EPRI Overview

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Energy Efficiency & Industrial Studies
EPRI
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Together…Shaping the Future of Electricity

Collaborative Research & Development

Non-Profit

Serving Members and Society
Overview

• The Electric Power Research Institute was established in 1973 as an independent, nonprofit center for public interest energy and environmental research.

• EPRI brings together members, participants, the Institute’s scientists and engineers, and other leading experts to work collaboratively on solutions to the challenges of electric power.

• These solutions span nearly every area of electricity generation, delivery, and use, including health, safety, and environment.

• EPRI’s members represent over 90% of the electricity generated in the United States. International participation represents nearly 15% of EPRI’s total research, development, and demonstration program.
EPRI Facts

• 33-year history
• 450 participants in over 40 countries
• 66 technical programs
• 1600+ research and demonstration projects annually
• 10 to 1 average funding leverage
Extensive Technology Portfolio

Generation & Distributed Resources
- Environmental Controls
- Major Component Reliability
- Combustion Turbines
- Maintenance, Operations and Workforce
- Advanced Coal Plant Portfolio
- Distributed and Renewable Generation Resources
- Generation Planning: Economics and Fuels

Nuclear Power
- Material Degradation/Aging
- High Performance Fuel
- Radioactive High-Level Waste & Spent Fuel Management
- NDE & Material Characterization
- Equipment Reliability
- Instrumentation & Control Hardware and Systems
- Nuclear Asset-Risk Management
- Safety/Risk Technology & Application
- New Nuclear Plant Deployment
- Environmental Benefits
- Low-Level Waste & Radiation Management

Power Delivery & Markets
- Strategic Initiatives
- Security
- Power Markets & Risk
- Assets, Planning & Operations
- Power Quality
- Transmission Reliability & Performance
- Distribution Reliability & Performance
- Energy Utilization
- Enterprise Asset Management

Environment
- Air Quality
- Global Climate Change
- Land & Groundwater
- Water and Ecosystems
- EMF Health Assessment and RF Safety
- Occupational Health and Safety
Why This Initiative?

Increasing

Electricity prices
Shortage of new capacity
Vulnerability to foreign imports
Awareness to climate and the environment

Consumers are demanding change
Regulators and policy makers are demanding action
Utilities are responding
Program Elements

Analytics
• Technical, economic and environmental tools and assessments

Infrastructure
• Enabling communications and control to provide “prices to devices”

Devices
• Smart & efficient end-use devices that are IP addressable with control and meet highest efficiency standards
## Analytics: Economic and Environmental Assessment

### EIA Base Case 2007

<table>
<thead>
<tr>
<th>Technology</th>
<th>EIA 2007 Reference</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Load Growth ~ +1.5%/yr</td>
<td>Load Growth ~ +1.1%/yr</td>
</tr>
<tr>
<td>Renewables</td>
<td>30 GWe by 2030</td>
<td>70 GWe by 2030</td>
</tr>
<tr>
<td>Nuclear Generation</td>
<td>12.5 GWe by 2030</td>
<td>64 GWe by 2030</td>
</tr>
<tr>
<td>Advanced Coal Generation</td>
<td>No Existing Plant Upgrades 40% New Plant Efficiency by 2020–2030</td>
<td>150 GWe Plant Upgrades 46% New Plant Efficiency by 2020; 49% in 2030</td>
</tr>
<tr>
<td>CCS</td>
<td>None</td>
<td>Widely Deployed After 2020</td>
</tr>
<tr>
<td>PHEV</td>
<td>None</td>
<td>10% of New Vehicle Sales by 2017; +2%/yr Thereafter</td>
</tr>
<tr>
<td>DER</td>
<td>&lt; 0.1% of Base Load in 2030</td>
<td>5% of Base Load in 2030</td>
</tr>
</tbody>
</table>

Credible data on economic and environmental impact from dynamic energy management and smart end-use devices.
Dynamic Systems Infrastructure: Consumer Opportunities
Smart End-Use Devices

- Automatic Energy Management
- Building Integrated
- Efficiency
- Productivity
- Environment
Smart End-Use Devices: Industrial, Commercial, and Residential

Plasma Arc Torch

DC in Data Centers

Building Automation

Heat Pump
California Energy Commission
Public Interest Energy Research
High-tech Buildings Project
Research, develop, and demonstrate, innovative energy efficient technologies
10-year initiative focusing on high-tech industries – e.g. data centers
Help move market to more efficient technologies
Research and demonstration projects include technology transfer

Sponsored by:
California Energy Commission (CEC)—Public Interest Energy Research (PIER),
California Institute for Energy Efficiency (CIEE).
Data Center Power Use

Data center power use nationally is large and growing. Two studies estimated data center energy use:

- 2004 EPRI/Ecos estimated 14.8 TWh
- 2000 Arthur D. Little estimated 10.1 TWh

Saving a fraction of this energy is substantial
Typical Data Center Power Use

Power per component:
- Load: ~50%
- Power delivery: 0%
- Cooling: 0%

Cumulative Power:
- Total baseline: 100%

Source: Intel Corp.
Power Consumption: 100 W System Load

Source: Intel Corp.

