PHASING OUT ALTERNATING CURRENT DIRECTLY

AN ENGINEERING REVIEW OF DC POWER FOR DATA CENTERS

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STARLINE DC SOLUTIONS

SUMMARY

This is the first in a series of white papers defining and describing the benefits of 380V DC for the modern Data Center. The focus of this paper are the issues and ideas that make DC power the preferred power topology for modern data centers. We believe the financial and technical benefits are simply too compelling to think and act otherwise.

The technology focus for data center power is shifting from AC power conversion toward the perspective of the load's requirement for DC Power and away from a focus on converting AC Power to something usable. However, converting to Data Center DC Power Systems is only the beginning. This is not AC versus DC; not analog versus digital; not Westinghouse versus Edison. This is the utilization of the inherent qualities of DC power – reliability, lower cost & expense, dramatic real estate reduction, and effective green power integration – to make a compelling case for a DC solution. DC power plus, increased efficiency is important and DC does provide in all cases an improvement.

380V DC Power Systems is the global format of choice. While we want to say Edison's selection of DC was correct we need to recognize that the world has evolved and the demarcation line between AC and DC is shifting. The DC load is no longer simply the chip. The DC load now represents 85% of the building enabled by power electronics and clearly justifies the intrinsic business value of DC.

Understandably those who manufacture alternating current solutions are defensive about changing. This has led to the generation of misinformation which has added to a general misunderstanding of the facts about direct current. Leading universities, government agencies and IT leaders familiar with the facts are moving quickly to help dispel the misrepresentation of the facts. This paper will briefly address why higher voltage DC (380V DC) is not only as safe as its AC equivalence but arguably offers a solution which offers greater reliability in less space with a reduced total cost of ownership.
Just as important is that it is available NOW!

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THE DIRECT CURRENT (DC) POWER SHIFT

This paper focuses on the multiple issues and ideas that make DC power the preferred power topology for data centers because the financial and technical benefits are simply too compelling to think and act otherwise.

While our hearts tell us "Edison was right", today's available technology brings us the reversed force of 100 years ago and demonstrates that DC Power now embodies the future holistic business value.

Discussions of DC and AC power systems take our technical emotions back to the "Current Wars" fought between Westinghouse and Edison at the dawn of the electrical age. AC Power prevailed due to the technology available at the time. However, today's technology is driving us back to DC power systems. As engineers we have heard repeatedly that "Digital loads should be supported by digital power". Digital power is DC. And, unlike in Edison's day, the AC power source is a support characteristic not the focus. While our hearts tell us "Edison was right", today's available technology brings us the reversed force of 100 years ago and demonstrates that DC Power now embodies the future holistic business value.

The Case for Edison – The Dawn of the 21st Century

- **The Era of Electronics:** Increasingly, equipment operates on DC, requiring conversion from AC sources
- **Ease of Integration:** Distributed generation systems produce DC power **Ease of Integration:** Storage devices such as batteries, flywheels and capacitors store and deliver DC power
- **Electronics in Transportation:** DC power could help power hybrid automobiles, transit buses, and commercial fleets (and vice versa)
- **The Era of Information Technology:** DC power delivery could potentially enhance energy efficiency in data centers, a pressing need
- **Removing the Transformation Bottleneck:** Improved inverters and power electronics allow DC power to be converted easily and efficiently to AC power and to different voltage levels.
- **Standardization of DC Voltage:** The evolution of central power architecture in computers and other equipment simplifies DC power delivery systems

Consider these facts. Total data center energy consumption by itself is growing at a rate of 12% per year. If the internet was rated as a country, its total energy consumption would be 5th in the world. In 2008, 50% of data centers had insufficient power and cooling. Now add the remainder of the building to the data center impact and more than just efficiency is demanding designs based on the DC load and not the source of the power. Before looking at DC Power from the load perspective revisit "The Case for Edison".

