



U.S. Department of Energy  
Energy Efficiency and Renewable Energy

# **Power Electronics: Workshop on System Driven Approach for Inverter R&D**

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# Outline

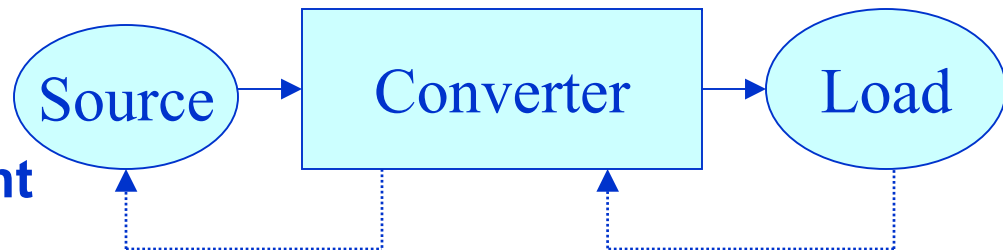
- **Converter Overview**
- **Technology Features**
- **Major Markets**
- **Converter Cost**
- **Ward Bower (Converter Issues, Challenges, & Key Logistics Issues)**











## Power Electronics Connect a Power Source To a Power Load

- Convert AC to DC, DC to AC, AC to AC, and DC to DC
- Requires
  - Control Systems
  - Thermal Management
  - Protection
  - Filters



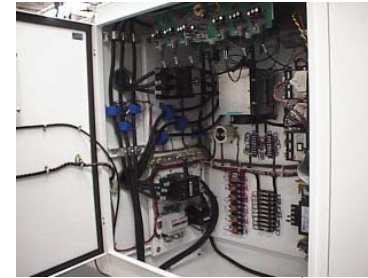


# Typical System Requirements for Power Converters

the <b>power</b> the converter can handle:		rated power
the <b>size</b> of the system:		small footprint
the <b>speed</b> of the system response:		fast response
power <b>quality</b> it can supply:		low harmonic
the <b>reliability</b> of the system:		long term use
the <b>cost</b> of the system:		low cost

