Energy Storage

5. Introduction to Power Converters

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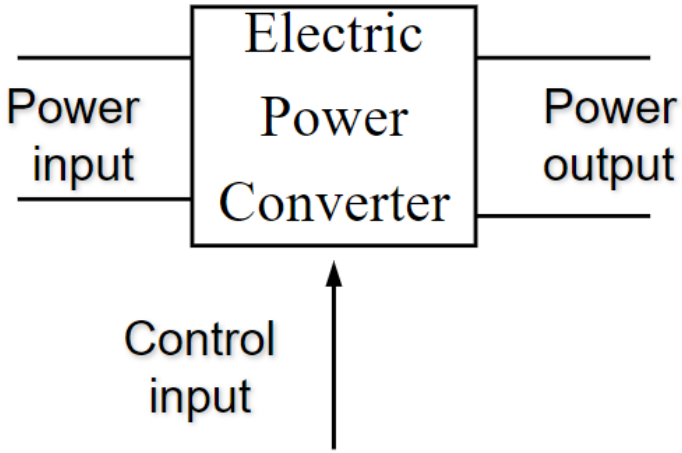
Conversion of Electric Power



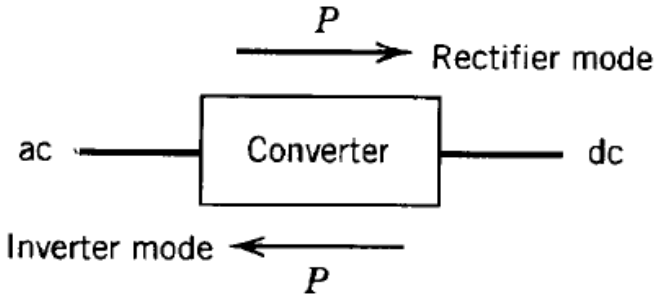
- **Other names for electric power converter:**
  - Power converter
  - Converter
  - Switching converter
  - Power electronic circuit
  - Power electronic converter

Two types of electric power	Changeable properties in conversion
DC(Direct Current)	Magnitude
AC (Alternating Current)	Frequency, magnitude, number of phases

Classification of Power Converters

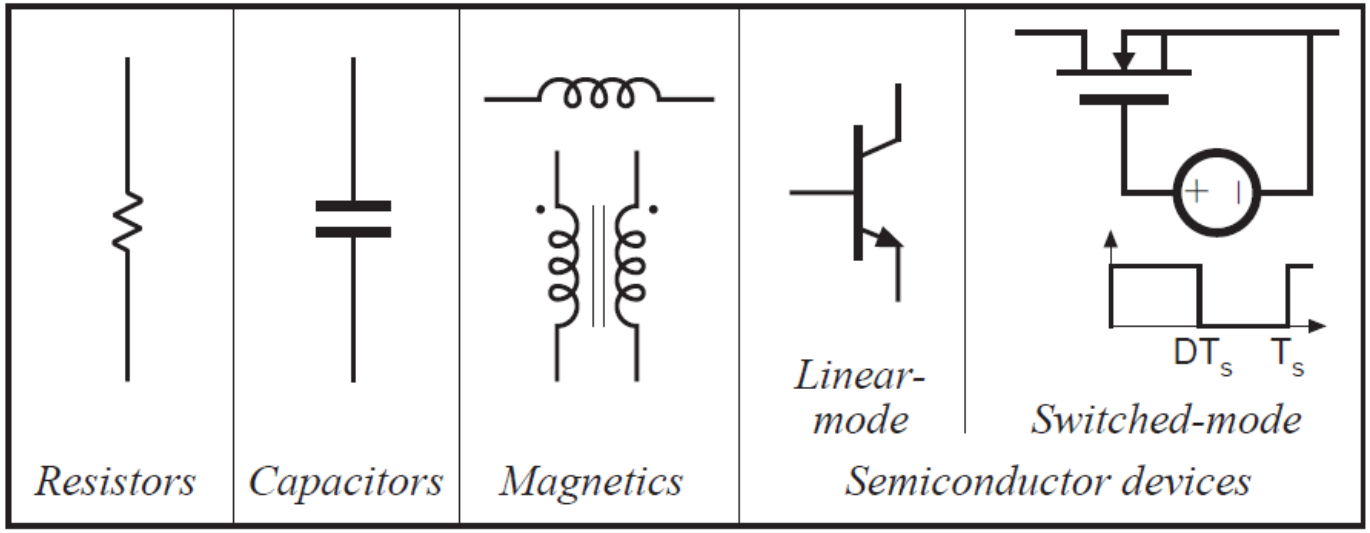
Power input \ Power output	DC	AC
AC	AC to DC converter (Rectifier)	AC to AC converter (Fixed frequency : AC controller Variable frequency: Cycloconverter or frequency converter)
DC	DC to DC converter (Chopper)	DC to AC converter (Inverter)