A fundamental reason for the shift to DC Power is the data center and will be the focus of the remainder of this paper. Central to the shift are these four immutable parameters:

1. **The data center's ability to adapt to current & future power generation systems** (Solar, Wind, Fuel Cells, etc.) is here now in the form of reliable 380V DC.
2. **The digital age demands that support systems such as power are focused on the chip systems that drive data center revenue.** The managers, users, designers, and those financially responsible for data centers desire to put their attention on the data center and require power support systems to be adaptable to new & evolving power generation techniques without affecting data center operations.
3. **Now considered large power consumers, data centers are focusing more on operations.** This requires power support systems that include flexible modularity, higher efficiency, more cost effective reliability and a smaller footprint, while enjoying the security of global safety listings.
4. **All necessary technology to reap the benefits of DC Power is available now.**

TECHNOLOGY AND BUSINESS ADVANTAGES

Chip2Grid™ is the first data center power technology developed from the perspective of the load (the chip) instead of the source (the grid) yielding to data center operators and managers significant benefits not previously available.

Chip2Grid™ Technology

An IT Power Engineer would readily and intuitively design, adapt, and optimize power from the perspective of the chip toward the power grid and yet tradition has been just the opposite. The unique concept of *Chip2Grid™* technology captures the power design from the chip perspective. Looking back from the chip, the internal power supply distribution for computers is at 380V DC, therefore all IT power supplies can easily migrate to this solution. In the 380V DC architecture the grid is an AC source, and therefore the alternating current must be changed to DC only once (half a typical UPS system). In the typical AC solution the current is converted multiple times in the legacy UPS and data center power system architectures. More to the point, if the power grid is already DC, there is no need to change it back & forth. An example would be to power a computer directly from solar. The power supply for the server does not have to change AC to DC, and it always sees 380V DC. Power supply providers who manufacture over 70% of servers globally embrace this technology. *Chip2Grid™* makes it happen.

Too much focus on efficiency gains is a hard concept to digest. Chip2Grid™ employs a unique concept to arrive at the best available efficiency while focusing on the critical issues of reliability, scalability, and financial security of the data center.

