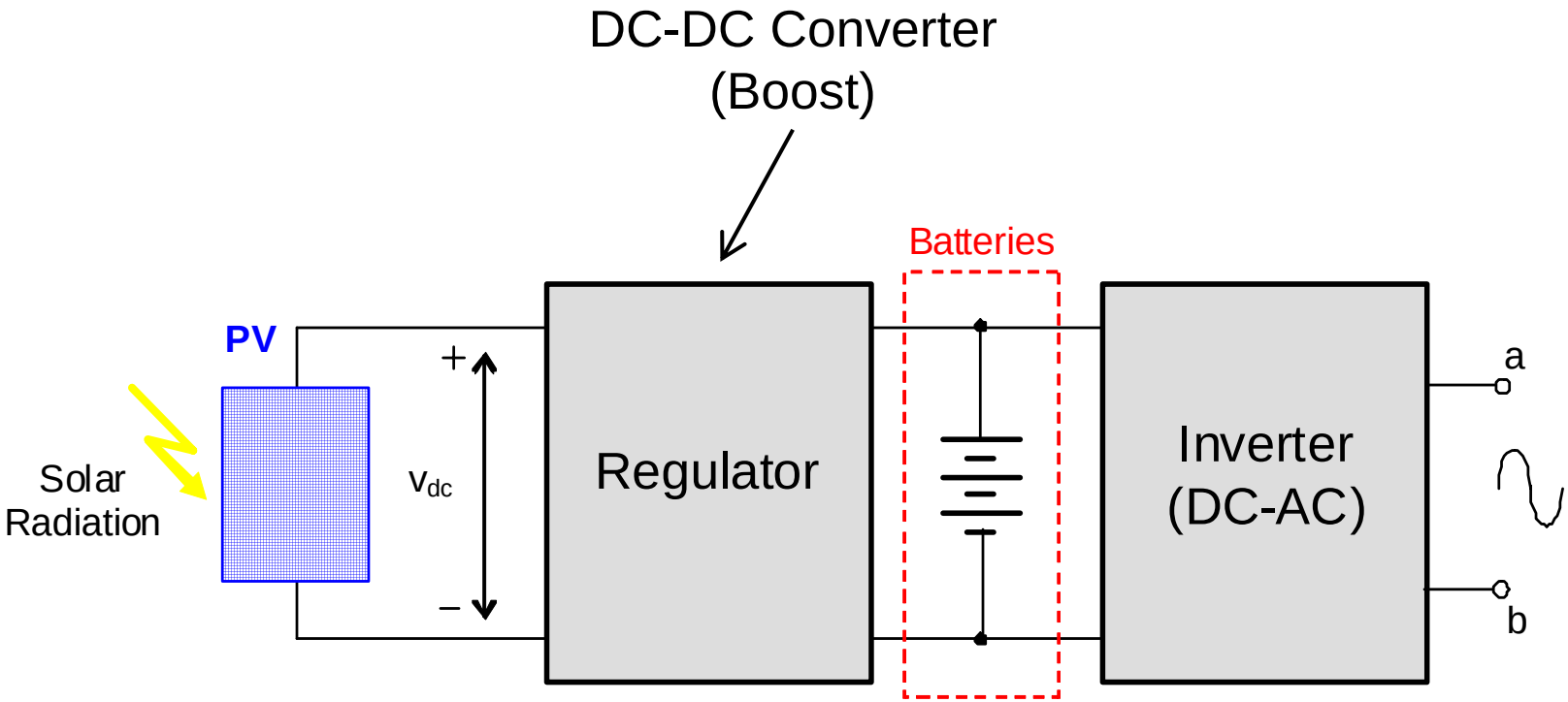
Low Power Systems (up to 5kW – 10kW)

Three-Phase PV System



High Power Systems (above 10kW)

Autonomous PV System



Example in Terrassa

Science Museum

Example in Barcelona

Forum Area

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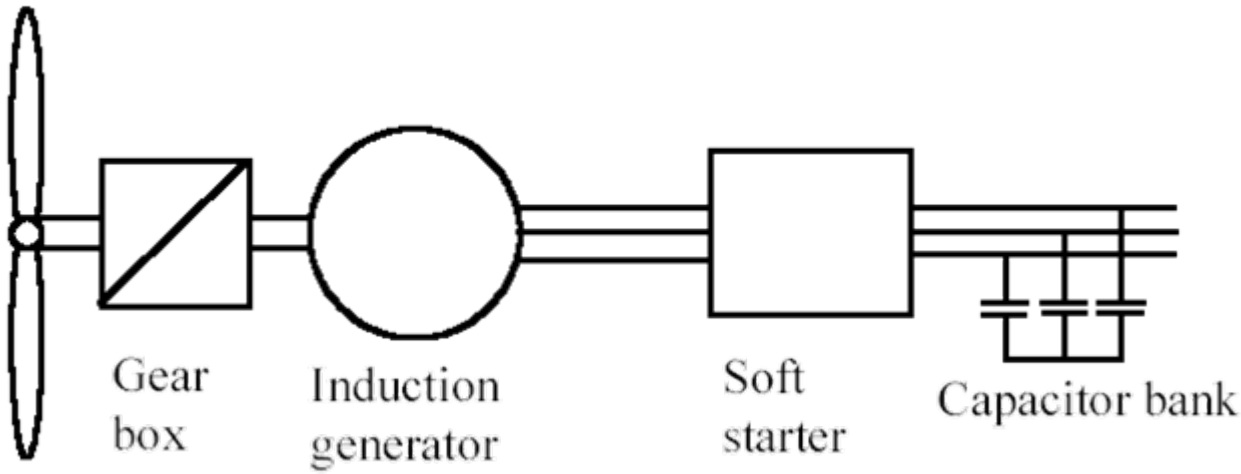
3. Wind Generation

Main classification:

- Fixed-speed wind turbines.
- Variable-speed wind turbines.

Fixed-Speed Wind Turbines



The electrical generator is connected directly to the grid.

- An induction generator is normally used.

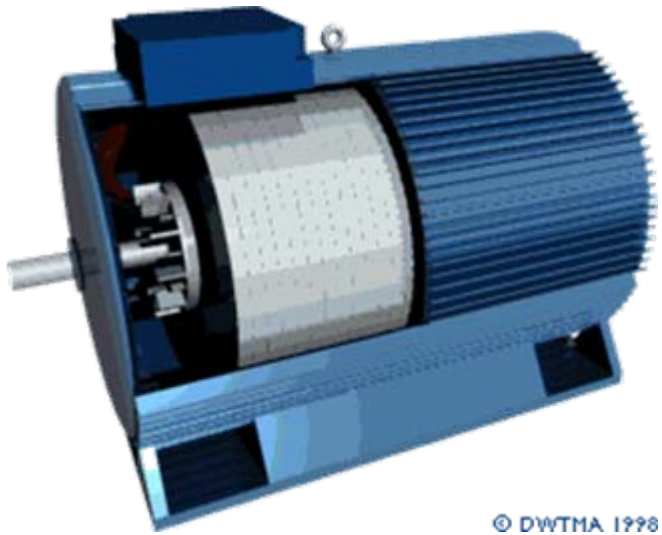
- Since the grid frequency is fixed, the speed of the wind turbine is settled by the ratio of the gearbox and by the number of poles in the generator.

Fixed-Speed Wind Turbines

Induction generator operating at fixed speed

Advantages:

- Robust design.
- No need for maintenance.
- Well enclosed.
- Produced in large series.
- Low price.
- Can withstand overloads.

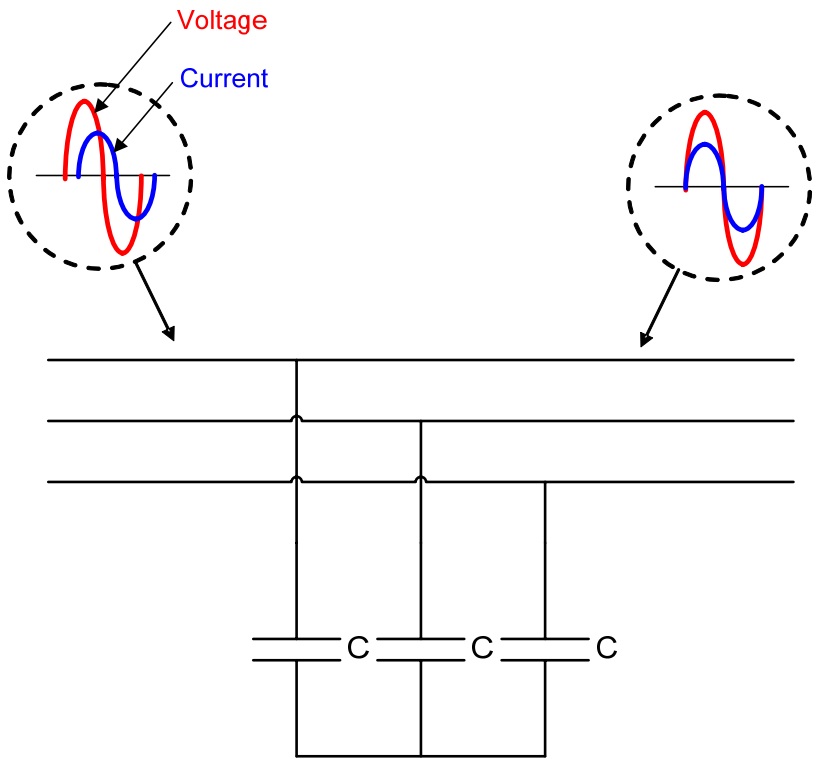


Disadvantages:

- Uncontrollable reactive power consumption.
- Fixed speed means more mechanical stress.

