Module 1: Introduction

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Reference Textbook:
First Course on Power Electronics by Ned Mohan,
www.mnpere.com
Module 1: Introduction to Power Electronics

Chapter 1  Power Electronics: An Enabling Technology

1-1  Introduction to Power Electronics
1-2  Applications and the Role of Power Electronics
1-3  Energy and the Environment
1-4  Need for High Efficiency and High Power Density
1-5  Structure of Power Electronics Interface
1-6  Voltage-Link Structure
1-7  Recent and Potential Advancements

References
Problems
The power electronics interface facilitates the transfer of power from the source to the load by converting voltages and currents from one form to another, in which it is possible for the source and load to reverse roles. The controller shown in Fig. 1-1 allows management of the power transfer process in which the conversion of voltages and currents should be achieved with as high energy-efficiency and high power density as possible.
Powering the Information Technology

Figure 1-2 Regulated low-voltage dc power supplies.
Boost Converter

Battery Cell (1.5 V) 9 V (dc)

Figure 1-3 Boost dc-dc converter needed in cell operated equipment.
Adjustable Speed Drives

Figure 1-4 Block diagram of adjustable speed drives.
Induction Heating

Figure 1-5 Power electronics interface required for induction heating.
Electric Welding

Figure 1-6 Power electronics interface required for electric welding.
Energy and the Environment: The Percentage Energy Consumption

Figure 1-7 Percentage use of electricity in various sectors in the U.S.

- Lighting 19%
- HVAC 16%
- Motors 51%
- IT 14%
Role of adjustable speed drives in pump-driven systems

Figure 1-8 Role of adjustable speed drives in pump-driven systems.
Compact Fluorescent Lamps

Figure 1-9 Power electronics interface required for CFL.
Transportation

Figure 1-10 Hybrid electric vehicles with much higher gas mileage.

- Hybrid electric vehicles with much higher gas mileage
- light rail, fly-by-wire planes
- all-electric ships
- drive-by-wire automobiles.
Renewable Energy

Photovoltaic Systems

Figure 1-11 Photovoltaic Systems.

(a) Power Electronics Interface

(b) DC Input

Utility
Wind-Electric Systems

Figure 1-12 Wind-electric systems.
Uninterruptible Power Supplies

Figure 1-13 Uninterruptible power supply (UPS) system.
Applications in Power Systems
Strategic Space and Defense Applications

More Electric Aircraft

Electric Warship

Source: James Soeder, NASA and Terry Ericsen, ONR.
NEED FOR HIGH EFFICIENCY AND HIGH POWER DENSITY

\[ \eta = \frac{P_o}{P_o + P_{loss}} \]

\[ P_o = \frac{\eta}{1 - \eta} P_{loss} \]

Figure 1-14 Power output capability as a function of efficiency.
Summarizing the Role of Power Electronics

Figure 1-15 Block diagram of power electronic interface.
STRUCTURE OF POWER ELECTRONICS INTERFACE

Voltage-link structure of power electronics interface

- Unipolar voltage handling transistors used
- Decoupling of two converters
- Immunity from momentary power interruptions

Figure 1-16 Voltage-link structure of power electronics interface.
• Current-Link Systems
• Matrix Converters
Figure 1-17 Current-link structure of power electronics interface.
Matrix Converters

Figure 1-18 Matrix converter structure of power electronics interface [13].
Voltage-link System

Figure 1-19 Load-side converter in a voltage-source structure.
SWITCH-MODE LOAD-SIDE CONVERTER

- **Group 1**  Adjustable dc or a low-frequency sinusoidal ac output in
  - dc and ac motor drives
  - uninterruptible power supplies
  - regulated dc power supplies without electrical isolation

- **Group 2**  High-frequency ac in
  - compact fluorescent lamps
  - induction heating
  - regulated dc power supplies where the dc output voltage needs to be electrically isolated from the input, and the load-side converter internally produces high-frequency ac, which is passed through a high-frequency transformer and then rectified into dc.
Switch-Mode Conversion: Switching Power-Pole as the Building Block

Figure 1-20 Switching power-pole as the building block in converters.
Pulse-Width Modulation (PWM) of the Switching Power-Pole