Power Converter

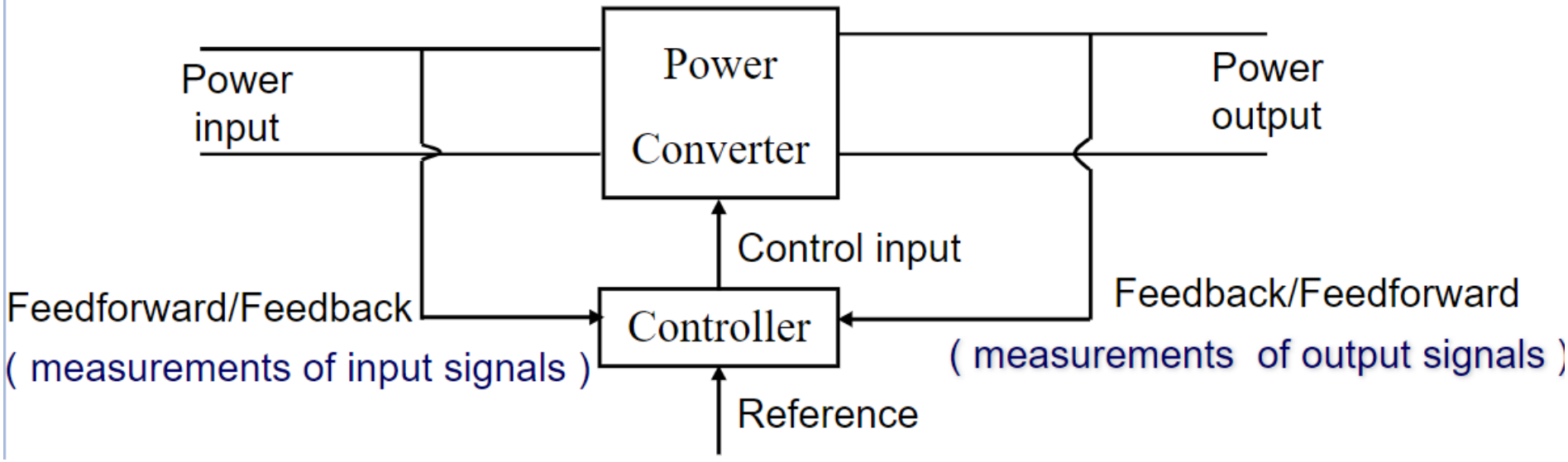


- Converter is a general term – an AC/DC converter is shown above.
  - Rectifier Mode of operation when power from AC to DC
  - Inverter Mode of operation when power from DC to AC
- Power converters can also convert
  - DC-to-DC
  - AC-to-AC
- Practical switching devices are selected based on their power handling rating – the product of their voltage and current rating – rather than their power dissipation ratings.

