EEE213 Power Electronics and Electromechanism

1. INTRODUCTION

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Room EE318

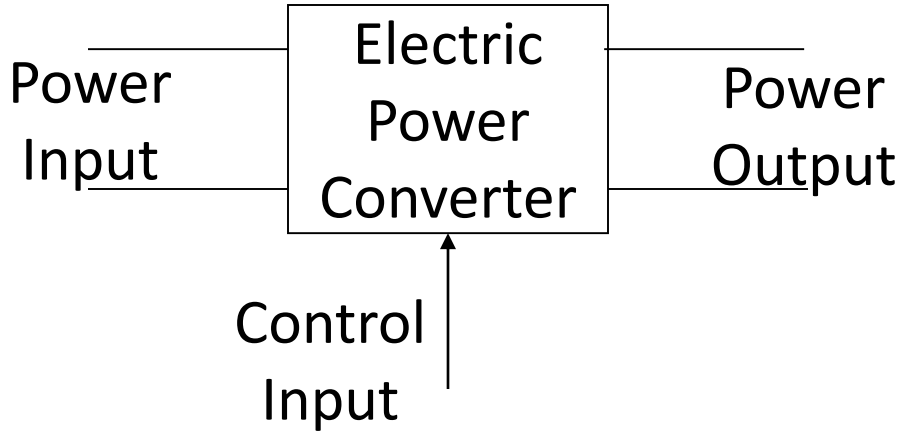
Introduction - Outline

- 1. What is Power Electronics?
  - Definition
  - Relation with information electronics
  - The interdisciplinary nature
  - Significance in the human society
- 2. The brief history
- 3. Typical applications
- 4. Efficiency of power electronic system
  - Importance of the efficiency
  - Introduction to power processing

1.1 Definition

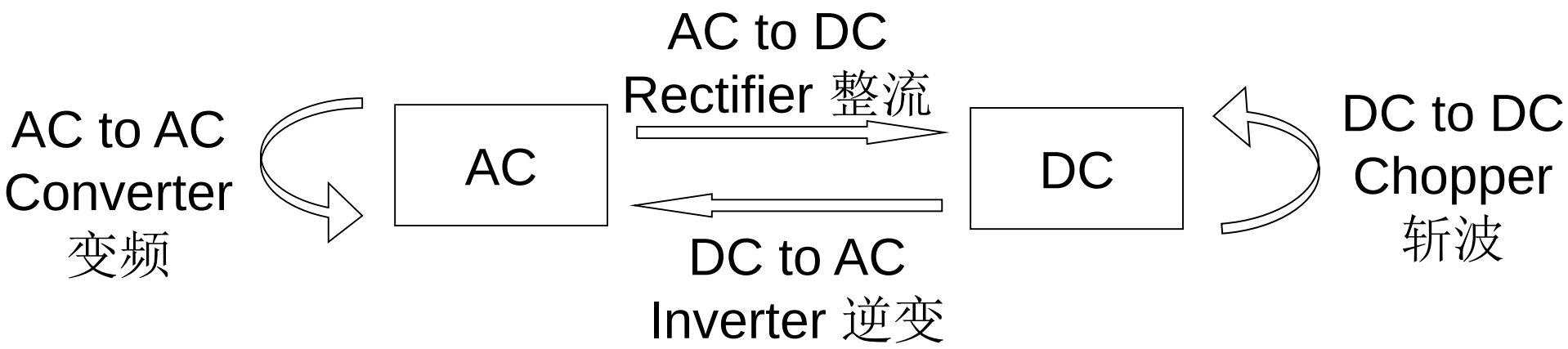
- Power Electronics:
  - is the electronics applied to the conversion and control of electric power.
  - Range of power scale:

    milliwatts (mW) -> megawatts (MW) -> gigawatts (GW)
- Electric power converter also called:
  - Power converter
  - Converter
  - Switching converter
  - Power electronic circuit
  - Power electronic converter