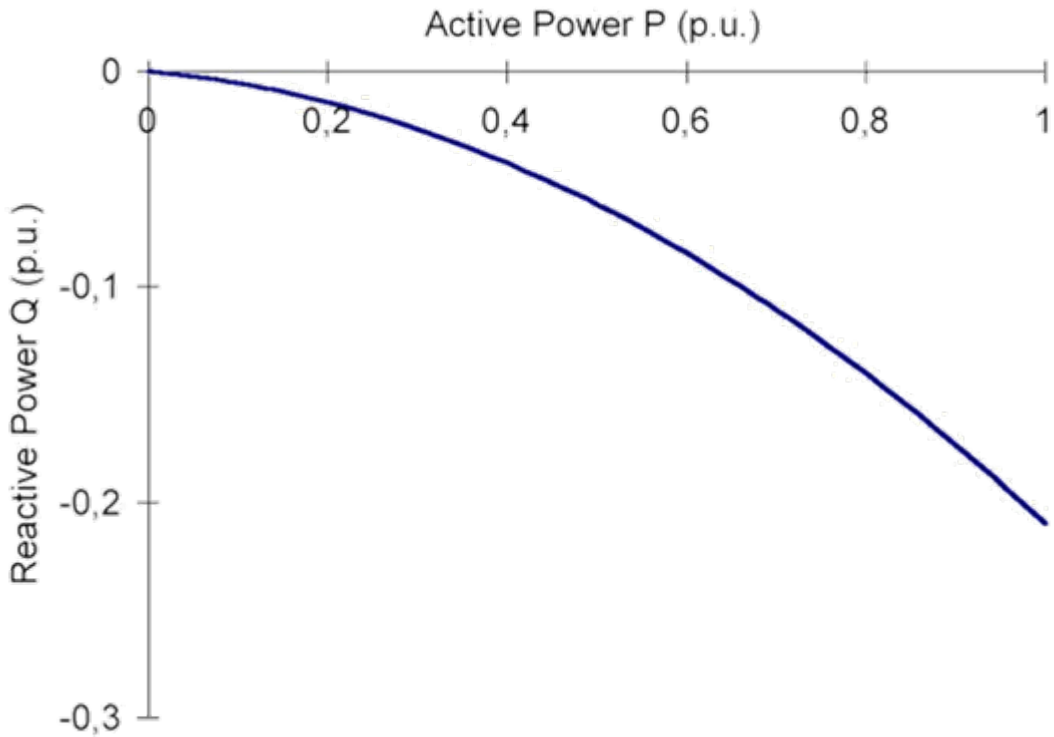
Capacitor Banks

- Capacitors banks compensate for reactive power from the induction generator.
- Maxim use of the electrical grid is done operating at unity power factor.



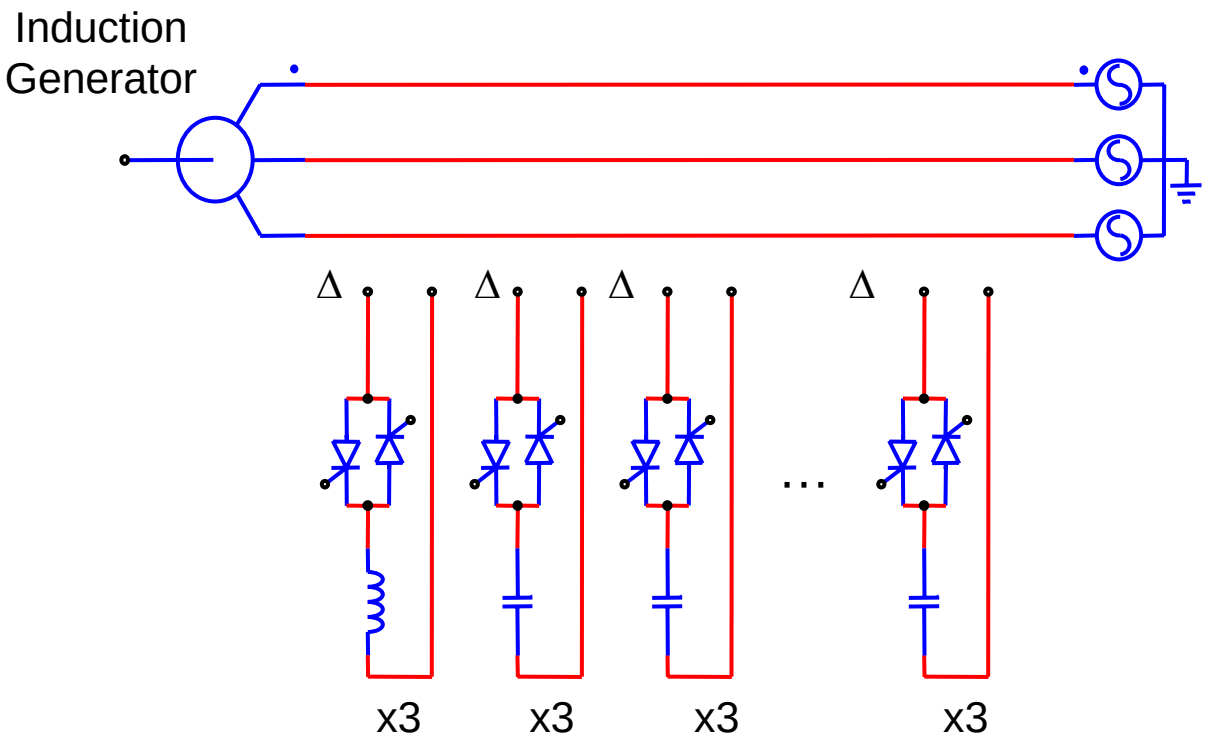
Reactive Power Compensation

Example of reactive power as a function of the active power
(The reactive power is compensated by capacitors at no-load)



Static VAr Compensator (SVC)

This device allows for a continuous compensation using switched capacitor banks and some inductors. They are connected to the grid by thyristors (SCR: Silicon Controlled Rectifier).



Gearbox

Why a gearbox is needed?

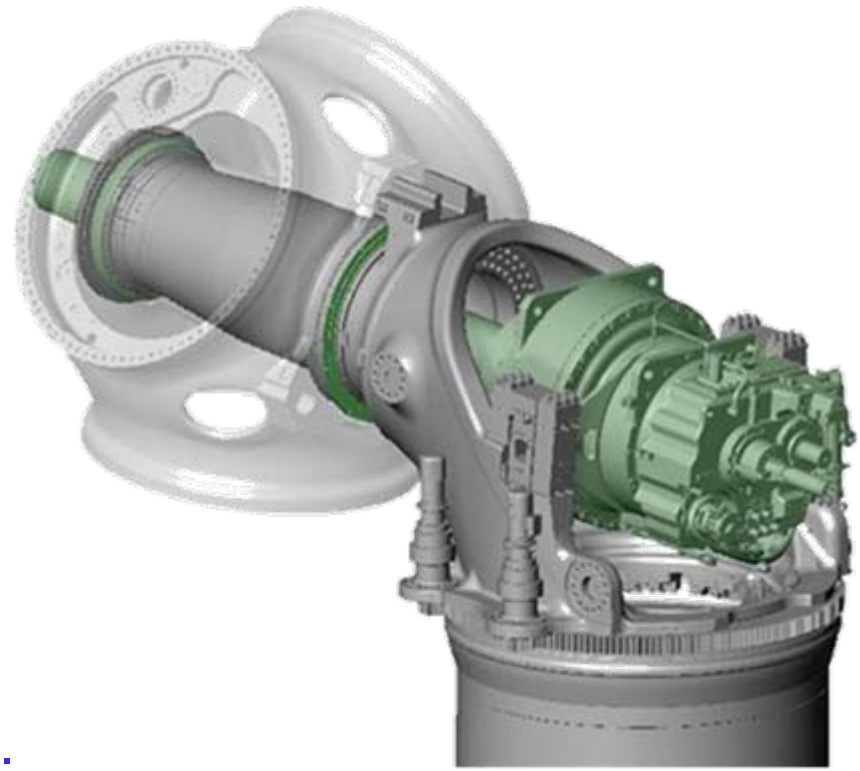
-The gearbox is used to increase the speed of the electrical generator.

- Without a gearbox, for a wind turbine rotational speed of 30 rpm, a generator of 100 pair of poles (!!!!) would be needed (assuming 50-Hz grid frequency).

- Furthermore, the mass of the rotor has to be roughly proportional to the torque.

