DIRECT POWER TECHNOLOGIES, INC.

HIGH VOLTAGE DC (HVDC) POWER SOLUTIONS FOR CRITICAL POWER ENVIRONMENTS

A PATENT PENDING SYSTEM PRESENTATION

Mark Baldwin - President
Direct Power Technologies, Inc.

David Geary, PE - VP of Engineering
Direct Power Technologies, Inc.

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
THOMAS ALVA EDISON

1889

SCIENTIFIC AMERICAN

“My personal desire would be to prohibit entirely the use of alternating currents. They are as unnecessary as they are dangerous. I can therefore see no justification for the introduction of a system which has no element of permanency and every element of danger to life and property”

NICOLA TESLA PRESENTED A LECTURE TO THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS: “A NEW SYSTEM OF ALTERNATING CURRENT MOTORS AND TRANSFORMERS”. THIS WAS EDISON’S RESPONSE TO THIS NEW AC POWER CONCEPT.
In the final decades of the nineteenth century, three brilliant and visionary titans of America’s Gilded Age—Thomas Edison, Nikola Tesla, and George Westinghouse—battled bitterly as each vied to create a vast and powerful electrical empire. In Empires of Light, historian Jill Jonnes portrays this extraordinary trio and their riveting and ruthless world of cutting-edge science, invention, intrigue, money, death, and hard-eyed Wall Street millionaires. At the heart of the story are Thomas Alva Edison, the nation’s most famous and folksy inventor, creator of the incandescent light bulb and mastermind of the world’s first direct current electrical light networks; the Serbian wizard of invention Nikola Tesla, elegant, highly eccentric, a dreamer who revolutionized the generation and delivery of electricity; and the charismatic George Westinghouse, Pittsburgh inventor and tough corporate entrepreneur, an industrial idealist who in the era of gaslight imagined a world powered by cheap and plentiful electricity and worked heart and soul to create it.

Edison struggled to introduce his radical new direct current (DC) technology into the hurly-burly of New York City as Tesla and Westinghouse challenged his dominance with their alternating current (AC), thus setting the stage for one of the eeriest feuds in American corporate history, the War of the Electric Currents. The battlegrounds: Wall Street, the 1893 Chicago World’s Fair, Niagara Falls, and, finally, the death chamber—Jonnes takes us on the tense walk down a prison hallway and into the sunlit room where William Kemmler, convicted ax murderer, became the first man to die in the electric chair.

Empires of Light is the gripping history of electricity, the “mysterious fluid,” and how the fateful collision of Edison, Tesla, and Westinghouse left the world utterly transformed.
INTRODUCTION

High density computer environments, utilizing Alternating Current (AC) power supply blade server technology, are presenting major challenges to owners and operators. Typical facility infrastructures cannot accommodate the added heat loads and reliability requirements of such installations.

Servers equipped with Direct Current (DC) power supplies, instead of AC power supplies, operate with 20-40% less heat, reduce power consumption by up to 30%, increase server reliability, offer flexibility to installations and decrease maintenance requirements.

Utilizing current off-the-shelf components, it is possible to install and operate a high reliability DC power distribution system for a DC powered server environment - without batteries or complicated AC power system drawbacks. This High Reliability DC Power Distribution System could be the next generation power system for server environments.
THE PROBLEM

Google to Push for More Electrical Efficiency in PC's
By JOHN MARKOFF

SAN FRANCISCO, Sept. 25 — Google is calling on the computer industry to create a simpler and more efficient power supply standard that it says will save billions of kilowatt-hours of energy annually.

Running Wild

Powering and cooling computers cost more than the machines themselves. Now, new technologies are reducing those expenses.

By CHRISTOPHER LAWTON
January 29, 2007, Page RD

Servers have gotten much more powerful in recent years. But they've also gotten hungrier.

In 2006, businesses worldwide spent about $55.4 billion on new servers, according to market-research firm IDC. To power and cool those machines, they spent $29 billion, almost half the cost of the equipment itself — and that number is rising.

With the average server system, the customer spends 'more on power and cooling over its entire life cycle than what they will spend up front,' says Michelle Bailey, research vice president at IDC.
THE PROBLEM

IBM to Launch Push for Green

New Business to Address Cutting Energy Thirst Of Computer Centers

By William M. Bulkeley

Big Blue sees green in going green. Under an initiative it has dubbed "Project Big Green," International Business Machines Corp. plans to start a major business to help customers slash energy use in data centers that are running up ever larger electricity bills.

IBM has scheduled a press event for today in New York to inaugurate the business, which is part of its global services offering. The business will help customers maximize energy efficiency of their computers and redesign the layout of their data centers to minimize cooling costs.

In addition, IBM, which says it is the world's biggest operator of data centers, will explain its own plans for reducing power consumption.

The amount of energy used by computers—both for running the machines and cooling the rooms they sit in—has increased sharply, both about cost and environmental impact. Global electricity consumption by servers and ancillary equipment doubled to $73 billion from 2000 to 2005, Jonathan Koomey, a staff scientist at Lawrence Berkeley National Laboratory and consulting professor at Stanford University, estimated in a study released this year.

Christopher Mines, an analyst with market researcher Forrester Research, Cambridge, Mass., says it found in a recent survey of corporate computer buyers "a high degree of awareness of environmental issues surrounding computing, but a low degree of activity." He said most corporate computer managers focus on high performance and reliability for their networks and ignore electricity use. "They don't pay the bill in the vast majority of companies," he said, adding that energy bills are the province of operations managers.