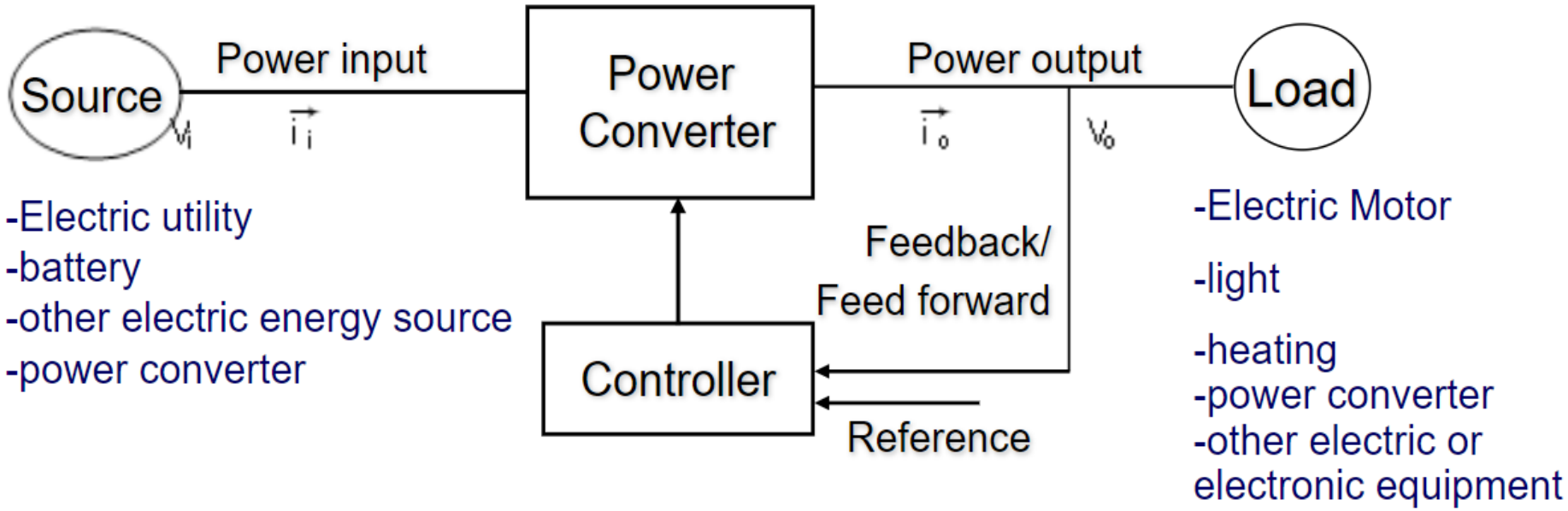
Elements of Power Electronic Devices



Generic Structure of a Power Electronic System



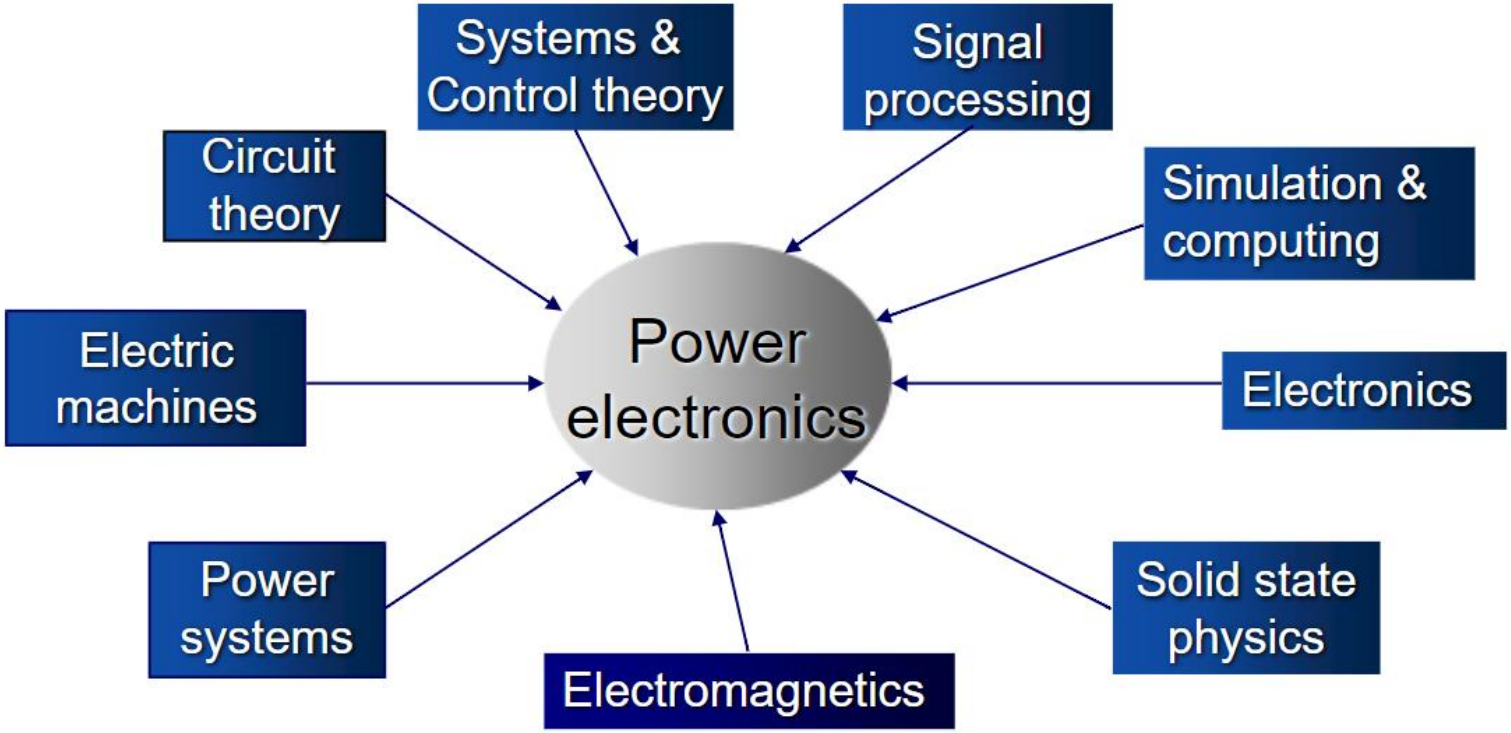
Typical Power Sources and Loads for Power Electronic System



-Electric utility
-battery
-other electric energy source
-power converter

-Electric Motor
-light
-heating
-power converter
-other electric or electronic equipment

Relation with Other Disciplines



Power electronics is currently the most active discipline in electric power engineering worldwide.

Power Electronic Applications

Residential

- Refrigeration and freezers
- Heating
- Air conditioning
- Cooking
- Lightning

Commercial

- Heating, ventilating, and air conditioning
- Central refrigeration
- Lightning
- Computers and office equipment
- Uninterruptible power supplies (UPSs)
- Elevators

Industrial

- Pumps
- Compressors
- Welding
- Induction heating

Transportation

- Traction control of electric vehicles
- Battery chargers for electric vehicles
- Electric locomotives
- Street cars, trolley buses
- Subways

Utility systems

- High-voltage dc transmission (HVDC)
- Static var compensation (SVC)
- Renewable energy resources (wind, PV)
- Energy storage systems

Aerospace

- Aircraft power systems
- Satellite power systems

Telecommunications

- Baterry chargers
- Power supplies (DC and UPS)

Power Electronics Applications – AC Motor Drive

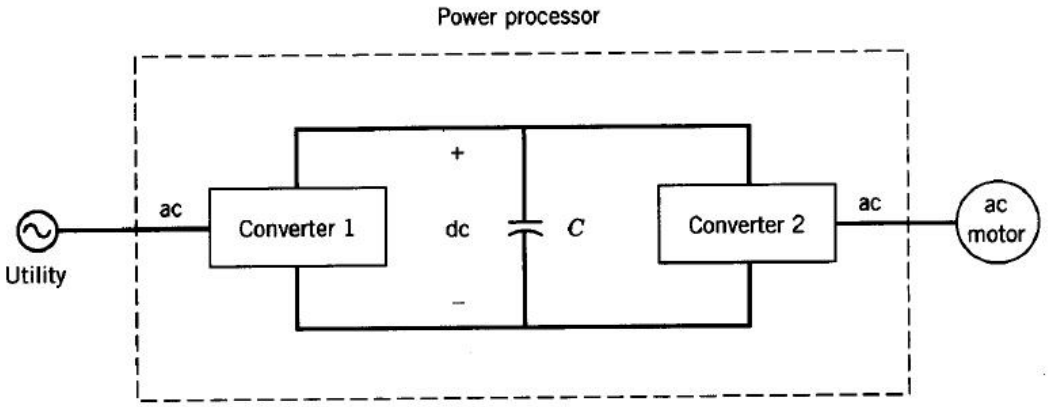
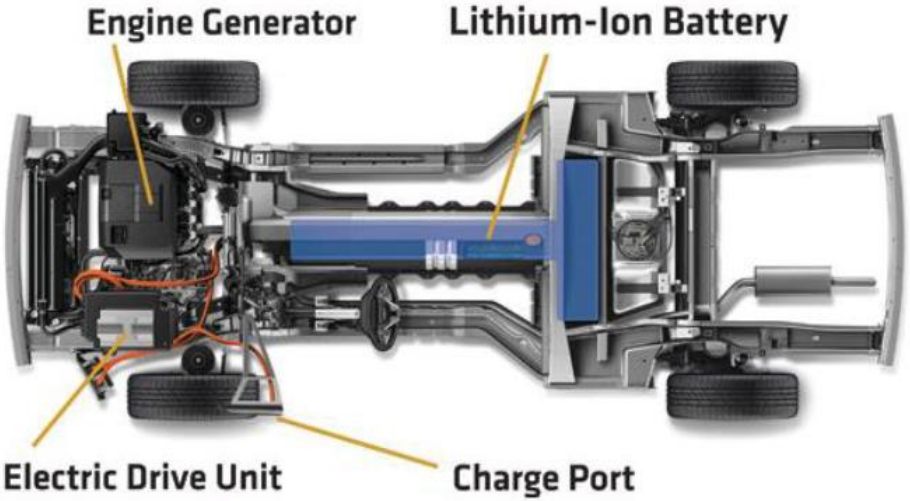


Figure 1-8 Block diagram of an ac motor drive.

