Discussion Topics

- Definition of Power Electronics
- Industry Overview/Market Share Analysis
- Multidisciplinary Nature of Power Electronics
- The Need for Power Electronics
- Types of Power Conversion
- Figures of Merit for Power Electronics Converters
- Applications for Power Electronic Converters
- Future Trends
What is Power Electronics?

- **Electronics**: Solid State Electronics Devices and their Driving Circuits.
- **Power**: Static and Dynamic Requirements for Generation, Conversion and Transmission of Power.
- **Control**: The Steady State and Dynamic Stability of the Closed Loop system.

**POWER ELECTRONICS** may be defined as the application of Solid State Electronics for the Control and conversion of Power.
The Worldwide Electronics Market Overview

Power Electronics is an Enabling Technology
Equipment Sales: $30B

Hardware Electronics
$570B

Total Electronics Market
$1,000B

Source: Microtech
National Critical Technology Areas

Technology Category

Energy
Environmental Quality
Information and Communication
Living Systems
Manufacturing
Materials
Transportation

Technology Area

Energy Efficiency
Energy Storage
Power Conditioning
Power Distribution

Distributed Power Supplies
Process Control Automation
Avionics and Controls
Power System Integration
Propulsion for Mass Transit
Hybrid Electric Vehicles

Source: President's Committee of Advisors on Science and Technology
Historical Perspective

• **Traditional power conversion**
  – *Linear Electronics*—Transistors in active mode (linear region)
    • Transistor acts as variable resistor for control
    • Terrible efficiency (50% not uncommon)
    • Low conversion range (greater Vd smaller efficiency)
    • Low power applications
  – *Motor-Generator Sets (AC-DC or AC-AC)*
    • Can still be found in use
    • Large physical size
    • Maintenance intensive
    • Low efficiency
    • Poor Load regulation
Modern Power Electronics

• Can have efficiencies approaching 100%
  – Uses switches in saturation mode (On of Off)
  – On state-resistance can be down in tenths of Ohms

• Are much smaller than predecessors
  – High switching frequency means smaller magnetic components.
  – Reduced losses means smaller package size

• Net effect is better efficiency, greater power density (5W/in^3 attainable)
Simplified Block Diagram of a Power Electronics System

Power Electronic "Power" Circuit

Electrical Inputs "Sources"

Feedback "Control Circuit"

Electrical or Mechanical Output "Loads"
Detailed Block Diagram of Power Electronics System

- **Input**: Form of electrical energy
  - Mostly unregulated dc voltage
  - Mostly ac line voltage (single or three phase)

- **Pre-stage**
  - Filter & Rectify

- **Power proc. stage**
  - PE Circuit

- **Post stage**
  - Filter & Rectify
  - Could generate undesirable waveforms

- **Control Circuit**
  - Switch Drives
  - Process feedback signals and decide on control
  - Interface between control and power circuits

- **Output**
  - Load
  - Electrical Variable Feedback
  - Mechanical Variable Feedback
  - Electrical or mechan. energy
Multidisciplinary Nature of Power Electronics

• Power electronics is comprised of:
  – Semiconductor Devices
  – Analog Circuits
  – Control Design
  – Magnetics
  – Electric Machines
  – Power Systems Engineering
  – Circuit Simulation
Power Electronics
Focus Areas

**Conversion Technology**
- circuit theory
- conversion efficiency
- switching matrices
- signal processing
- EMI and filter circuit
- magnetic components
- rotating machines

**Power Semiconductor Technology**
- power devices
- power IC's
- drive circuits
- protection circuits
- heat sinks

**Power Control Technology**
- IC control packages
- microelectronics circuits
- microprocessors circuits
- digital and analog electronic circuits
- control theory: transient and stability issues
- digital and information signal processing
- simulation

*Fig. 1.1 Power Electronics encompasses three Technologies: Conversion, Power Semiconductor, and Power Control Technologies*
Growth In Power Electronics

• The technology boom of the semiconductor market creates power devices with significant power handling and switch speed capability (ICs for control as well)
• The expanding market demand for new power electronic applications that require the use variable-speed motor drives, regulated power supplies, robotics, uninterruptible power supplies.
• The ever increasing demand for smaller size and lighter weight power electronic systems.
• A result of this increasing reliance on power electronic systems made it mandatory that all such systems have radiated and conducted electromagnetic interference (EMI) be limited within regulated ranges.
The Drivers for Power Electronics