IBM compares the new project with the commitment it made 10 years ago to embrace the Internet and later Linux free software, both for its own use and as a service business for corporate and governmental customers. Both plans have improved the company's internal business operations and created an opportunity for huge additional services and software revenue.

IBM is training 1,000 services experts in green technology to help clients redesign their data centers and improve their efficiency.

According to materials prepared for the press event, IBM expects to double the computing capacity of its own data centers by 2010 without using additional energy. Under that scenario, it would avoid incurring $500 million in electricity costs.

IBM's announcement today is expected to feature several technologies for reducing air-conditioning costs in data centers, where computers must be kept cool to function optimally. Among those technologies is the IBM Data Center Storied Cooling Solution, which sits outside the data center and uses a synthetic liquid solution to cool chillers that regulate air-conditioning units. The product was named the "best new energy product" by the American Society of Heating, Refrigeration and Air Conditioning Engineers.

Other aspects of IBM's green services include a software program that can analyze heat and air-conditioning use in a data center to find hot spots and suggest ways to move servers to optimize cooling capabilities.

IBM's news event today is expected to include representatives from a number of partner companies, including General Electric Co., PG&E Corp., Pacific Gas & Electric Co. and Schneider Electric SA.
THE MARKET

APPROX. $3 BILLION ON BLADE SERVER REVENUE BY 2009

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
TODAY’S ENVIRONMENT

• THE ALTERNATING CURRENT (AC) WORLD
• HIGH COST - LOW EFFICIENCY/HIGH LOSS - MAINTENANCE INTENSIVE
• PARALLEL OPERATION REQUIRES HIGH COST ACTIVE PARALLELING CONTROLS
• AC POWERED BLADE SERVERS CANNOT BE ACCOMMODATED WITHIN THE TYPICAL DATA CENTER ENVIRONMENT
• MULTIPLE CONVERSIONS REQUIRED:
  • AC (UTILITY) to DC (UPS INPUT) to AC (UPS OUTPUT) to DC (WITHIN DATA PROCESSING POWER SUPPLIES)
TYPICAL SMALL AC POWER SYSTEM UP TO APPROX. 300KVA
TYPICAL MEDIUM AC POWER SYSTEM UP TO APPROX. 1,000KVA
TYPICAL LARGE AC POWER SYSTEM UP TO APPROX. 2,000KVA
THE SOLUTION - TOMORROW’S ENVIRONMENT

DC POWER:
- REDUCED POWER CONVERSIONS = HIGHER EFFICIENCY
- REDUCED POWER CONVERSIONS = HIGHER RELIABILITY
- REDUCED POWER CONVERSIONS = LESS COMPONENTS (MAINTAINABILITY)
- DC POWER = EASIER TO ADAPT TO ALTERNATIVE ENERGY SOLUTIONS
DC-UPS Computer Room Plan View Layout

**BladePower**

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
1ST DEMONSTRATION SYSTEM - CHATSWORTH, CA. - PENTADYNE POWER HQ - MARCH 2005
COMPONENT PARTS OF THE DC POWER DISTRIBUTION SYSTEM

**RECTIFIERS:**
- Converts utility or generator sourced AC power to 400VDC (nominal) in any combination of building block sizing for capacity and/or redundancy.

**ENERGY STORAGE:**
- Provides DC power ride through without batteries. Upon loss of the AC power source to the rectifiers, the Pentadyne flywheel technology based system will support the 400VDC bus while engine generators are brought on line.
COMPONENT PARTS OF THE DC POWER DISTRIBUTION SYSTEM - CONT’D

**EQUIPMENT RACK DISTRIBUTION:**
- PROVIDES UL LISTED 400VDC POWER DISTRIBUTION TO EQUIPMENT RACK LOCATIONS WITHIN A COMPACT PACKAGE WITH HOT SWAPPABLE / MOVABLE CONNECTORS. BUSWAY HAS THE CAPABILITY OF BEING FED FROM 2 SEPARATE 400VDC SOURCES FOR REDUNDANCY.

**DC - DC VOLTAGE CONVERTERS:**
- NOT REQUIRED IN THIS NEW TOPOLOGY: DISTRIBUTE AT A 380-400V DC AND CONNECT DIRECTLY INTO DC POWERED SERVER RACKS. HIGHEST EFFICIENCY CONFIGURATION!
NEXT GENERATION DC POWER ARCHITECTURE:

400VDC BLADE-POWER SERVER RACKS

THE UNIVERSAL COMPUTER POWER SUPPLY -

SPECIFICATIONS

<table>
<thead>
<tr>
<th>AC Input Range</th>
<th>110/240V 47-63Hz. Limits: 85 - 264 VRMS (270V Surge), 47 to 63 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Input Voltage Range</td>
<td>110 to 373V DC (380V DC surge)</td>
</tr>
</tbody>
</table>

- 1ST LEVEL POWER CONVERSION IN TODAY’S COMPUTERS IS A DIODE RECTIFIER THAT TAKES 85 - 264VAC AND CONVERTS TO 110 - 373V DC.
- DIODE BRIDGE RECTIFIER
  - 264VAC X SQUARE-ROOT OF 2 = 373VDC
- A NOMINAL 400VDC DISTRIBUTION SYSTEM CAN ELIMINATE THE FIRST STAGE CONVERSION WITHIN COMPUTERS!
- STUDIES ARE UNDER WAY WITH COMPUTER MANUFACTURER’S FOR A 400VDC “DISTRIBUTION-TO-THE-RACK” ARCHITECTURE.
INTEL’S VISION

480V 3φ AC: 48V DC: 93% x 97% x 93% x 86% = 72%
380V DC: 97% x 97% x 93% x 86% = 76%