- Converter 1 rectifies line-frequency AC into DC
- Capacitor acts as a filter – stores energy and decouples the two converters
- Converter 2 inverts DC to variable frequency AC – as needed by the motor.

Power Electronics Applications – Pure Electric and Plug-In Hybrid Vehicles



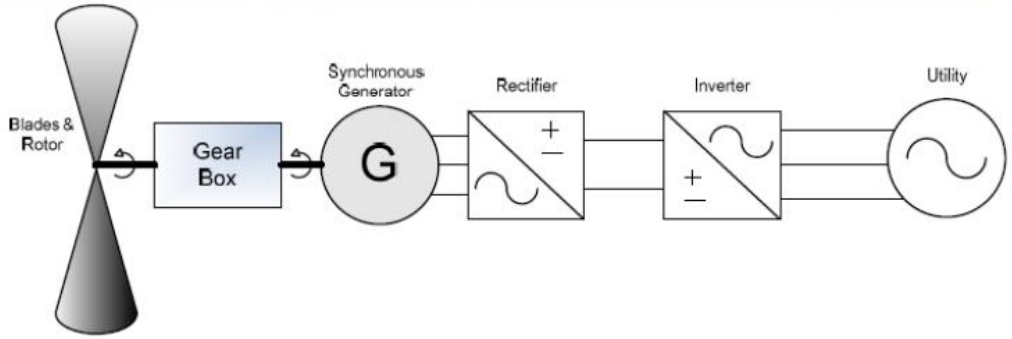
Electric Drive System: DC-AC Converter

Battery Charger: AC-DC converter

Power Electronics Applications – Renewable Energy Resources (PV)

PV Inverter: DC-AC Converter

Power Electronic Applications – Renewable Energy Resources (Wind)



The rectifier-inverter converts variable-frequency AC to fixed line-frequency AC.

Nonisolated/isolated Power Electronics Converters

- Non-isolated power electronic converters – the circuit does not consist of magnetic or electric insulation
- Isolated power electronic converters – the circuit consists of magnetic or electric insulation

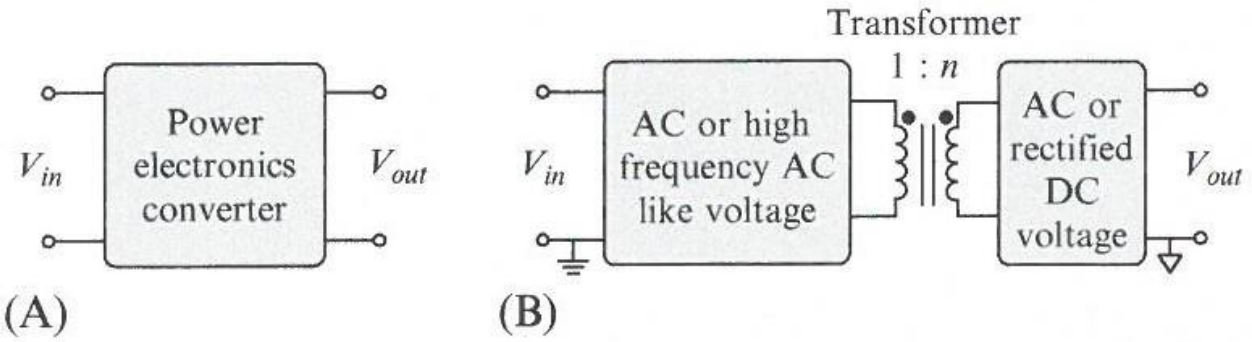


FIG. 1.1 General layouts of (A) nonisolated and (B) isolated power electronics converters.

Voltage-Fed/Current-Fed

- Depending on input circuitry power electronics converters can be classified as either voltage-or current-fed converters

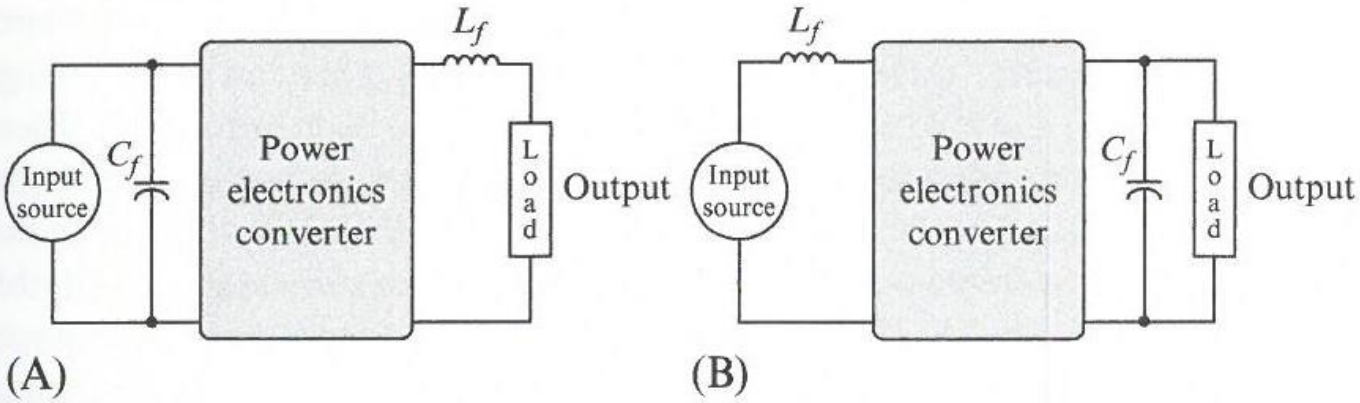


FIG. 1.2 General layout of (A) voltage-fed and (B) current-fed power electronics converters.