$T=P/\omega$; if $\omega\downarrow$ then $T\uparrow$ for a constant P.

T: Torque, P: Power, ω: Rotational speed

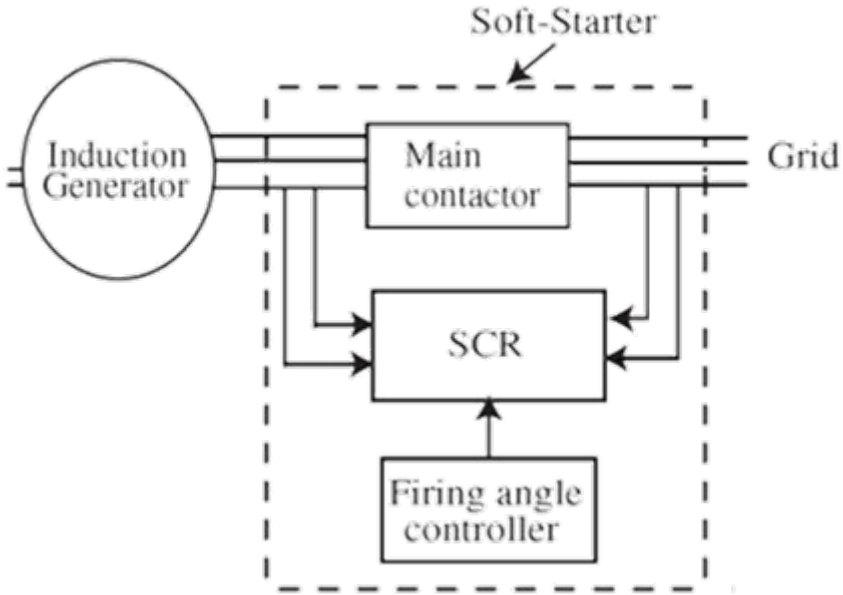


Soft-Starter

- If you connected (or disconnected) a large wind turbine generator to the grid with a normal switch, you would be quite likely to damage both the generator and the gearbox. Also large currents in the neighborhood grid would be produced.

- To prevent this situation, wind turbines connect and disconnect gradually to the grid using thyristors.

- To avoid thyristor losses under normal operation mode, a bypass switch is activated (main contactor).



Variable-Speed Wind Turbines

Variable speed

The frequency of the generator voltages can be different from the electrical grid (50-60 Hz) and therefore the turbine speed can change.

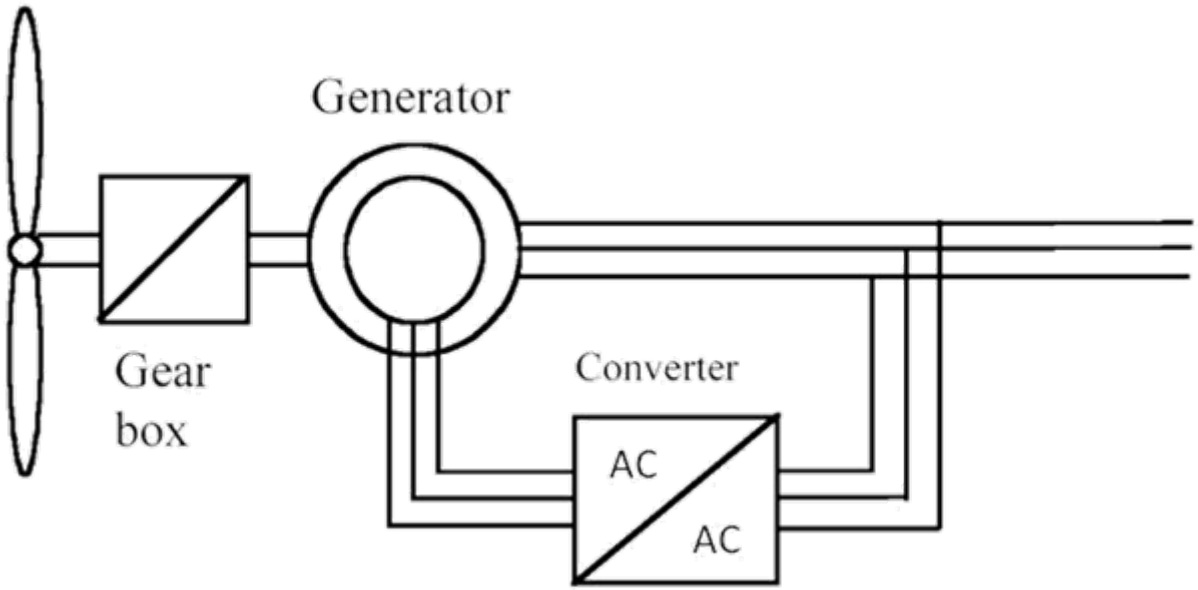
Advantages:

- More energy production.
- Less mechanical stress.
- Reduce power fluctuation.
- Capacity of noise reduction.
- May have more control on the grid currents.

Drawbacks:

- The system requires power electronic converters.
- More expensive.

Doubly-Fed Induction Generator (DFIG)

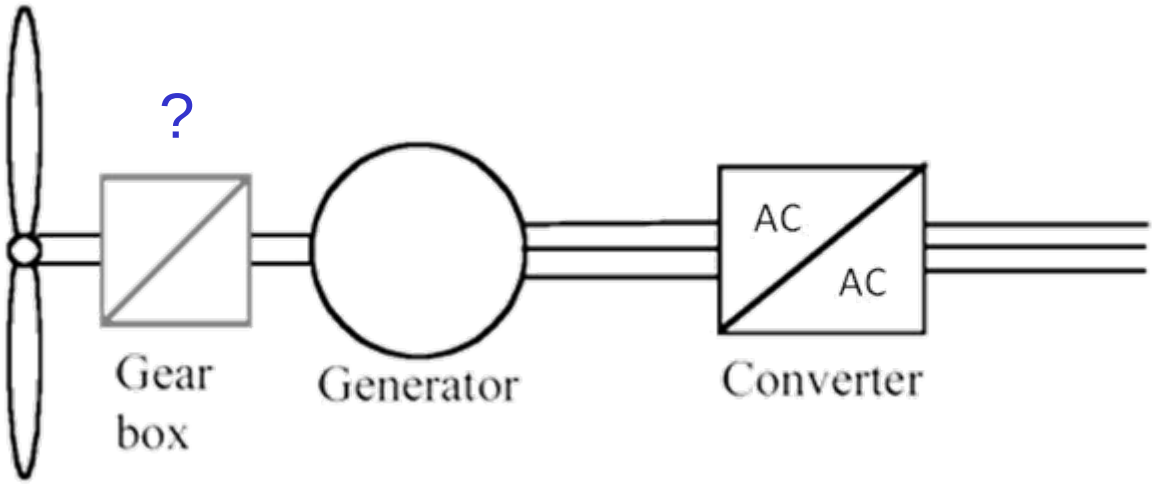


ALSTOM-ECOTECNIA

- The slip of the rotor can change within a wide range (and therefore the wind-turbine speed as well).

- It is the most common topology produced by large manufacturers nowadays.

Multipole Synchronous Generators (MPSG)



ENERCON E-126 (7 MW)

-Multipole synchronous generators may not need a gearbox (these generators have a large diameter).

- The rotational speed can change within a wide range.

- This is expected to be the most common wind turbine configuration in the future.

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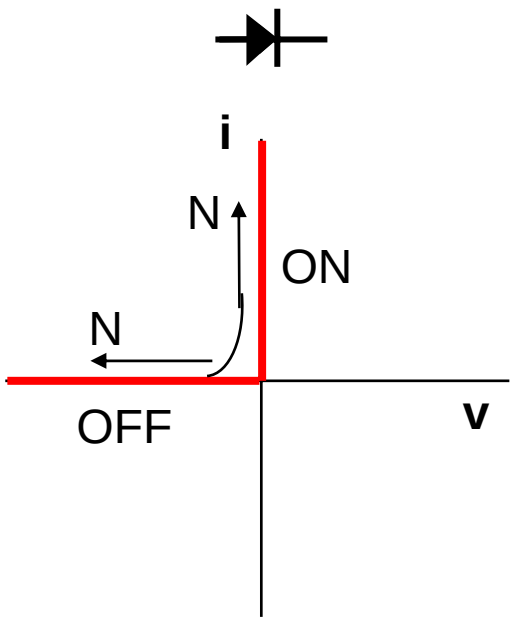
4. Power Electronics

- Power electronics is the engineering **study of converting electrical power from one form to another**.
- At a world-wide average rate of 12 billion kilowatts every hour of every day of every year, **more than 40% of the power generated is being reprocessed or recycled through some form of power electronic systems. By 2010, it is expected this will increase up to 80%.**

