Fundamentals of Power Electronics

Robert W. Erickson
University of Colorado, Boulder

Chapter 1: Introduction

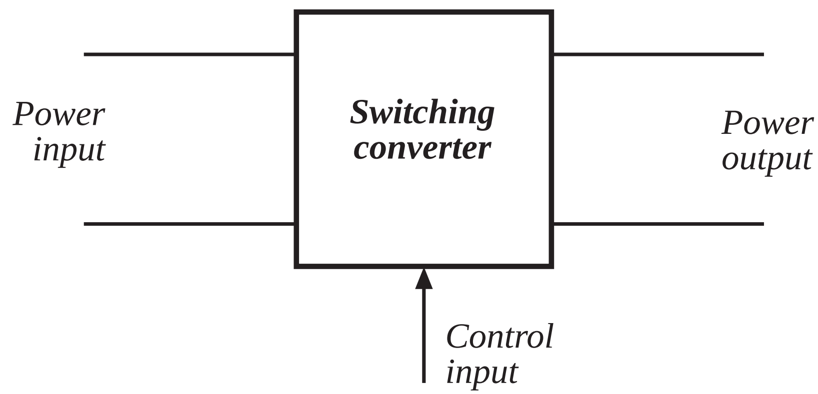
1.1. Introduction to power processing

1.2. Some applications of power electronics

1.3. Elements of power electronics

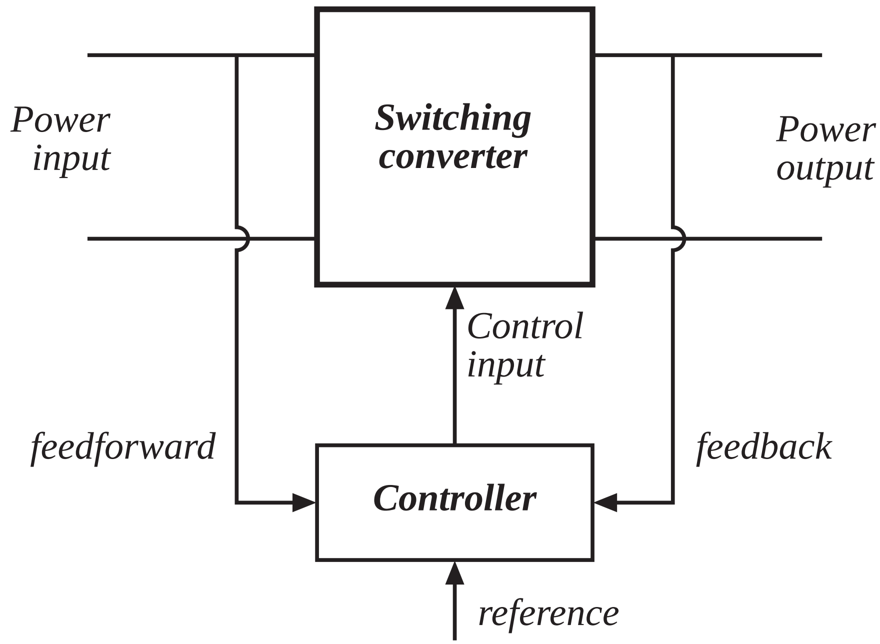
Summary of the course

1.1 Introduction to Power Processing



Dc-dc conversion:	Change and control voltage magnitude
Ac-dc rectification:	Possibly control dc voltage, ac current
Dc-ac inversion:	Produce sinusoid of controllable magnitude and frequency
Ac-ac cycloconversion:	Change and control voltage magnitude and frequency

Control is invariably required



High efficiency is essential

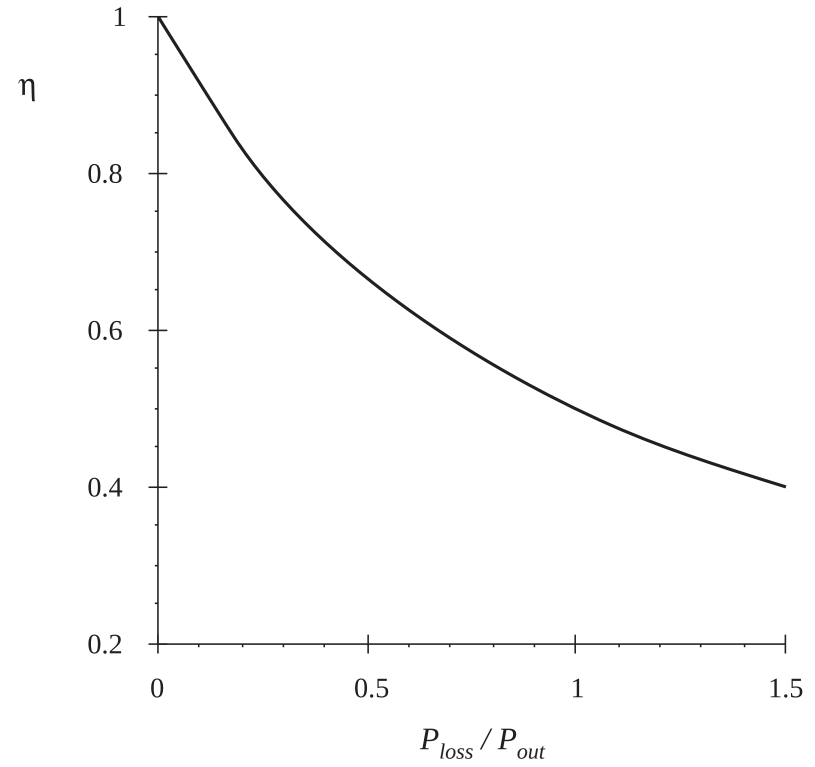
$$\eta = \frac{P_{out}}{P_{in}}$$

$$P_{loss} = P_{in} - P_{out} = P_{out}\left(\frac{1}{\eta} - 1\right)$$

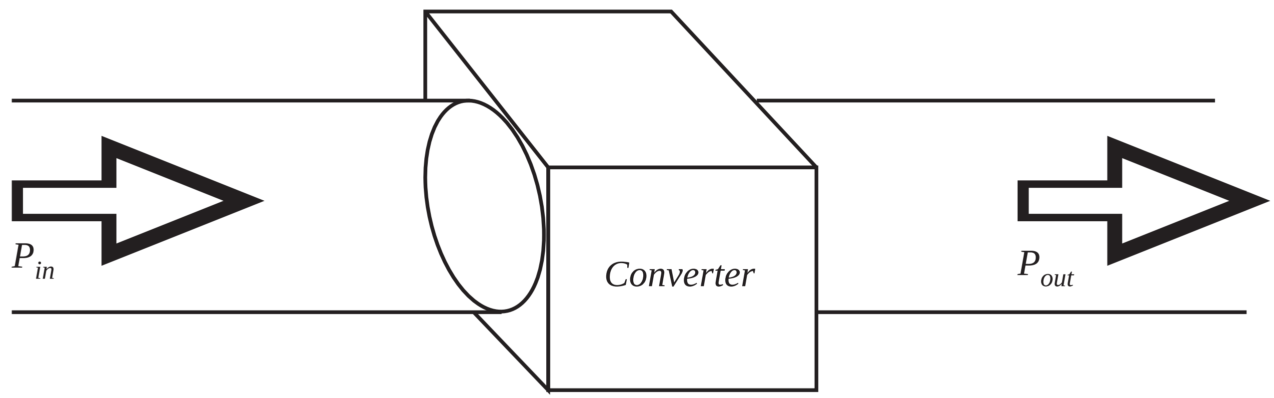
High efficiency leads to low power loss within converter