- Primary Factors Locally (KSC/Florida)
  - Microprocessor-based technology has been producing devices that often require tight regulation and uninterruptible power
  - Increased sensitivity to power system harmonics
  - Energy Conservation and Environmental Management are now grouped within US Domestic Policy and are receiving significant focus from Bush Administration
    - New Legislation from Bush on Energy Conservation Requirements
    - New Florida Building Code will Require Variable Speed Air Handlers
  - Industrial Process Control and Automation is BOOMING with new/refined motor drive applications
    - HVAC (VAV, Chilled Water Flow, Chiller)
    - Elevator Drives (DC Drives)
Power Flow
Unidirectional: input-to-output

**Diagram:**
- **Source Side:** (input) 
- **Power Processing Circuit:** $P_{loss}$ 
- **Load Side:** (output) 
- **Load**
Power Flow – Bi-directional

(source) Source Side

Power Processing circuit (Ploss)

(output) Load Side

Load

II III

I IV
Power Conversion Dictates
Change in Current and/or Voltage:

- Voltage/Current form $ac$ or $dc$
- Voltage/Current level (magnitude)
- Voltage frequency (line or otherwise)
- Voltage/Current waveshape (sinusoidal or nonsinusoidal such as square, triangle, sawtooth, etc.)
- Voltage phase (single or three-phase).
Power Electronic systems perform one or more of the following conversion functions:

a) Rectification \((ac\text{-to-}dc)\)
b) Inversion \((dc\text{-to-}ac)\)
c) Cycloconversion
   \((ac\text{-to-}ac\ \text{different frequencies})\ \text{or} \ \(ac\text{-to-}ac\ \text{same frequency}\)\)
d) Conversion \((dc\text{-to-}dc)\)
Types Of Power Conversion
Figures of Merit for Power Electronic Converters

• What is the objective?
  – Overall goal: To produce a converter that performs well in these areas:
    • Efficiency
    • Transient Response
    • Load and Line Regulation
    • Power Density
    • Input/Output Distortion (Input Power Factor)
    • Reliability (MTBF)
    • Cost
  – In the final analysis, the job is to process and control the flow of electric energy by supplying currents/voltages in a form most suited to both the load and energy source.
Industrial Applications

• SMPS
  – PFC
  – Universal Input
  – Soft-Switching
• Uninterruptible Power Supplies
  – Hot-Sync Paralleling
• Process Control
  – Motor Drives (DC Drives-VSDs, VFD)
Motor Drive

- Rectifier
- Dc link
- Inverter

3Ø ac line
50/60Hz

variable-frequency
variable-voltage ac

Ac machine
Typical PC Power Supply

- $v_{ac}(t)$: ac line input, 85-265Vrms
- $i_{ac}(t)$: current
- Rectifier
- dc link
- Dc-dc converter
- regulated dc outputs
- loads
Classic Inverter Scheme

![Inverter Scheme Diagram]
Typical Commercial Power Supply-Univ. PFC 600V

### INPUT CHARACTERISTICS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PFC Mini</th>
<th>PFC Micro</th>
<th>PFC MicroS</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>85-264</td>
<td>85-264</td>
<td></td>
<td>Vac</td>
<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>47-500</td>
<td></td>
<td></td>
<td>Hz</td>
<td></td>
</tr>
<tr>
<td>DC Input</td>
<td>100-380</td>
<td>100-300</td>
<td></td>
<td>Vdc</td>
<td></td>
</tr>
<tr>
<td>Line Regulation</td>
<td>0.4</td>
<td></td>
<td></td>
<td>%</td>
<td>From low line to high line</td>
</tr>
<tr>
<td>Inrush Current @ 115Vac</td>
<td>30</td>
<td>5</td>
<td></td>
<td>A rms</td>
<td></td>
</tr>
<tr>
<td>Inrush Current @ 230Vac</td>
<td>60</td>
<td></td>
<td>10</td>
<td>A rms</td>
<td></td>
</tr>
<tr>
<td>Ride Through Time</td>
<td></td>
<td>&gt;20</td>
<td></td>
<td>ms</td>
<td></td>
</tr>
<tr>
<td>@ load</td>
<td>1,200</td>
<td></td>
<td>500</td>
<td>W</td>
<td></td>
</tr>
<tr>
<td>Conducted EMI/RFI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCC Class A</td>
<td></td>
<td>FCC Class A</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EN55022 Class A</td>
<td></td>
<td>EN55022 Class A (consult factory)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power Factor</td>
<td>&gt;0.98</td>
<td></td>
<td></td>
<td></td>
<td>&gt;75% load</td>
</tr>
<tr>
<td>Harmonic Current Limits</td>
<td></td>
<td>EN61000-3-2/A14</td>
<td></td>
<td>Class A</td>
<td></td>
</tr>
</tbody>
</table>