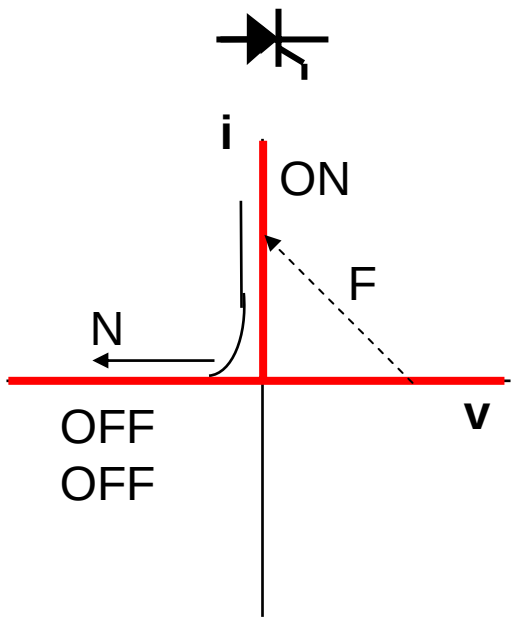
Source: North Carolina State University, Department of Electrical and Computer Engineering (http://www.ece.ncsu.edu/research/pes)

Power Electronic Semiconductors

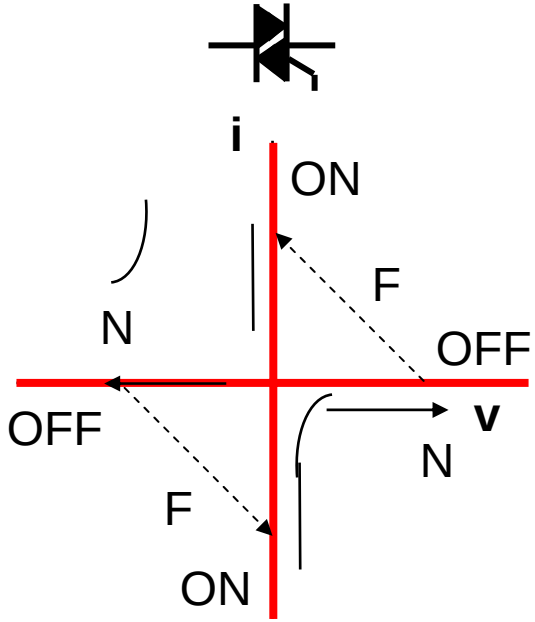
Diode



Thyristor or SCR
(Silicon Controlled
Rectifier)

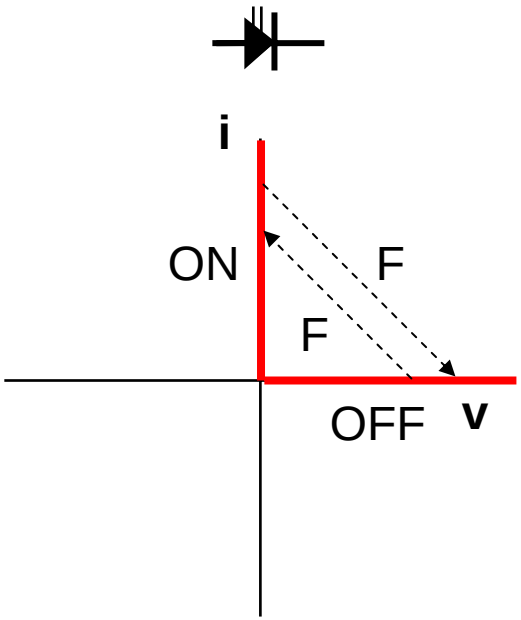


Triac

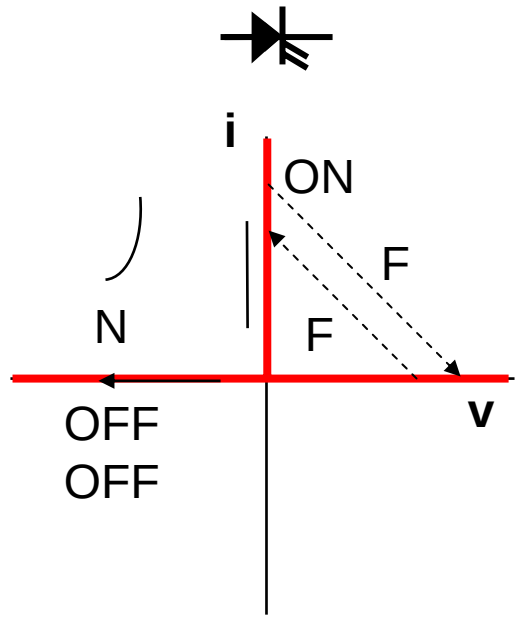


Power Electronic Semiconductors

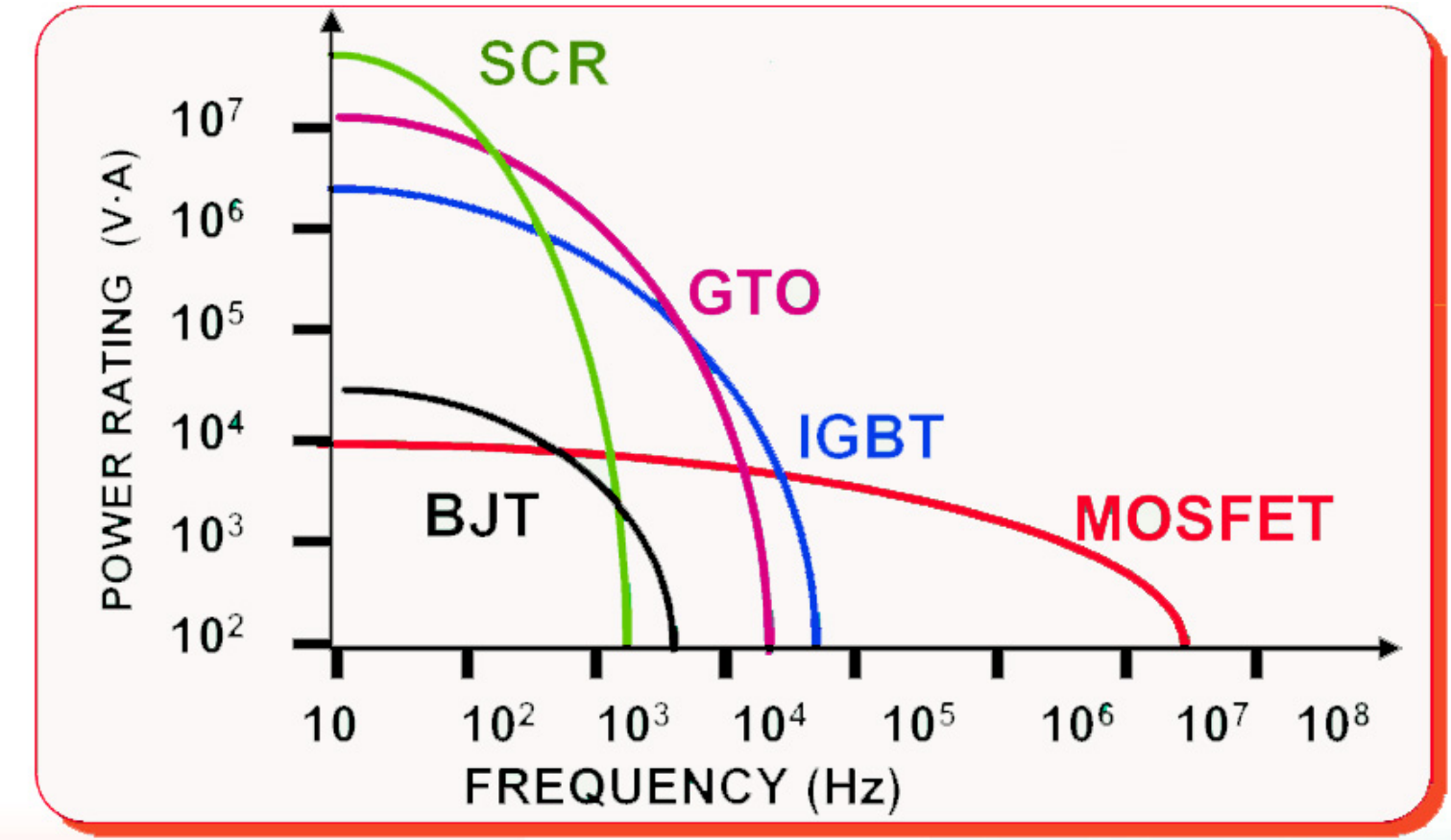
Transistor
(BJT, MOSFET, IGBT,...)