Chip2Grid™ Perspective

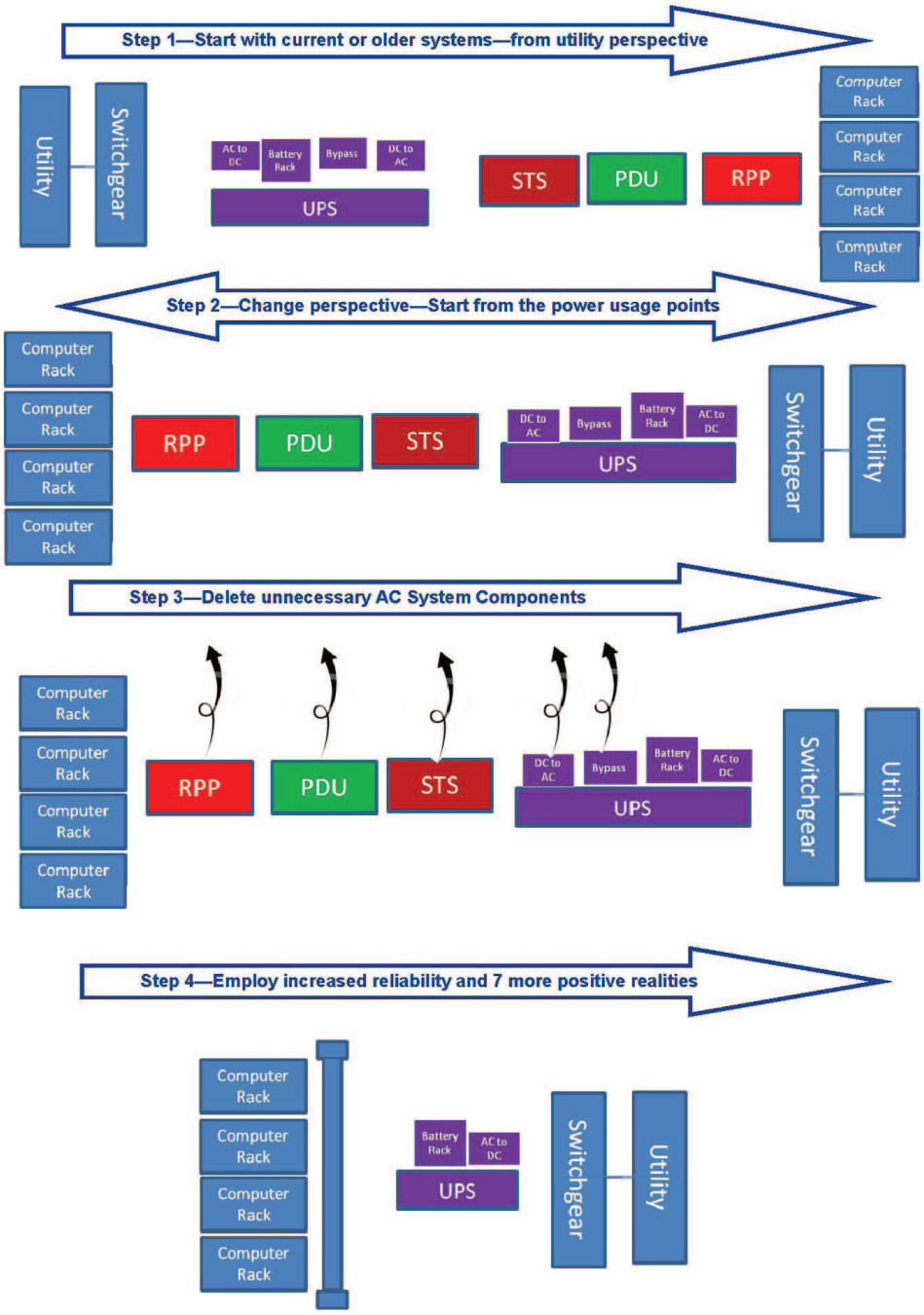
Today's AC industry focuses too much attention on the efficiency gains, (or lack there-of), when transitioning to a DC infrastructure topology. This paper focuses on the multiple engineering issues and ideas that will make DC power the power topology of the future because the future benefits will be shown to be too compelling to think otherwise.

This paper includes a *Chip2Grid™* journey in three distinct areas:

1. How to invest more in your business systems.
2. The positive and upscale realities of components used and available now in 380V DC.
3. DC Power Topology of the 380V DC infrastructures. Key issues addressed include: power supply details, connectors, wire and cords, power distribution units(PDUs), branch circuit protection, metering, busway, distribution level circuit protection and control, grounding, load balancing, equipment space, reliability, short circuit and arc flash protection, voltage drop, DC motors and control, and cross industry collaboration.

Too much focus on efficiency gains is a hard concept to digest. Chip2Grid™ employs a unique concept to arrive at the best available efficiency while focusing on the critical issues of reliability, scalability, and financial security of the data center.

Four Steps To The *Chip2Grid*™ Conversion



INVEST MORE IN TO BUSINESS SYSTEMS

For data center designers, *Chip2Grid*™ provides a consistent methodology allowing them to invest more in their business systems and not the power support systems. Every data center stakeholder, from the operations staff to the Chief Financial Officer, will benefit from the *Chip2Grid*™ contribution to data center operations and the improved bottom-line it yields. If you are a stakeholder consider these positive impacts:

If you operate a data center on a fixed budget Chip2Grid™ technology enables you to transfer funds directly into your business systems and at the same time improve your power support system.

