Direct Current power and cooling solutions for the next generation data center
Validus DC, A Member of the ABB Group
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.

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.
The History of AC vs. DC

- 1752 By tying a key onto a kite string during a storm, Ben Franklin, proved that static electricity and lightning were the same. His correct understanding of the nature of electricity paved the way for the future.
- 1800 First electric battery invented by Alessandro Volta. The “volt” is named in his honor.
- 1808 Humphry Davy invented the first effective “arc lamp.” The arc lamp was a piece of carbon that glowed when attached to a battery by wires.
- 1821 The first electric motor was invented by Michael Faraday.
- 1826 Georg Ohm defined the relationship between power, voltage, current and resistance in “Ohms Law.”
- Thomas Edison founded the Edison Electric Light Co. (US), in New York City. He bought a number of patents related to electric lighting and began experiments to develop a practical, long-lasting light bulb.
- 1879 After many experiments, Thomas Edison invented an incandescent light bulb that could be used for about 40 hours without burning out. By 1880 his bulbs could be used for 1200 hours.
- 1882 Thomas Edison opened the Pearl Street Power Station in New York City. The Pearl Street Station was one of the world’s first central electric power plants and could power 5,000 lights. The Pearl Street Station was a direct current (DC) power system, unlike the power systems that we use today which use alternating current (AC).
- 1883 Nikola Tesla invented the “Tesla coil”, a transformer that changes electricity from low voltage to high voltage making it easier to transport over long distances. The transformer was an important part of Tesla’s alternating current (AC) system, still used to deliver electricity today.
- 1884 Nikola Tesla invented the electric alternator, an electric generator that produces alternating current (AC). Until this time electricity had been generated using direct current (DC) from batteries.
- 1888 Nikola Tesla demonstrated the first “polyphase” alternating current (AC) electrical system. His AC system including everything needed for electricity production and use: generator, transformers, transmission system, motor (used in appliances) and lights. George Westinghouse, the head of Westinghouse Electric Company, bought the patent rights to the AC system.
  1893 The Westinghouse Electric Company used an alternating current (AC) system to light the Chicago World’s Fair.
- 1958, two young engineers, Ed Pagano and Al Prinz (Ed-Al), pioneered rectifier technology and today offers the broadest range of diodes, bridges, high voltage devices, and power semiconductors of any manufacturer.
- 1990’s First non-telecom DC data center trial.
- 2012 First full scale North American Direct Current data center.
Direct Current: Already a part of our lives

High Voltage Continental and Intercontinental Transmission

Commercial Data Centers

Every Day Devices

Cell Phones  LEDs  All Servers  Heart Defibrillator  Batteries
Zurich, Switzerland, May 12, 2011 – ABB, the global power and automation technology group, has purchased a controlling interest in US-based Validus DC Systems, a leading provider of direct current (DC) power infrastructure equipment for energy-intensive data centers.

ABB and io to Deliver World's Direct Current-Powered Data Center Module
Zurich, Switzerland, Nov. 2, 2011
New module is 10 – 20% more energy efficient than traditional alternating current technology

UEC INTRODUCES DIRECT CURRENT (DC) SOLUTIONS TO PROVIDE DATA CENTERS MORE ENERGY SAVINGS AND RELIABILITY.
CANONSBURG, Pa., April 7, 2011 /PRNewswire/ -- STARLINE DC Solutions is a 380 VDC Computer Infrastructure that yields 200% increase in reliability, energy savings up to 15%, capital expenditures reduction up to 16%, floor space reduction up to 33%, and operating expense decrease up to 35% as compared to conventional AC powering solutions.

ABB to Supply Innovative DC Power Distribution System to Green Data Center
A new direct current (DC) solution in Switzerland will provide maximum energy efficiency and minimum environmental impact for the green.ch data center facility.
Zurich, Switzerland, July 13, 2011
Validus Equips IBM/Syracuse With DC Power
June 30, 2009
Validus DC Systems has been selected by Syracuse University to deliver the direct current (DC) power infrastructure in a new data center designed to be among the world’s most energy-efficient facilities.