GTO (Gate Turn-Off) Thyristor,
IGCT (Integrated Gate Commutated Thyristor)

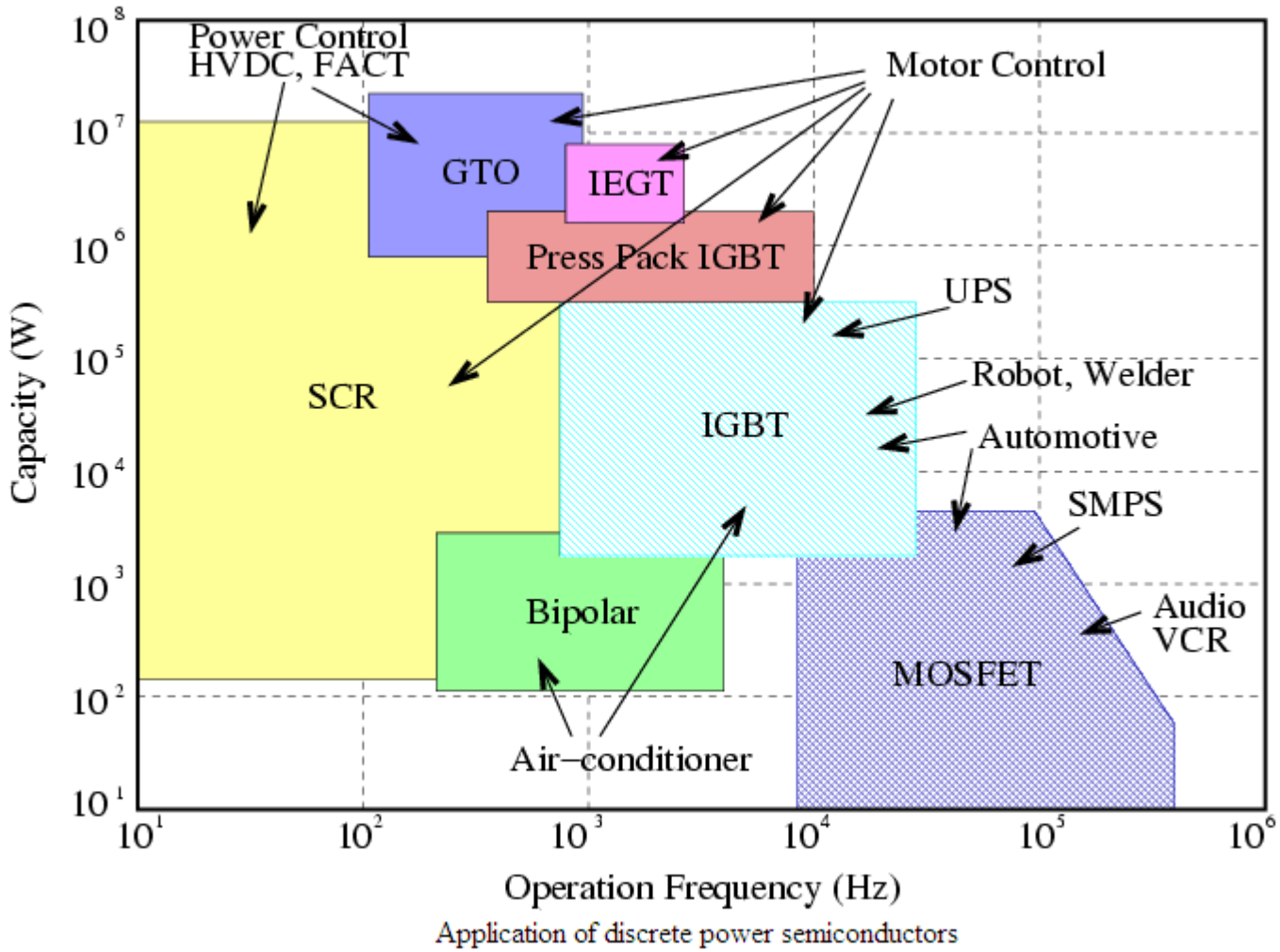


Power Electronic Semiconductors



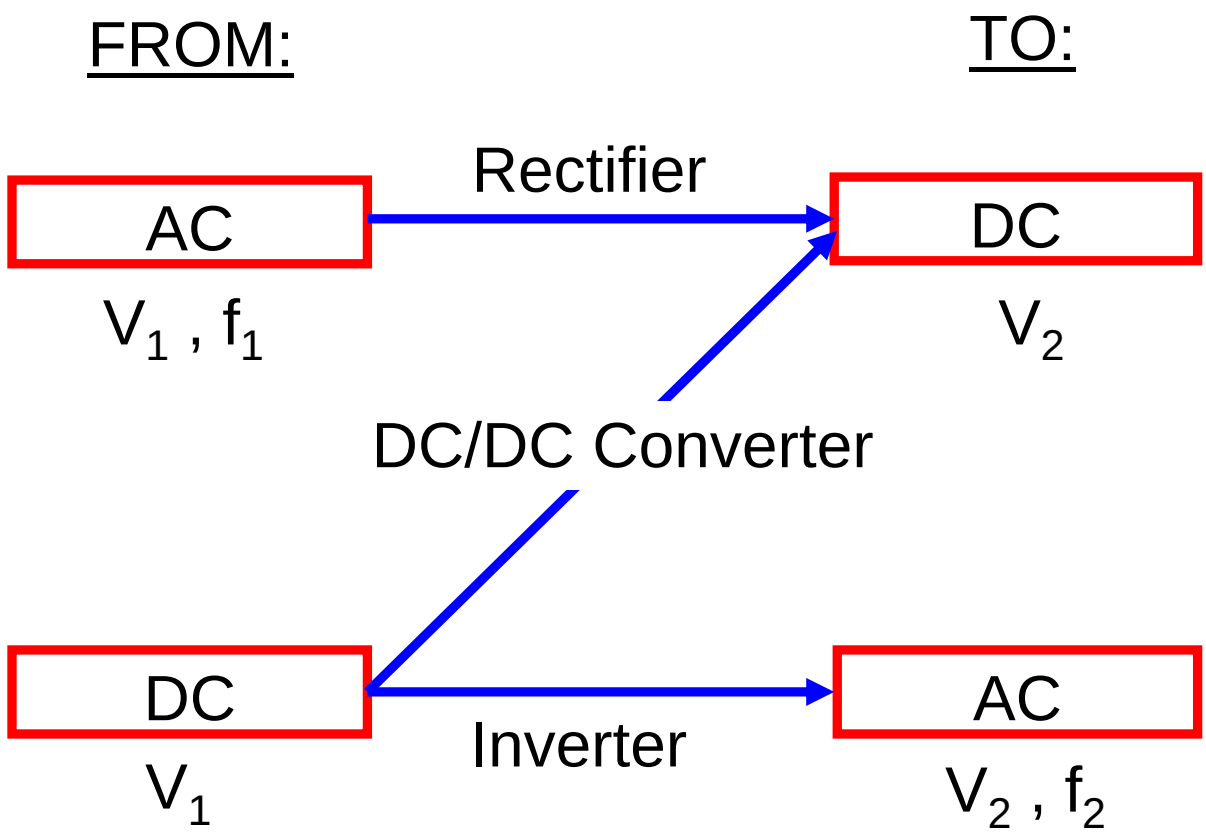
Source: L.M. Tolbert, "High Power Electronics for a Sustainable 21st Century," NSF Workshop for Sustainable Energy Systems, The University of Tennessee, Dec. 2000, Atlanta, Georgia.