Small size and reliable operation is then feasible

Efficiency is a good measure of converter performance

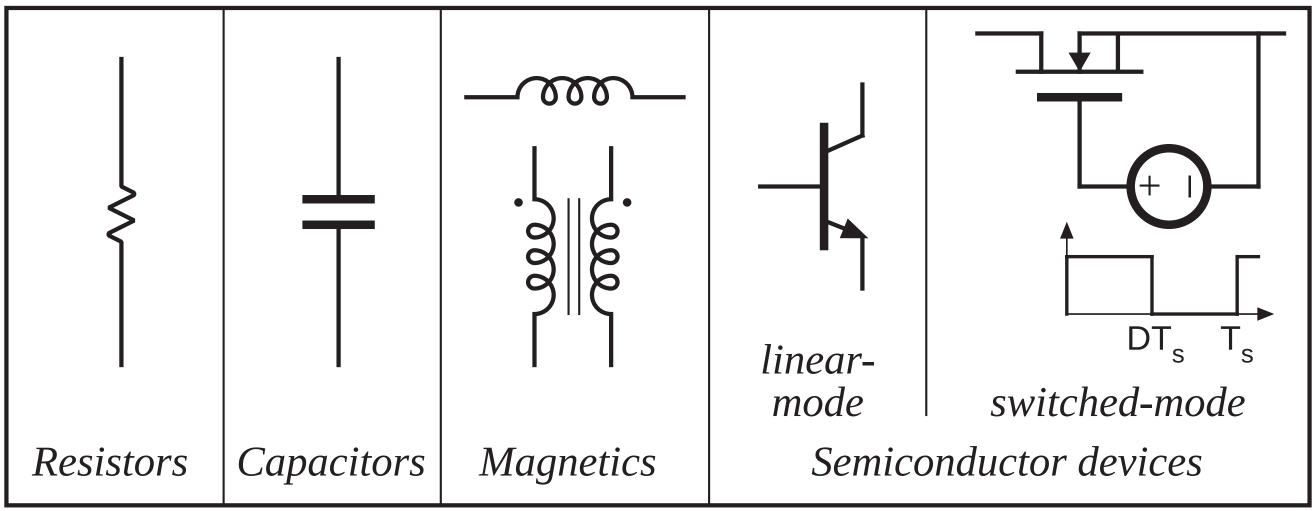


A high-efficiency converter

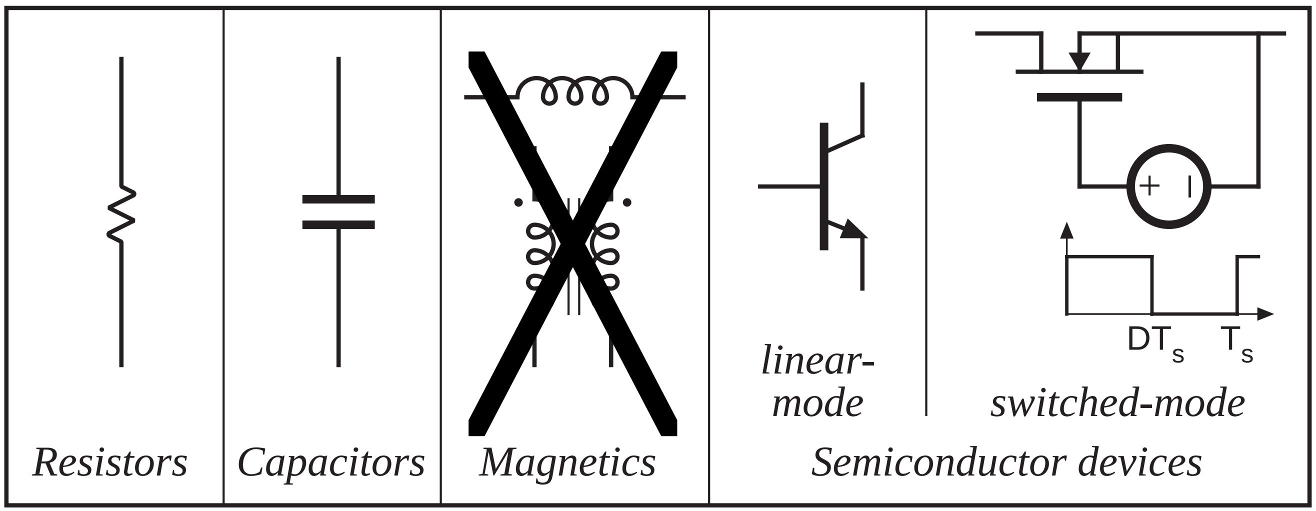


A goal of current converter technology is to construct converters of small size and weight, which process substantial power at high efficiency