Baseline 88% x 93% x 79% x 75% = 48%
High efficiency: 94% x 94% x 89% x 86% = 68%
## System Efficiency Impacts

For a load power of 500kW:

<table>
<thead>
<tr>
<th>Architecture</th>
<th>System Efficiency</th>
<th>Input Power</th>
<th>Annual Energy costs @ 10 cents / kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline AC</td>
<td>50%</td>
<td>1000</td>
<td>876</td>
</tr>
<tr>
<td>Best-in-Class AC</td>
<td>63%</td>
<td>793</td>
<td>695</td>
</tr>
<tr>
<td>Rack Level HVDC</td>
<td>63%</td>
<td>793</td>
<td>695</td>
</tr>
<tr>
<td>-48 V DC</td>
<td>70%</td>
<td>715</td>
<td>625</td>
</tr>
<tr>
<td>HVDC Data Center</td>
<td>72%</td>
<td>695</td>
<td>608</td>
</tr>
</tbody>
</table>

63% to 70% ⇒ $70K per annum savings
70% to 72% ⇒ Additional $17K per annum savings
$370,000 savings per year at 0.1$/kWh
SUN MICRSYSTEMS’ VISION

DC Distribution Configuration

Slide 24
### SUN MICRSYSTEMS’ VISION

#### Summary of efficiencies

<table>
<thead>
<tr>
<th></th>
<th>High efficiency</th>
<th>Nominal efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard data center distribution</td>
<td>78</td>
<td>65</td>
</tr>
<tr>
<td>Rack data center distribution</td>
<td>81</td>
<td>72</td>
</tr>
<tr>
<td>DC data center distribution</td>
<td>88</td>
<td>80</td>
</tr>
</tbody>
</table>
ALTERNATIVE / RENEWABLE ENERGY POTENTIALS WITH DC POWER SOLUTIONS
DC POWER SOLUTIONS
DC POWER PAC - 1 - RENEWABLE ENERGY ©

Optional Solar Array 300VDC

AC to DC Rectifier 75kW Power Gateway

DC-DC Converter OR DC Powered Server Equipment

600VDC Rated 4-Bus Universal Busway with Dedicated Drops to Server Equipment Racks

NEXTek POWER GATEWAY INTERFACE FOR RENEWABLE ENERGY APPLICATIONS

NOTES:
1. Multiple 75kW Power Gateways can be used to achieve increased capacity or n+1 redundancy.
2. The 75kW NEXTek Power Gateway is protected by US Patents 5,706,642, 6,252,210, 6,614,130 and other patents pending.

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
FLOW BATTERY TECHNOLOGY

Flow batteries can turn intermittent wind power from a utility manager's headache to a green and reliable energy source.

This 30 MW wind farm in Japan is augmented by a battery system that can supply 4 MW of power for up to 90 minutes.
FLOW BATTERY TECHNOLOGY

Principle of Vanadium Redox Flow Battery

Generator

Charge

Discharge

Load

AC / DC

Cell

+ V⁵⁺ / V⁴⁺

Electrolyte Tank

Pump

Electrode

Membrane

Pump

- V³⁺

V⁴⁺

+ e⁻

V⁵⁺

V⁴⁺

V²⁺

V³⁺

V⁴⁺

SUMITOMO ELECTRIC

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
DC POWER SOLUTIONS
DC POWER PAC - 1 - RENEWABLE ENERGY:
FLOW BATTERY ©

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
DC POWER SOLUTIONS

DC POWER PAC - 2 - RENEWABLE ENERGY: FLOW BATTERY ©
DC POWER SYSTEM BENEFITS AND STUDIES
DC SYSTEM BENEFITS

- LOWER COMPONENT COUNT = HIGHER SYSTEM EFFICIENCIES, GREATER RELIABILITY, LESS MAINTENANCE COST & LOWER TOTAL COST OWNERSHIP
- MODULAR & FLEXIBLE: SYSTEM CAN GROW WITH LOAD REQUIREMENT
- ENVIRONMENTALLY FLEXIBLE: SYSTEM FRONT-END COMPONENTS CAN BE LOCATED IN NON-CONDITIONED SPACES OR ON THE RAISED FLOOR NEAR LOAD
- PENTADYNE ENERGY STORAGE ELIMINATES NEED FOR CHEMICAL BATTERIES
- UNIVERSAL STARLINE BUSWAY PROVIDES A MODULAR “GO-AS-YOU-GROW” STRATEGY FOR DC DISTRIBUTION AS RACK POPULATION CHANGES
- UNIVERSAL STARLINE BUSWAY PROVIDES A DOUBLE END-FEED FEATURE TO PERMIT REDUNDANT DC SOURCES AT CRITICAL LOADS
- NO DOWN-STREAM STATIC OR TRANSFER SWITCHES ARE REQUIRED, VOLTAGE MATCHED DC SYSTEMS CAN INHERENTLY BE COUPLED TOGETHER
- DC DISTRIBUTION ELIMINATES HARMONICS
DC SYSTEM BENEFITS - CONT’D

- SIMPLIFIED GROUNDING: POSITIVE GROUNDING OR NEGATIVE GROUNDING

- ALTERNATIVE ENERGY FRIENDLY – DC POWER SYSTEMS ARE MORE EASILY ADAPTED TO ALTERNATIVE ENERGY SOURCE APPLICATIONS

- SYSTEM CONFIGURATION IS A UNIQUE APPLICATION AND PARTNERSHIP OF EXISTING, AND PROVEN “COMMERCIAL OFF-THE-SHELF” (COTS) EQUIPMENT

- THIS DC SYSTEM HAS NO REQUIREMENT FOR A UPS IN ORDER TO PROVIDE HIGH SYSTEM RELIABILITY WITH UTILITY POWER OUTAGE RIDE THROUGH.