As ICT services continue to grow in popularity, the power consumption of ICT equipment continues to rise. This rise in power consumption is linked, in turn, to increased operational costs and environmental damage due to CO₂ emission. The developed high-voltage DC power-supply system supplies electricity (at DC 380V) to ICT equipment housed in data centers. Implementing this system makes it possible to construct an “Earth Friendly” power-supply system that is more efficient, more reliable and more economical than conventional AC power supplies.

SAP Data Center to Go DC to Save Big Bucks

The Next Big Thing for Data Centers: DC power
By Michael Kanellos   Jan. 13, 2012, 8:55am PT

The Time Has Come for 380 VDC
By Dennis Cronin   February 07, 2012
Comparative Power Systems

AC Architecture

1. MV ac
2. 480Vac
3. 480Vac
4. 480Vac
5. 208Vac

Utility
MV/LV transformers
Switchgear
UPS
PDU
IT Power supply
Servers

DC Architecture

1. 34kVac
2. 380Vdc

Utility
MV/LV Transformer
DC Rectifier
IT Power supply
Servers

- Less Costly to Install
- Greater Reliability
- Higher Efficiency
- Less Space Required
- Decreased Maintenance Cost
Global DC Data Center Power Systems

- US Intel Corp 380VDC
- US Syracuse University 380VDC
- US Facebook AC-DC
- US UCSD 380VDC
- US I/O 380VDC
- US Duke University 380VDC
- US Steel Orca 380VDC
- US Validus 380VDC
- French Telecom 380VDC
- Sweden Netpower 350/380VDC
- Switzerland Gr.ch 380VDC
- China Telecom 240/380VDC
- China Mobile 380VDC
- Korea 380VDC
- Japan NTT Group 380VDC
- Japan Other Demos 380VDC
- Taiwan IT 380VDC
- New Zealand Telecom NZ 220VDC
Why all the interest in DC as an alternate path?

- IT equipment is ultimately powered by DC
- Opportunity to improve efficiency
- Desire to “green” facilities
- Opportunity to enhance reliability
- Need to integrate renewable/alternative energy sources
- Need to support higher load densities
- Desire to reduce total cost of ownership (TCO)
- Creation of micro-grid systems
- Gives tech bloggers something to do
All Hardware Servers in Data Centers Run Direct Current 7x24x365

- Blade & 1 U Servers
- Large Scale SMP Servers
- Mainframes
- Database Servers
- Network Switches

DC Servers utilize the same power supply but without the AC/DC input rectification stage!!

Server Power Supply

120vAC 240vAC
Input Voltage

-380vDC
Chopper Phase

400vAC
High Isolation Phase

-12vDC
Chopper Phase

Server
Input voltage agnostic
**AC vs. DC Power System**

*All Hardware Servers in Data Centers Run Direct Current 7x24x365*

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- Large Scale SMP Servers
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DC Servers utilize the same power supply but without the AC/DC input rectification stage!!

**Server Power Supply**

- Input voltage agnostic

- Chopper Phase
  - -380vDC
  - 400vAC
  - High Isolation Phase
  - -12vDC

- CPU
- Point of Load
- Memory, Fans, etc.

*Server*
Evolution of the Server Power Supply

- Architecture that (accepts 380 VDC)
- Rectification stage taken out - not required
- Safe +190VAC
- Less heat less fans
- Reduced cost
- Increased reliability
Early Generation 2N DC System for Power, 2.5MW
Today’s 2N DC System for Power, 2.5MW

Typical N+1 Direct Current System Arrangement

- MV or LV AC Input
- Battery Plant N+1
- DC DS
- Modular Active Rectifiers
- Optional 2N Battery Inputs
- DC Link
- Modular DC-DC Converters
- Optional Tie Breaker NO
- +/- 190 VDC Output
- DC Feeder 1,200 to 5,000 Amps

Typical DC RPP Feeder

380 VDC Rack Mount Power Strips in Server Cabinets

Typical DC Server Cabinets

© 2012 Valibux DC Systems, LLC
Integrated 2.5MW DC Power Systems

Simple - Reliable - Fast - Modular - Scalable

- Easily integrate renewables (photovoltaic, fuel cells, wind), storage (batteries) and DC consumers (consumer electronics, electric car fast charger, motors and drives, etc.) = DC micro grid
- No synchronization required to connect multiple sources

