Introduction to Power Electronics

Fang Z. Peng
Dept. of Electrical and Computer Engineering
Michigan State University
Phone: 517-336-4687, Fax: 517-353-1980
Email: fzpeng@egr.msu.edu

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Chapter 1

Introduction of Power Electronics

- What is Power Electronics?
- Power Conversion and Basic Principle
- Switching Power Devices in General
- Diode, Thyristor and Power Transistor
- Power MOSFET and IGBT
- GTO and MCT
- Power IC

What is Power Electronics?

Power Electronics is power conversion and control from one form of power (energy) source to a desired form by using electronic means. Example: An electric vehicle drive must convert dc input to ac output that has variable voltage and variable frequency.

- Power electronics is power processing circuits and control
**What is Power Electronics? Cont.**

- **Power Processor (PE Circuits)**
  - Raw power in
  - Desired power out (V, I, P, F)
  - Control
  - To loads:
    - Motor
    - Utility line
    - Computer
    - Equipment
    - Process

- **Raw power in**
  - Battery
  - Fuel Cell
  - Utility
  - Solar
  - Wind
  - Capacitor/Inductor
  - Dc or ac

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**Multi-disciplinary Nature of Power Electronics**

- **Power Electronics**
  - Circuit theory
  - Systems & Control theory
  - Comm. & Signal processing
  - Electronics
    - DSP, FPGA

- **Solid-state physics**
- **Simulation & computing**
- **Electric machine**
- **Power systems**
- **Electromagnetics**
- **EMI**
- **DSP Control Board**
Principle of Power Control Using Switch

- Current Control Using Variable Resistor

\[ V_d/RL \]
\[ i_L \]
\[ 0 \]
\[ t \]

- Current Control Using Switching Device

\[ V_d \]
\[ V_{DF} \]
\[ T_{ON} \]
\[ T_{OFF} \]
\[ T \]

Category of Power Conversion

- AC-DC Converter (Rectifier)
- AC-AC Converter (Power Controller, Cycloconverter, Matrix converter)
- DC-AC Converter (Inverter)
- DC-DC Converter (DC Chopper - Buck/Boost/Buck-Boost Converter)
Principle of AC-DC Converter (Rectifier)

- **V\(_1\)** - AC Source
- **V\(_2\)** - DC Load
- Waveforms of AC-DC Converter

Principle of AC-AC Converter (AC Power Controller)

- **V\(_1\)** - AC Source
- **V\(_2\)** - AC Load
- **S** - AC Switch
- Waveforms of AC Power Adjuster
**Principle of AC-AC Converter**

*(Cycloconverter or Frequency Changer)*

- $V_1$ - AC Source
- $V_2$ - AC Load
- $S$ - AC Switch

**Waveforms of Cycloconverter**

**Principle of DC-AC Converter (Inverter)**

- $V_{dc}$ - DC Source
- $S_1, S_4$ - ON
- $S_2, S_3$ - OFF

**Voltage-Source Inverter**

**Waveforms of Inverter**
Why Switching?

Power Loss: \[ \left( \frac{V_{dc}}{r + R_L} \right)^2 R_L \]

Power Consumption: \[ \left( \frac{V_{dc}}{r + R_L} \right)^2 R_L \]

Switching Devices

<table>
<thead>
<tr>
<th>Current</th>
<th>Uncontrollable</th>
<th>On - Controllable</th>
<th>On and Off Controllable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uni-Direction</td>
<td>+ v - i Diode</td>
<td>+ v - i Thyristor</td>
<td>Transistor</td>
</tr>
<tr>
<td>Bi-Direction</td>
<td>Triac</td>
<td></td>
<td>MOSFET</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>GTO</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>IGBT</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>SIT, SITH, MCT, MTO, etc.</td>
</tr>
</tbody>
</table>

* Metal Oxide Semiconductor Field Effect Transistor
Diode and Rectifier

![Diode and Rectifier Diagram]

Thyristor and Phase-Controlled Rectifier

![Thyristor and Phase-Controlled Rectifier Diagram]
Power Transistor and Inverter

Gate Drive Circuit of IGBT

Safe Operating Area and Snubber Circuit

Traditional Snubber Circuits
IGBT Technology

![Graph showing the progress of saturation voltage and turn-off time with different generations of IGBTs.](image)

Progress of Large VA Rated GTO

![Graph showing the progress of turn-off current and year for different ratings of GTOs.](image)
Chapter 1
What We have Learned:

- What’s Power Electronics
- How to use ideal switches to do power conversion
- How to model and analyze PE circuits (basic principle)
- Real switching devices (D, Thy, IGBT, MOSFET, GTO, IGCT, etc)
- Snubber circuits for safer operation
- Combinations of transistor(s) and diode(s) for
  - Bi-directional current and unidirectional voltage switches
  - Bi-directional current and bi-directional voltage switches (ac switch)
Chapter 2  Basic Circuits of Power Conversion

Contents
• Natural (Line, Load) Commutated Converter, Rectifier, and Cycloconverter
• Self-commutated Converter
  – Voltage-Source (Voltage-Fed) Inverter
  – Current-Source (Voltage-Fed) Inverter
• DC Chopper and DC/DC Converter
• AC Switch: AC Power Adjusting and Matrix Converter
• Multilevel inverters

Diode Rectifier

Half Bridge Rectifier

Half Bridge Rectifier with Smoothing Inductor
Diode Rectifier (Cnt’d)

With Free-Wheeling Diode

Full Bridge Rectifier

Diode Rectifier (Cnt’d)

\[ V_{DC} \]

\[ V_{Sab} \quad V_{Scb} \quad V_{Scan} \]
Diode Rectifier (Cnt’d)

Natural Commutated Converter

- phase-controlled rectifier (1 phase) -
Natural Commutated Converter

- phase controlled rectifier (3 phase) -

Self-Commutated Power Converter

- voltage-source inverter -

Single Phase Full Bridge Inverter and Freewheeling Diode or Antiparallel Diode

Rec. Mode

Inv. Mode
Self-Commutated Power Converter

- current-source inverter -

Dual Relationship of PE Circuits

- Voltage-source
- Voltage
- Current
- Parallel connection
- Series connection
- Inductive component
- Capacitive component
- Switch open
- Switch close
- Line-to-line voltage

- Current-source
- Current
- Voltage
- Series connection
- Parallel connection
- Capacitive component
- Inductive component
- Switch close
- Switch open
- Line /or phase current
General Purpose Motor Drive System

Voltage-Source Inverter (6-step)

\[ V_a = (\text{Gap} - G_{an})E/2 \]
\[ V_b = (G_{bp} - G_{bn})E/2 \]
\[ V_c = (G_{cp} - G_{cn})E/2 \]

\[ V_n = E/6 \]
\[ -2E/3 \]
\[ 2E/3 \]
\[ -E/3 \]
\[ E/6 \]
Voltage-Source Inverter (PWM)

\[ V_{a} = (\text{Gap} - \text{Gan}) \frac{E}{2} \]
\[ V_{b} = (\text{Gbp} - \text{Gbn}) \frac{E}{2} \]
\[ V_{c} = (\text{Gcp} - \text{Gcn}) \frac{E}{2} \]

DC/DC Converter  a) Buck Converter
DC/DC Converter  b) Boost Converter

\[ E_{out} = E_{in} \]

DC/DC Converter  c) Buck/Boost Converter

\[ E_{out} = 0 \]

\[ E_{out} = E_{in} \rightarrow \infty \]
AC Switches: AC Power Regulator

AC Switches: Matrix Converter