Devices available to the circuit designer

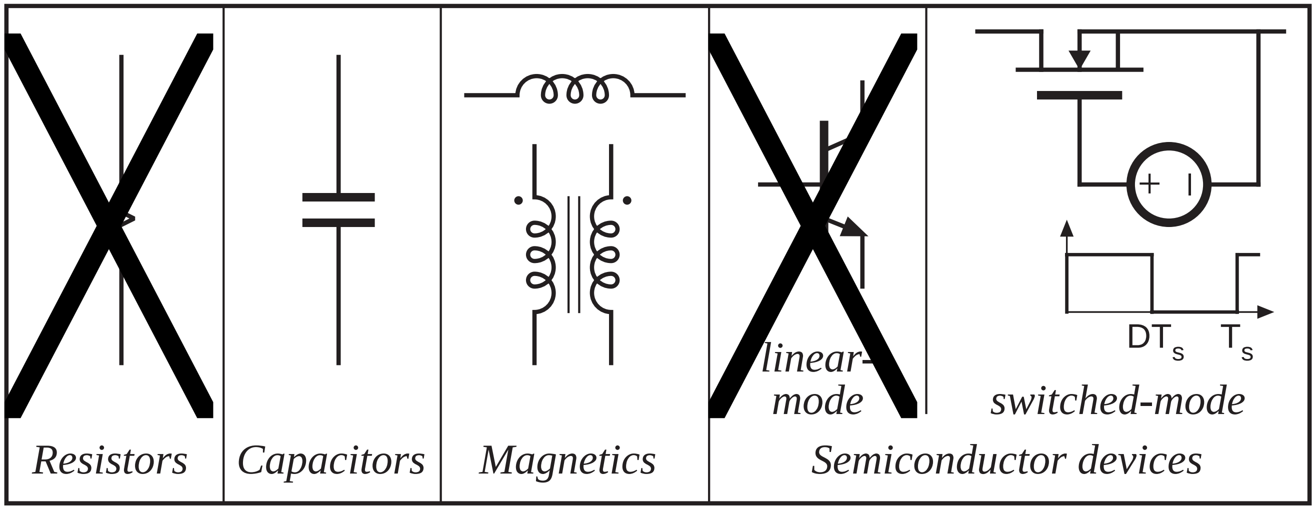


Devices available to the circuit designer



Signal processing: avoid magnetics

Devices available to the circuit designer



Power processing: avoid lossy elements

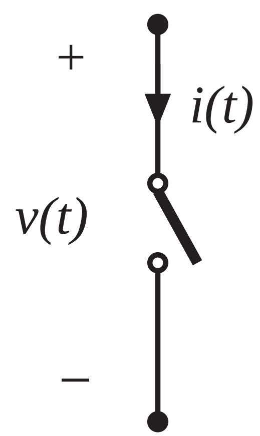
Power loss in an ideal switch

Switch closed: $v(t) = 0$

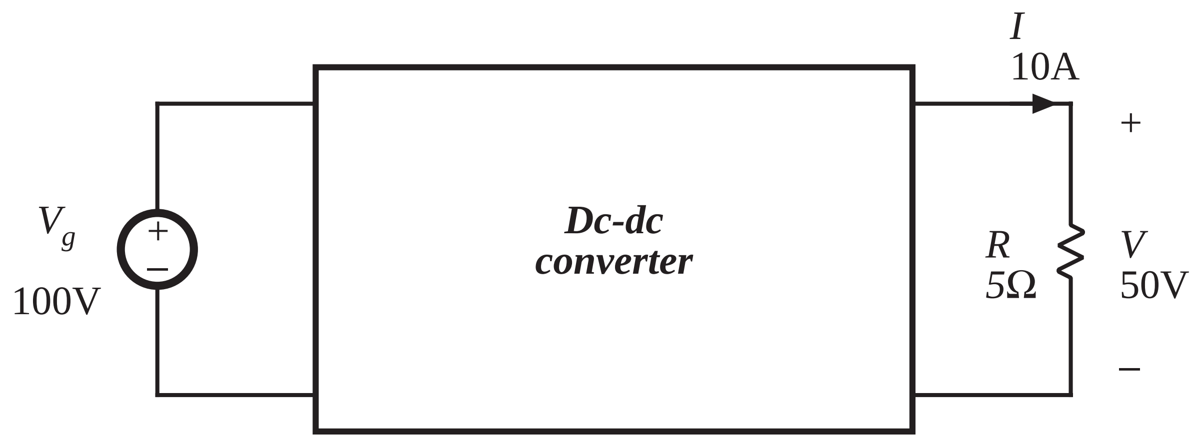
Switch open: $i(t) = 0$

In either event: $p(t) = v(t)\ i(t) = 0$

Ideal switch consumes zero power



A simple dc-dc converter example



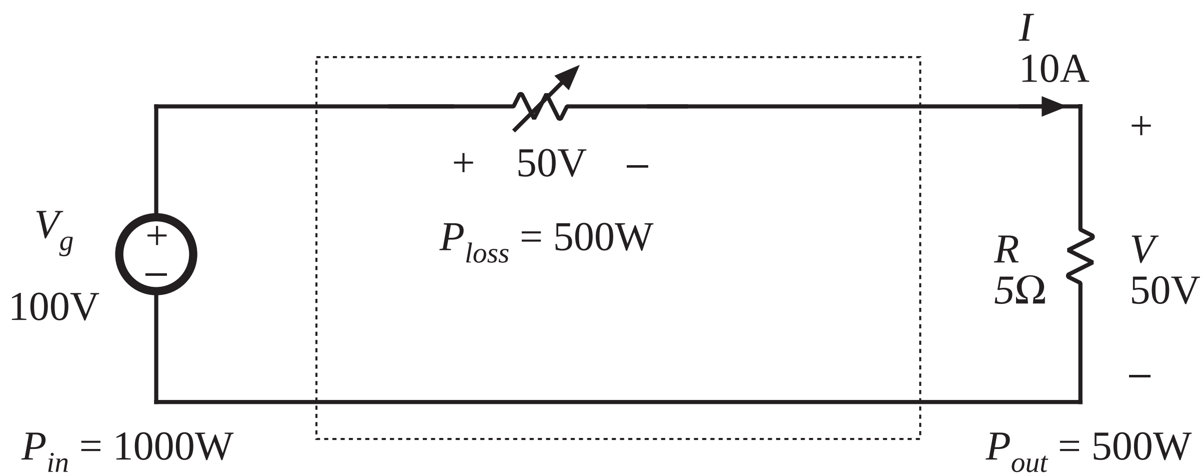
Input source: 100V

Output load: 50V, 10A, 500W

How can this converter be realized?