AC-to-DC Converter Topologies – Single-phase Half/full Wave Rectifier

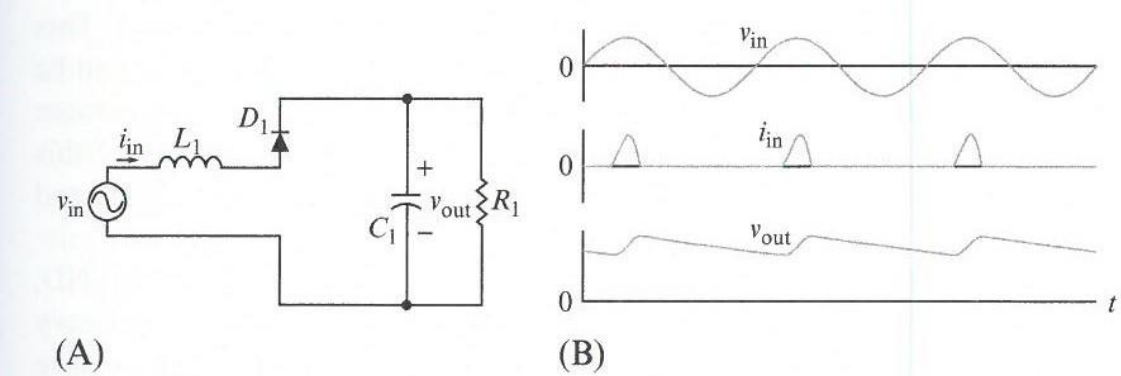


FIG. 1.4 Half-wave rectifier: (A) circuit diagram and (B) its waveforms.

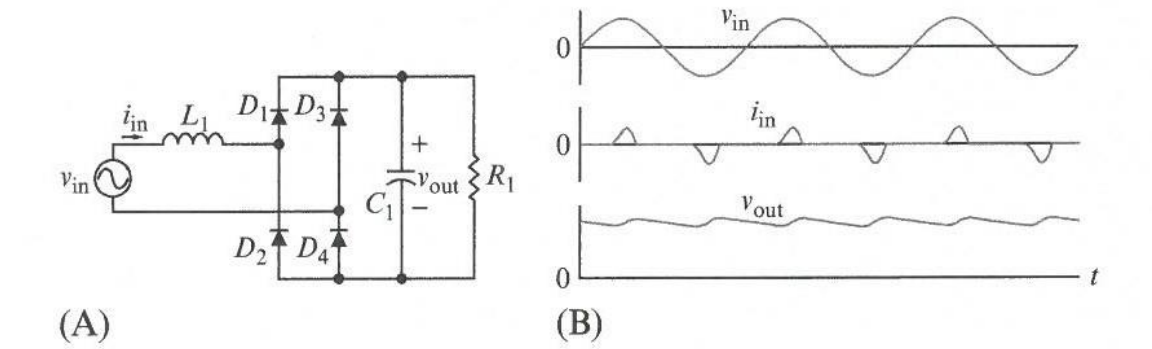
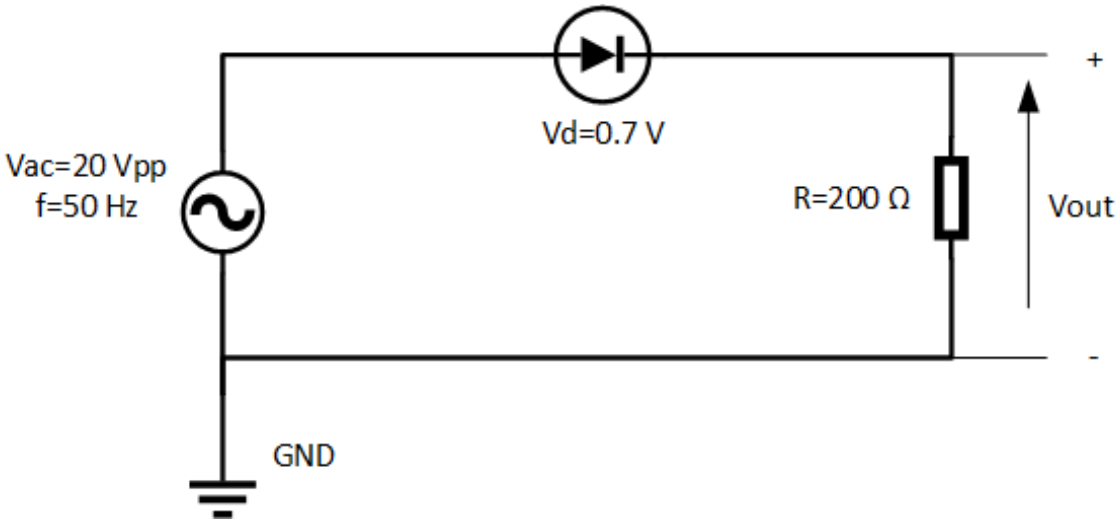


FIG. 1.5 Full-wave rectifier: (A) circuit diagram and (B) its waveforms.