**Reliability and Cost are Key!**



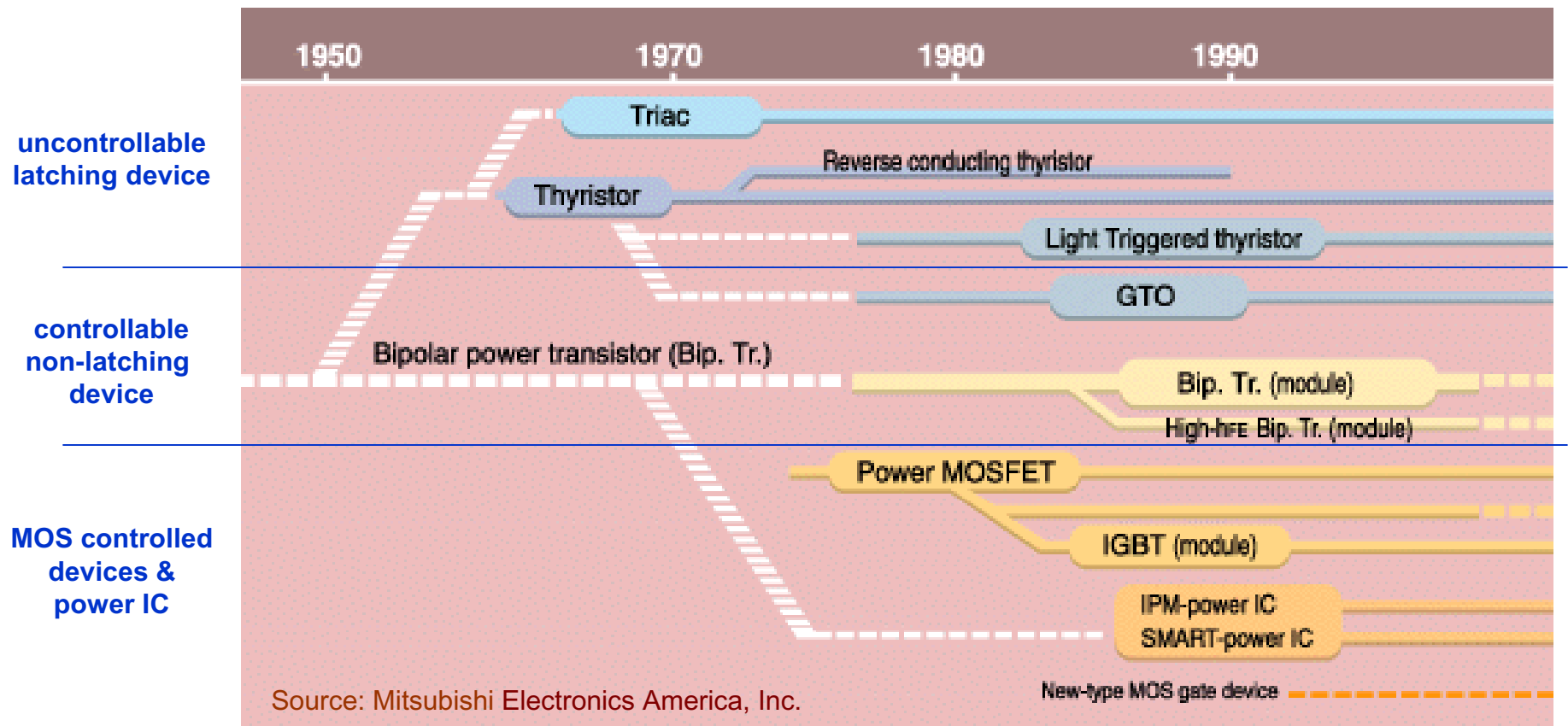


- Technology Feature**
- 1. Power Electronic Devices
  - 2. Switching Technology
  - 3. Control Technology
  - 4. Passive Components
  - 5. Packaging Technology
  - 6. Thermal Management
  - 7. Manufacturing Technology