- DC DISTRIBUTION ELIMINATES POWER FACTOR CONCERNS

- REDUCES HEAT LOAD AT SERVER RACKS BY 20-40%

- REDUCES POWER CONSUMPTION BY UP TO 30%

- INCREASES SERVER RELIABILITY BY AS MUCH AS 27%
<table>
<thead>
<tr>
<th></th>
<th>AC SYSTEM 1</th>
<th>AC SYSTEM 2</th>
<th>DC SYSTEM (48VDC)</th>
<th>DC SYSTEM (400VDC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>% LOSS</td>
<td>11.0%</td>
<td>5.0%</td>
<td>3.0%</td>
<td>3.0%</td>
</tr>
<tr>
<td>% EFF</td>
<td>89.0%</td>
<td>96.0%</td>
<td>RECTIFIER</td>
<td>RECTIFIER</td>
</tr>
<tr>
<td>% EFF</td>
<td>9.0%</td>
<td>97.0%</td>
<td>PENTADYNE</td>
<td>PENTADYNE</td>
</tr>
<tr>
<td>% EFF</td>
<td>95.0%</td>
<td>97.0%</td>
<td>97.0%</td>
<td>97.0%</td>
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<tr>
<td>INSIDE SERVER</td>
<td>13.0%</td>
<td>13.0%</td>
<td>4.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>% LOSS</td>
<td>12.0%</td>
<td>12.0%</td>
<td>10.0%</td>
<td>10.0%</td>
</tr>
<tr>
<td>% EFF</td>
<td>88.0%</td>
<td>88.0%</td>
<td>DC CONVERTER</td>
<td>NO DC CONVERTER</td>
</tr>
<tr>
<td>% EFF</td>
<td>88.0%</td>
<td>88.0%</td>
<td>96.0%</td>
<td>96.0%</td>
</tr>
<tr>
<td>% EFF</td>
<td>88.0%</td>
<td>88.0%</td>
<td>90.0%</td>
<td>90.0%</td>
</tr>
<tr>
<td>TOTAL LOSSES</td>
<td>37.5%</td>
<td>31.5%</td>
<td>17.0%</td>
<td>13.0%</td>
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<tr>
<td>TOTAL EFFICIENCY</td>
<td>67.1%</td>
<td>71.6%</td>
<td>83.8%</td>
<td>87.3%</td>
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<tr>
<td>PDU &amp; STATIC SWITCH</td>
<td>1.5%</td>
<td>1.5%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>COMPUTER POWER SUPPLY: AC - DC</td>
<td>13.0%</td>
<td>13.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COMPUTER POWER SUPPLY: AC - DC</td>
<td>87.0%</td>
<td>87.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SERVER RAIL VOLTAGE: DC - DC</td>
<td>12.0%</td>
<td>12.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SERVER RAIL VOLTAGE: DC - DC</td>
<td>88.0%</td>
<td>88.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC CONVERTER: 500VDC - 48VDC</td>
<td>4.0%</td>
<td>4.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC CONVERTER: 400VDC TO RACK</td>
<td>0.0%</td>
<td>0.0%</td>
<td></td>
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<tr>
<td>INSIDE SERVER</td>
<td>10.0%</td>
<td>10.0%</td>
<td>10.0%</td>
<td>10.0%</td>
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<tr>
<td>INSIDE SERVER</td>
<td>90.0%</td>
<td>90.0%</td>
<td>90.0%</td>
<td>90.0%</td>
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</tbody>
</table>
Group Studies Dc Power in Data Centers

November 21, 2005

New power delivery infrastructure solutions are needed for the high power densities of the next generation data centers. High-density computer environments, utilizing alternating current (ac) to deliver power to blade server technology and other high-density computing devices, are presenting major challenges to owners and operators. Typical facility infrastructures cannot accommodate the added heat loads and reliability requirements of such installations.

Servers equipped with direct current (dc) power supplies, instead of ac power supplies, operate with 20-40% less heat, reduce power consumption by up to 30%, increase server reliability, offer flexibility to installations and decrease maintenance requirements.

Utilizing current off-the-shelf components, it is possible to install and operate a high-reliability, high-voltage dc power distribution system for a dc-powered server environment without batteries or complicated ac power system drawbacks. This high-reliability dc power distribution system could be the next generation power system architecture for data centers.

An industry group is being formed to study and demonstrate the use of dc power for data center applications. This group, sponsored by the California Energy Commission through Lawrence Berkeley National Laboratory, will be headed by a partnership between EPRI Solutions and Ecos Consulting. Companies represented at the initial meeting include HP, Sun Microsystems, Baldwin Technologies, Inc., Pentadyne Power Corp., SATCON, SquareD, TDI, CCG Facility Integration Inc., Nextek Power Systems, and Dranetz-BMI.
DC Power for Data Centers of the Future

Overview

An alternative approach to conventional alternating-current (AC) power uses a direct-current (DC) power distribution scheme throughout a data center. Most data center server racks are not currently powered this way, but with the advent of servers on the market that can operate with either AC or DC, it is possible to use the DC powering approach, thus eliminating extra power conversion steps and losses. Other benefits include reduced cooling needs, higher equipment densities, and reduced heat-related failures.

Parties interested in participating in this project should contact William Tschudi, My Ton, or Brian Fortenbery.