AC-to-DC Converter Ttopologies

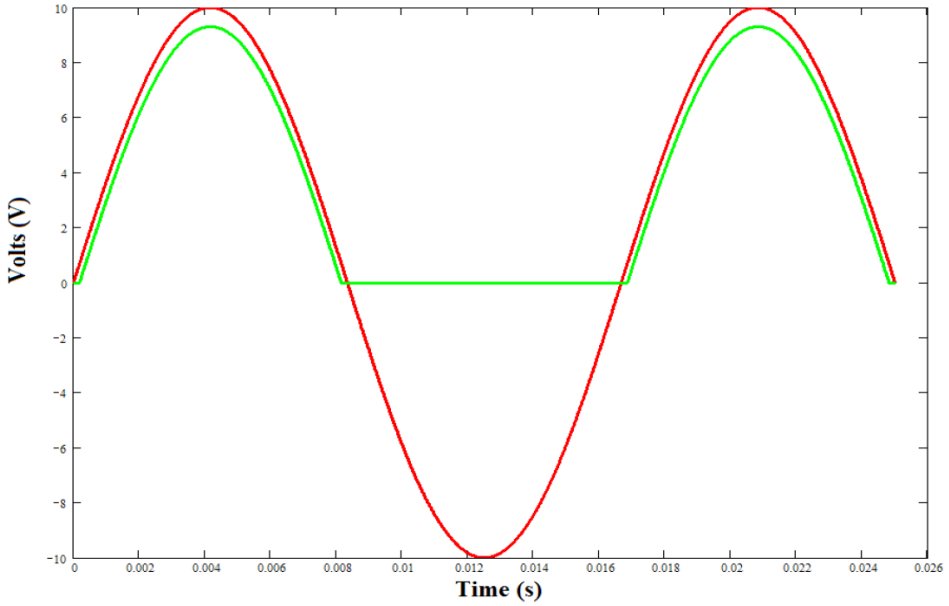
- An AC-to-DC converter converts AC voltage to a stable DC output voltage.
- Unidirectional AC to DC converters are also called rectifiers. The simplest construction of a rectifier is made from diodes.
- Diode rectifiers creates nonnegligible distortion in its current and thus requires a significant effort in filter design so that the distortion does not affect the AC grid.
- Half-wave rectifier converts single-phase AC voltage to DC voltage via single diode.
- Full-wave rectifier employs four diodes to converts both positive and negative cycles to the DC side before stabilizing the output voltage with the capacitor.

Example – Half-wave Rectifier



Output Voltage as a Function of Time - solution

- Since the input voltage was actually an AC power supply, the output voltage must vary with time.
  - The maximum output voltage is 9.3 V.
  - The output voltage is 0V when input voltage is 0.7 V.
  - The minimum output voltage is 0V.



AC-to-DC Converter Topology – Three-phase Rectifier

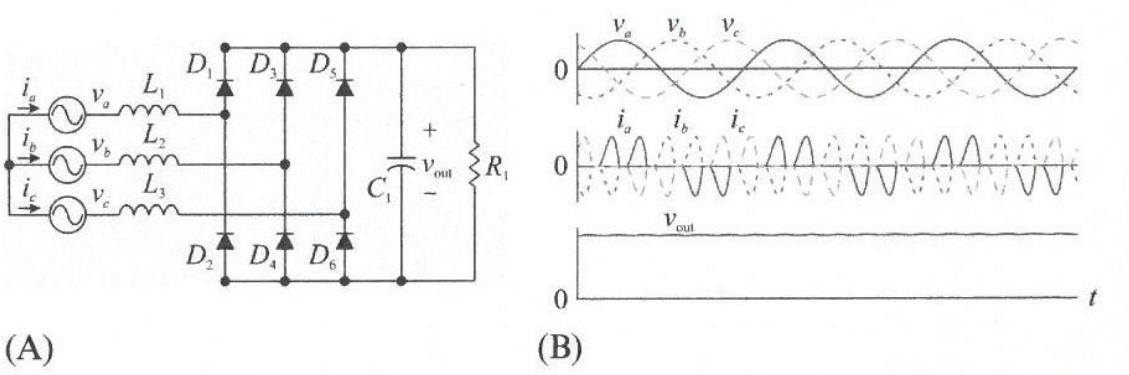


FIG. 1.6 Three-phase rectifier: (A) circuit diagram and (B) its waveforms.

DC-to-AC Converter Topologies

- DC-to-AC converters or an inverter is a device that produce an AC output of a definite phase, frequency and magnitude from a DC source.
- Based on the type of the source and load inverters are segregated into two distinct categories: voltage source inverters (VSIs) and Current Source Inverters (CSI).

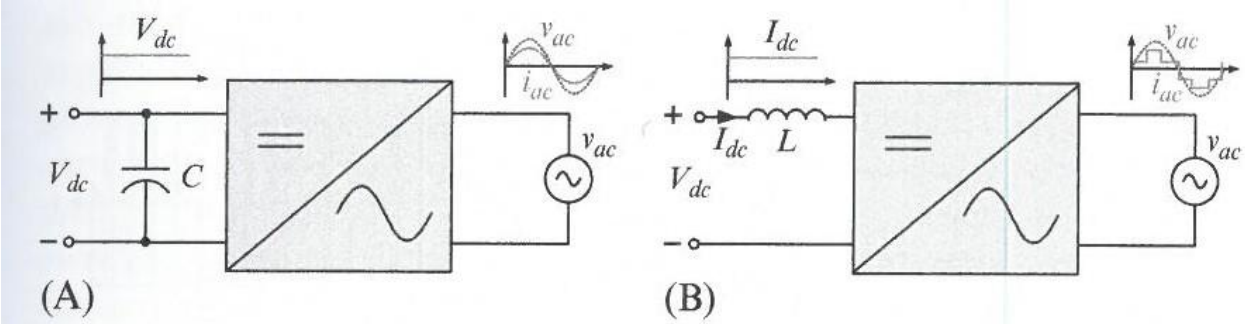


FIG. 1.16 DC-AC converter topologies: (A) VSI topology and (B) CSI topology.