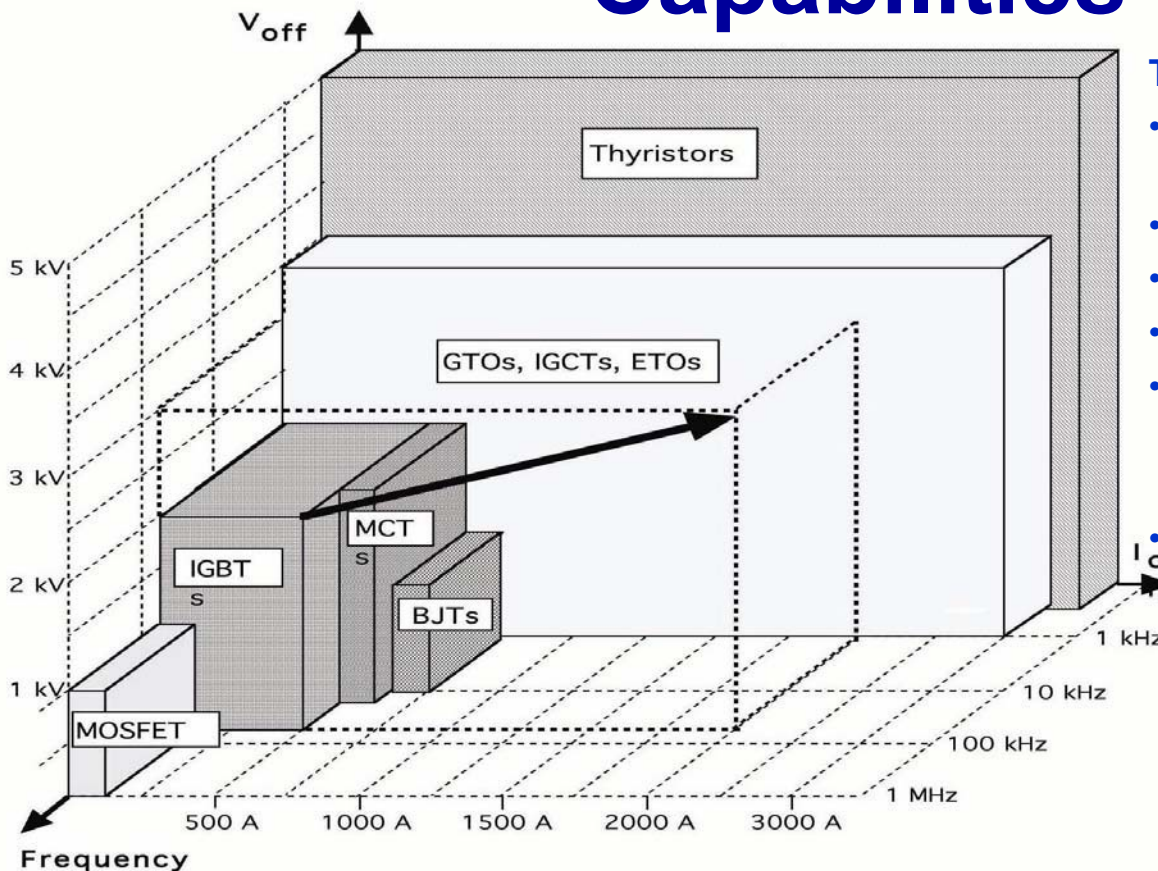


# Advancement of Power Devices





# Summary of Silicon Power Device Capabilities



## Trends:

- Increase Voltage/Current Ratings
- Increase Switching Frequency
- Lower Switching Losses
- Improve Drives
- More Integration
  - Self Protection & Diagnostics
- Lower Inductance

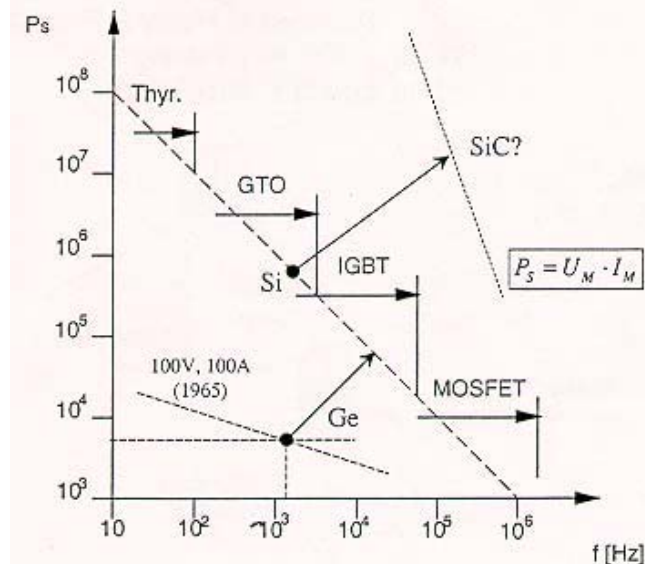


Source: Mohan, Undeland, and Robbins, Power Electronics: Converters, Applications and Design 3<sup>rd</sup> Edition (John Wiley & Sons, 2002)



# SiC Device Research

- **Advantages**
  - High Frequency Operation
  - Less Switching Losses
  - Higher Blocking Voltages
  - Higher Operating Temperature
- **Disadvantages**
  - Expensive
  - Limited Current Level
- **Today's Manufacturers**
  - Cree Inc. and Infineon Technologies (SiC Schottky Diodes)
- **Three Terminal Devices in ~2005** Source: Dr. T. Paul Chow, RPI



Source: Power Electronics Technology at the Dawn of the New Millenium – Status & Future