### OUTPUT CHARACTERISTICS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>PFC Mini</th>
<th>PFC Micro</th>
<th>PFC MicroS</th>
<th>Units</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setpoint Accuracy</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>%</td>
<td>of Vnom</td>
</tr>
<tr>
<td>Load Regulation</td>
<td>0.06</td>
<td>0.2</td>
<td></td>
<td>%</td>
<td>10% to full load</td>
</tr>
<tr>
<td>Temperature Regulation</td>
<td>0.005</td>
<td></td>
<td></td>
<td>%/°C</td>
<td>-20° to +65°C</td>
</tr>
<tr>
<td>Long Term Drift</td>
<td>0.02</td>
<td></td>
<td></td>
<td>%/khr</td>
<td></td>
</tr>
<tr>
<td>Output Ripple &amp; Noise</td>
<td></td>
<td>100</td>
<td>100</td>
<td>mV</td>
<td>20 MHz bandwidth</td>
</tr>
<tr>
<td>≤10Vout</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;10Vout</td>
<td>1.0</td>
<td></td>
<td></td>
<td>% Vout</td>
<td>20 MHz bandwidth</td>
</tr>
<tr>
<td>Voltage Trim Range</td>
<td></td>
<td>50-110</td>
<td>50-110</td>
<td>% Vout</td>
<td>±10% on 10-15 Vout</td>
</tr>
<tr>
<td>1st Gen Slots</td>
<td></td>
<td>10-110</td>
<td>10-110</td>
<td>% Vout</td>
<td>Preload may be required</td>
</tr>
<tr>
<td>Remote Sense Compensation</td>
<td>0.5</td>
<td></td>
<td></td>
<td>Vdc</td>
<td>Autosense (See page 2)</td>
</tr>
<tr>
<td>QVP Set Point</td>
<td>125</td>
<td></td>
<td></td>
<td>% Vout</td>
<td>Not available on 1st Gen Minis</td>
</tr>
<tr>
<td>Current Limit</td>
<td>115</td>
<td></td>
<td></td>
<td>% Imax</td>
<td>Auto recovery</td>
</tr>
</tbody>
</table>
## Typical Commercial Power Supply-Universal PFC 150W

### OUTPUT SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total regulation</td>
<td>±2.0%</td>
</tr>
<tr>
<td>(Line and load)</td>
<td></td>
</tr>
<tr>
<td>Main output</td>
<td></td>
</tr>
<tr>
<td>Auxiliary outputs</td>
<td>±5.0%</td>
</tr>
<tr>
<td>Rise time</td>
<td>1.5s, max.</td>
</tr>
<tr>
<td>Transient response</td>
<td>Main output 5.0% or 250mV max. dev., 1ms max. recovery to 1%</td>
</tr>
<tr>
<td>Temperature coefficient</td>
<td>±0.02%/°C</td>
</tr>
<tr>
<td>Overvoltage protection</td>
<td>Main outputs 125%, ±10%</td>
</tr>
<tr>
<td>Short circuit protection</td>
<td>Cyclic operation Continuous</td>
</tr>
<tr>
<td>Minimum output current</td>
<td>Single and multiple See table</td>
</tr>
</tbody>
</table>

### INPUT SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input voltage range</td>
<td>Universal input 90 to 264VAC</td>
</tr>
<tr>
<td>Input frequency range</td>
<td>47Hz to 63Hz</td>
</tr>
<tr>
<td>Input surge current</td>
<td>264VAC (cold start) 40A max.</td>
</tr>
<tr>
<td>Safety ground leakage current</td>
<td>264VAC, 60Hz 0.99mA</td>
</tr>
<tr>
<td>Input current</td>
<td>120VAC @ 150W 1.95A rms</td>
</tr>
<tr>
<td></td>
<td>230VAC @ 150W 1.10A rms</td>
</tr>
<tr>
<td>Input fuse</td>
<td>UL/IEC127 F3.15A H, 250VAC</td>
</tr>
</tbody>
</table>