Impact The Data Center In These Positive Ways

Effect on Data Center	*Chip2Grid™*	Benefit
Data Center Reliability	Higher Reliability	200 to 1000% increase in reliability due to fewer points of failure
Funds Reduction #1	Lower capital cost	Capital costs of electrical facility reduced by 15% or more.
Funds Reduction #2	Lower O&M	On average the operation and maintenance costs will be 33% less than AC data center power systems.
Funds Reduction #3	Smaller Footprint	With a 33% space savings in the electrical infrastructure, a whole variety of savings are received maybe even including the avoidance of physical building expansion.
Convert Now	Easier Data Center Conversions	When changing to a new and innovative technology usually a "rip & replace" approach is needed. With *Chip2Grid™* a "swap out" now and at your pace makes your decision making and planning easy.
Use Renewables	Easier Integration of Renewable Energy	Most renewables are DC to start. a. Wind, Solar b. Energy Storage c. Resilient Power – Fuel Cell
Efficiency #1	Higher Efficiency System	Start with an inherent energy savings and work for more.
Efficiency #2	Lower Heat Load	Overall heat load of this technology is less.

POSITIVE REALITIES OF COMPONENTS

Components involved and aspects of electrical design engineering with *Chip2Grid*™ technology illustrate some of the positive realities of this approach.

While system performance is critical to the up-front decision the smart selection of components impact your everyday interface with the unit. Safety, component availability, and harmonics are just a few of the considerations.

IT power supplies	Accept 380V DC input and uses what has been shown to be an optimal voltage level. The bus can be center grounded (+/- 190V DC) to further reduce hazards.
Universal 380V DC	For existing power supplies not currently at 380V DC all that is required is an off-the-shelf receptacle and elimination of AC power components.
Safety connectors to the servers	Breaking arc is fully extinguished before opening the connector and passes UL jointed test finger proof tests.
Power Distribution System	380V DC allows for more power delivery than AC using the same amount of copper.
Rack mount PDU's	Modularity not previously available that allows easier design decisions.
380V DC UPS	No need to do an AC-DC conversion followed by a DC-AC conversion.
Load balancing	Not required for 380V DC, becoming a bigger issue for AC.
System overload, short circuit and arc flash protection	380V DC offers new opportunities for new circuit protection technologies with the potential of providing safer systems. As AC data center distribution moves to higher voltages (400vac, 415vac, 480vac) arc flash and circuit protection at the rack becomes a bigger issue.
Server fans	Can run off 380V DC and inherently provide a reduction in power consumption with simpler and more precise control.
Cooling systems	Cooling systems can also utilize 380V DC motors.
Harmonics	Harmonics can be treated at the DC source thus allowing for the elimination of filtering at the component level.
Traditional or Green Power Grid	Sources such as wind, solar, batteries are already DC and by removing the AC conversion there is improved efficiency and ROI.

Today both AC Power and DC Power are main stream technologies and infrastructures. In both cases the designer and user specify their application based on the load and not the source.

DC POWER TOPOLOGY

First Know Where We Came From & Why We Are Shifting To a New Topology

Until recently AC Power has been the predominant topology. Key factors show that transmission technology, power need by the load, centralization and government policy attracted users to AC Power. When the transistor was invented we did not realize we would make a steady march to DC micro-grids. Experts from the IT OEMs and government labs have already gathered, and asked and answered the following question:

Why did we move to an AC based centralized power system rather than stick with Edison era DC microgrids?

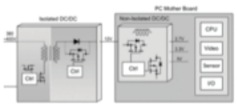
- **With the technology of the era,** AC transmission was the only means that allowed us to bring power from remote areas (such as large remote hydro resources) - DC could not easily be stepped up or down in voltage like AC.
- **AC was not only suitable for transmission** - but also more suitable for distribution with the technology of the era.
- **The AC induction motor** (invented by Tesla) was a big improvement over the commutated DC motor for many types of applications.
- **Large centralized plants had lower cost** per unit of energy produced (due to economies and efficiencies of scale). In addition, interconnecting all regions together on a large centralized grid improved reliability, cost and efficiency.
- **Government policies** of the era encouraged centralized generation at the expense of small scale generation and micro-grids.

Why Consider DC for Power Distribution Again?