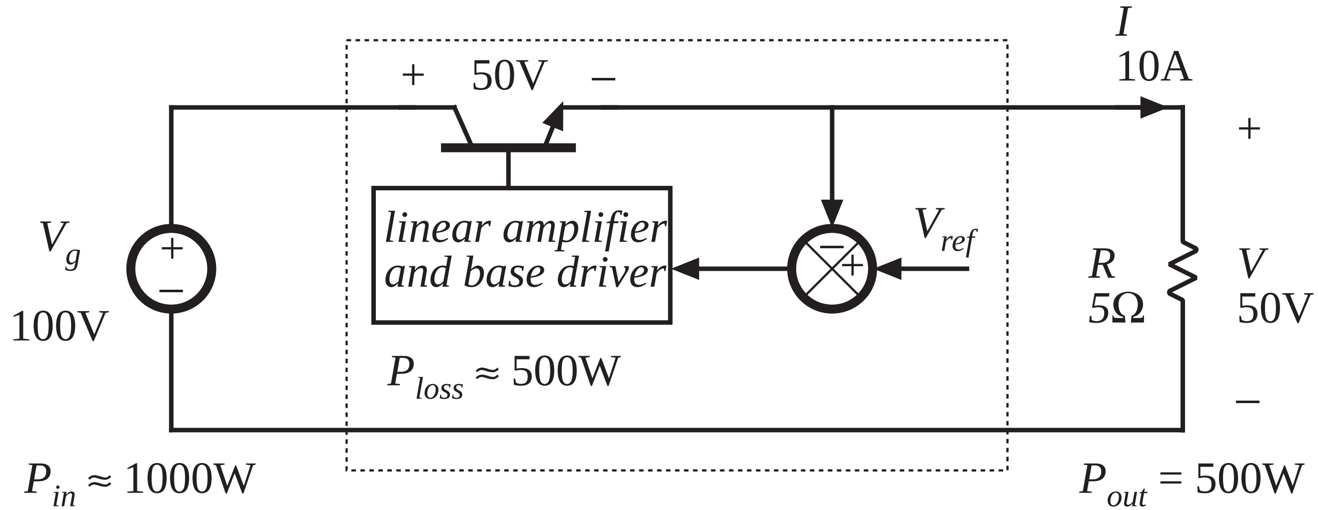
Dissipative realization

Resistive voltage divider

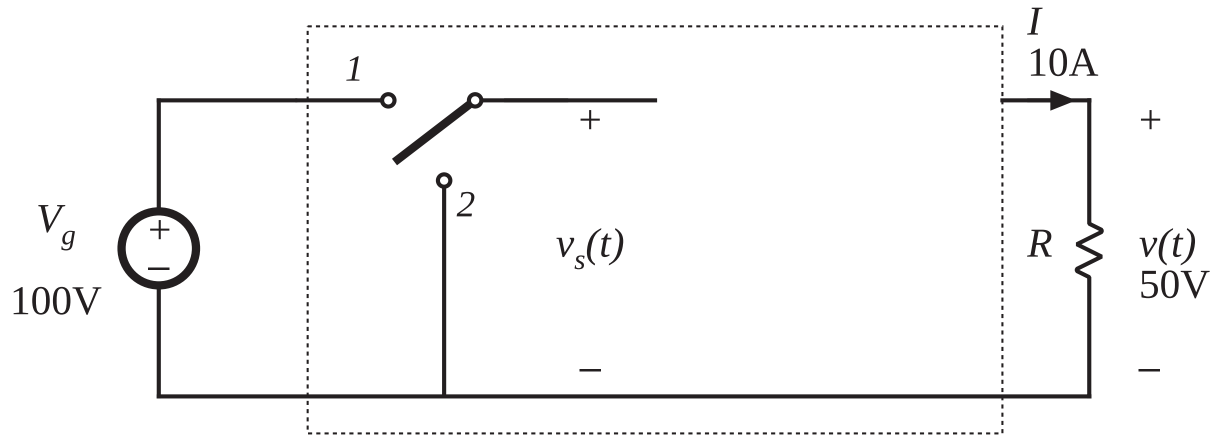


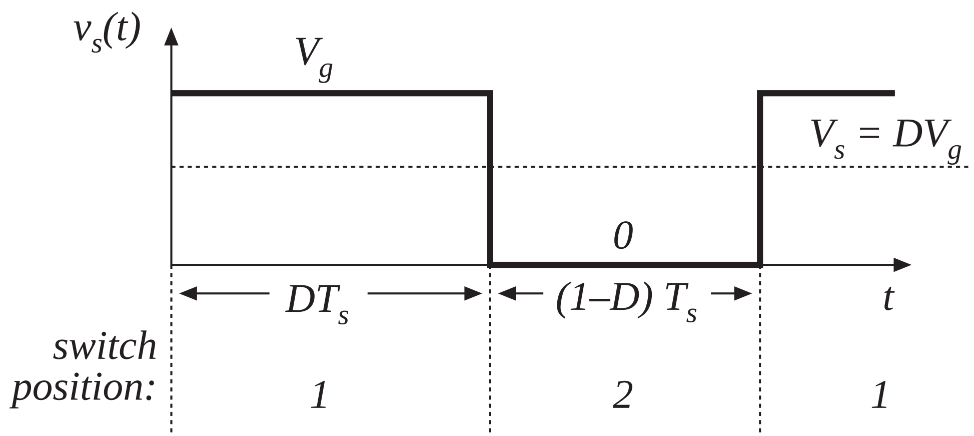
Dissipative realization

Series pass regulator: transistor operates in active region

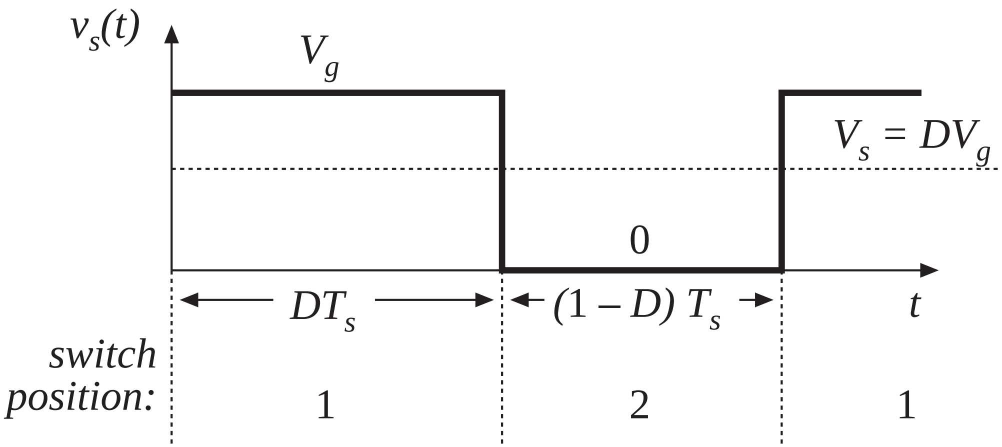


Use of a SPDT switch





The switch changes the dc voltage level



D = switch duty cycle

$0 \le D \le 1$

T_s = switching period

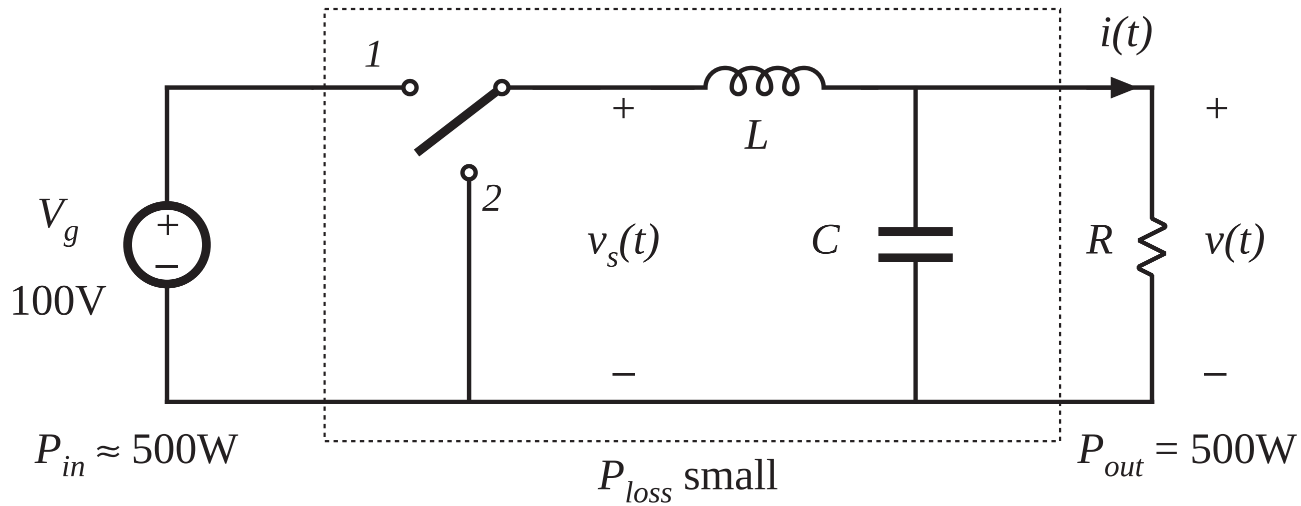
f_s = switching frequency
$= 1 / T_s$

DC component of $v_s(t)$ = average value:

$$V_s = \frac{1}{T_s} \int_0^{T_s} v_s(t)\, dt = DV_g$$

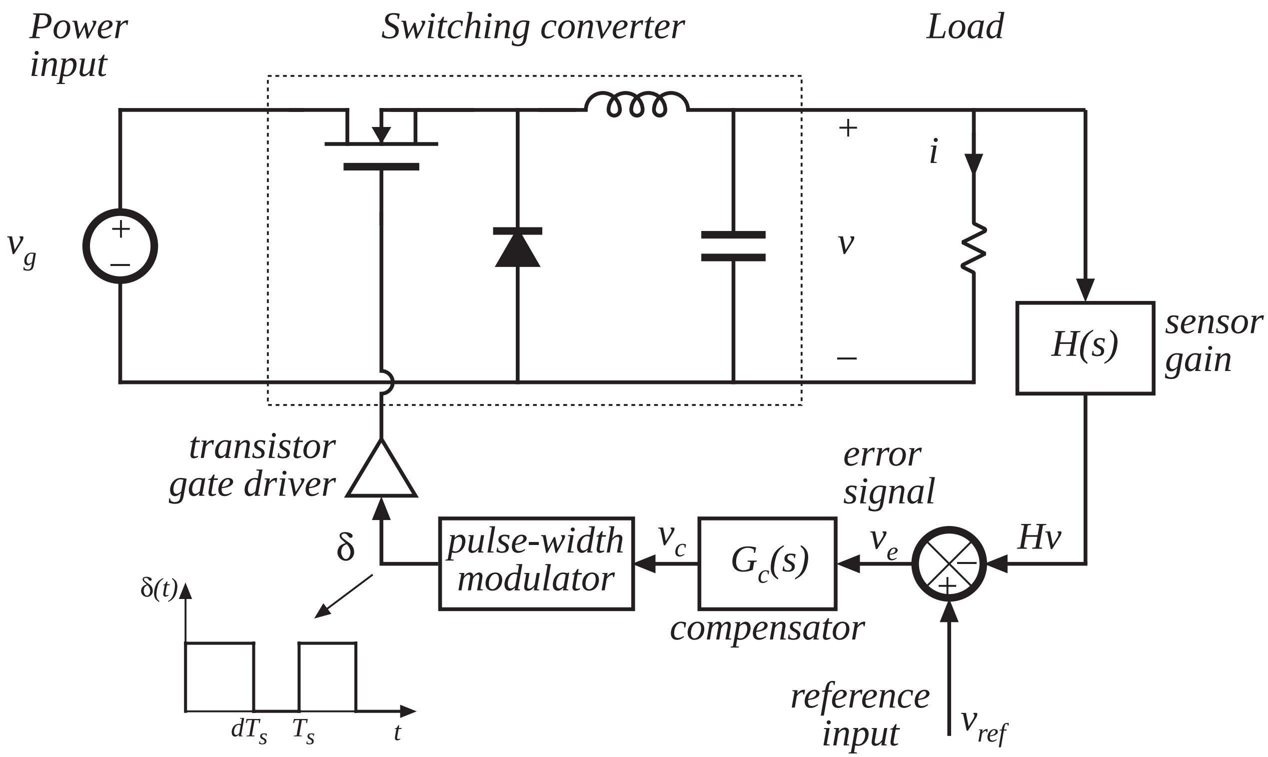
Addition of low pass filter

Addition of (ideally lossless) *L*-*C* low-pass filter, for removal of switching harmonics:

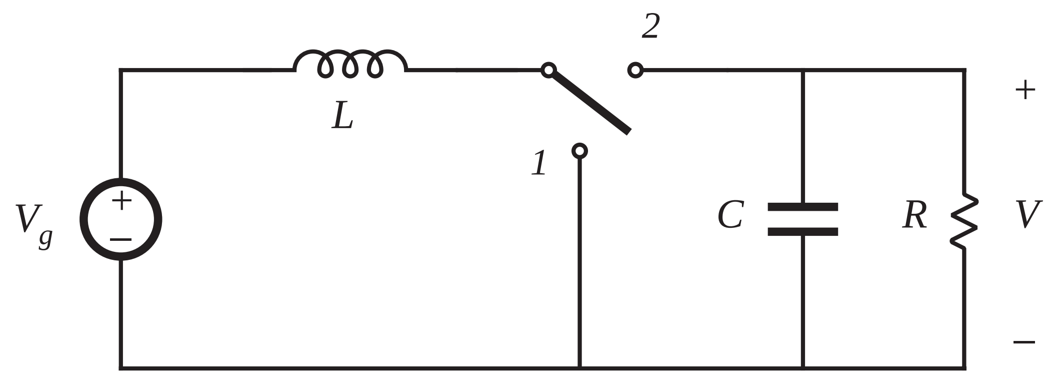


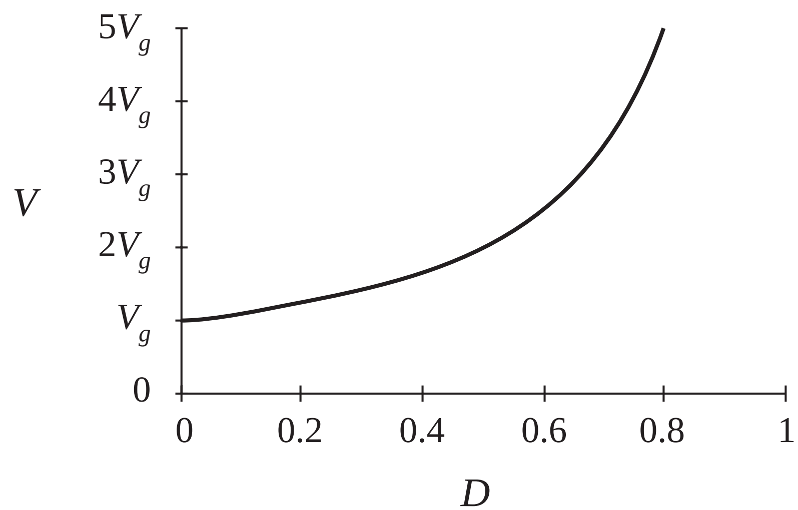
- Choose filter cutoff frequency f_0 much smaller than switching frequency f_s
- This circuit is known as the “buck converter”