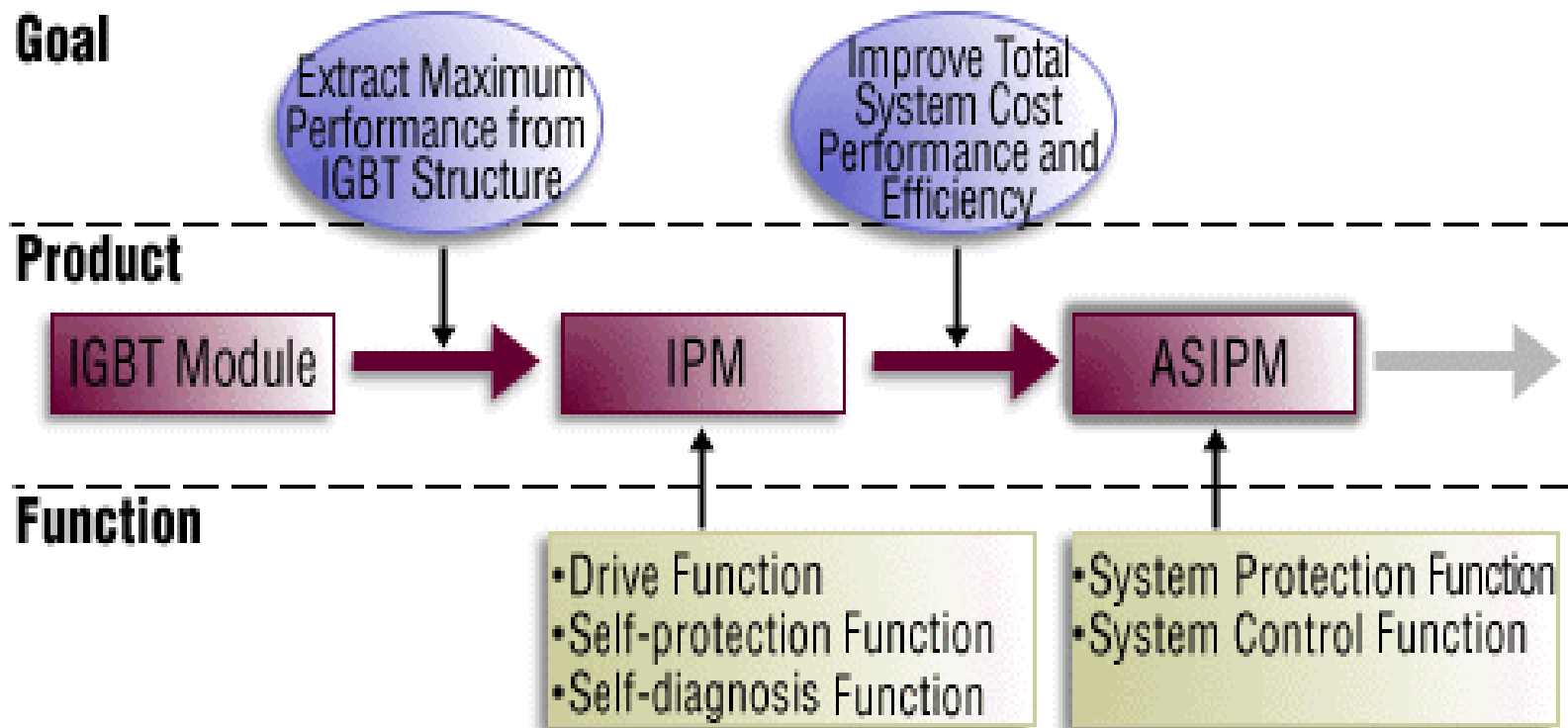
# Power Electronic Devices (Low Power)

- **One of the More Mature Technologies in Power Electronics**
- **Rapid Power Semiconductor Advances Continue!**
- **Rapid Advances Result in Opportunities Related to Operating Parameters, Power Capabilities and Packaging**