Single-Phase DC-to-AC Converter

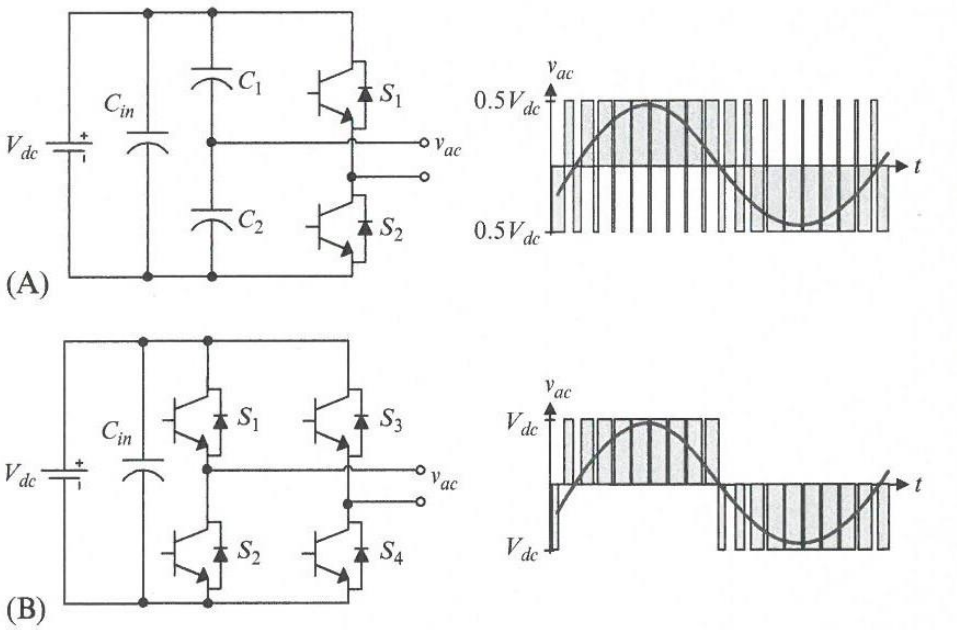


FIG. 1.18 Voltage source inverter showing its AC output voltage for the SPWM: (A) half-bridge and (B) full-bridge.

Three-Phase DC-to-AC Converter

- DC-AC

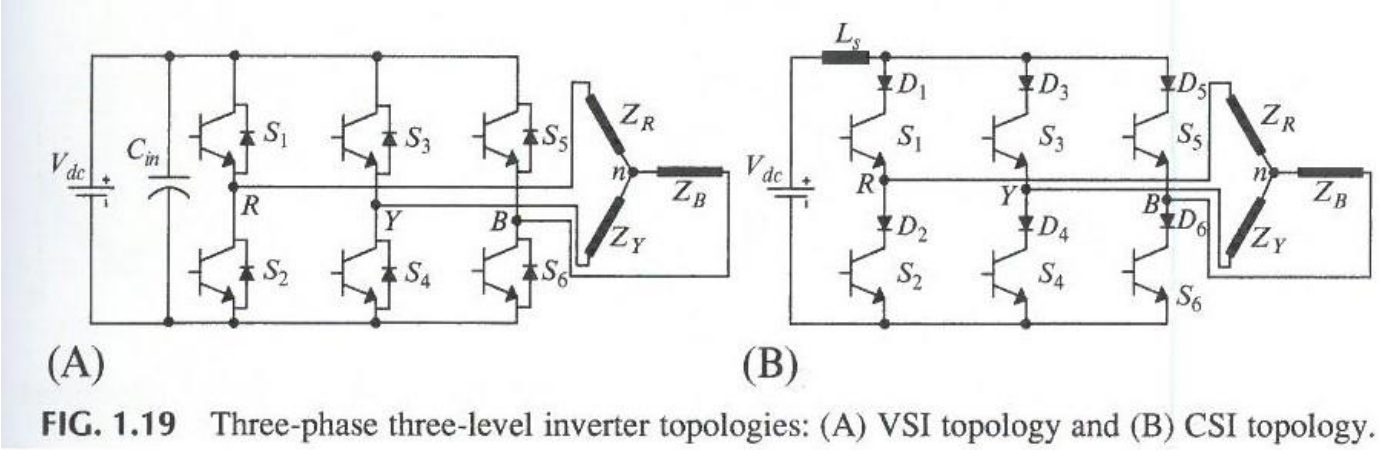


FIG. 1.19 Three-phase three-level inverter topologies: (A) VSI topology and (B) CSI topology.

DC-to-DC Converters

- A DC-DC converter changes the DC input to a higher or lower DC output voltage.
- The DC equivalent of an AC transformer.

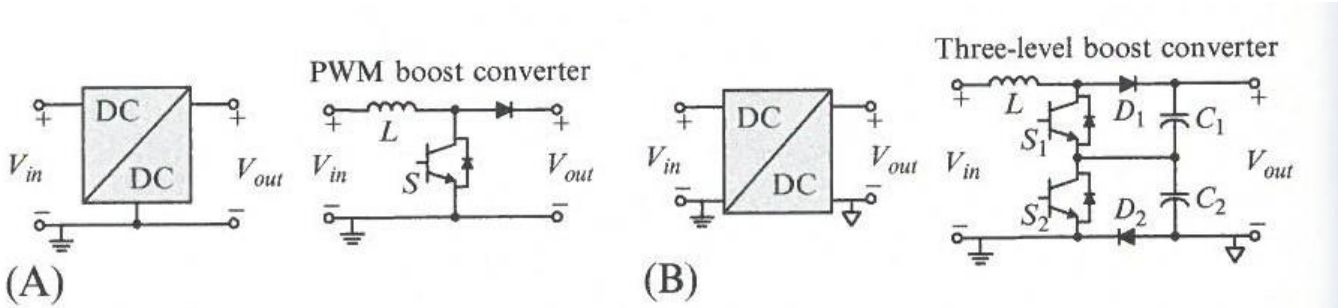


FIG. 1.24 Nonisolated DC-DC converters, (A) common grounded nonisolated DC-DC converter and (B) floated output nonisolated DC-DC converter.

Buck Converters

- A DC-DC converter changes the DC input to a lower DC output voltage.

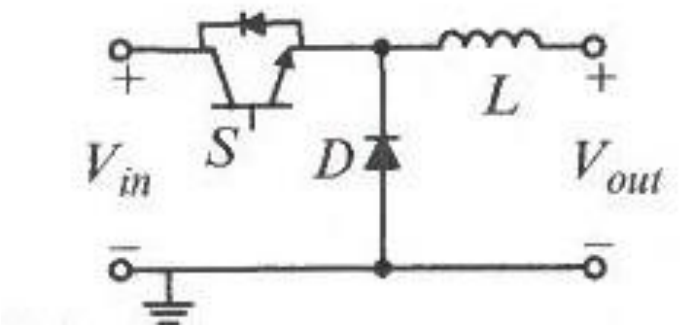


FIG. 1.25 Nonisolated DC-DC converters: Buck converter

Boost Converters

- A DC-DC converter changes the DC input to a higher DC output voltage.