Figure 1-21 PWM of the switching power-pole.

\[ d_A = \frac{T_{up}}{T_s} \]

\[ \bar{V}_A = \frac{T_{up}}{T_s} V_{in} = d_A V_{in} \quad 0 \leq d_A \leq 1 \]
Switching Power-Pole in a Buck DC-DC Converter: An Example

![Diagram of a Buck converter with switching power-pole](image)

Figure 1-22 Switching power-pole in a Buck converter.

\[ V_o = \overline{V}_A = d_A V_{in} \quad 0 \leq V_o \leq V_{in} \]
Example 1-2

In the converter of Fig. 1-22a, the input voltage \( V_{in} = 20V \). The output voltage \( V_o = 12V \). Calculate the duty-ratio \( d_A \) and the pulse width \( T_{up} \), if the switching frequency \( f_s = 200kHz \).

Solution

\[ \bar{V}_A = V_o = 12V \]. Using Eq. 1-4, \( d_A = \frac{V_o}{V_{in}} = \frac{12}{20} = 0.6 \) and \( T_s = \frac{1}{f_s} = 5\mu s \).

Therefore, as shown in Fig. 1-23, \( T_{up} = d_A T_s = 0.6 \times 5\mu s = 3\mu s \).

Figure 1-23 Waveforms in the converter of Example 1-2.
Simulations using PSpice

SwitchingWaveform.Sch

V1=0
V2=8V
PW=7.5us
PER=10us

V_Pulse

5uH
IC=9

IC=5.5V

100uF
C

R
0.5ohm
Simulation Results

$V_A$  

$V_o \approx V_o$
**Fourier Analysis**

**Fourier Components of Transient Response V(\(vA\))**

DC Component = \(6.080000E+00\)

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<th>Phase (Deg)</th>
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FOURIER COMPONENTS OF TRANSIENT RESPONSE V(\(\text{vo}\))

DC COMPONENT =  6.083044E+00

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Currents

![Graph showing current waveforms for inductance (i_L), capacitance (i_C), and resistance (i_R) over time.](Image)
Frequency Analysis

SwitchingWaveform_AC-Analysis.Sch
Simulation Results

![Graph showing simulation results. The graph plots frequency against DB(V(vo)/V(VA)). The x-axis represents frequency ranging from 100 Hz to 1 MHz, while the y-axis represents decibels (DB). The graph includes data points at 100 kHz with a value of -45.867 dB.](image-url)
Transistor and diode forming a switching power-pole in a Buck converter

Figure 1-24 Transistor and diode forming a switching power-pole in a Buck converter.
Hardware Lab: very low-cost

Switching Power - Pole Board

Experiments:
- Buck, Boost, Buck-Boost
- Feedback Control: Voltage-Mode, Peak-Current-Mode
- Flyback, Forward

USERS MANUAL
www.ece.umn.edu/groups/power

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RECENT AND POTENTIAL ADVANCEMENTS

• Devices that can handle voltages in kVs and currents in kAs
• ASICs
• DSPs
• Micro-controllers
• FPGA
• Integrated and intelligent power modules
• Packaging
• SiC-based solid-state devices
• High energy density capacitors
CONCEPT OF PEBB

Power Electronics Building Block (PEBB) [15] is a broad concept that incorporates the progressive integration of power devices, gate drives, and other components into building blocks, with clearly defined functionality that provides interface capabilities able to serve multiple applications. This building block approach results in reduced cost, losses, weight, size, and engineering effort for the application and maintenance of power electronics systems. Based on the functional specifications of PEBB and the performance requirements of the intended applications, the PEBB designer addresses the details of device stresses, stray inductances, switching speed, losses, thermal management, protection, measurements of required variables, control interfaces, and potential integration issues at all levels.

It has numerous benefits such as technology insertion and upgrade via standard interfaces, reduced maintenance via plug and play modules, reduced cost via increased product development efficiency, reduced time to market, reduced commissioning cost, reduced design and development risk, and increased competition in critical technologies [14].
Summary

- Power Electronics an Enabling Technology
- Applications
- Need for High Efficiency and High Power Density
- Structure of Power Electronic Converters
- Switching Power-Pole as the Building Block
- Potential for Advancements