Demonstration Goal and Objectives

A stakeholder group has been formed by industry and the California Energy Commission to investigate:

1. Whether or not DC powered server(s) and/or server racks can provide the same level of functionality and computing performance when compared to similarly configured and operating servers (and/or server racks) containing AC powered server(s), as measured with industry standard measurement devices and software tools.
2. Document any efficiency gains from the elimination of multiple conversion steps in the delivery of DC power.
3. Feasibility for both facility-level as well as rack-level DC conversion and delivery.
4. Identify issues/best practices and make recommendations for implementation.

Additional Information

- Facility-Level Overview [Download]
- Rack-Level Overview [Download]
- Frequently-asked Questions
BERKELEY LABS

High-Performance Buildings for High-Tech Industries

DC DEMONSTRATION SYSTEM AT SUN MICROSYSTEMS, NEWARK, CA.

http://hightech.lbl.gov/

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
DC DEMONSTRATION - TIMELINE

- Stakeholders first met – Fall 2005
- Kick-off meeting – April 2006
- Equipment assembly – May 2006
- Initial “Team Open House” June 7, 2006
- Public Open House events: June 21, July 12, 26; Aug 9, 16
- End date – August 16, 2006
THE RESULTS

DC Power for Improved Data Center Efficiency
January 2007
THE RESULTS

1.4 Project Results

Our results indicate that the DC approach does provide an increase in conversion efficiency. We were fortunate enough to have access to two AC distribution systems as well as two DC conversion/distribution systems, and the efficiency ratios were determined for both sets.

Table ES1

<table>
<thead>
<tr>
<th>System Efficiency</th>
<th>UPS Efficiency</th>
<th>Transformer Efficiency</th>
<th>PS Efficiency</th>
<th>System Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC System A: Measured Efficiency</td>
<td>90%</td>
<td>98%</td>
<td>90%</td>
<td>79%</td>
</tr>
<tr>
<td>AC System B: Measured Efficiency</td>
<td>90%</td>
<td>98%</td>
<td>90%</td>
<td>79%</td>
</tr>
<tr>
<td>DC System A: Measured Efficiency</td>
<td>94%</td>
<td>100%</td>
<td>92%</td>
<td>87%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy Consumption</th>
<th>Compute Load (kWh)</th>
<th>Input Load (kWh)</th>
<th>Efficiency Gain</th>
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<tbody>
<tr>
<td>AC System A: Measured Consumption</td>
<td>23.3</td>
<td>26.0</td>
<td></td>
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<tr>
<td>AC System B: Measured Consumption</td>
<td>23.3</td>
<td>25.9</td>
<td></td>
</tr>
<tr>
<td>DC System A: Measured Consumption</td>
<td>22.7</td>
<td>24.1</td>
<td></td>
</tr>
<tr>
<td>% Energy Consumption Improvement vs. AC System A</td>
<td>7.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% Energy Consumption Improvement vs. AC System B</td>
<td>7.0%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
THE RESULTS

It should be noted that both of the AC distribution system used represent the best on the market with regard to efficiency. Both of the AC UPSs are high efficiency units, and the efficiencies of the power supplies in the AC servers – at 90%, are much higher than units currently found in today’s data centers. By comparison, a typical AC system in today’s data center would have a UPS that was about 85% efficient, and power supplies around 73% efficient. The estimated improvement of the DC system over these “typical” systems is shown in Table ES3 below.

Table ES3

<table>
<thead>
<tr>
<th>System Efficiency</th>
<th>UPS Efficiency</th>
<th>Transformer Efficiency</th>
<th>PS Efficiency</th>
<th>System Efficiency</th>
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<tbody>
<tr>
<td>AC Typical Distribution Efficiency</td>
<td>85%</td>
<td>98%</td>
<td>73%</td>
<td>61%</td>
</tr>
<tr>
<td>DC Distribution Efficiency</td>
<td>92%</td>
<td>100%</td>
<td>92%</td>
<td>85%</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Energy Consumption</th>
<th>Compute Load (W)</th>
<th>Input Load (W)</th>
<th>Efficiency Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical AC Distribution Efficiency</td>
<td>10,000</td>
<td>16,445</td>
<td></td>
</tr>
<tr>
<td>DC Distribution Option (Optimized)</td>
<td>10,000</td>
<td>11,815</td>
<td></td>
</tr>
<tr>
<td>% Energy Consumption Improvement vs. Typical AC Distribution</td>
<td>28.2%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In this case, an improvement of over 28% is possible in an average data center. This means the DC distribution system, as demonstrated, will have the potential of using 28% less energy than the typical AC system found in today’s data centers. Since data center HVAC loads are typically about the same as the IT load, this means that a 28% improvement in distribution and conversion also means a 28% overall facility level efficiency improvement.
OVER SEAS STANDARDS ACTIVITIES

ETSI EN 300 132-3 V1.2.1 (2003-06)

Environmental Engineering (EE):
Power supply interface at the input to telecommunications equipment;
Part 3: Operated by rectified current source, alternating current source or direct current source up to 400 V
Can DC Power Cut Data Center Costs?
March 27, 2006
By Jeffrey Bart

Gannett is revamping its Washington data center's power infrastructure, having added another string of traditional AC power supplies prompted in part by the move to bring the company's Web hosting operation in-house.

However, Gannett officials expect the media company's hosting capacity to grow and are already planning for ways to keep the 15,400-square-foot data center powered up and cooled as that occurs. One option under study is the use of DC power distribution within the data center.

"The question for us is: Does it make sense to go down the same [AC] road if there's an option out there that can save us money?" said Gary Gummersen, IT architect for Gannett in McLean, Va., an eWEEK Corporate Partner.