Addition of control system for regulation of output voltage

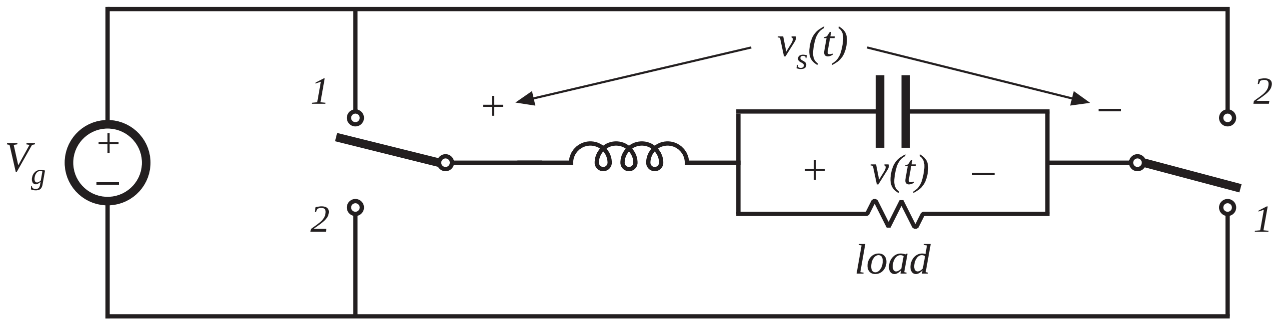


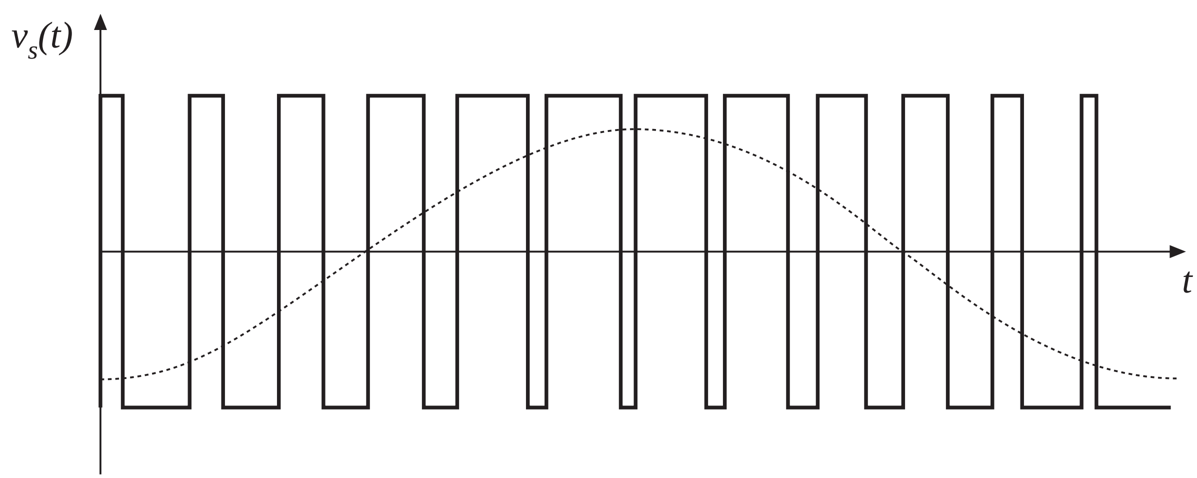
The boost converter





A single-phase inverter





"H-bridge"

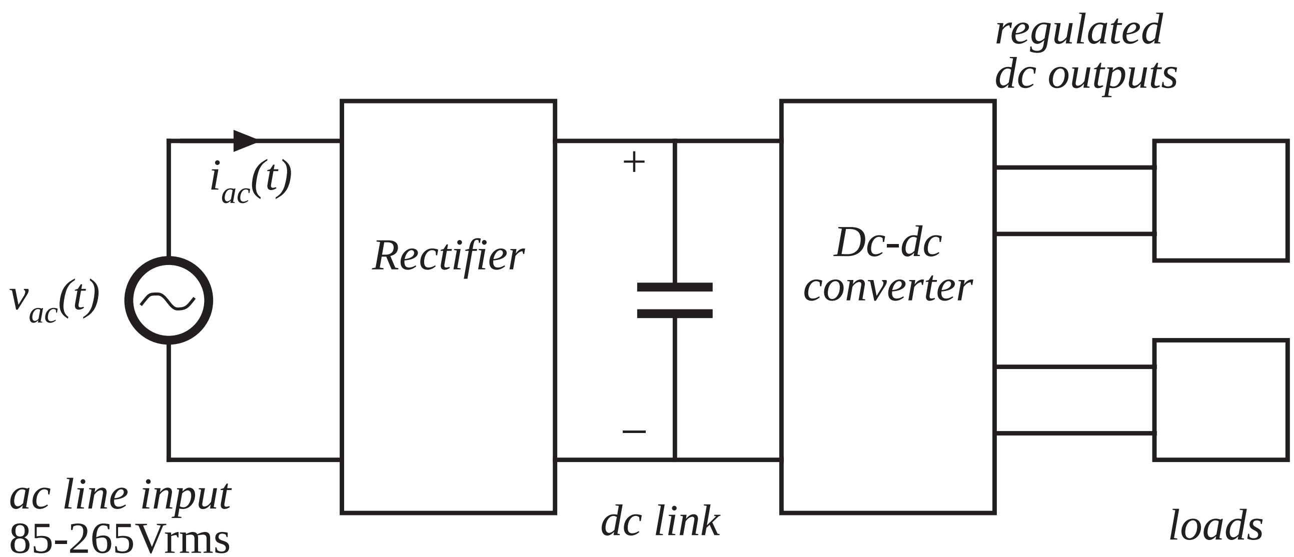
Modulate switch duty cycles to obtain sinusoidal low-frequency component