- +/-190 VDC
- Phase and frequency agnostic
- Simplified wiring
- Only resistive voltage drop in wires
- No reactive power flow
- No harmonic distortion
Direct Current Distribution

380V direct current
+/- 190 VDC to ground to address safety concerns of DC

Breakers with electronic trip units in DC, listed for DC Breaker AIC ratings in DC an issue with non-isolated systems

Very low arc flash levels with isolated DC-DC converters
May have an issue with Non-isolated battery systems

DC RPPS available (Remote Power Panel)
- (ABB, Thomas and Betts, PDI, Starline,)

DC Busway
- (ABB, PDI, Starline, GE)
DC Power safety

Separating Fact from Fiction

- 30 volts is the threshold value for dangerous voltage. AC or DC above 30 volts can be potentially dangerous. Electric currents above 30 volts can cause dangerous involuntary muscle action.
- Low-frequency (50- to 60-Hz) AC used in households is 3 to 5 times more dangerous than DC of the same voltage and amperage. Low-frequency AC produces extended muscle contraction (tetany), which may freeze the hand to the current's source, prolonging exposure. DC is most likely to cause a single convulsive contraction, which often forces the victim away from the current's source.
- AC can throw the heart into fibrillation, whereas DC tends to just make the heart stand still. Once the current is removed a still heart has a better chance of regaining a normal beat than a fibrillating heart. This is why "defibrillating" equipment used by emergency medics is DC.

Some “shocking potential” equivalents:
## Wire Size Matters

### Wire size comparison

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>Load (KW)</th>
<th>Load (KVA)</th>
<th>Maximum Current</th>
<th>Min OCPD Rating (I Max * 1.25)</th>
<th>Recommended OCPD rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>53.7 VDC</td>
<td>8</td>
<td>148.98</td>
<td></td>
<td>186.22</td>
<td>200 Amp</td>
</tr>
<tr>
<td>120 VAC</td>
<td>8</td>
<td>74.08</td>
<td></td>
<td>92.60</td>
<td>100 Amp</td>
</tr>
<tr>
<td>208 VAC, 1ø, 2 W</td>
<td>8</td>
<td>42.74</td>
<td></td>
<td>53.43</td>
<td>60 Amp</td>
</tr>
<tr>
<td>230 VAC, 1ø, 2 W</td>
<td>8</td>
<td>38.65</td>
<td></td>
<td>48.32</td>
<td>50 Amp</td>
</tr>
<tr>
<td>240 VDC</td>
<td>8</td>
<td>33.33</td>
<td></td>
<td>41.67</td>
<td>50 Amp</td>
</tr>
<tr>
<td>277 VAC</td>
<td>8</td>
<td>32.09</td>
<td></td>
<td>40.12</td>
<td>50 Amp</td>
</tr>
<tr>
<td>380 VDC</td>
<td>8</td>
<td>21.05</td>
<td></td>
<td>26.32</td>
<td>30 Amp</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System Voltage</th>
<th>Load (KW)</th>
<th>Load (KVA)</th>
<th>Maximum Current</th>
<th>Min OCPD Rating (I Max * 1.25)</th>
<th>Recommended OCPD rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>53.7 VDC</td>
<td>250</td>
<td>4655.49</td>
<td></td>
<td>5819.37</td>
<td>5900 Amp</td>
</tr>
<tr>
<td>120 VAC</td>
<td>250</td>
<td>277.78</td>
<td></td>
<td>2083.33</td>
<td>2700 Amp</td>
</tr>
<tr>
<td>208 VAC, 1ø, 2 W</td>
<td>250</td>
<td>1201.92</td>
<td></td>
<td>1502.40</td>
<td>1600 Amp</td>
</tr>
<tr>
<td>230 VAC, 1ø, 2 W</td>
<td>250</td>
<td>1086.96</td>
<td></td>
<td>1358.70</td>
<td>1400 Amp</td>
</tr>
<tr>
<td>240 VDC</td>
<td>250</td>
<td>1041.67</td>
<td></td>
<td>1302.08</td>
<td>1400 Amp</td>
</tr>
<tr>
<td>277 VAC</td>
<td>250</td>
<td>902.53</td>
<td></td>
<td>1128.16</td>
<td>1200 Amp</td>
</tr>
<tr>
<td>380 VDC</td>
<td>250</td>
<td>657.89</td>
<td></td>
<td>822.37</td>
<td>900 Amp</td>
</tr>
<tr>
<td>277/480VAC</td>
<td>250</td>
<td>334</td>
<td></td>
<td>417</td>
<td>450 Amps</td>
</tr>
</tbody>
</table>

Relative copper wire size
380V DC Saves!