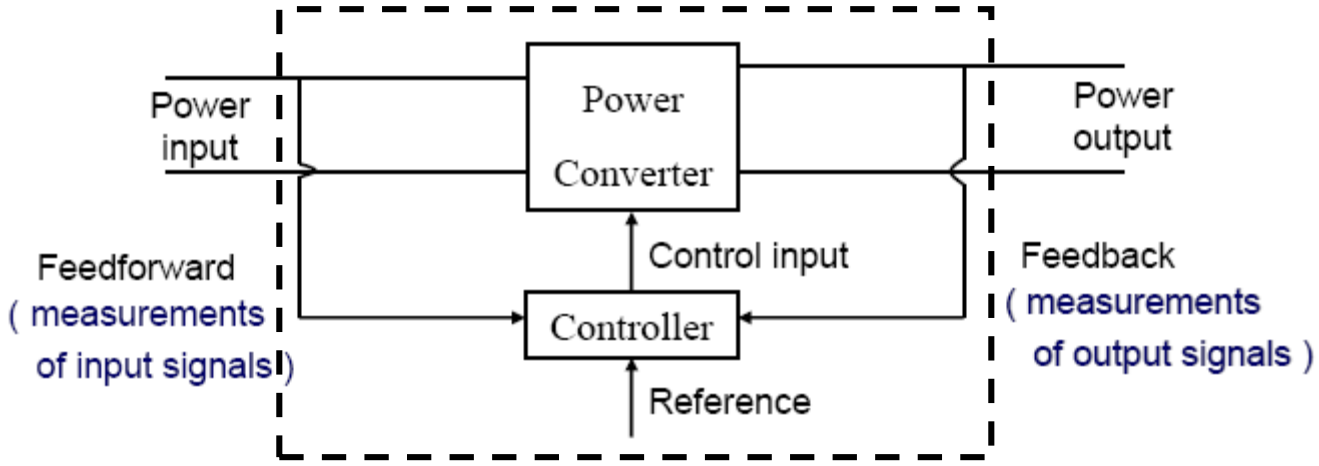


Conversion of electric power

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



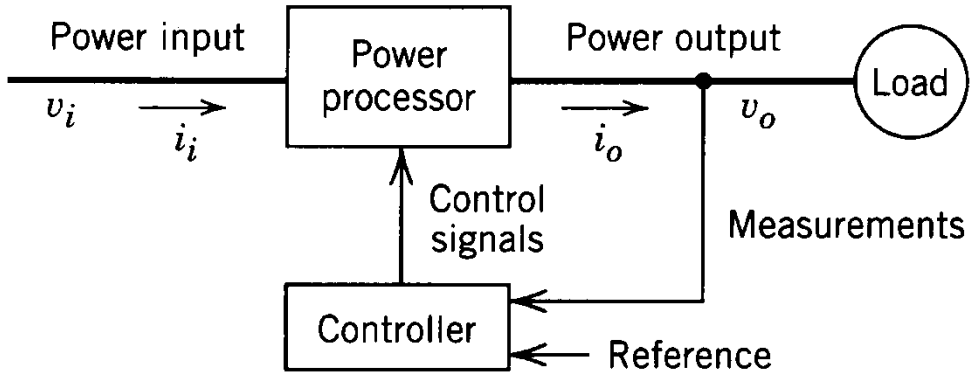
Generic structure of a power electronic system



Power Electronic System

- Control is invariably required.
- Power converter along with its controller including the corresponding measurement and interface circuits, is also called power electronic system.

A typical power electronic system



- The task of power electronics has been recently extended to also ensuring the currents and power consumed by power converters and loads to meet the requirement of electric energy sources.

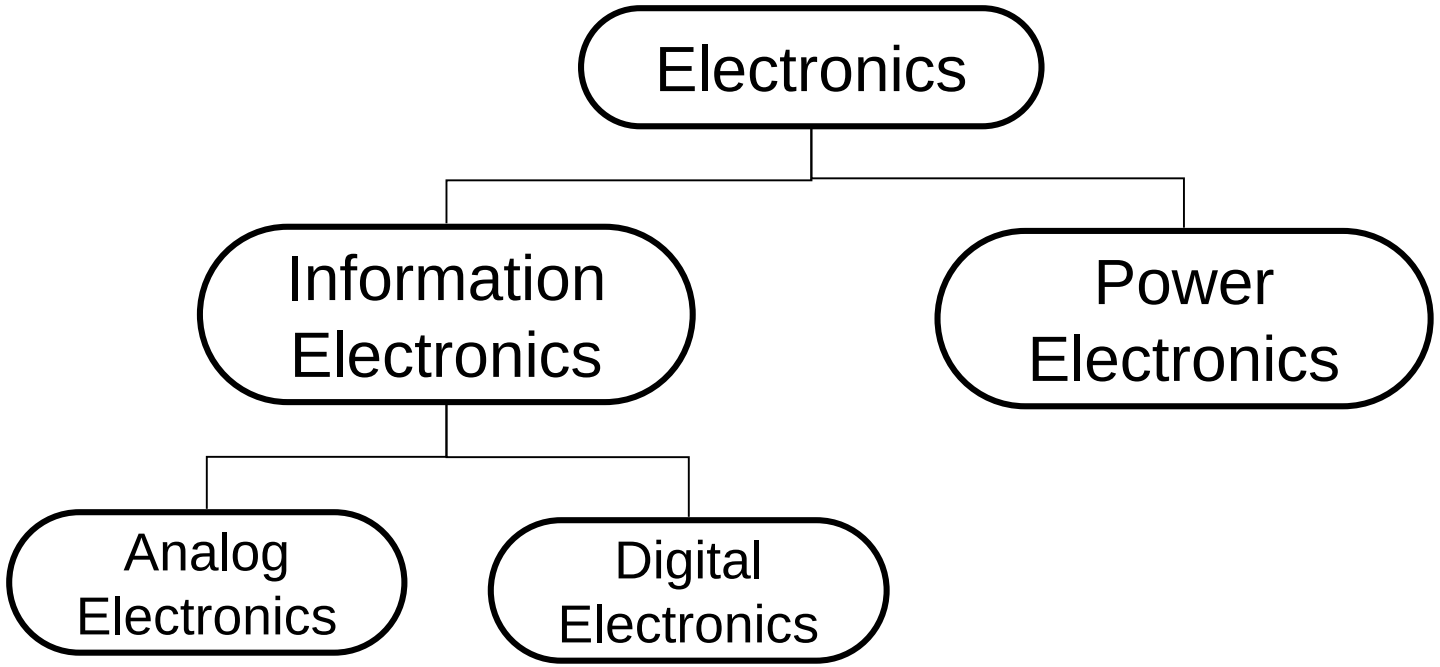
1.2 Classification of electronics

- A classification of electronics by processing object:
  - Information electronics: to process information
  - Power electronics: to process electric power
- A classification of electronics by devices:
  - Vacuum electronics: using vacuum devices

    e.g. vacuum tubes devices
  - Solid (solid state) electronics: using solid state devices

    e.g. semiconductor devices
- A classification of electronics by targets:
  - Physical electronics: physics, material, fabrication, and manufacturing of electronic devices
  - Applied electronics: application of electronic devices to various areas

1.2 Relationship with information electronics



- A classification of electronics by processing object:
  - Information electronics: to process information
  - Power electronics: to process electric power