Application of Power Semiconductors

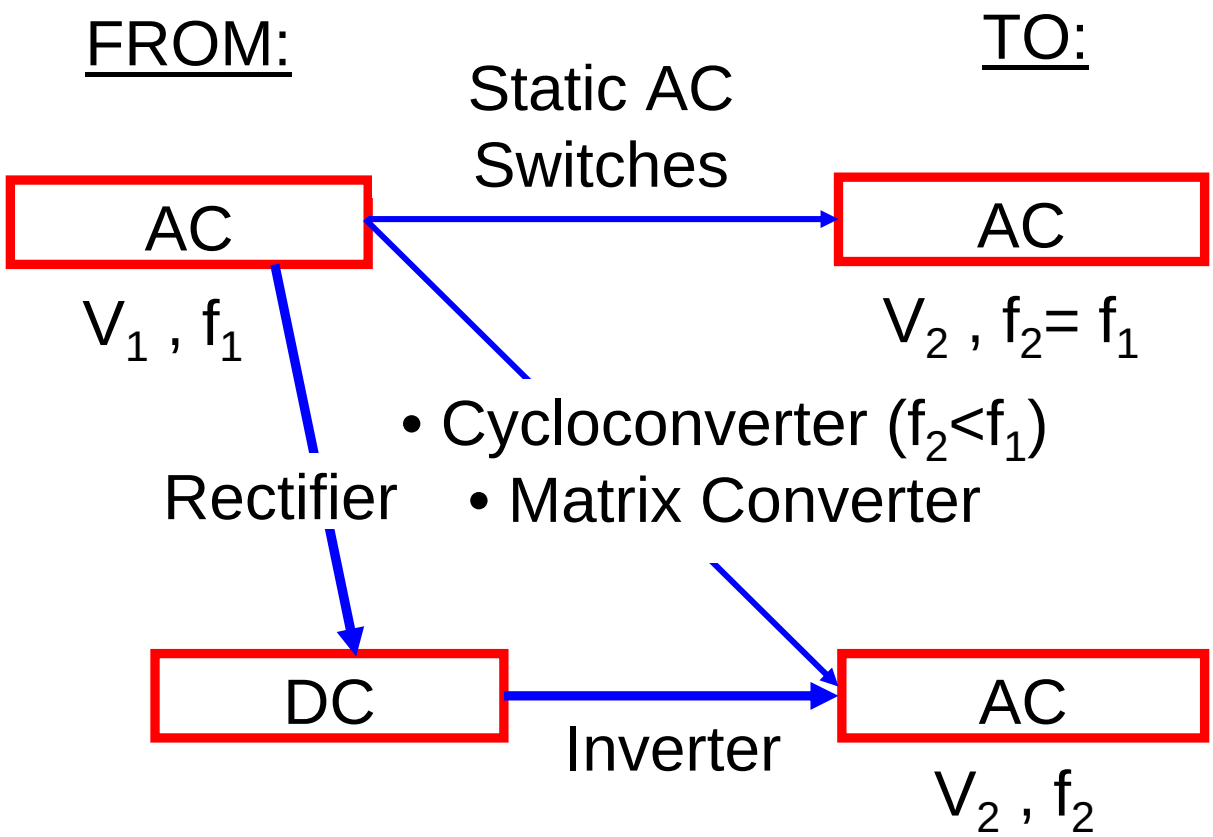


Application of discrete power semiconductors

Classification of Power Electronic Converters

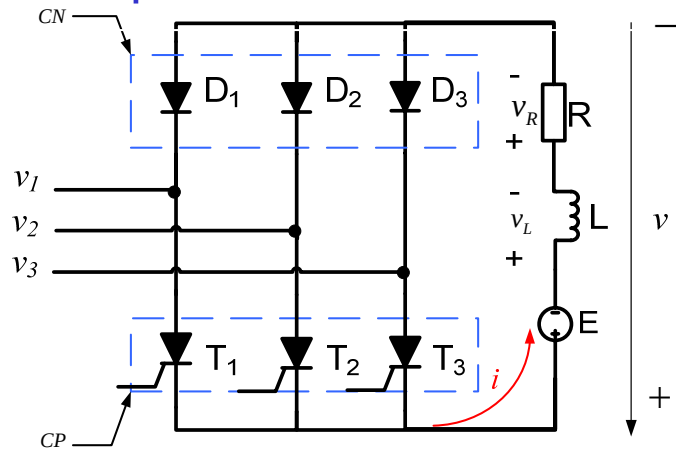


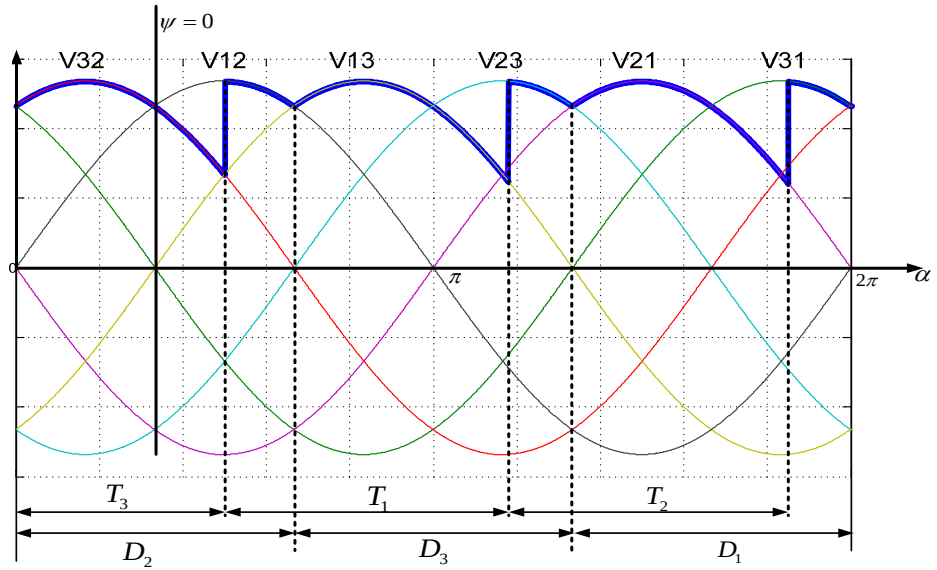
Classification



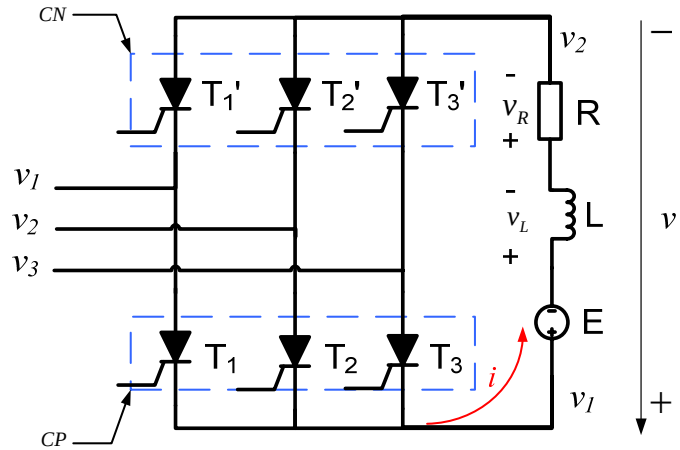
Rectifier Examples (from AC to DC)