Analysts said the drumbeat for DC power is likely to increase through June, when the Electric Power Research Institute will host a two-day data center conference focusing on DC power in Washington.

While many in the industry have brushed off DC power, calling it more marketing hype than reality, others—including Intel, Hewlett-Packard and Sun Microsystems—are interested. That bid is part of a project funded by the California Energy Commission in which industry players are working with Lawrence Berkeley National Laboratory, in Berkeley, Calif., to create a prototype of a DC-powered data center in Chatsworth, Calif., by September.

Meanwhile, there seems to be some traction for DC power in the industry. Rackable Systems officials say that 35 percent of the $83 million in revenue the company generated in the fourth quarter of last year was related to DC power deployments. Rackable offers DC solutions at the rack, row and data center levels.
PRODUCT DEVELOPMENT IN PROCESS
RECTIFIERS & DC - DC CONVERTERS

- DPTI is working with SATCON POWER SYSTEMS to develop high efficiency rectifiers and dc-dc converters specific for this system architecture application.

- SATCON is currently providing power conversion products for the Navy's new DD(X) destroyer program for a DC based Integrated Power System.
150kW Rectifier PDU

Rectifier 400Vdc, 500A
- Rittal Enclosure
- 300A Thermal Mag in-put AC breaker
- AC Line Harmonic filter & fusing to meet IEEE519 requirements
- 480/283Vac auto transformer
- 3 semiconductor line fuses with blown fuse indicators and switches
- 500Adc, 400Vac diode bridge 40°C rated with cooling provided
- DC filter for ripple reduction
- Output DC fuses 500A rated with blown fuse indicator & switches
  OR 500A DC OUTPUT CIRCUIT BREAKER (BREAKER PREFERRED)
- POWER QUALITY METERING – INPUT & OUTPUT VIA DRANETZ-BMI ENCORE SYSTEM

150kW PDU Rectifier Power Schematic
RECTIFIERS & DC - DC CONVERTERS

- DPDI is also working with EPRI to develop high efficiency rectifiers and dc-dc converters specific for this system architecture application.
Intelligent Universal Transformer - EPRI

Core Technologies Needed

New State-of-the-Art
High-voltage multilevel IUT
Topology – Lab
Bench Development

Demonstrated 2004-2005

New High-Voltage, Low-Current Power
Semiconductor Devices

Interoperable with
Open Communication
Architecture

All Solid-State Replacement for Distribution Transformers

Product Spin-offs

Patent application for EHV version of IUT (substations)
Other power electronic applications

Functions and Value

Traditional voltage stepping, plus...

New service options, such as dc

Real-time voltage regulation, sag correction, system monitoring, and other operating benefits

Other benefits: standardization, size, weight, oil elimination

Cornerstone device for advanced distribution automation (ADA)

Slide 49
EPRI’s Advanced Solid State Transformer Design using HV Power Electronics

The multi-level IUT transformer concept is based on using HV-IGBTs at the distribution voltage level.

One major advantage in using multilevel converter approach is its effective switching frequency is multiplied, and thus the ripples are significantly reduced.

Voltage sharing problems can be eliminated with the use of clamping circuits.

Lesser series connected modules at the input stage are required making the design to be more reliable as compared to ABB/Purdue design.
380/400VDC CONNECTORS

- DPTI is working with Anderson Power to develop a 380/400VDC connector

PowerPak configurations for 400 VDC

30 amp Receptacle
- Sun Micro

10 Amp Receptacle
- Intel

30 amp Plug w/latch
- Sun Micro

10 Amp Plug w/latch
- Intel

Red spacer location will be replaced by future 4 circuit signal module
380/400VDC PLUG STRIP

DPTI is working with multiple companies to develop a 380/400VDC plug strip.
OVERSEAS DEVELOPMENT OF 400VDC CONNECTORS
ENERGY STORAGE SYSTEM

The Pentadyne Voltage Support Solution™ provides ride-through power and voltage stabilization in a variety of areas, including:

1. Uninterruptible Power Supply (UPS)
2. Adjustable Speed Drive (ASD)
3. Distributed Generation (DG)
4. Utility Premium Power
5. Electric Urban Rail

Specifications

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>120 kW</td>
</tr>
<tr>
<td>Duration at Rated Power</td>
<td>20 seconds</td>
</tr>
<tr>
<td>Useable Energy Storage</td>
<td>0.67 kW.h (2400 kW.s)</td>
</tr>
<tr>
<td>Max. Recharge Power</td>
<td>120 kW</td>
</tr>
<tr>
<td>Typical Idle Power Consumption</td>
<td>300 W</td>
</tr>
<tr>
<td>Total Weight</td>
<td>590 kg (1300 lb)</td>
</tr>
<tr>
<td>Dimensions (W x D x H)</td>
<td>63 x 83 x 180 cm (25 x 33 x 71 in.)</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>-20°C to 50°C (-4°F to 122°F)</td>
</tr>
<tr>
<td>Non-operating Temperature</td>
<td>-20°C to 80°C (-4°F to 176°F)</td>
</tr>
<tr>
<td>Output Voltage</td>
<td>500 to 850 VDC*</td>
</tr>
<tr>
<td>Output Voltage Regulation</td>
<td>+/- 5% DC</td>
</tr>
<tr>
<td>Weatherproof Enclosure</td>
<td>Optional</td>
</tr>
<tr>
<td>Forklift Compatible</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Parameters are set by the user through the Pentadyne system user interface console; for other voltages, please consult Pentadyne.