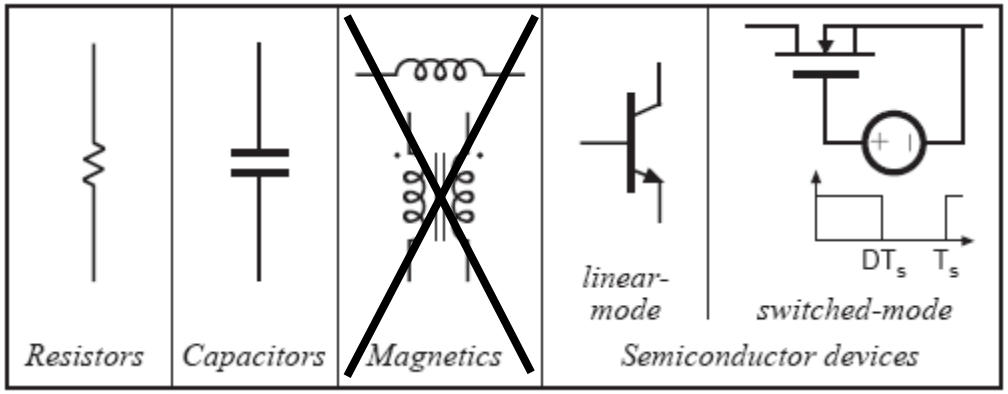
Relationship with Information Electronics

- Common:
  - Both of them have two branches, devices and applications;
  - Devices: material, fabrication and manufacture are similar, using microelectronics;
  - Application: fundamental theory, analysing methodology and software are similar;
- Differentia:
  - Devices for information electronics work both in switching status and amplifying status;
  - Devices for power electronics usually work in switching status only.

Devices available to the circuit designer

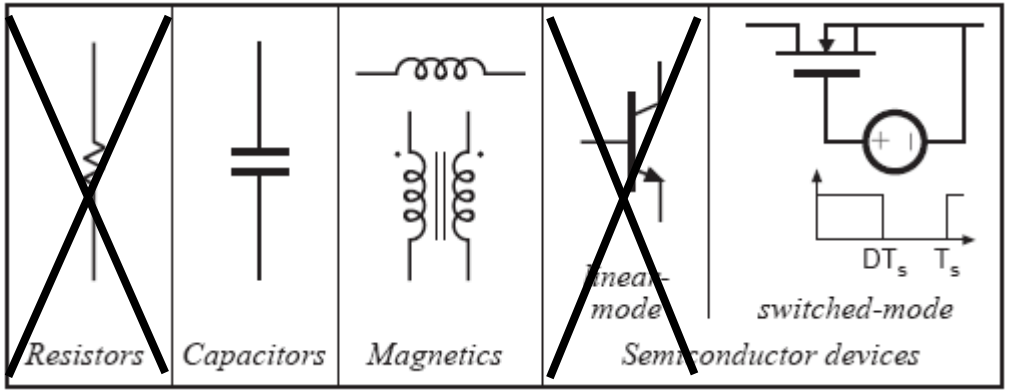
Signal processing

(avoid magnetics)



Power processing

(avoid lossy elements)

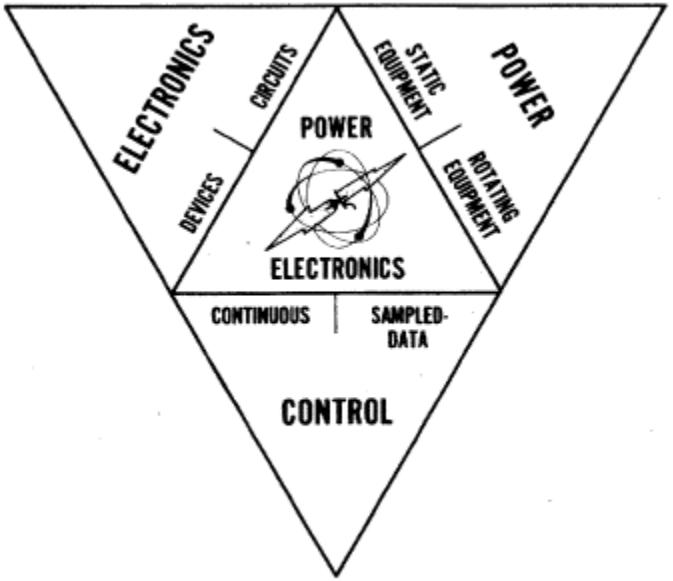


1.3 The interdisciplinary nature

Dr. William E. Newell

Research Laboratories

Westinghouse Electric Corporation



Power electronics: interstitial to all major disciplines of electrical engineering.

W. E. *NEWELL*, "Power Electronics—Emerging from Limbo," *IEEE Power Electronics Specialists Conference*, *1973*

Relationship with Power (Electrical Engineering)