1.2 Several applications of power electronics

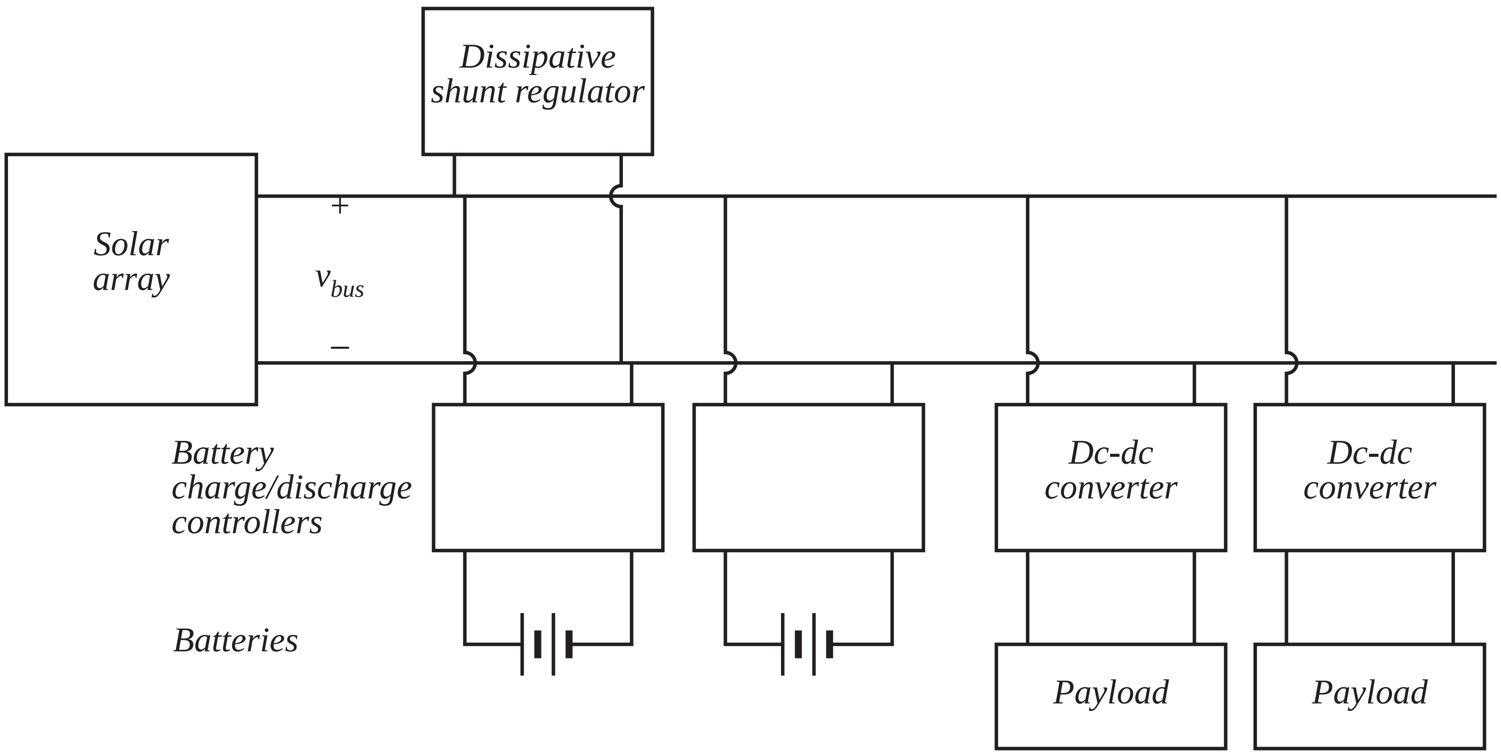
Power levels encountered in high-efficiency converters

- less than 1 W in battery-operated portable equipment
- tens, hundreds, or thousands of watts in power supplies for computers or office equipment
- kW to MW in variable-speed motor drives
- 1000 MW in rectifiers and inverters for utility dc transmission lines

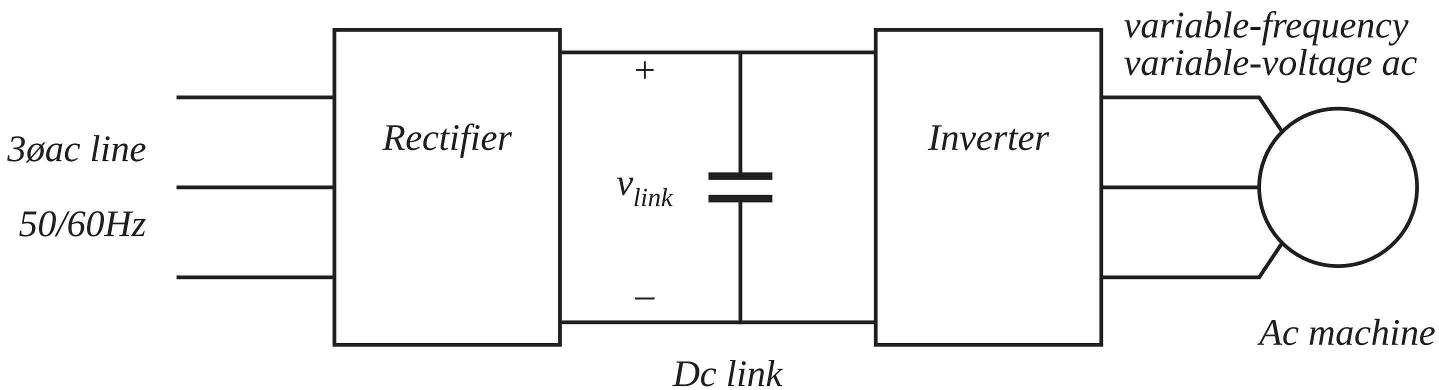
A computer power supply system



A spacecraft power system



A variable-speed ac motor drive system



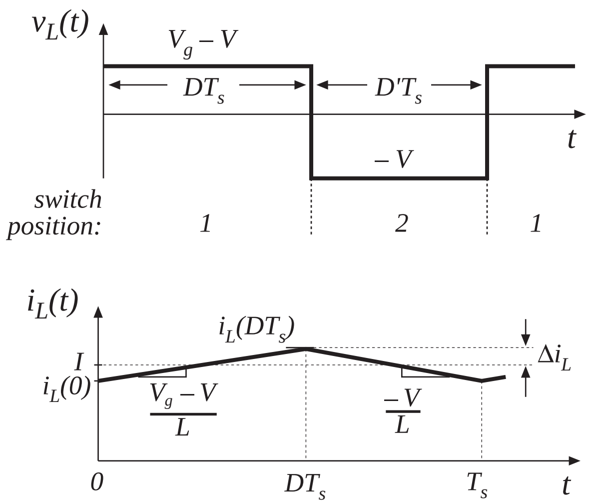
1.3 Elements of power electronics

Power electronics incorporates concepts from the fields of

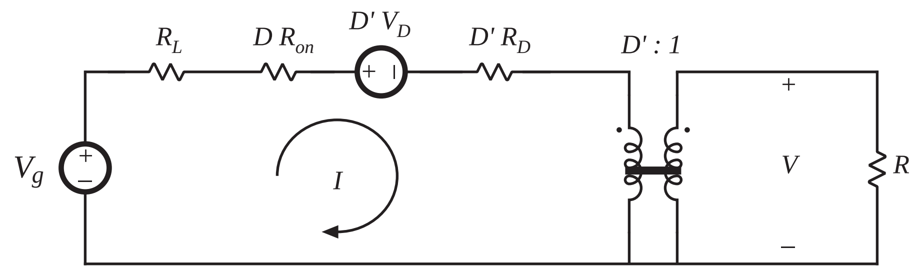
- analog circuits
- electronic devices
- control systems
- power systems
- magnetics
- electric machines
- numerical simulation