Operational Flexibility

The Pentadyne Voltage Support Solution™ can provide clean constant DC output (or AC output with optional hardware) for 20 seconds at 120 kW or other combinations of power and time equaling 2400 kW-seconds of energy (as shown below).
Pentadyne Voltage Support Solution™

Pentadyne Flywheel Technology. Unique technology features create unique economic benefits.
Superior customer economic benefits come from Pentadyne Power Corporation’s choice of innovative technologies, which include:

Features
- Active magnetic bearings
- Internal, integrated vacuum system
- Synchronous reluctance motor-generator
- Fiber composite flywheel
- Unique patented safety system

Economic Benefits
- No mechanical losses
- Very low aerodynamic losses
- Very low standby losses
- Low cost energy storage
- Low installation cost

Pentadyne’s flywheel technology provides precise electrical power for ride-through and voltage stabilization during electrical disturbances.

The Pentadyne Flywheel Module

Molecular Vacuum Pump
Carbon Fiber Flywheel
Stator
Liquid Cooling Passages

Upper Magnetic Bearing
Inner Housing
Synchronous Reluctance M-6 Rotor
Lower Magnetic Bearing
Outer Housing

Why Choose Pentadyne Flywheels Instead of Batteries?
Pentadyne’s flywheel technology provides superior performance without the high cost of ownership and the environmental impacts that batteries present. Further, due to the unique operating features such as rapid recharging and broad operating temperature range, the Pentadyne flywheel can be used where batteries have been ruled out.

Pentadyne Flywheel
- Very low standby costs
- Low maintenance costs
- Low installation costs
- Small footprint and lightweight
- Long life

Batteries
- Large float and cooling costs
- High maintenance costs
- Air conditioned room required
- Large footprint and heavy
- Frequently replaced

Reliability
- Rapid recharge
- Broad operating temperature range
- Remotely monitored

Fast recharge
- Narrow operating temperature range
- High failure rate

Save 50–70% of the cost of owning batteries
Over a 10 year period, considering the space conditioning energy requirements, high maintenance, and frequent cell replacements, the battery energy storage may cost 2 to 3 times as much as the Pentadyne flywheel system on a lifecycle basis.

Pentadyne’s flywheel technology provides ride-through power for 20 seconds or more—which exceeds the duration of 98% of all industrial and commercial power quality problems—and provides voltage stabilization during electrical disturbances. Get the facts. Contact your Pentadyne Distributor.
FUTURE – PROTOTYPE 2 FLYWHEEL BLADE-POWER CONFIGURATION:
400VDC DISTRIBUTION TO EQUIPMENT RACKS

Standard B225 Amp System to 600 Volts

Also B160 or 160 Amp Systems

2, 3 or 4 pole with/without Isolated ground

Support Hardware

End Cap

Housing Section

Tee

End Piece

Coupler

Elbow

Installation Tool

Accessories - Closure Strip, Wt. Hook, etc

Power Feed

Plug-In Units

Providing Efficient Reliability
BUSWAY IS RATED AT 200 Amps AT 600V DC

Slide 58

StarLine Track Busway housing section consists of an extruded aluminum shell with "spring-pressure" type copper channel busbars contained in a full length PVC insulator mounted on one side on the interior wall. The aluminum extrusion acts as a 100% ground path meeting UL 857 Standard and complies with applicable paragraphs of Section 250 of the NEC. Each housing has an open access slot over its entire length for the insertion of turn-n-lock plug-in units. Housing configurations include 2, 3 and 4 pole varieties with 600 Volt maximum rating. Each housing section has male stabs protruding at one end which fit into the channels of the adjoining section. Installation tool is used to force the stabs into the busbar channels for a solid "spring-loaded" electrical connection.

MATERIAL: Extruded Aluminum 6005-T5 unpainted
RATINGS: 100% Ground Path 225 Amp, 600 Volt
LENGTH: 5 Ft, 10 Ft, 20 Ft.
INSULATION: PVC
VOLTAGE DROP: distributed load

225 Amp
HOUSING SECTIONS

Housing sections are joined by inserting male end into open female end so that stabs are parallel to female slots. Installation tool is then rotated to force stabs into slots.
NEW BUSWAY IS RATED AT 400Amps AT 600V DC
DC RATED BUSWAY PLUG FOR HVDC POWER DROP
600VDC RATED BREAKER FOR POWER DROPS

**S3**

150/225A
Standard thermal-magnetic

---

**General**

The S3 breaker family ranges from 15 through 225 amperes. The S3 trip mechanisms are non-interchangeable and are controlled by an electromagnetic range for universal breaker protection. Most series breakers are used for thermal Overcurrent protection. S3 circuit breakers extend the range of the breaker and classifies magnetic actuation. Varies by

**Variants**

To meet all application needs, the S3 is available in various versions:

- **T** = Thermal-magnetic
- **M** = Magnetic only
- **C** = Combination (T + M) only

**Performance level**

Each variant is also available in different main and managing classes:

- **G** = 240VAC
- **H** = 480VAC

**Number of poles**

In the UL/CSA form, the S3 is available in two, three or four pole versions, both with the same characteristics. Each pole size can also be available in UL/CSA forms for the European market. For UL/CSA forms, all poles of standard and higher pole breakers contact ABB Control for details.