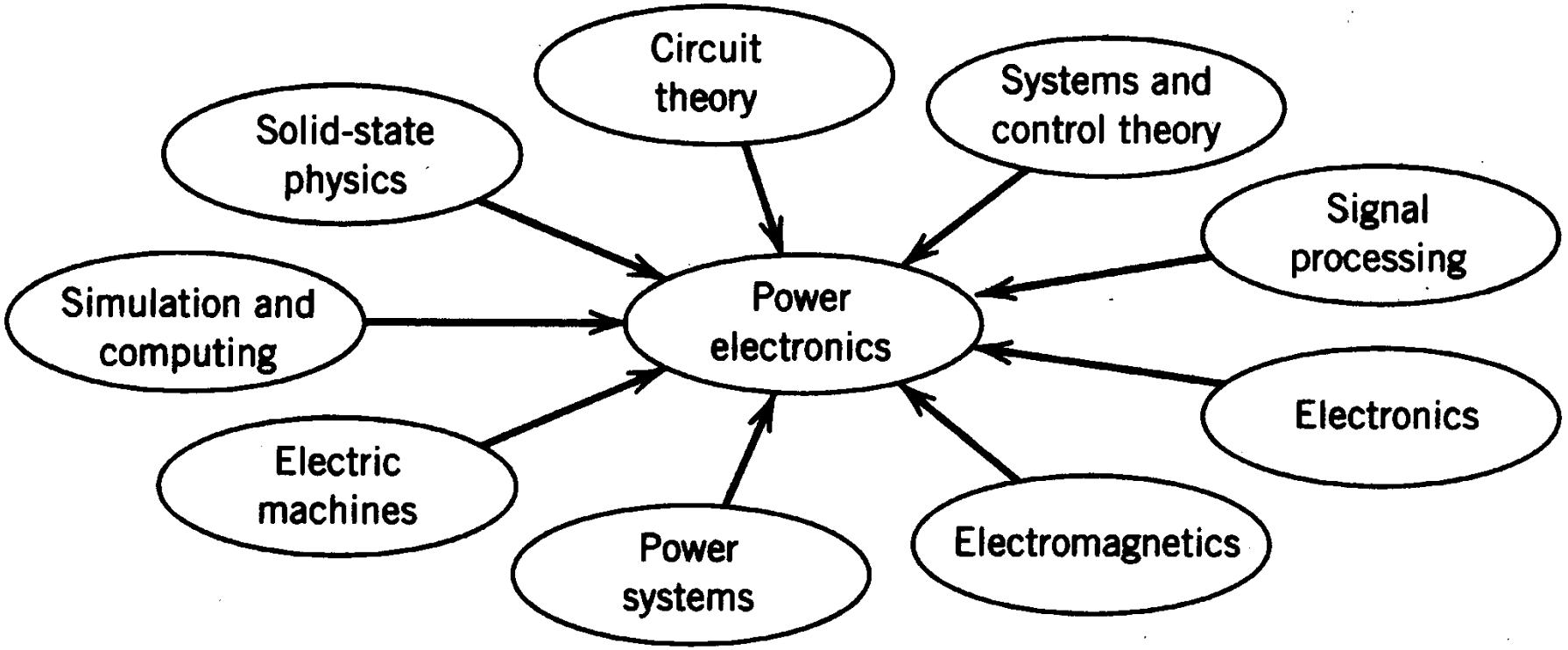
- Power electronics has been broadly applied in electrical engineering
  - High voltage DC power transmission
  - SVC (Static VAR Compensator)
  - Electric locomotive traction
  - AC/DC drive
  - High performance AC/DC power supply

- Power electronics is classified as one branch of electrical engineering

Relationship with Control (Automatisation)

- Control theory has been broadly applied in power electronics;
- Power electronics is to use light-current to control heavy-current;
  - The interface between the light-current system and heavy-current system;
- Power electronics is the important element and supporting technique in automatisation;
- Power electronics is currently the most active discipline in electric power engineering.

Relationship with multiple disciplines



Interdisciplinary nature of power electronics

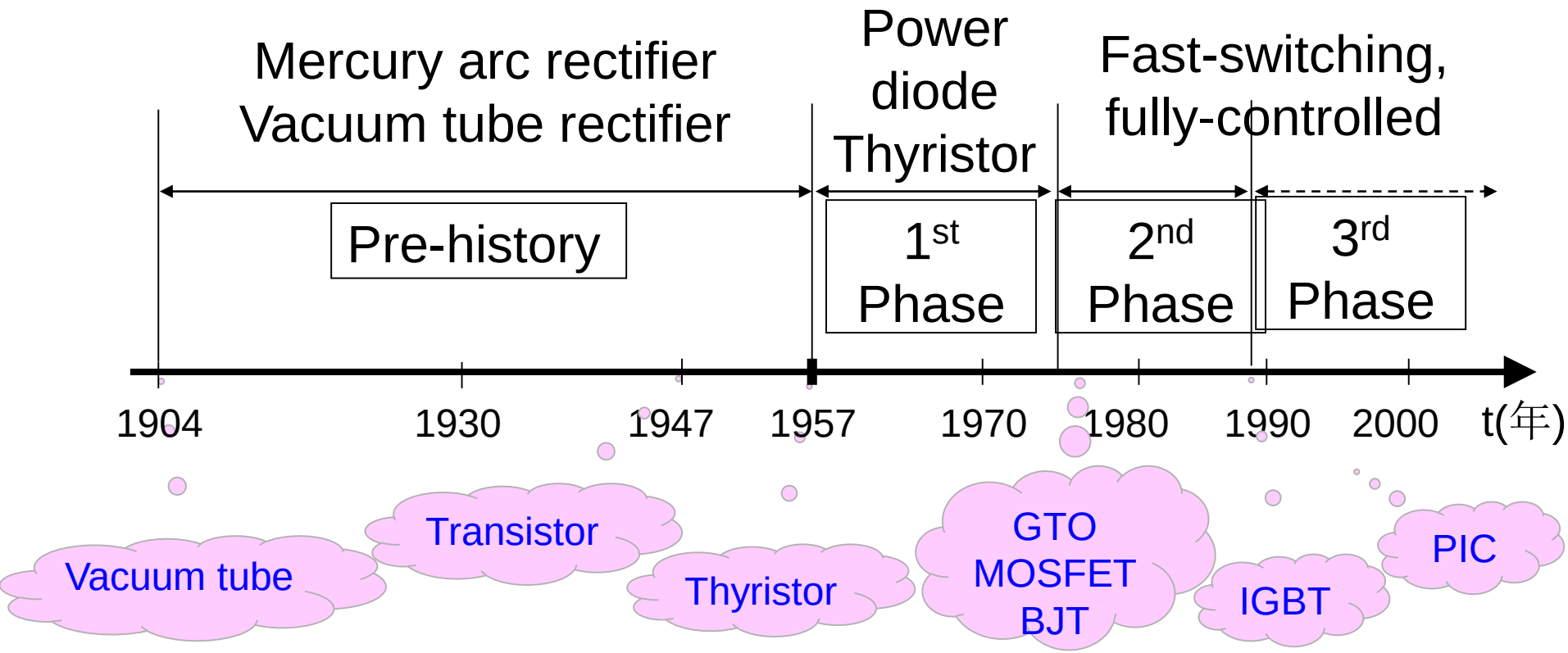
1.4 Significance in human society

- Electric power is used in almost every part and everywhere of modern human society. It is the major form of energy source used in modern human society.

- The objective of ***power electronics*** is right on how to use electric power, and how to use it effectively and efficiently, and how to improve the quality and utilization of electric power.