- Loads are becoming more DC compatible.
- Better DC to DC Converters and Inverters are becoming available that will allow us to change DC voltage levels and regulate the system (overcoming a key drawback of DC).
- Use of DC may allow improved power quality and reliability features compared to an AC grid.
- Use of DC may allow low voltage microgrids to be more viable and there are some interface advantages for DC such as touch safe powering of the occupied space of commercial offices and homes.
- DC Power is needed for DC Loads.

DC POWER FOR DC LOADS – THE POWER SUPPLY STORY

No.	Item	Specification
1	Input voltage	200VDC~430VDC
2	Input current	3.77A@200VDC
3	Output	12V/54A,5VSB/3A
4	Hold-up time	More than 10mS
5	Interface	PMBUS



380V DC POWER SUPPLY & SPECIFICATIONS

More and more of our everyday power loads are inherently DC. In data centers that are especially true and data center load growth has resulted in an industry looking for different ways of doing things to increase efficiency and reliability. So, let us begin with the data center. The primary loads in the date center are the processor chip, data storage, communication interfaces and data transmission – all inherently DC power loads fed through an AC to DC power supply.

The story begins with the power supply:

Chip2Grid™ topology has many compelling features. The Appendix in this paper adds further detail. Keep in mind fewer parts and shorter paths are inherently better and more reliable.

Distributed DC power can be provided at a voltage already native to power supplies. We will investigate the details of how this is done. It is important to recognize that the legacy AC power environment has required that technology needed to be added to make the power supplies more reliable by mitigating the challenges created by the characteristics of alternating current. These are constraints and components dictated by the AC power system operational specifications we can offer a very stable, narrow range voltage (380V DC +/- 5%), this opens a range of possibilities including:

- Reduced or elimination of hold-up requirements
- No harmonic filtering required
- Many other opportunities as advanced materials are being developed in the semi-conductor industry today

Given this evolving reality, what are the engineering challenges that will allow for optimized power supply design? Intuitively the power supply design will improve.

Chip2Grid™ is the first data center power technology developed from the perspective of the load (the chip) instead of the source (the grid) yielding to data center operators and managers significant benefits not previously available.

THE 380V DC TOPOLOGY, A BRIEF REVIEW:

Codes & Standards: First, we are not talking about High Voltage DC! Two standards are expected by mid-year 2012. The recommended topology is a center tap ground that will limit voltage to ground to + 190V DC and – 190V DC. Of course other code and standards are actively in process. High voltage is referred to as1000V and above.

Short circuit, arc flash, load flow and circuit protection: DC power has distinctive characteristics that differ from AC power. As such there are multiple opportunities to do things differently such as circuit protection, system coordination and control, arc flash protection and load flow control. New and existing technologies can be applied to take advantage of these characteristics to make this DC topology more reliable, safer, and easier to monitor and maintain.

Harmonics – No harmony in the AC world: Harmonics can be addressed at the bulk conversion point from AC to DC power. This feature allows for the elimination of the burden for point-of-use treatment at each stage of power conversion that exists in today AC power system.

Load Balancing: Load balancing within an AC system where multiple single phase loads are used is critical and not easily achieved. The lack of complete load balancing within an AC system results in a built-in, ever changing de-rating effect that must be addressed.

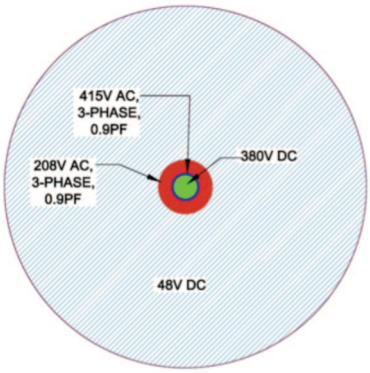
Voltage drop: If everything is equal DC has less voltage drop than AC. Less voltage drop is simply less energy waste. A detailed review of voltage drop will show this inherent benefit.