**Accessories mounting**

- They should be mounted on wall or pole

**Reversing**

All versions of the S3 family are suitable for reverse two applications

**Molded case switches**

UL/CSA molded case switches are not recommended for reverse two applications

---

**UL/CSA Interrupting capacity (kA RMS)**

<table>
<thead>
<tr>
<th>Voltage</th>
<th>N</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>208VAC</td>
<td>60</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>480VAC</td>
<td>60</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>600VAC</td>
<td>45</td>
<td>60</td>
<td>100</td>
</tr>
</tbody>
</table>

**IEC-947 Interrupting capacity (kA RMS)**

<table>
<thead>
<tr>
<th>Voltage</th>
<th>N</th>
<th>M</th>
<th>L</th>
</tr>
</thead>
<tbody>
<tr>
<td>230VAC</td>
<td>60</td>
<td>70</td>
<td>100</td>
</tr>
<tr>
<td>480VAC</td>
<td>60</td>
<td>85</td>
<td>100</td>
</tr>
<tr>
<td>600VAC</td>
<td>45</td>
<td>60</td>
<td>100</td>
</tr>
</tbody>
</table>

---

**Diagram C:** Breaking with 3 poles in series per polarity

---

**CONNECTION DIAGRAM FOR 600VDC BREAKER APPLICATIONS**

---

**DIRECT POWER TECHNOLOGIES, INC.**

Providing Efficient Reliability
OTHER DC RATED BREAKERS

A complete DC offer from 16 to 4000 A

500 Vdc Rated
UL Listed
Class 600

The UL Listed thermal-magnetic molded case circuit breakers shown below are specifically designed for use on systems having a maximum short-circuit voltage of 550 Vdc or a maximum operating voltage of 400 Vdc. The circuit breakers are suitable for use only in UPS (uninterruptible power supplies) and unregulated systems.

This two-level rating allows these circuit breakers to be applied to battery systems having a short-circuit capability of 25,000 amperes for I, II, IL, and IIIF circuit breakers and 25,000 amperes for IIIIF circuit breakers at 600 Vdc.

The UL listed 500 Vdc circuit breakers are provided with an adjustable magnetic trip that is easily adjusted by means of a single adjustment on the rear of the circuit breaker. The circuit breakers have a fixed magnetic trip range.

These circuit breakers are UL listed for the interrupting ratings shown only if applied with these protective circuit breakers (part numbers are noted in the notes). See chapter for notes. Due to external series connection, 450° C circuit breakers are not available for this application.

<table>
<thead>
<tr>
<th>Circuit Breaker Code</th>
<th>Adjustable Magnetic Trip Range</th>
<th>DC Ampere</th>
<th>Interrupting Rating</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>P001</td>
<td>10 A</td>
<td>0</td>
<td>25,000 A</td>
<td>$X</td>
</tr>
<tr>
<td>P002</td>
<td>20 A</td>
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<td>$X</td>
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<tr>
<td>P003</td>
<td>30 A</td>
<td>0</td>
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<td>$X</td>
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<td>P004</td>
<td>40 A</td>
<td>0</td>
<td>25,000 A</td>
<td>$X</td>
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<tr>
<td>P005</td>
<td>50 A</td>
<td>0</td>
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<tr>
<td>P006</td>
<td>60 A</td>
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<td>25,000 A</td>
<td>$X</td>
</tr>
<tr>
<td>P007</td>
<td>70 A</td>
<td>0</td>
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<tr>
<td>P008</td>
<td>80 A</td>
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<td>P009</td>
<td>90 A</td>
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<tr>
<td>P010</td>
<td>100 A</td>
<td>0</td>
<td>25,000 A</td>
<td>$X</td>
</tr>
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<td>P011</td>
<td>150 A</td>
<td>0</td>
<td>25,000 A</td>
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<td>P012</td>
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<td>0</td>
<td>25,000 A</td>
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<td>450 A</td>
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</tr>
<tr>
<td>P028</td>
<td>1000 A</td>
<td>0</td>
<td>25,000 A</td>
<td>$X</td>
</tr>
</tbody>
</table>

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
SYSTEM MONITORING/METERING

DRANETZ-BMI Encore Series

Product Summary -

- Revolutionary, next generation product family from Dranetz-BMI for the permanently (and semi-permanent) installed market
- Encore Series Model 61000
  - All new instrument design that builds upon the strengths of:
    - Signature System
      - Strong Power Quality capabilities
      - Web browser based interface
    - 4400/ PX5
      - Power Quality compliance capabilities
      - Visualization – Bright, colorful, easy to use local user interface
    - Measuring Pad
      - Physical measurements
Encore Series
Possible Configurations

Utility Substation Distribution Analyzer
*Three instruments in one*

Multiple voltage bus/circuit monitoring
*Four instruments in one*

Key
- **V₄**: 4 Channel Voltage Module
- **I₄**: 4 Channel Current Module
- **T₄**: 4 Channel Analog Input Module
- **D**: Digital Input or Output Module

Encore Series

Direct Power Technologies, Inc.
Providing Efficient Reliability
Encore Series

Sample Rear Panel
(actual instrument depends on your configuration)

- Voltage Module Safety Connectors
- Current Module TR Connectors
- Voltage Module Screw Terminals
- Voltage/Current Inputs
- Voltage Module Pod interface
- Communication
- Power Supply Output For GSM
- Power Supply Output for Flex CT's
- Power Switch
- RS232, RS485
- GPS Antenna
- Encore Series Power Supply
- Output for Flex CT's
- USB
- Ethernet
- 12VDC Instrument Power Supply

DIRECT POWER TECHNOLOGIES, INC.
Providing Efficient Reliability
DC-UPS

- Allows you to field more blade servers per sq. foot using existing air conditioning
- System provides higher overall power efficiencies with a lower component count
- Designed for IT management – can be installed on existing raised floor and expanded by data center staff as new blade servers are added
- Provides a battery-less UPS feature and saves valuable raises floor space