# “Intelligent Power” Technology Trends



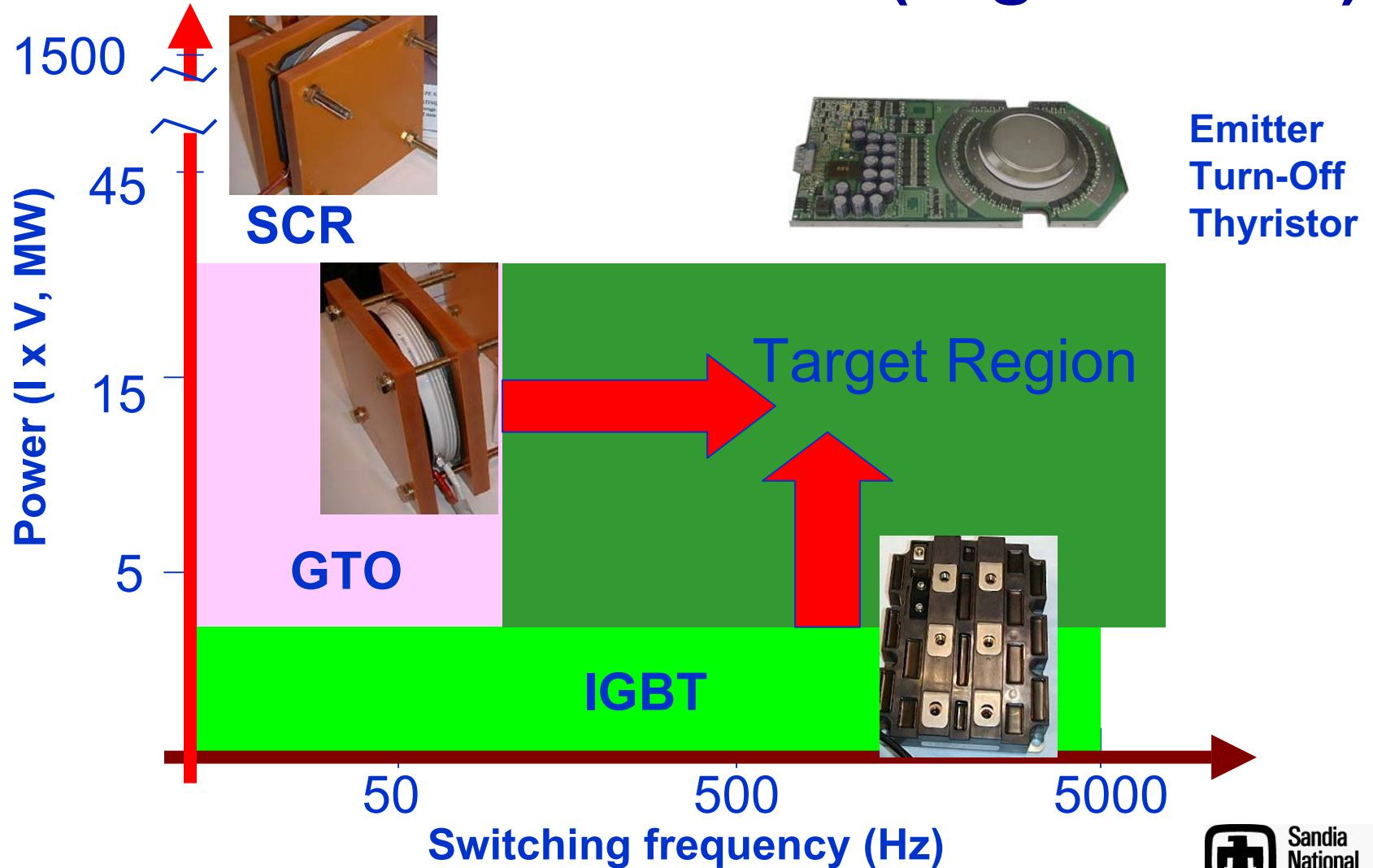
Source: Mitsubishi Electronics America, Inc.