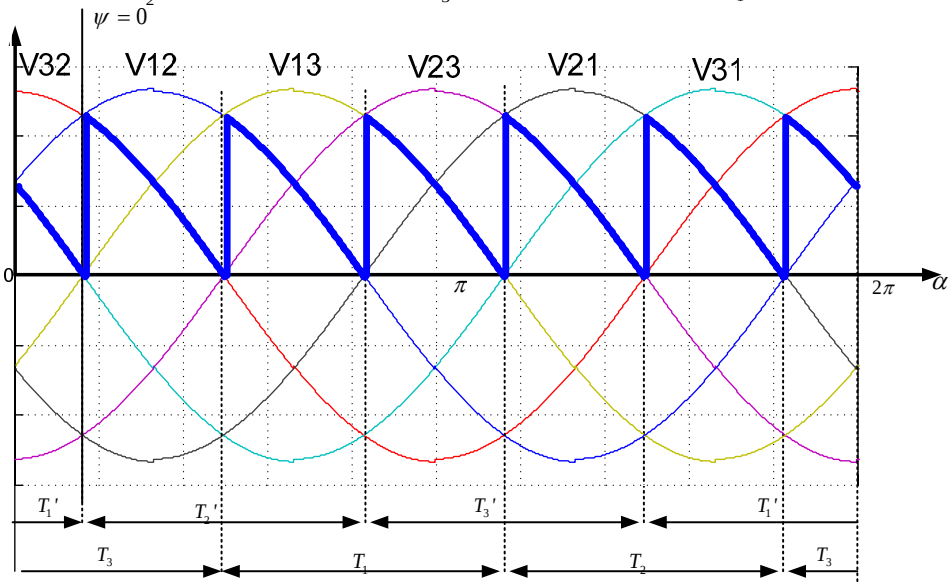
Three-phase half-controlled rectifier





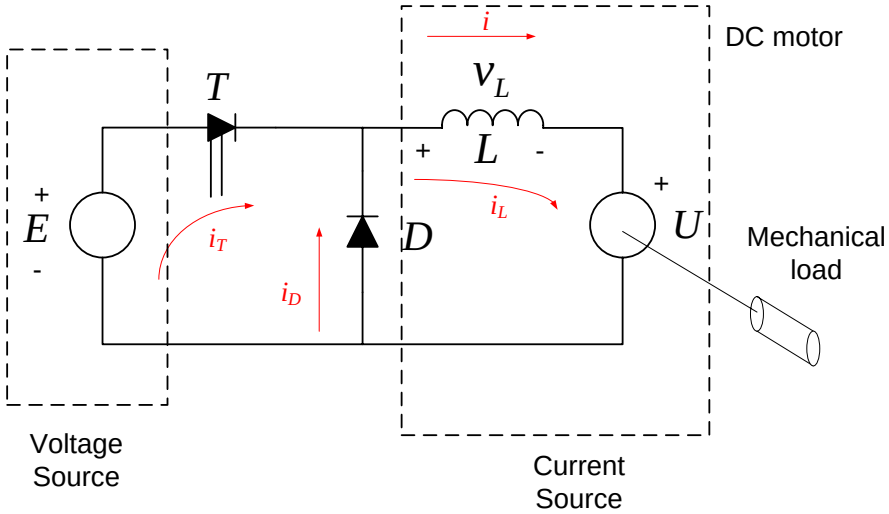
Three-phase fully-controlled rectifier

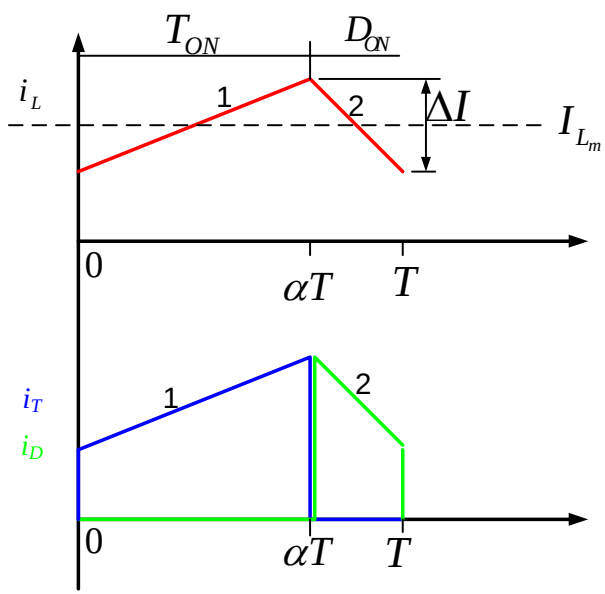




DC-DC Converter Examples

Buck

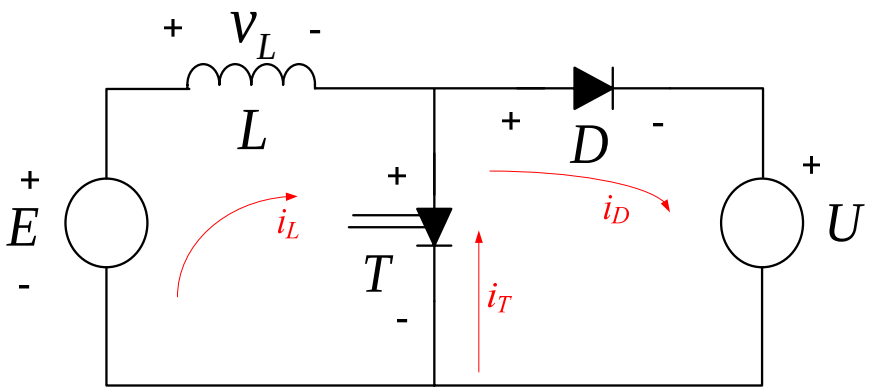




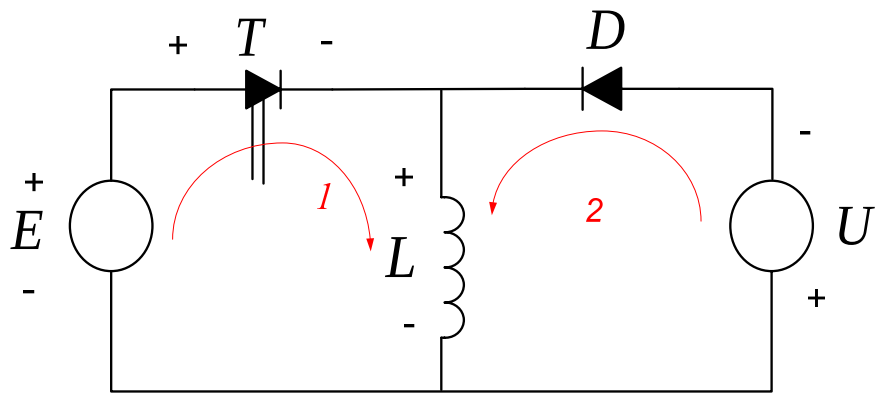
1 $\frac{E-U}{L}$

2 $\frac{-U}{L}$

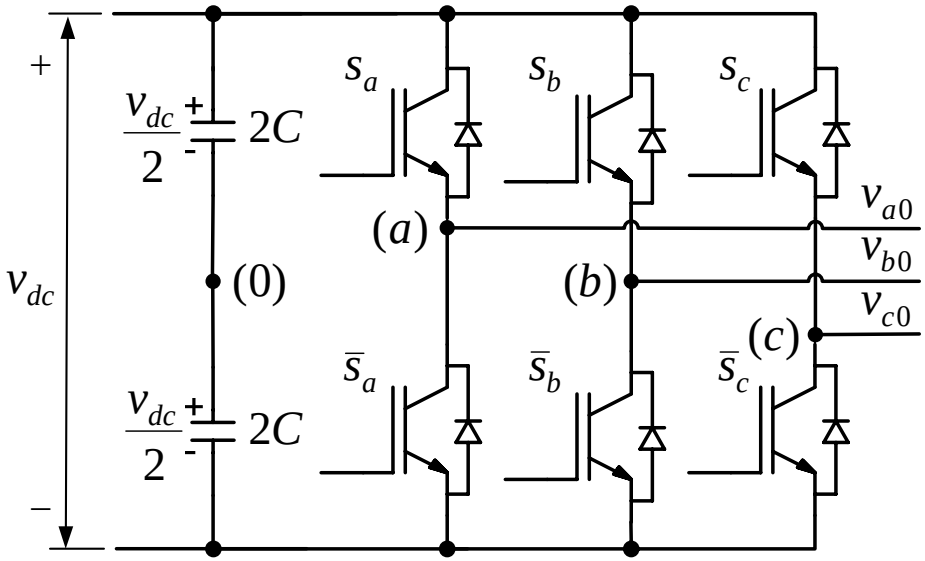
Boost

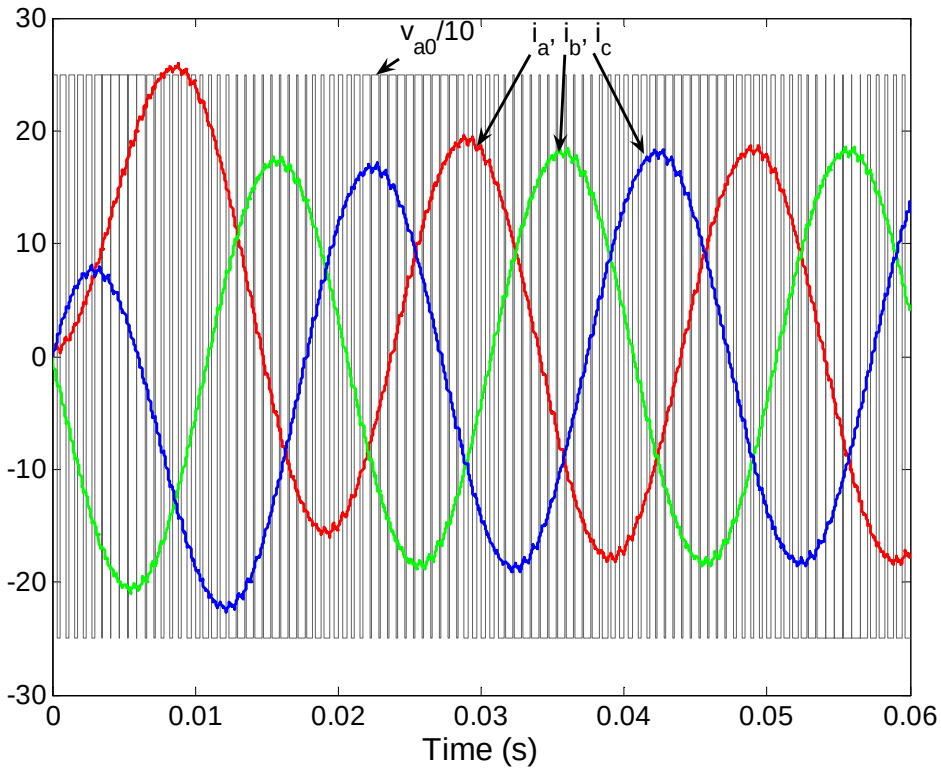


Buck-Boost

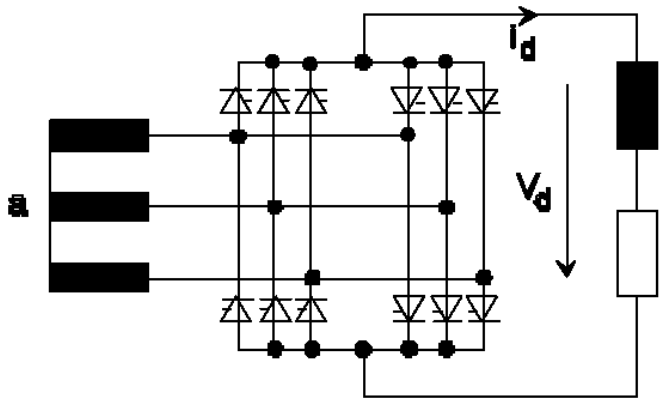


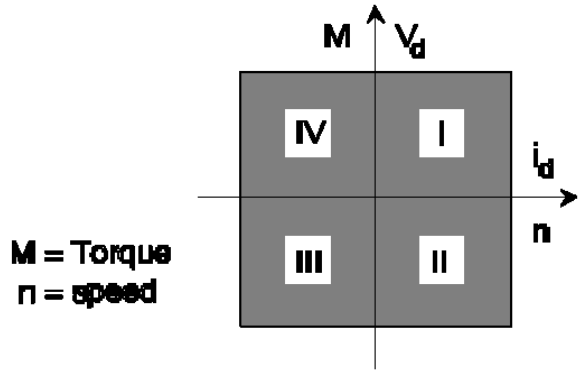
Inverter Example (from DC to AC)