Chip2Grid™ topology has many compelling features. The Appendix in this paper adds further detail. Keep in mind fewer parts and shorter paths are inherently better and more reliable.

Chip2Grid™ is the first data center power technology developed from the perspective of the load (the chip) instead of the source (the grid) yielding to data center operators and managers significant benefits not previously available.

Connectors: Power connectors have been developed and some are UL listed for 380V DC use. Additionally there are new cords and connectors that insure the computer load is turned off prior to physical connections and disconnections.

Additionally there are new solid state technologies that will supplement connectors which will automatically open the DC circuit as connections are made and un-made.



Relative Copper Size based on 260KW

Wires and cords: DC wire and cable has a higher voltage rating and thus a higher power rating. AC power is rated as an RMS voltage and not a peak-peak voltage.

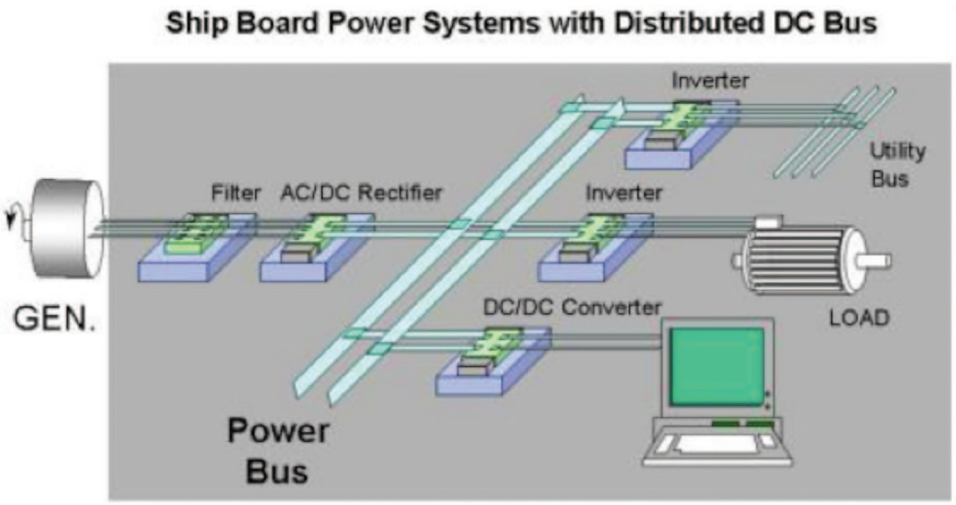
2 Wire (DC) has a distinct advantage over 3-Phase, 4-Wire (AC). In addition to cost & labor savings of 2 wires versus 4 wires per NEC requirements, adjustment/de-rating factors must be applied to conductors when four or more conductors are installed in a single raceway.

Metering/monitoring: Power quality metering for AC systems has become very costly when WAVE FORM CAPTURE and high speed measurements which are required to determine what has happened in a power quality event. The constant nature of DC voltage and current allow for simpler metering requirements along with the ability to decide more quickly when a problem occurs.

Busway distribution: DC is inherently a 2-wire system as proposed with a ground that is run separately or accommodated by a busway frame. As such, DC presents various options with system distribution configurations that AC power cannot compete.

Cross industry collaboration: Virginia Tech CPES developed a number of innovative power conversion technologies that are essential for the improvement of power conversion efficiency, higher power density, and more integrated solutions based on the modular building block concept. CPES research in this area includes power system architecture for distributed power systems, system interface stability and requirements, electromagnetic interference/electromagnetic compatibility at the systems level, filter design issues, single-phase power factor correction circuits, three-phase power factor correction circuits, high-frequency DC-DC PWM converters, as well as resonant converters, integrated single-phase PFC/DC-DC converters, and integrated three-phase PFC and DC-DC converters. Other topics include digital control and modeling and analysis, at the circuit level as well as the systems level.

Chip2Grid™ topology has many compelling features. The Appendix in this paper adds further detail. Keep in mind fewer parts and shorter paths are inherently better and more reliable.