### ELECTROMAGNETIC COMPATIBILITY SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conducted emissions</td>
<td>EN55022, FCC part 15 Level B</td>
</tr>
<tr>
<td>Radiated emissions</td>
<td>EN55022, FCC part 15 Level A</td>
</tr>
<tr>
<td>Harmonic current emission correction</td>
<td>EN61000-3-2 Compliant</td>
</tr>
<tr>
<td>ESD air</td>
<td>EN61000-4-2 Level 3</td>
</tr>
<tr>
<td>ESD contact</td>
<td>EN61000-4-2 Level 3</td>
</tr>
</tbody>
</table>

### ELECTROMAGNETIC COMPATIBILITY SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surge</td>
<td>EN61000-4-5 Level 3</td>
</tr>
<tr>
<td>Fast transients</td>
<td>EN61000-4-4 Level 3</td>
</tr>
<tr>
<td>Radiated immunity</td>
<td>EN61000-4-3 Level 3</td>
</tr>
<tr>
<td>Conducted immunity</td>
<td>EN61000-4-6 Level 3</td>
</tr>
</tbody>
</table>

### GENERAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hold-up time</td>
<td>120VAC @ 60Hz 20ms @ 150W</td>
</tr>
<tr>
<td>Efficiency</td>
<td>120VAC @ 150W 73% typical</td>
</tr>
<tr>
<td>Isolation voltage</td>
<td>Input/output 3000VAC</td>
</tr>
<tr>
<td></td>
<td>Input/chassis 1500VAC</td>
</tr>
<tr>
<td>Approvals and standards</td>
<td>EN60950, VDE0805, IEC950</td>
</tr>
<tr>
<td></td>
<td>UL1950, CSA C22.2 No. 950</td>
</tr>
<tr>
<td>Weight</td>
<td>540g (19oz)</td>
</tr>
<tr>
<td>MTBF (@ 25°C)</td>
<td>MIL-HDBK-217F 350,000 hours min.</td>
</tr>
<tr>
<td></td>
<td>Ball core 800,000 hours min.</td>
</tr>
</tbody>
</table>

### ENVIRONMENTAL SPECIFICATIONS

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal performance</td>
<td>Operating ambien, (See derating curve) 0°C to +50°C</td>
</tr>
<tr>
<td></td>
<td>Non-operating -40°C to +85°C</td>
</tr>
<tr>
<td></td>
<td>50°C to 70°C ambient, convection cooled 50% load 110W</td>
</tr>
<tr>
<td></td>
<td>0°C to 50°C ambient, convection cooled 0°C to 50°C ambient, 300LPM forced air 150W</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Non-condensing 5% to 95% RH</td>
</tr>
<tr>
<td>Altitude</td>
<td>Operating 10,000 feet max.</td>
</tr>
<tr>
<td></td>
<td>Non-operating 30,000 feet max.</td>
</tr>
<tr>
<td>Vibration (See Note 6)</td>
<td>5Hz to 500Hz 2.4G rms peak</td>
</tr>
<tr>
<td>Shock</td>
<td>per MIL-STD-810E 516.4 Part IV</td>
</tr>
</tbody>
</table>
Future Trends

- Continue in the technological improvement of high power and high frequency semiconductor devices.
- Attempts to improve energy density with increased efficiency and performance
- Improvement in the design of driver circuits for switching devices (DSP)
- Improvement in control techniques including optimal and adaptive control.
- Integration of power and control circuitry on a single IC
- Distributed Power Systems (DPS).
- Power factor correction techniques and EMI reduction.
- New Power Transmission Concepts
UCF Power Electronics
FloridaPEC

Florida Power Electronics Center
Director: Dr. Batarseh
http://apec.engr.ucf.edu

• Power Factor Correction (PFC) circuits
• Soft-Switching DC-DC Converters
• Low Voltage AC-DC and DC-DC converters
• Low Voltage high-current fast-transient VRMs
• Dynamic Modeling and Control
• Electromagnetic Interference and Compatibility (EMI/EMC)
• Modeling of Power Devices
• Solar/Wind Source Converters