Part I. Converters in equilibrium

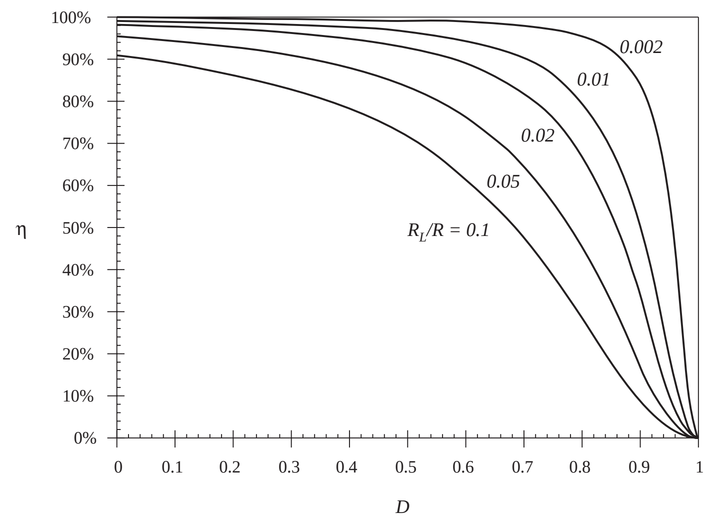
Inductor waveforms



Averaged equivalent circuit



Predicted efficiency

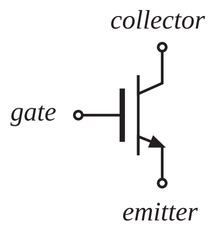


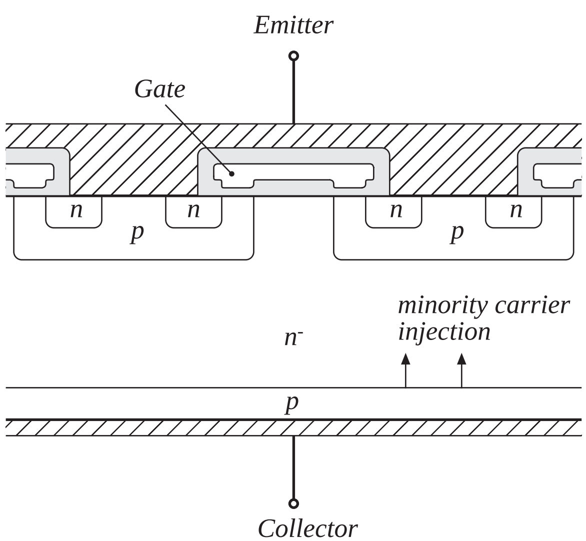
Discontinuous conduction mode

Transformer isolation

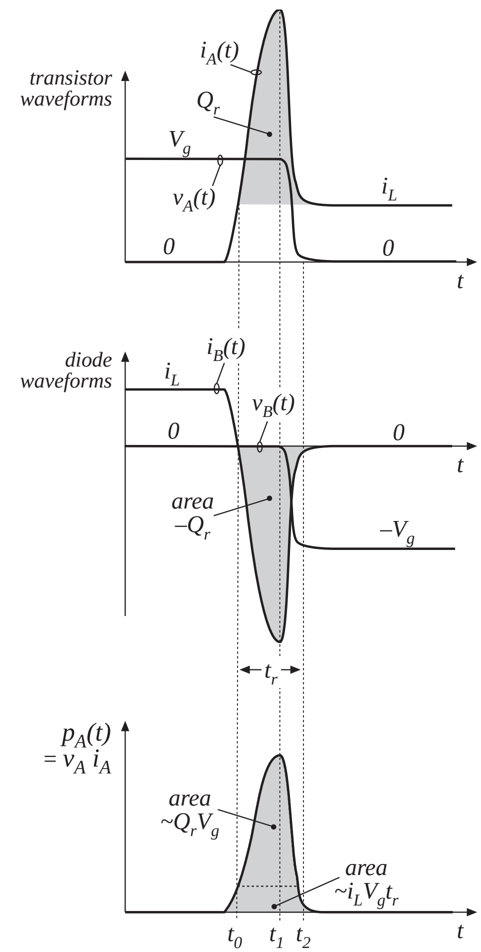
Switch realization: semiconductor devices

The IGBT





Switching loss

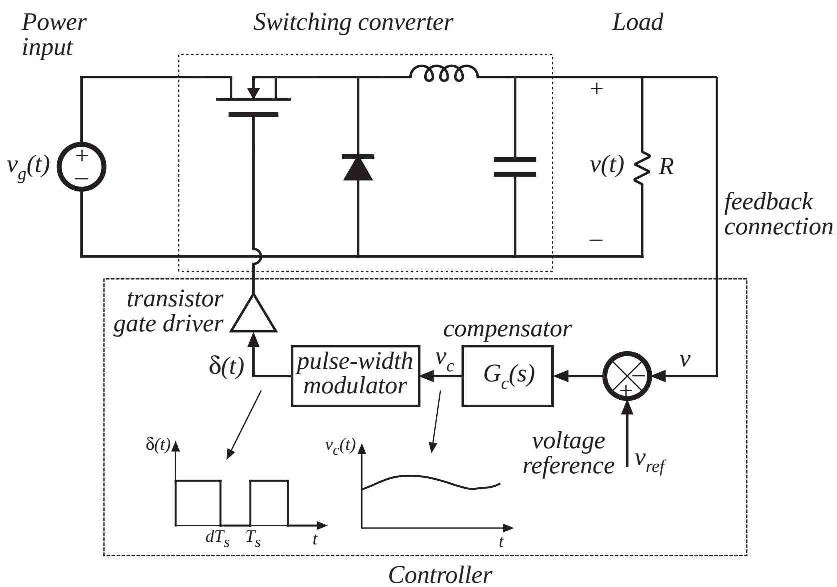


Part I. Converters in equilibrium

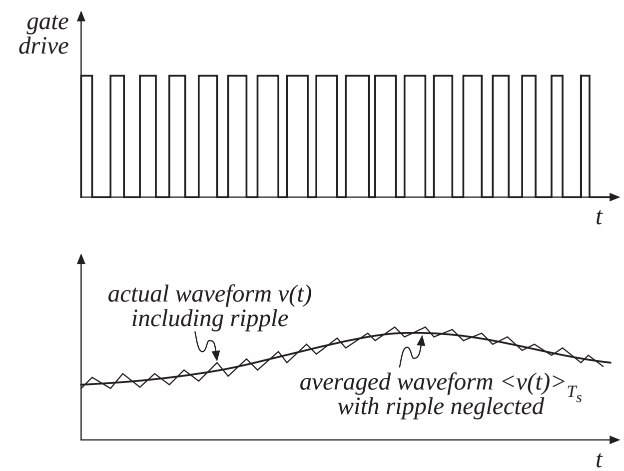
2. Principles of steady state converter analysis
3. Steady-state equivalent circuit modeling, losses, and efficiency
4. Switch realization
5. The discontinuous conduction mode
6. Converter circuits

Part II. Converter dynamics and control

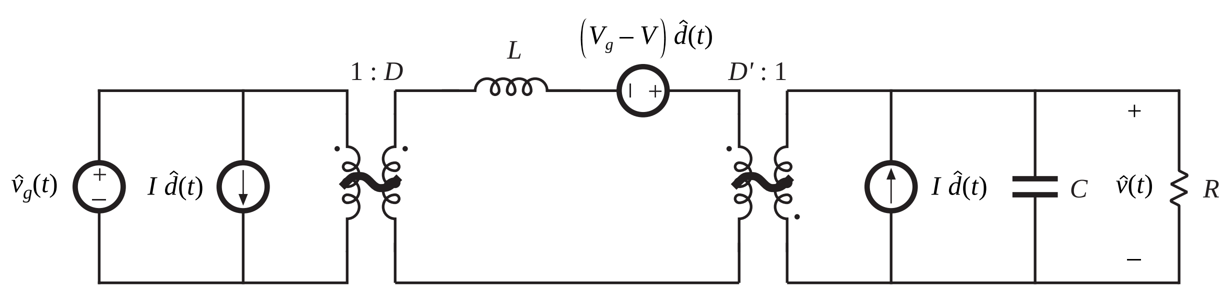
Closed-loop converter system



Averaging the waveforms



Small-signal averaged equivalent circuit

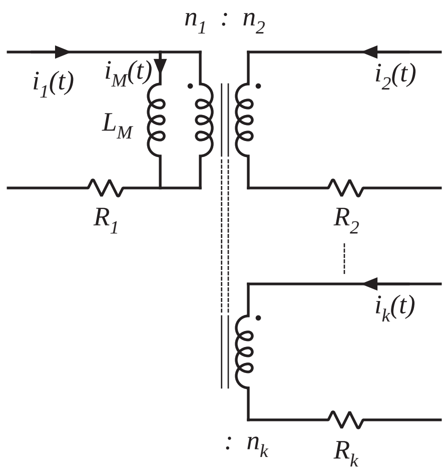


Part II. Converter dynamics and control

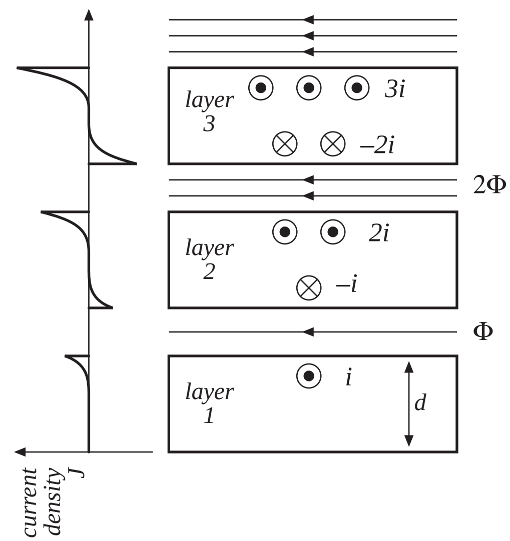
7. Ac modeling
8. Converter transfer functions
9. Controller design
10. Ac and dc equivalent circuit modeling of the discontinuous conduction mode
11. Current-programmed control