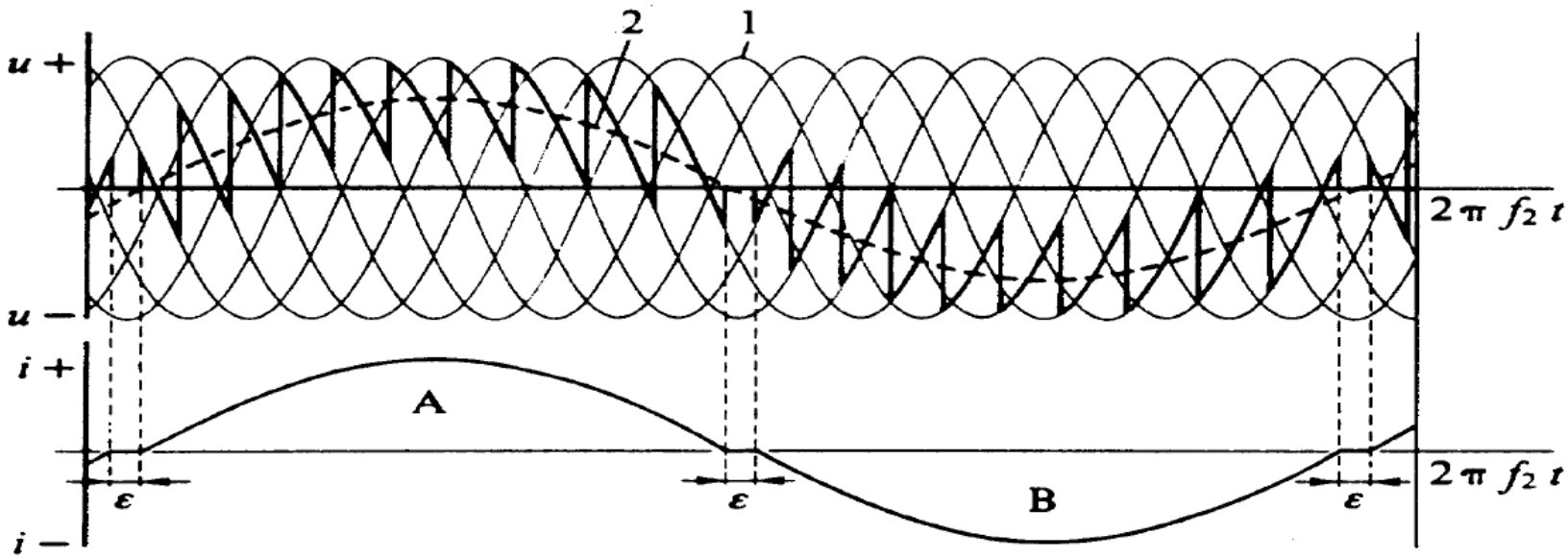




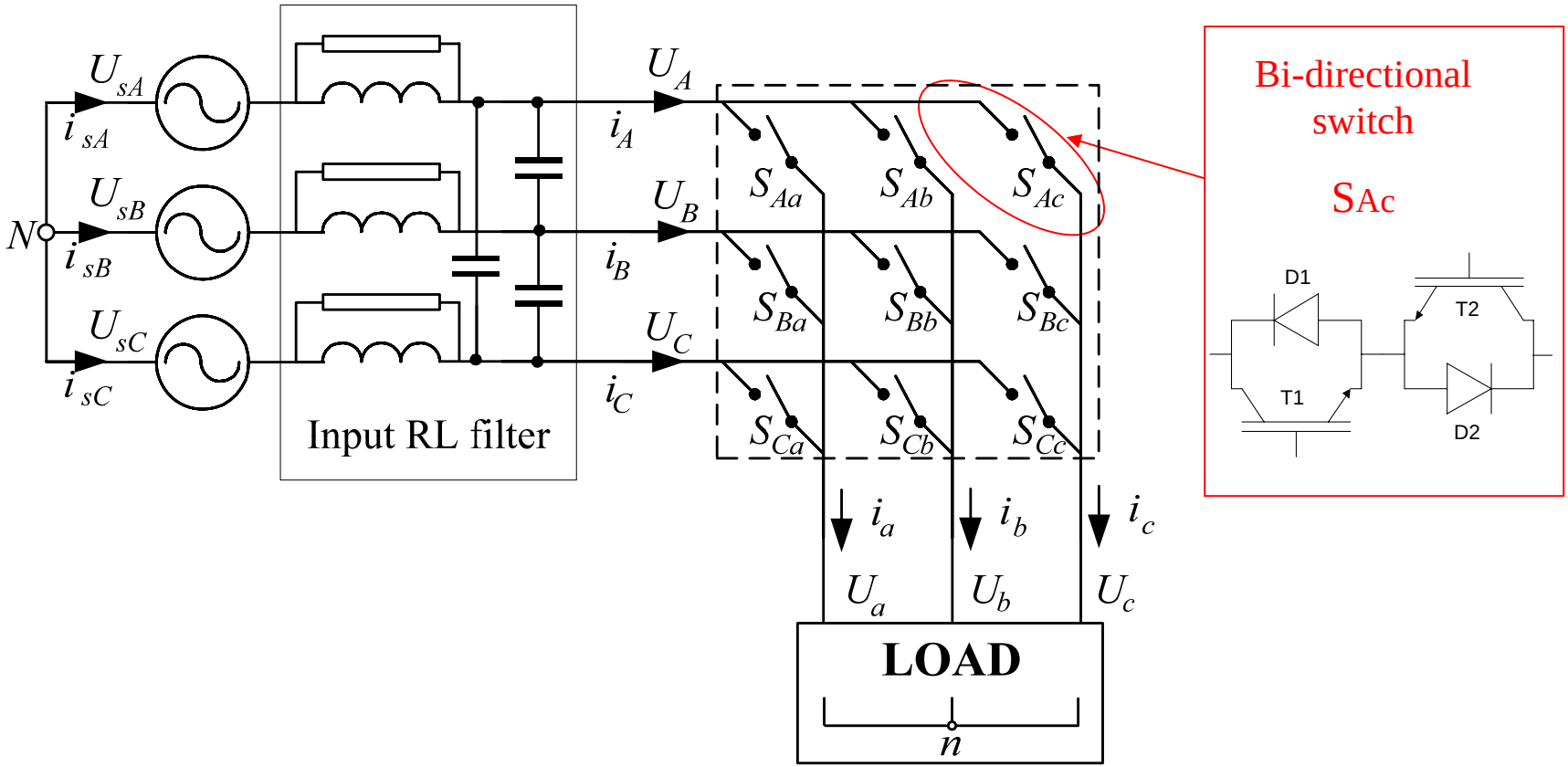
Cycloconverter (from AC to AC)



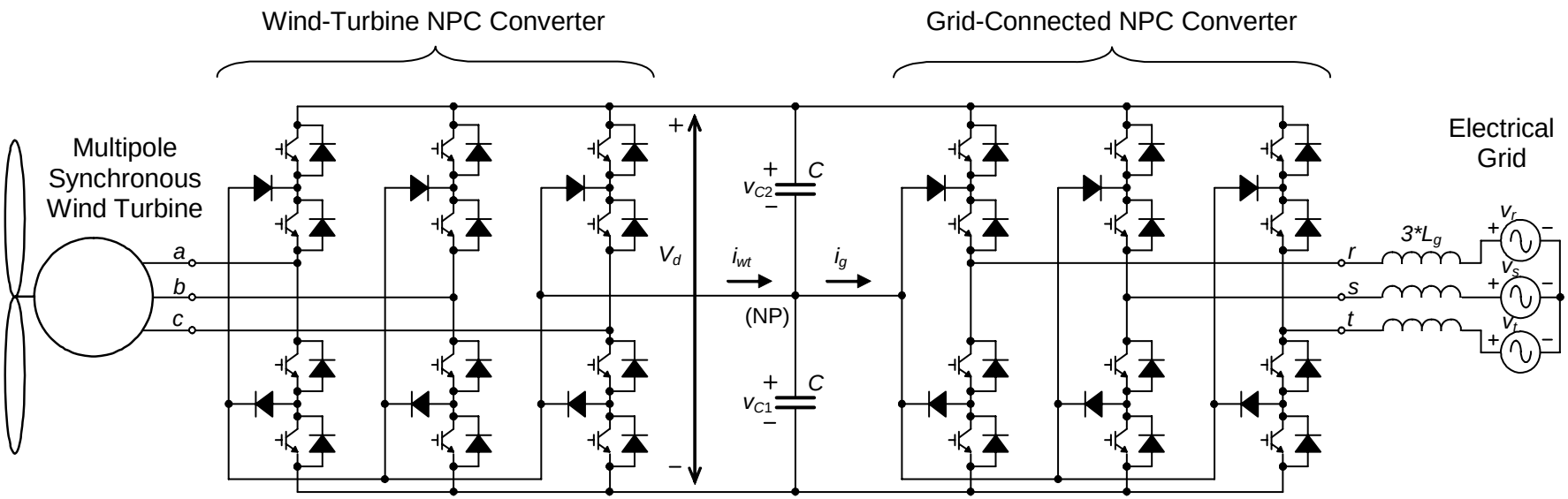




Matrix Converter (from AC to AC)



AC-DC-AC System Example



- Back-to-back-connected three-level converters. These converter topologies can provide three voltage a the outputs. Example of application to wind turbines.