- Power electronics and information electronics make two poles of modern technology and human society: information electronics is the brain, and power electronics is the muscle.

2. The history



- The thread of the power electronics history is the break-through and evolution of power electronic devices

3. Applications

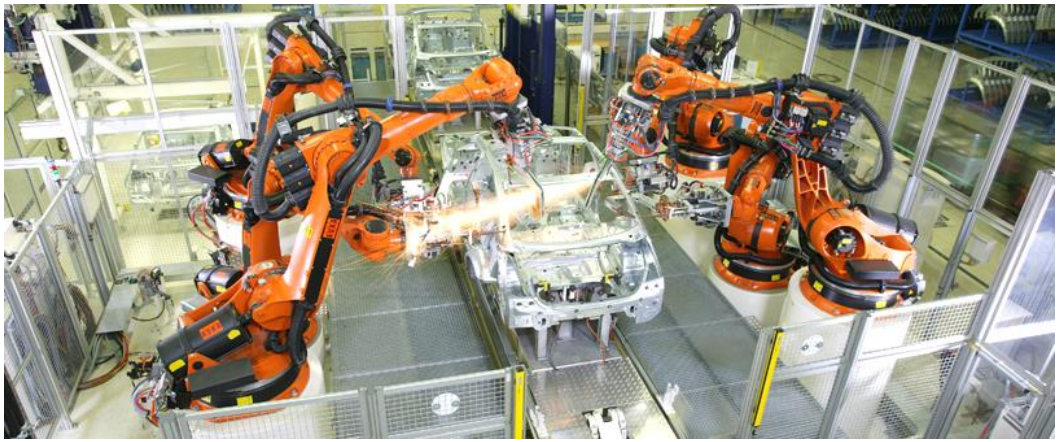
- Industrial
- Transportation
- Utility systems
- Renewable energy
- Residential and home appliances
- Other applications

3.1 Industrial Applications

- Motor drives
- Electrolysis
- Electroplating
- Induction heating
- Welding
- Arc furnaces and ovens
- Lighting

Port Machinery

Electrolytic aluminum



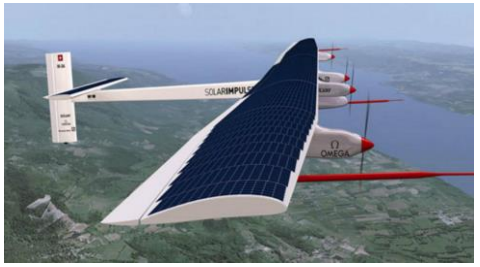
KUKA Robot

3.2 Transportation Applications

- Trains & locomotives
- Subways
- Trolley buses
- Magnetic levitation
- Electric vehicles
- Automotive electronics
- Ship power systems
- Aircraft power systems

CRH

Tesla Model s



Solar impulse 2

Zumwalt
All-Electric Destroyer

3.3 Utility systems Applications

- High-voltage dc transmission (HVDC)
- Flexible ac transmission (FACTS)
- Static var compensation (SVC)
- Solid State Transformer (SST)
- Suppression: TCR, TSC, SVG, APF
- Custom power & power quality control

Solid State Transformer (SST)

▶ Classical Transformer - Basics

- Advantages

- Relatively Inexpensive
- Highly Robust / Reliable
- Highly Efficient (98.5%...99.5% Dep. on Power Rating)

- Weaknesses

- Voltage Drop Under Load
- Losses at No Load
- Sensitivity to Harmonics
- Sensitivity to DC Offset Load Imbalances
- Provides No Overload Protection
- Possible Fire Hazard
- Environmental Concerns

▶ SST Functionalities

- Protects Load from Power System Disturbance
  - Voltage Harmonics / Sag Compensation
  - Outage Compensation

- Protects Power System from Load Disturbance
  - Load Voltage Regulation (Load Transients, Harmonics)
  - Unity Inp. Power Factor Under Reactive Load
  - Sinus. Inp. Curr. for Distorted / Non-Lin. Load
  - Symmetrizes Load to the Mains
  - Protection against Overload & Output Short Circ.

- Further Characteristics
  - Operates on Distribution Voltage Level (MV-LV)
  - Integrates Energy Storage (Energy Buffer)
  - DC Port for DER Connection
  - Medium Frequency Isolation → Low Weight / Volume
  - Definable Output Frequency
  - High Efficiency
  - No Fire Hazard / Contamination

3.4 Renewable energy application

- Wind
- Photovoltaic
- Fuel cells
- Energy storage systems

3.5 Residential and home appliances

- Lighting
- Heating
- Air conditioning
- Refrigeration & freezers
- Cooking
- Cleaning
- Entertaining

FINsix (MIT Spin off company）

Smart home device

3.6 Other applications

- Power systems for particle accelerators
- Space technology
- Military application

Electromagnetic gun

Particle accelerator

Electromagnetic Aircraft Launch System (EMALS)

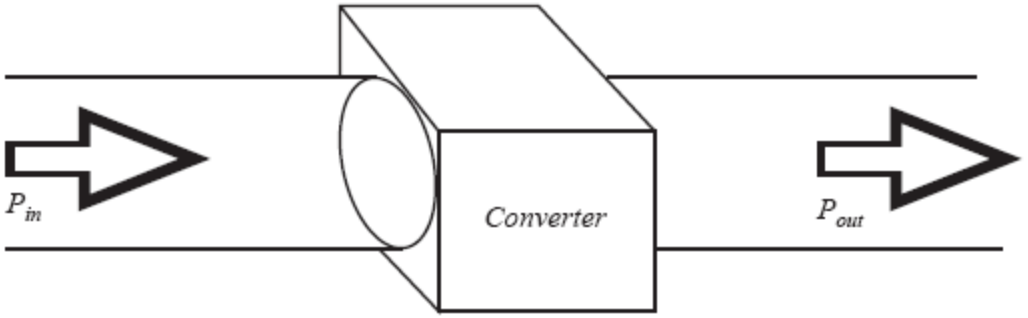
Trends

- It is estimated that in developed countries now 60% of the electric energy goes through some kind of power electronics converters before it is finally used.
- Power electronics has been making major contributions to:
  - better performance of and better control of power supplies
  - electric equipment
  - energy saving
  - environment protection
    - reduction of energy consumption leads to less pollution
    - reduction of pollution produced by power converters
    - direct applications to environment protection technology