High-Performance Buildings for High-Tech Industries
This demonstration focuses on reducing power delivery and conversion losses:

**Power Supplies in IT equipment**

Factory Measurements of UPS Efficiency (tested using linear loads)

**Uninterruptible Power Supplies (UPS)**

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Data Center Power Delivery System

**UPS** 85 - 92%

**Power Dist** 98 - 99%

**Power Supply** 68 - 72%

**DC/DC** 78 - 85%

The heat generated from the losses at each step of power conversion requires additional cooling power.

**HVAC:** Additional 35% to 76% of Power Loss for Cooling
Can we eliminate some of the conversion steps and measure reduction in losses?
DC Demonstration - Objectives

The demonstration’s objectives are to show the following:

1. DC powered server equipment exists in the same form factor or can readily be built from existing components.

2. DC powered server equipment can provide the same level of functionality and computing performance when compared to similarly configured and operating AC server equipment.

3. Efficiency gains from the elimination of multiple conversion steps can be measured by comparing traditional AC delivery to a DC architecture.

4. DC system reliability is as good or better than AC system reliability.
Industry Partners Made it Happen

Equipment and Services Contributors:

- Alindeska Electrical Contractors
- Baldwin Technologies
- Cisco Systems
- Cupertino Electric
- Dranetz-BMI
- Emerson Network Power
- Industrial Network Manufacturing (IEM)
- Intel
- Nextek Power Systems
- Pentadyne
- Rosendin Electric
- SatCon Power Systems
- Square D/Schneider Electric
- Sun Microsystems
- UNIVERSAL Electric Corp.

Opportunities for IT equipment participation remain
Other Partners Collaborated

Stakeholders:

- 380voltsdc.com
- CCG Facility Integration
- Cingular Wireless
- Dupont Fabros
- EDG2, Inc.
- EYP Mission Critical
- Gannett
- Hewlett Packard

- Morrison Hershfield Corporation
- NTT Facilities
- RTKL
- SBC Global
- TDI Power
- Verizon Wireless
Today: AC Distribution

480 VAC Bulk Power Supply

AC/DC → DC/AC → UPS → PDU → AC/DC → DC/DC → PSU

Server

12 V

VRM → 12 V
VRM → 5 V
VRM → 3.3 V
VRM → 1.2 V
VRM → 1.8 V
VRM → 0.8 V

Loads using Legacy Voltages

Loads using Silicon Voltages

5 V

3.3 V

1.2 V

1.8 V

0.8 V

Server
Facility-Level DC Distribution

480 VAC
Bulk Power
Supply

AC/DC

DC UPS
or
Rectifier

380 VDC

DC/DC

PSU

12 V

VRM

VRM

VRM

VRM

12 V

5 V

3.3 V

1.2 V

1.8 V

0.8 V

Loads using
Legacy Voltages

Server

Loads using
Silicon Voltages
## Data Center Power Delivery

<table>
<thead>
<tr>
<th>Efficiency Measured - UPS 1</th>
<th>UPS</th>
<th>XFMR</th>
<th>Power Supply</th>
<th>Total Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>89.6%</td>
<td>98.0%</td>
<td>90.0%</td>
<td>79.03%</td>
</tr>
<tr>
<td>Efficiency Measured - UPS 2</td>
<td>89.9%</td>
<td>98.0%</td>
<td>90.0%</td>
<td>79.29%</td>
</tr>
<tr>
<td>Efficiency Measured - DC</td>
<td>94.2%</td>
<td>100.0%</td>
<td>92.0%</td>
<td>86.66%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Power Measured - UPS 1</th>
<th>Output Load (kWh)</th>
<th>Input Load (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>23.3</td>
<td>26.0</td>
</tr>
<tr>
<td>Power Measured - UPS 2</td>
<td>23.3</td>
<td>25.91</td>
</tr>
<tr>
<td>Power Measured - DC</td>
<td>22.7</td>
<td>24.1</td>
</tr>
<tr>
<td><strong>Power Improvement - 1</strong></td>
<td></td>
<td>7.31%</td>
</tr>
<tr>
<td><strong>Power Improvement - 2</strong></td>
<td></td>
<td>6.99%</td>
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</tbody>
</table>
Measured Performance was Viewable On-line

Lawrence Berkeley National Laboratory websites for more information

- http://hightech.lbl.gov/
- http://hightech.lbl.gov/dc-powering/
A Typical Data Center Would See Even Greater Benefits

- Redundant UPS and server power supplies operate at reduced efficiencies.