Minimize: Parasitics & Interconnects



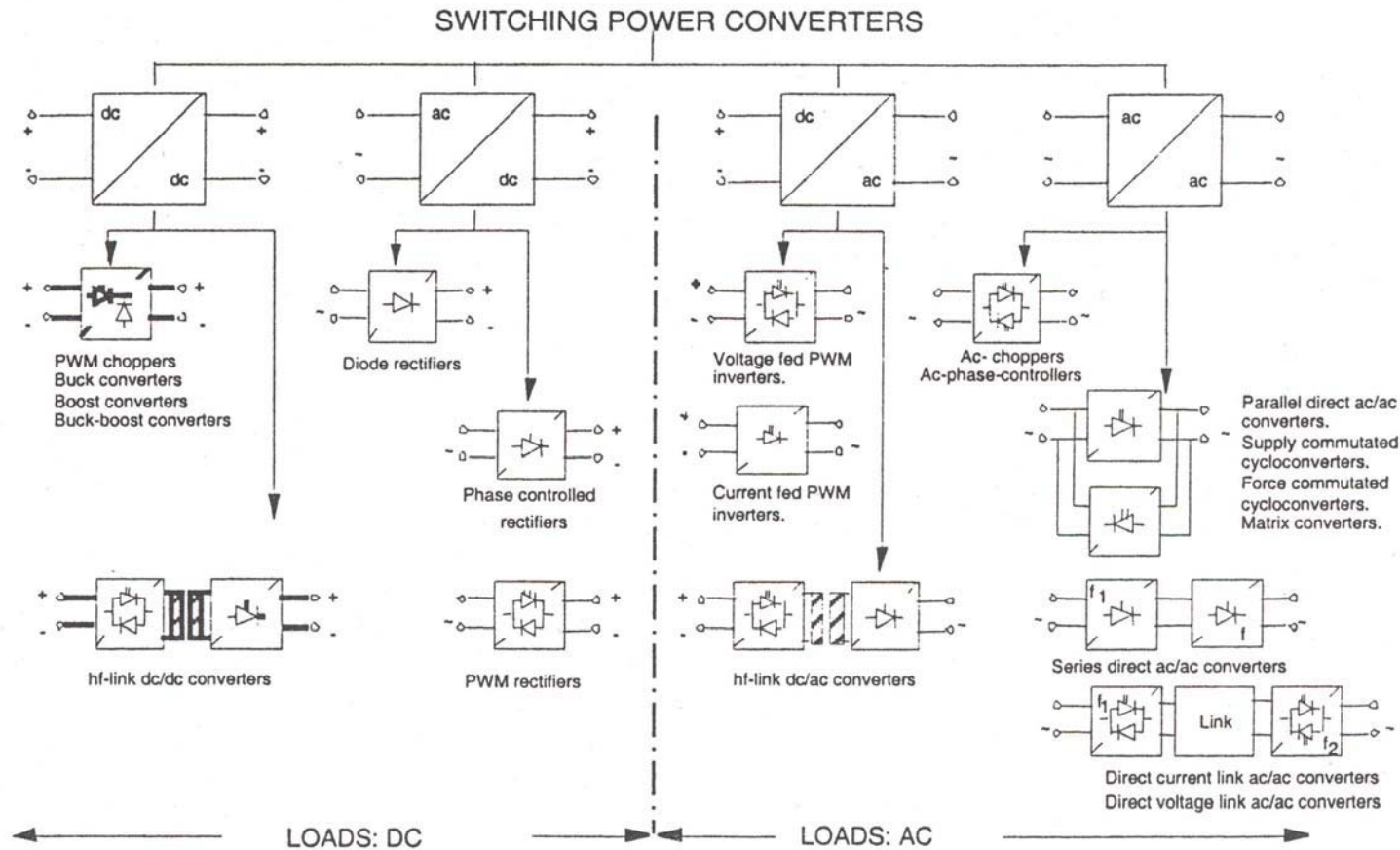


# Power Electronic Devices (High Power)





# Switching Technologies

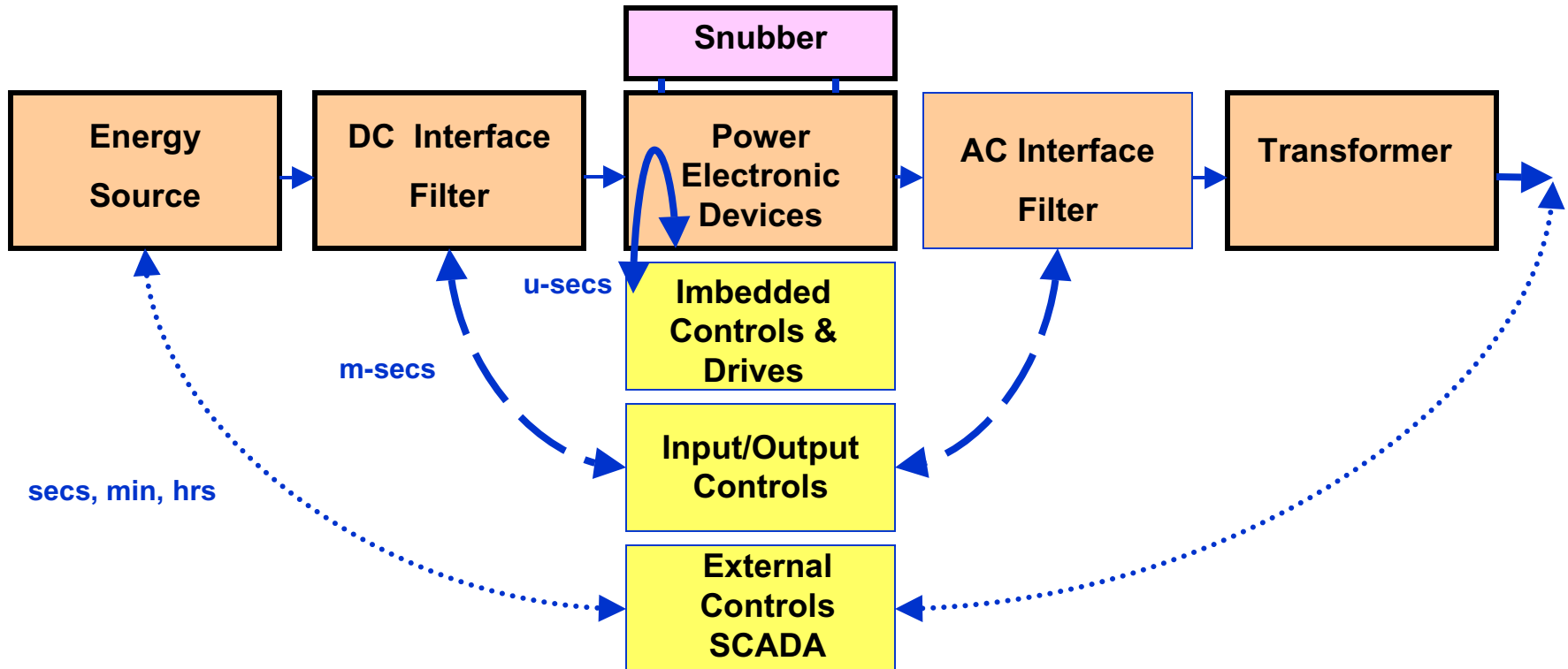


Source: Power Electronics Technology at the Dawn of the New Millenium – Status and Future





# Converter Controls



**Opportunities:**

**Digital Signal Processing (DSP)  
Adaptive or Genetic Algorithms  
Advanced Master Controls for  
Multiple Distributed Inverters**





# Components, Packaging, & Cooling

- **Passive Components: Designers Typically Use Off-the-Shelf Discrete Components**
- **Packaging is Strongly Influenced by Cooling Needs, Component Layout and Components**
- **Cooling Technology Has Improved With Better Heat Transfer From the Power Electronics**





# Manufacturing Technology

- **Currently Most Converters Often Rely Heavily on Manual Assembly.**
- **The Disparity in Sizes and Methods of Interconnection Increase the Cost and Reduce Quality, Flexibility, & Reliability.**
- **A Next Step Is a System-Driven Design Approach Using Integrated Packaging Techniques and Focused R&D**





# Technology Summary

Technology Feature	Status (low power)	Status (high power)
<b>1. Power Electronic Devices</b>	<b>Significant Progress</b>	<b>Evolving</b>
<b>2. Switching Technology</b>	<b>Significant Progress</b>	<b>Evolving</b>
<b>3. Control Technology</b>	<b>Evolving</b>	<b>Evolving</b>
<b>4. Passive Components</b>	<b>Old Technology</b>	<b>Old Technology</b>
<b>5. Packaging Technology</b>	<b>Old Technology</b>	<b>Old Technology</b>
<b>6. Thermal Management</b>	<b>Old Technology</b>	<b>Old Technology</b>
<b>7. Manufacturing Technology</b>	<b>Old Technology</b>	<b>Old Technology</b>