Chip2Grid™ is the first data center power technology developed from the perspective of the load (the chip) instead of the source (the grid) yielding to data center operators and managers significant benefits not previously available.

Equipment size, space and cost: DC power is not a new idea, however, the way it can now be deployed and the innovation potential that exists will prove to be a positive factor when relating equipment size, space and cost. As industry volume increases, volume pricing and system optimization will occur. Recent studies have confirmed potential cost savings of approximately 15%, and space savings of approximately 35% when compared to Uptime Institute verified Tier 4 level legacy designs.

Efficiency & Reliability: Less equipment is required within a power path/chain that gets usable power to point-A (the load/chip) from point-B (the source/grid) resulting in higher efficiency and increased reliability. This is an engineering fact. Actual numbers will vary based on the many perspectives that are possible but the fact remains.

Modularity and Commissioning: Like the other bullet comments above, much additional information can and will be provided in future papers. It has been our experience that the modularity of the DC UPS's we are familiar with, combined with the flexibility of busway systems that once the basic system has been commissioned, the end user can add additional power and racks as needed. A dual feed busway system additionally allows an end user to power each rack in either a single or redundant power sources.

CONCLUSIONS

The modularity of Chip2Grid™ and its topology will lead you designs which offer flexible financial and commissioning benefits.

Virtualization has changed the IT industry forever creating new power distribution challenges. The Chip2Grid™ approach using direct current solves these challenges. The more you virtualize the more you should consider using 380V DC.

If Edison is looking down now, you might think he would say "It is about time! I knew DC Power was more advantageous." Going further, he might say "Mr. Westinghouse, let's have a beer and decide where our systems can best be used. By the way Mr. Westinghouse, the data center is mine!"

The required topology is available now. When coupled with the economic benefits, inherent reliability, and reduced real estate requirements, and increased adaptability, the need to shift is compelling. For data centers the *Chip2Grid*™ technology standard is established. It is a simple matter of shifting time and money to the output of the data center.

Chip2Grid™ Technology can offer powerful benefits using currently available off the shelf technologies. The great potential for new technological power consumption can provide even greater benefits reducing real estate, cost & operation expense. With an increased focus on the chip, unnecessary components and expense are never added into the topology. An added benefit is the increased connectivity to alternate energy solutions package rendering DC as the current choice having the greatest potential to solve many of today's data center power challenges. Virtualization is changing the industry forever and at the same time creating new power distribution challenges. Direct current enables facility planners to distribute power were they need it without the challenges faced by using alternating current.

Abbreviations and Acronyms

AC - alternating current
DC - direct current
EMC - electromagnetic compatibility
ETSI - European Telecommunications Standards Institute
HVdc - higher voltage direct current (200 to 600 volts)
IEC - International Electrotechnical Commission
IEEE - Institute of Electrical and Electronics Engineers
NEC - National Electrical Code (NFPA 70)
NEMA - National Electrical Manufacturers Association
NFPA - National Fire Protection Association (United States)
PDU - power distribution unit
PE - protective earthing
PPE - personal protective equipment
PSU - power supply unit
TCO - total cost of ownership
UPS - uninterruptible power supply (or uninterruptible power system)
VRLA - valve-regulated lead-acid (battery)

References

a) *Books:*
   i) J. Jones, The Empires of Light, New York, Random House, 2003

b) *Papers Presented at Conferences (Unpublished):*
   i) P.Barker, Nova Energy Specialists, LLC, "Use of DC for Micro-grids and Power Distribution", presented at the EPRI DC Power Workshop, Washington DC, 2006
   ii) C. Gellings, EPRI, "Are we at the Threshold of a New Era of DC Systems?", presented at the EPRI DC Power Workshop, Washington, DC, 2006
   iii) Pratt, A.; Kumar, P.; Aldridge, T.V., "Evaluation of 400V DC distribution in TELCO and Data Centers to Improve Energy Efficiency," Telecommunications Energy Conference, 2007. INTELEC 2007. 29th International, pp. 32-39, Sept. 30 2007 - Oct. 4 2007.
   iv) Aldridge, T.; Pratt, A.; Kumar, P.; Dupy, D.; AlLee, G., "Evaluating 400V Direct-Current for Data Centers," May 2010, http://blogs.intel.com/research/Direct%20400DC%20White%20Paper.pdf