Based on Table 310.16
# Distances for 5% Voltage Drop

<table>
<thead>
<tr>
<th>Conductor size</th>
<th>Load in amps</th>
<th>Distance in Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>20</td>
<td>250</td>
</tr>
<tr>
<td>10</td>
<td>30</td>
<td>270</td>
</tr>
<tr>
<td>8</td>
<td>40</td>
<td>320</td>
</tr>
<tr>
<td>6</td>
<td>55</td>
<td>370</td>
</tr>
<tr>
<td>4</td>
<td>70</td>
<td>460</td>
</tr>
<tr>
<td>2</td>
<td>95</td>
<td>540</td>
</tr>
<tr>
<td>1</td>
<td>130</td>
<td>470</td>
</tr>
<tr>
<td>0</td>
<td>150</td>
<td>520</td>
</tr>
<tr>
<td>00</td>
<td>175</td>
<td>560</td>
</tr>
<tr>
<td>000</td>
<td>200</td>
<td>620</td>
</tr>
<tr>
<td>0000</td>
<td>230</td>
<td>680</td>
</tr>
<tr>
<td>250KCM</td>
<td>255</td>
<td>720</td>
</tr>
<tr>
<td>350KCM</td>
<td>310</td>
<td>840</td>
</tr>
<tr>
<td>500KCM</td>
<td>380</td>
<td>960</td>
</tr>
<tr>
<td>14X500KCM</td>
<td>5000</td>
<td>1040</td>
</tr>
</tbody>
</table>

Assumptions based upon Copper conductors, 75c, steel conduit

Validus or ABB assume NO responsibility for calculations and the numbers. The numbers and wired sizes are subject to standard electrical practices and REQUIRE an engineering calculation performed for your specific application.
Data Center Power Utilization Projections

(Actuals through 2010, data based on PUE of 2.0)

Figure 3. Projection of total Electricity used by data centers used by the US and the World based on Koomey’s and EPA’s data.
DC will Power the Green Data Center

*30% of new data centers will have DC distribution, based upon OEM and cloud adoption of new center in 2015

Chart 1.1 Green Data Center Revenue by Region, World Markets: 2009-2015

(Sources: Pike Research)

- Pike Research
Annual Data Center Construction Spending
(actuals through 2010, data based on highly efficient Hyperscale Cloud Data Center)

Year-over-year data center construction market size
Direct Current Value Proposition In the Data Center

Measurement of end-to-end electrical and mechanical savings.

10% Less Space Savings:
Reduced component count requires less space for both the power room and IT floor.

10% Less Maintenance Savings:
Reduce component count means less annual maintenance costs.

30% Less Increased reliability:
2 x lower probability of failure as compared to a equivalent tier IV facility

Total Installation savings including Power Equipment Costs: Comparable system configurations. >30% Less
AC vs DC Cost Comparison 2N Installed

DC average is 29% less expensive than AC Power Equipment and Installation

*Study Conducted in the USA by independent third party
Raising Power System Efficiencies.

- Reduced component count
- Cost Savings through less inversions and rectifications
- Less cooling requirements
- Space savings
  - equipment
  - denser racks
- ROI model
  [http://www.validusdc.com/Executive_ROI.html](http://www.validusdc.com/Executive_ROI.html)
Reliability Assessment of AP Data Center

A prime factor for selecting the direct current topology is the increase in overall system reliability. As there are many fewer components to fail within a direct current environment, along with the reduced heat and elimination of sine wave (control wires, etc), the improvement is substantial. According to Calculations by EYP Mission Critical Facilities, a direct current system is 200% less likely to fail within a five year period:

Results & Comparisons: Reliability

**Reliability Analysis**

- Calculations by EYP Mission Critical Facilities

<table>
<thead>
<tr>
<th>Option</th>
<th>Availability</th>
<th>Unavailability</th>
<th>Probability of failure in 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AC Tier IV configuration</td>
<td>0.999996</td>
<td>3.9 e -06</td>
<td>13.63%</td>
</tr>
<tr>
<td>DC configuration**</td>
<td>0.999998</td>
<td>2.4 e -06</td>
<td>6.72%</td>
</tr>
<tr>
<td>DC Improvement</td>
<td></td>
<td>62.5%</td>
<td>200%</td>
</tr>
</tbody>
</table>

**2X lower probability of failure compared to equivalent Tier IV AC facility**
Reliability Field Data of Power Systems

![Graph showing unavailability of AC UPS and DC power supply from 1995 to 2005.](image)

- **AC UPS**
  - Unavailability: $10^{-6}$ to $10^{-7}$

- **DC power supply**
  - Unavailability: $10^{-10}$
  - Consistently reliable with no failures reported.

**NTT Facilities** (Field data for 10,000 UPSs and 23,000 DC systems)
What increases Reliability in DC?

Differentiators with Direct Current

- Fewer components
- Redundancy via multiple rectifier/converter arrays
- No static switches (internal or system level)
- UPS paralleling board not required
- Load bus synchronization not required
- Complex system controls mitigated
- No reflected THD on input (filters not required)
- Less heat generated
- Fewer battery strings and related components
- No reactive power elements after AC input to system
- Upstream AC sources do not need to be synchronized
DC 380 VDC Power Supplies

Power supply unit (PSU)

380 Vdc  100-240 Vac  Same output for servers (same dimensions)
# DC power supply data

<table>
<thead>
<tr>
<th>No.</th>
<th>Item</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Input voltage</td>
<td>270VDC~430VDC</td>
</tr>
<tr>
<td>2</td>
<td>Input current</td>
<td>2.67A@200VDC</td>
</tr>
<tr>
<td>3</td>
<td>Output</td>
<td>12V/54A, 5VSB/3A</td>
</tr>
<tr>
<td>4</td>
<td>Hold-up time</td>
<td>&gt; 10mS</td>
</tr>
<tr>
<td>5</td>
<td>Interface</td>
<td>PMBUS</td>
</tr>
<tr>
<td>6</td>
<td>Form Factor</td>
<td>40.2 x 54.5 x 322mm</td>
</tr>
</tbody>
</table>

- **Wide range:** 270vDC – 430vDC
- **Narrow range:** 350vDC – 430vDC

<table>
<thead>
<tr>
<th>Load</th>
<th>20%</th>
<th>50%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>208v AC</td>
<td>85</td>
<td>93.2</td>
<td>93.7</td>
<td>93.6</td>
</tr>
<tr>
<td>400v DC (wide range)</td>
<td>85.5</td>
<td>94.1</td>
<td>94.8</td>
<td>94.5</td>
</tr>
<tr>
<td>400v DC (narrow range)</td>
<td>89.8</td>
<td>95.6</td>
<td>96.2</td>
<td>94.9</td>
</tr>
</tbody>
</table>
Emerge Alliance

Mission Statement

An open industry association developing standards leading to the rapid adoption of DC power distribution in commercial buildings.

• These innovative standards integrate interior infrastructures, power, controls and devices in a common microgrid platform to facilitate the hybrid use of AC and DC power throughout buildings for unprecedented design and space flexibility, greater energy efficiency and improved sustainability.

• The Alliance will simplify and accelerate market adoption of EMerge Alliance standards. The Alliance will ensure that its standards deliver:
  • Required solutions based on market requirements and ecosystem approval
  • Buyer assurance with products base-lined to the standards
  • Increased supply choices in the value chain that spans the needs of different commercial interiors

The Right Choice for Data Centers is Direct Current

Thank you for participating

For white papers please visit www.validusdc.com
Facebook: www.facebook.com/validusdcsystems

Larry J Hess
Director of Sales and Marketing – The Americas
lhess@validusdc.com
646.688.2749

Scan the QR Code to find out more about Validus DC Systems, a member of the ABB Group

Thank you for participating