- Cooling loads would be reduced in the equipment and overall in the center.

- Both UPS systems used in the AC base case were “best in class” systems and performed better than typical benchmarked systems – efficiency gains compared to typical systems would be higher.

- Power supply efficiency in the demonstration was much better than typical.
Data Center Power Delivery

For a typical center energy savings could exceed 20%

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<th>UPS</th>
<th>XFMR</th>
<th>PS</th>
<th>Total Efficiency</th>
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</thead>
<tbody>
<tr>
<td>Typical Efficiency</td>
<td>85.00%</td>
<td>98.00%</td>
<td>73.00%</td>
<td>60.81%</td>
</tr>
<tr>
<td>DC Option</td>
<td>92.00%</td>
<td>100.00%</td>
<td>92.00%</td>
<td>84.64%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Compute Load (W)</th>
<th>Input Load (W)</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical Efficiency</td>
<td>10,000</td>
<td>16444.93</td>
<td></td>
</tr>
<tr>
<td>Optimized DC Option</td>
<td>10,000</td>
<td>11814.74</td>
<td>28.16%</td>
</tr>
</tbody>
</table>
Installation

High-Performance Buildings for High-Tech Industries
390V Input VRM for High Efficiency Server Power Architecture

Y. Liu*, A. Pratt**, P. Kumar**, M. Xu* and Fred C. Lee*

*Center for Power Electronics Systems
Virginia Polytechnic Institute and State University
Blacksburg, VA 24061 USA

**Intel Corporation
2111 NE 25th Avenue
Hillsboro, OR 97124

Abstract—This paper describes a highly efficient, high power density converter generating 3.3VDC from a 390VDC input, for use in a proposed power distribution architecture with a reduced number of conversion stages, which increases system efficiency. Key design considerations, theoretical and experimental results are presented for the LLC resonant converter.

I. INTRODUCTION

Performance per watt requirements are driving higher energy efficiency in datacom equipment designs for both idle and active power states. Hence there is a strong incentive to increase the overall efficiency of power delivery systems. Figure 1 shows two common power delivery architectures for datacom equipment.* Power Supply Units (PSUs) are used to

Figure 2. Proposed power delivery architecture

II. DESIGN OF 390V TO 3.3V CONVERTER

Key design goals for the proposed 390V input VRM is high power density with >90% efficiency over a load range from 10% to 100%. The converter with a 3.3V/25A output is
DC Power - next steps:

- DC power pilot installation(s)
- Standardize distribution voltage
- Standardize DC connector and power strip design
- Server manufacturers develop power supply specifications (including disturbances)
- Power supply manufacturers develop prototypes
- UL and communications certification
- Address other types of IT equipment (storage, switches, etc.)
Additional Information

Project Coordination & Contacts:

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Ecos Consulting
• My Ton
  mton@ecosconsulting.com
Program 1
Project Set C
Achieving Cost-Effective PQ Compatibility between the Electrical System and Loads

EPRI Webcast
April, 2007
PQ Master Plan Implementation
Success Statement #15
In 10 years, we will have a comparable level of understanding about compatibility and PQ issues for DC as we do for AC

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Milestone #1
Predict Level of Penetration at 10th Year

Milestone #2
Problem Identification Solution Development

Milestone #3
Standardize DC Equipment

Milestone #4
Standardize Configuration for Controls as well as Distribution

Milestone #5
DC Compatibility Standard

DC Understanding
Master Plan Development PS1C

Success Statement #15
In 10 years, we will have a comparable level of understanding about
compatibility and PQ issues for DC as we do for AC

<table>
<thead>
<tr>
<th>2007</th>
<th>2008</th>
<th>2009</th>
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<tbody>
<tr>
<td>Milestone #1 Predict Level of Penetration at 10th Year</td>
<td></td>
<td>Milestone #2 Problem Identification Solution Development</td>
</tr>
</tbody>
</table>

- Define Market Segments
- SCRPs
- IDG
- Other
- Field Demos
- Reliability Studies
- PQ, Efficiency Studies
- Lab Tests
- TAAG
- Power Conditioners
- Embedded Solutions