Part III. Magnetics

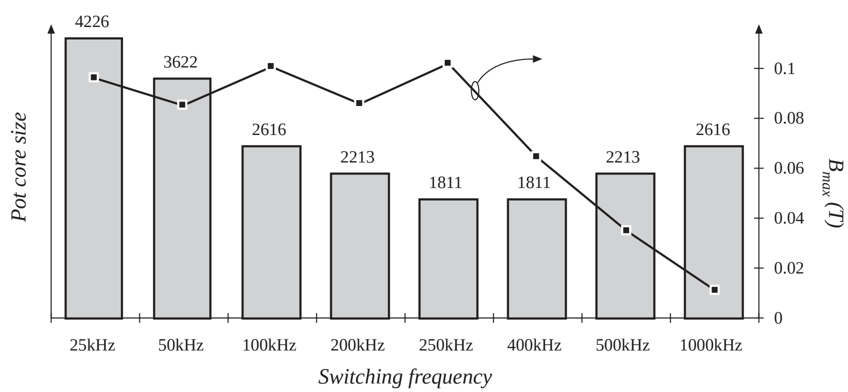
transformer design



the proximity effect



transformer size vs. switching frequency

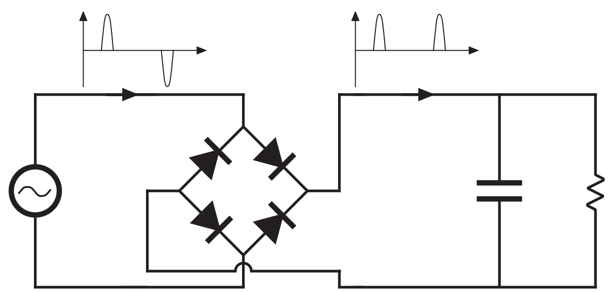


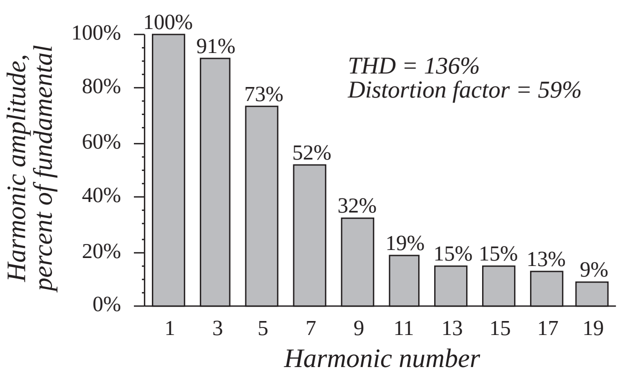
Part III. Magnetics

12. Basic magnetics theory
13. Filter inductor design
14. Transformer design

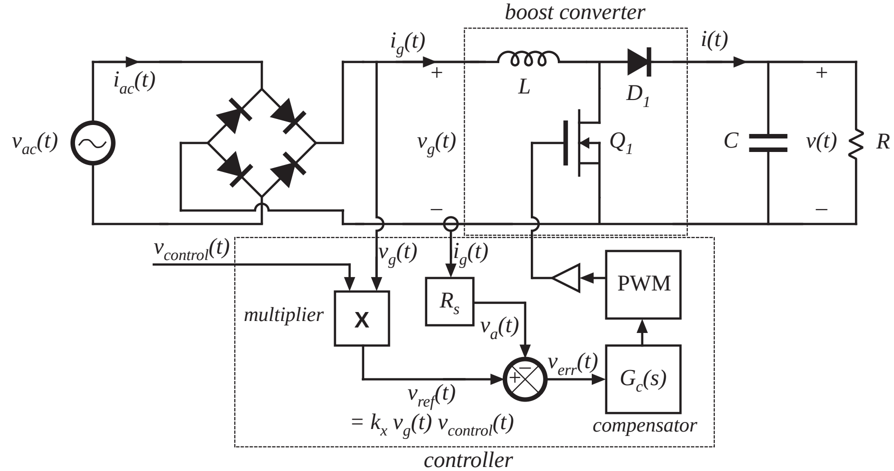
Part IV. Modern rectifiers,
and power system harmonics

Pollution of power system by rectifier current harmonics

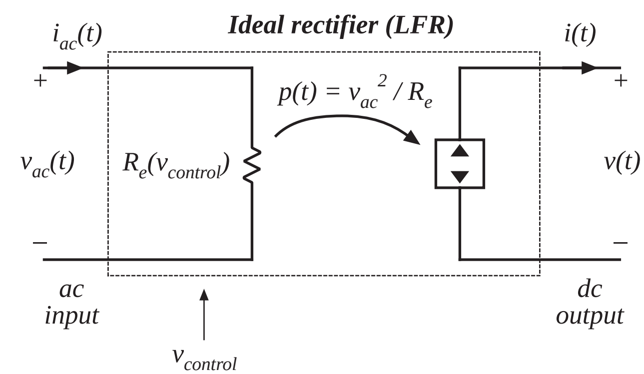




A low-harmonic rectifier system



Model of the ideal rectifier

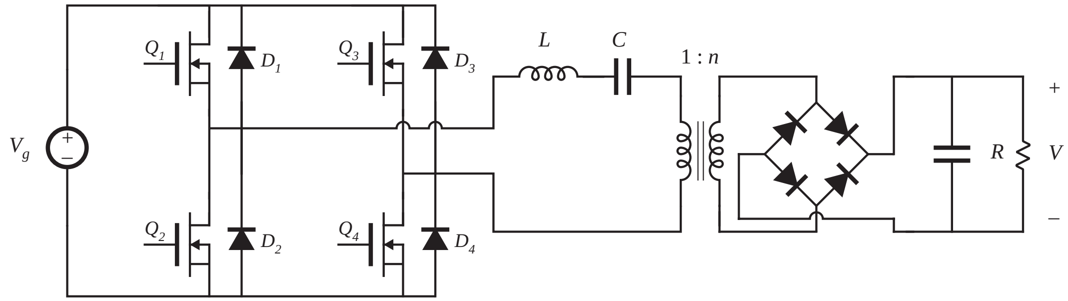


Part IV. Modern rectifiers,
and power system harmonics

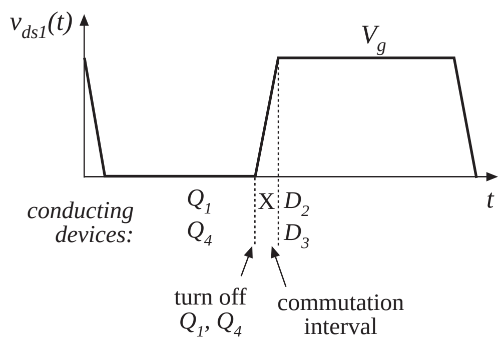
15. Power and harmonics in nonsinusoidal systems
16. Line-commutated rectifiers
17. The ideal rectifier
18. Low harmonic rectifier modeling and control

Part V. Resonant converters

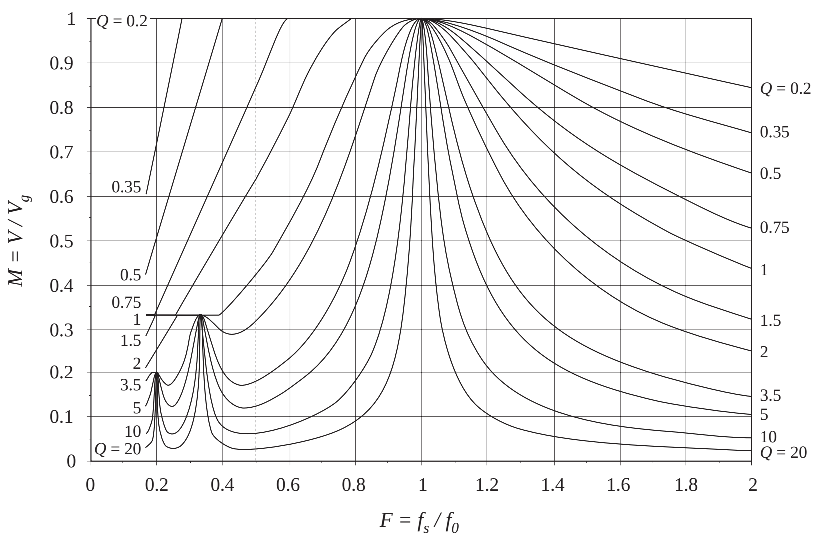
The series resonant converter



Zero voltage switching



Dc characteristics



Part V. Resonant converters