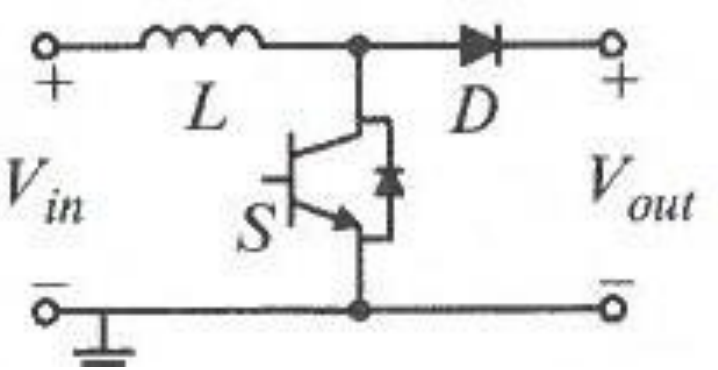


FIG. 1.26 Nonisolated DC-DC converters: Boost converter

Buck-Boost Converters

- A buck-boost converter can simultaneously step-down and step-up the input voltage.

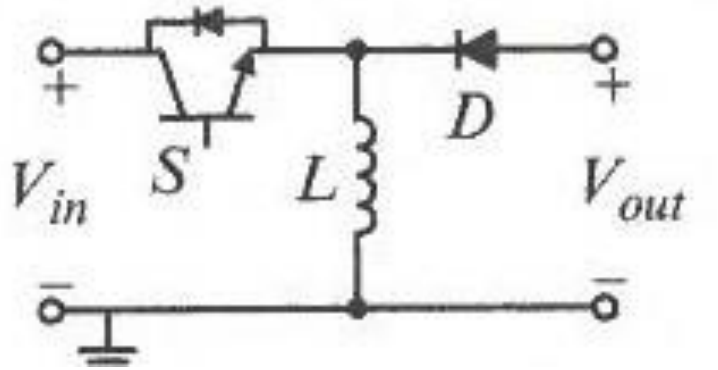
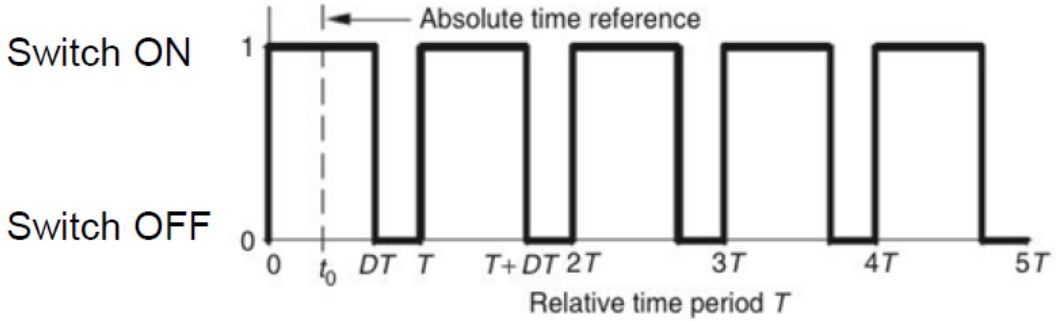


FIG. 1.26 Nonisolated DC-DC converters: Buck-Boost converter

Switching Function (switch control)



- T: period
- t_0: time delay
- f=1/T: switching frequency
- D: duty ratio – fraction of time during which the switch is ON

AC-to-AC Converters

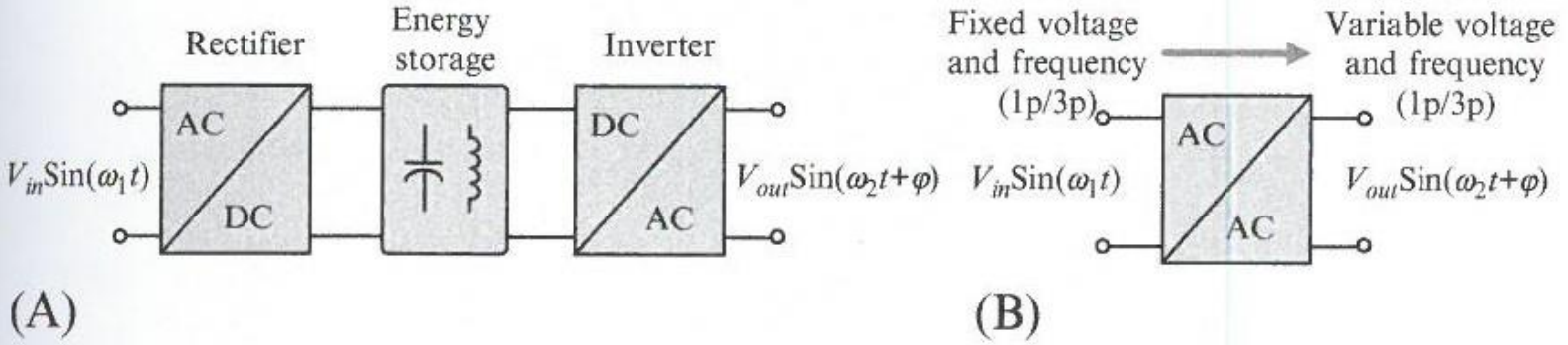


FIG. 1.28 General layouts of AC-AC converters, (A) indirect AC-AC converter and (B) direct AC-AC converter.

References

- Frede Blaabjerg, “Control of Power Electronic Converters and Systems”, Volume I, Academic Press 2018.