# Major Converter Markets

- **Motor Drives** Source: Electronic Motor Drives 2001-2005, Drive Research Corporation, August 2001
  - \$12.5 Billion Worldwide Market in 2000
  - \$19.1 Billion by 2005
- **Power Supplies** Source: AC/DC Power Supplies: Worldwide Market Forecasts, Competitive Environment and Industry Trends: Darnell.com Inc.
  - \$7.7 Billion in 2002
  - \$9.6 Billion by 2007
- **Uninterruptible Power Supplies** Source: The 2002 Power Protection Market Intelligence Report, Venture Development Corporation, August 2002
  - \$4.5 Billion Worldwide Market in 2001
  - \$5.2 Billion by 2006





# Major Converter Markets

- **Flywheels** Source: The 2002 The North American Market for Grid Power Solutions: Distributed Generation & Ride-Through Technologies, Venture Development Corp., June 2001
  - \$110 Million North American Market in 2000
  - \$250 Million by 2005
- **Fuel Cells** Source: The 2002 The North American Market for Grid Power Solutions: Distributed Generation & Ride-Through Technologies, Venture Development Corp., June 2001
  - \$42 Million North American Market in 2000
  - \$900 Million by 2005
- **Micro-turbines** Source: The 2002 The North American Market for Grid Power Solutions: Distributed Generation & Ride-Through Technologies, Venture Development Corp.
  - \$25 Million North American Market in 2000
  - \$500 Million by 2005
- **Inverters for Solar** Source: IEA PVPS T1-11:2002
  - \$264 Million Worldwide Market in 2002
  - \$515 Million Worldwide Market in 2005 With 25%/Annum Growth





# Converter Cost

- **Converter Cost Is Significant (>25% System Cost)**
- **Average List Price For Inverters Rated 1-5kW is \$834.00/kW** Source: Inverter prices: Solarbuzz, Inc., March 2003
- **Cost Range From \$100/kW (UPS) to \$1200/kW (Standalone) Has Been Seen**
- **Manufacturers Reluctant to Provide Detail Cost Information**
- **Market for PV Systems Are Small Compared to UPS or Motor Drives Market**
- **Cost Comparison Often Apples to Oranges**





# Inverter Issues

- Little Movement in Cost and Reliability
- Low Manufacturing Volume For Renewable/DER
- Low Profit Margin

## What is Needed

- Reduce Costs, Improve Reliability
- Develop State-of-art Inverters with Multiple Uses  
Increases Production Volume For Renewables  
and Distributed Energy Resources
- Improve Controls and Adaptability
- Improve Manufacturability





# Technical Challenges

- **Apply Advanced Technologies**
  - Digital Signal Processing (DSP)
  - Advanced or Made-to-order Power Electronics
  - Advanced Switching Techniques
  - Internal and External Controls
- **Improve Packaging and Layout**
- **Reduce Thermal Stresses**
  - Improved Thermal Management
  - Reduce Internal Losses





# Institutional Challenges

- **Develop Multi-Use Designs (Synergism!)**
  - Align With Huge Users of Similar Power Electronics (Motor Drives, Uninterruptible Power Supplies).
- **Provide Focused Government-sponsored R&D and Manufacturing Initiatives for Renewable/DER/Storage-Specific Requirements and Controls.**
- **Require Manufacturing Quality Control, Environmental & Reliability Testing! (HALTs™)**





# Key Logistics Issues

- **Demand for Renewables/DER and Storage Systems Will Not Drive Power Electronics or Silicon Technology Improvements**
- **Increased Sales Volume, Better Packaging and Manufacturing Techniques Can Reduce Cost and Increase Reliability**
- **Standardization is Possible for a Core Unit, but Custom Design Flexibility Must be Retained**
- **Focused Cross Technology R&D Can Be a Win-Win for Technologies and Inverter Manufacturers**





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