4. Efficiency of power electronic system

- 4.1 A high efficiency converter

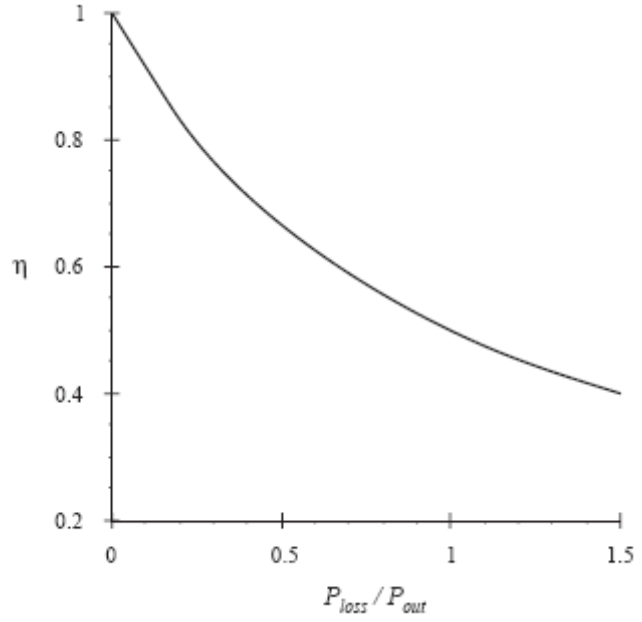
  A goal of current converter technology is to construct converters of small size and weight, which process substantial power at high efficiency



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

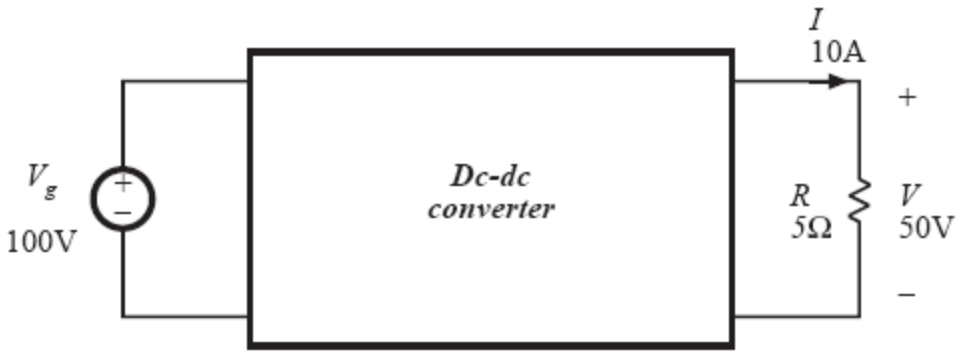
- $P_{loss}=P_{in}-P_{out}$ dissipated by the converter elements is converted in to heat;
- It causes the electronic elements within the converter to operate at high temperature, and it reduces the system reliability.
- It must be minimised in the converter.

- High efficiency is essential
  - 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



4.2 Introduction to power processing

- To build a circuit that changes the voltage yet dissipates negligible power.
  - Capacitive and inductive elements, as well as switched-mode semiconductor devices, are available for synthesis of high-efficiency converters.
- A simple DC-DC converter example:

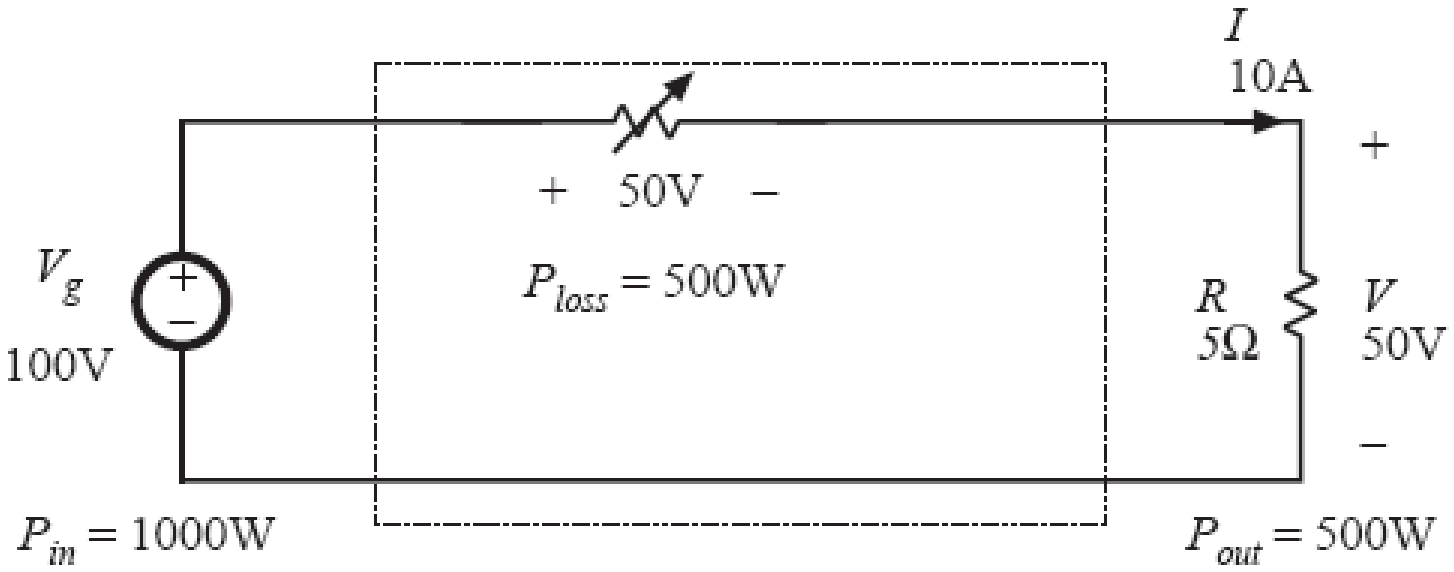


Input source: 100V
Output load: 50V, 10A, 500W

How can this converter be realized?

4.2.1 Resistive voltage divider

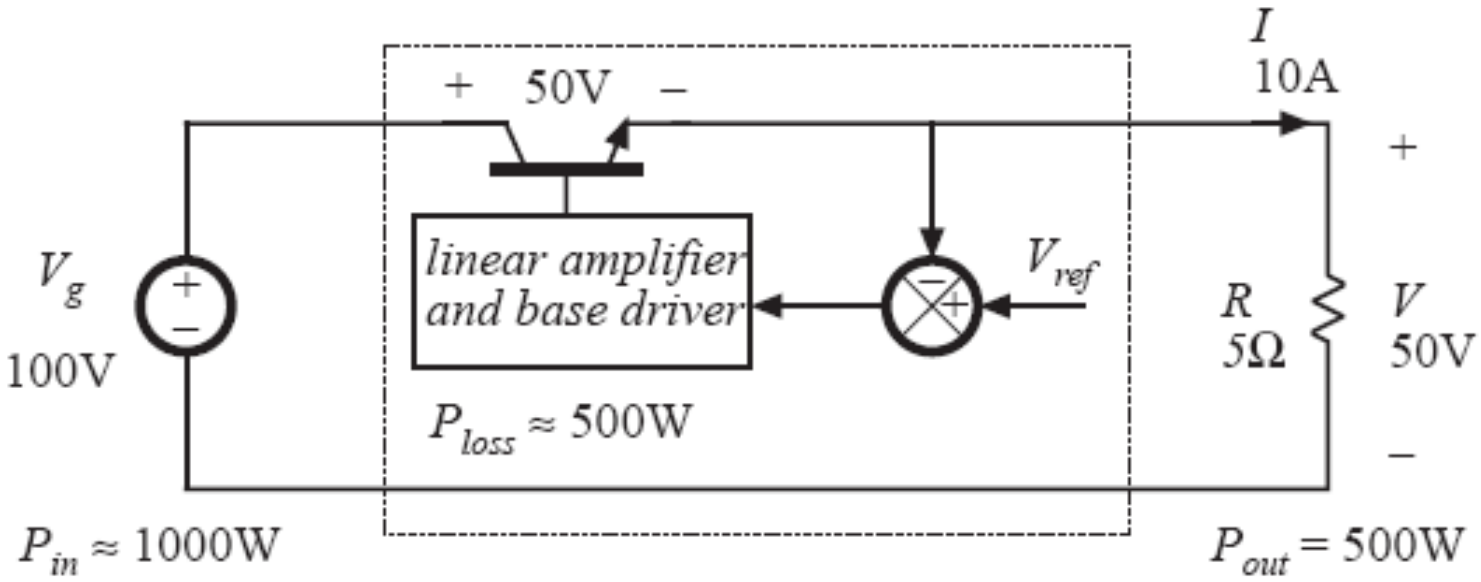
- Dissipative realisation



$$\eta = \frac{P_{out}}{P_{in}} = 50\%$$

4.2.2 Series pass regulator

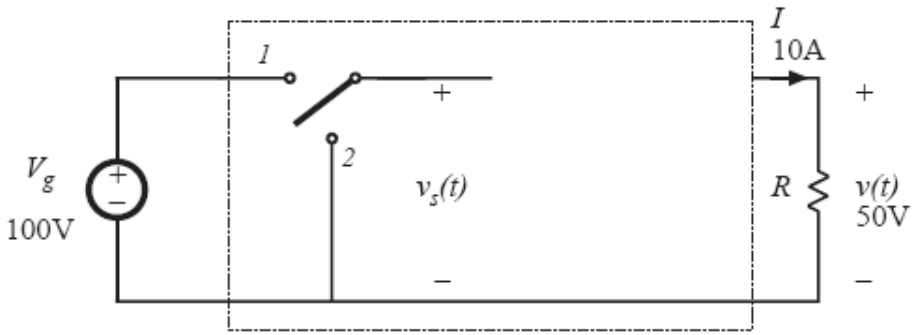
- Dissipative realisation

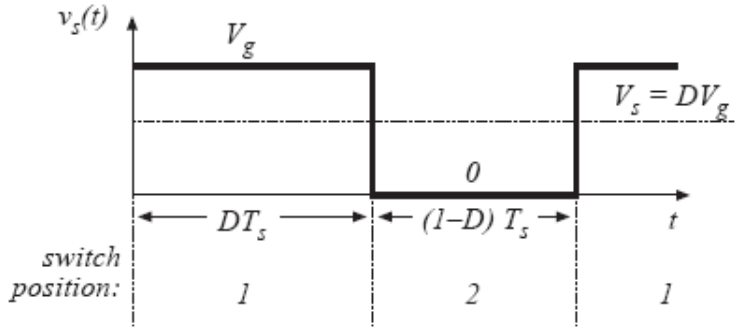


$$\eta = \frac{P_{out}}{P_{in}} = 50\%$$

4.2.3 Use of a SPDT switch

- The switch changes the dc voltage level





D = switch duty cycle
0 <= *D* <= 1

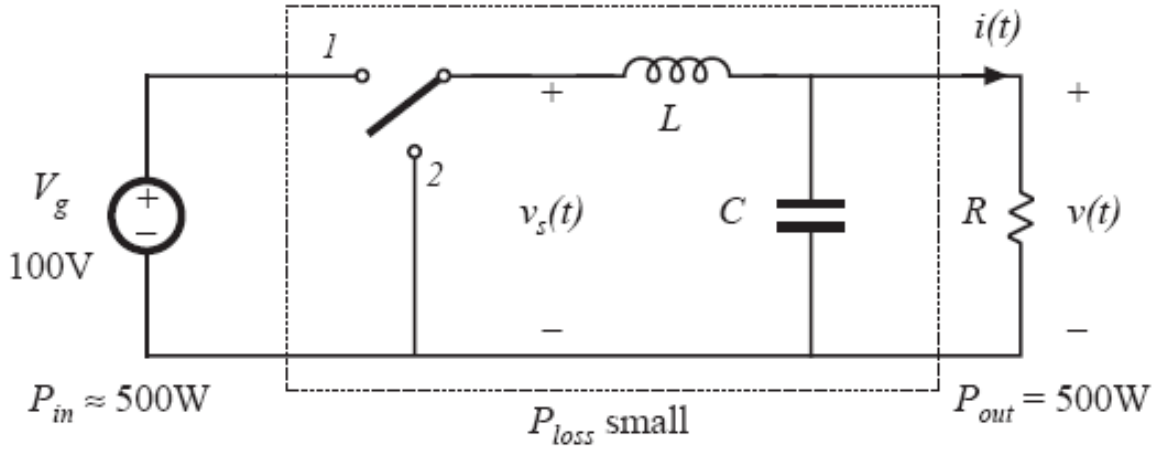
Ts = switching period
fs = switchin frequency = 1 / *Ts*

DC component of *vs(t)* = average value:

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

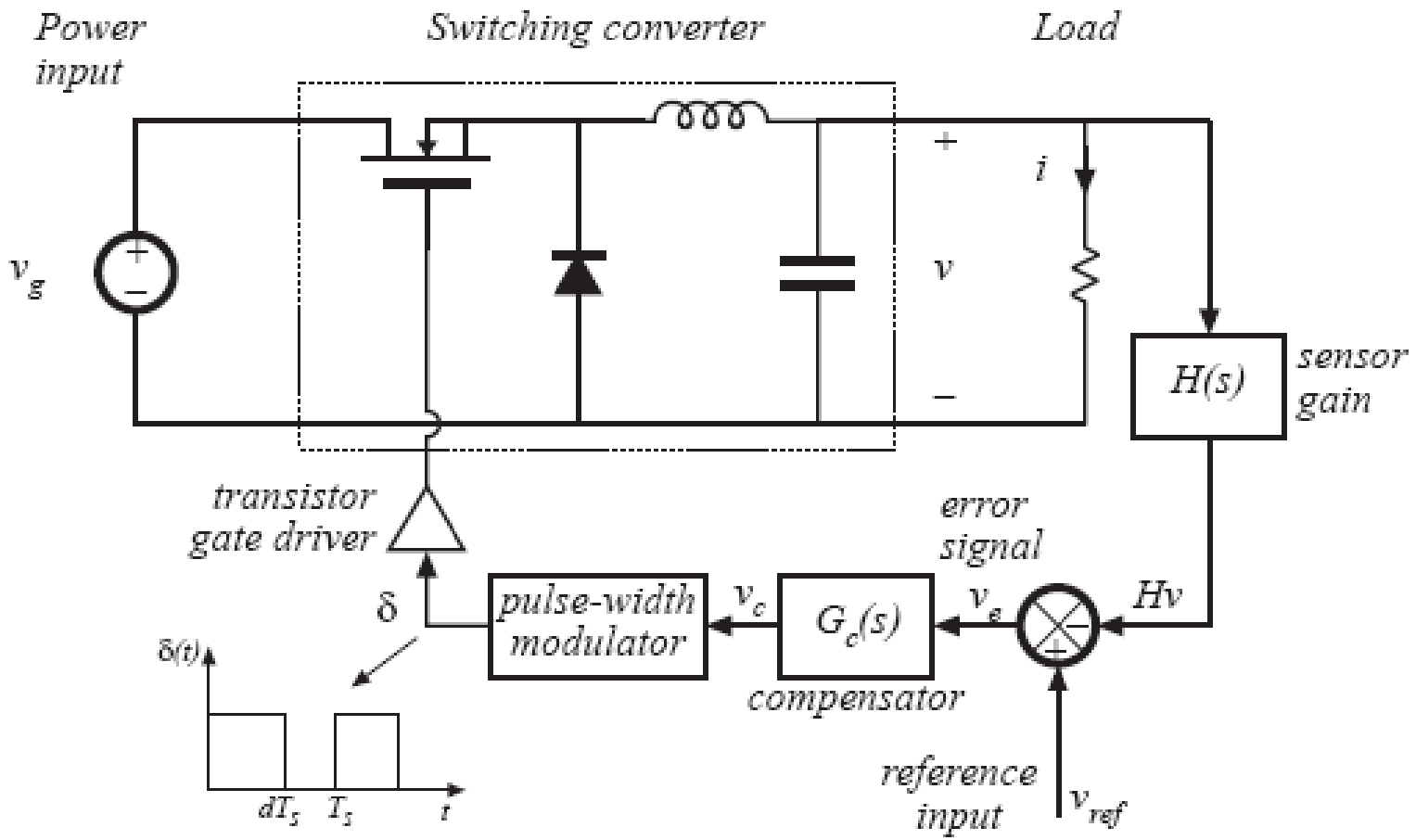
4.2.4 Addition of low pass filter

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



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

4.2.5 Addition of control system for regulation of output



Major issues in power electronics

- How to meet the requirement of the load or gain better control of the load
- How to improve the efficiency
  - for reliable operation of power semiconductor devices
  - for energy saving
- How to realize power conversion with less volume, less weight, and less cost
- How to reduce negative influence to other equipment in the electric power system and to the electromagnetic environment

Home work 1

- Install LTspice
- Learn how to use it by watching a video on ICE
- Simulate Buck converter
- Simulate Boost converter and answer the questions