c) *Patents:*
   i) M. Baldwin & D. Geary, "High Reliability DC Power Distribution System", U.S. Patent 7,492,057, Feb. 17, 2009

[1] e-merge alliance standard, www.emergealliance.org
[2] ETSI 300 132-3 Standard
[3] ITU International Telecommunication Union – www.itu.int
[4] ETSI – European Telecommunications Standards Institute – www.etsi.org
[5] NTT (Japan), Nippon Telegraph and Telephone – www.ntt.com
[6] IEC International Electrotechnical Commission– www.iec.ch
[7] TGG – The Green Grid, www.thegreengrid.org

APPENDIX – THE 380V DC TOPOLOGY

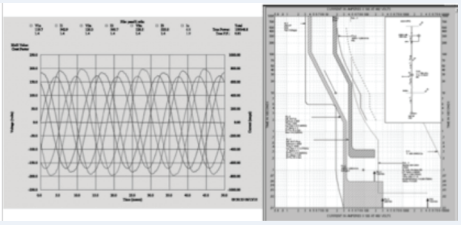
Codes & Standards: First of all we are not talking about High Voltage DC! Per the Emerge Alliance's, (www.Emergealliance.org), Standard for DC Power Distribution Systems for Data & Telecom Centers AND ETSI Standard EN 300 132-3; Power Supply Interface at the Input to Telecom & Data (ICT) Equipment; Direct Current up to 400V Solution, the nominal voltage is 380V DC. Both of these standards should be completed by mid-year 2012. The recommended topology is a center tap ground that will limit voltage to ground to + 190V DC and – 190V DC.

Other code and standard activities are in process with NFPA 70, National Electrical Code (NEC), NEMA, UL, IEEE and others to integrate and develop verbiage for the design, installation and operation of DC power systems with DC power rated devices.

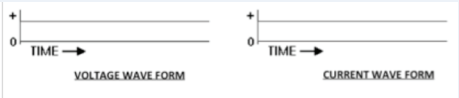
Short circuit, arc flash, circuit protection, load flow:

DC power has distinctive characteristics that differ from AC power. As such there are multiple opportunities to do things differently regarding circuit protection, system coordination and control, arc flash protection and load flow control. New and existing technologies can be applied to take advantage of these characteristics to make this DC topology more reliable, safer, and easier to monitor and maintain.

AC Circuit Protection - Why do this...



When all we have to address for DC Circuit Protection development



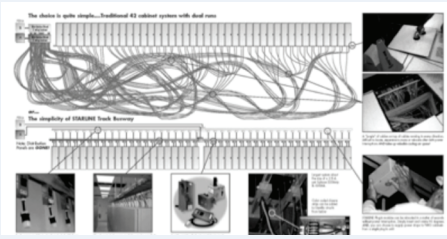
Protecting DC Power Systems?

- Voltage and current are somewhat constant.
- How long do we need to wait and watch before we decide to clear a circuit that experiences a change in voltage or current?
- We think rather quickly if not faster!
- Great opportunity to make DC Power Protection safer, smarter and more reliable.

Harmonics – No harmony in the AC world: Harmonics can be addressed at the bulk conversion point from AC to DC power. This feature allows for the elimination of the burden for point-of-use treatment at each stage of power conversion that exists in today AC power system.

Load Balancing: Load balancing within an AC system where multiple single phase loads are used is critical, and more often then not, not easily achieved. The lack of complete load balancing within an AC system results in a built-in, ever changing de-rating effect that must be addressed.

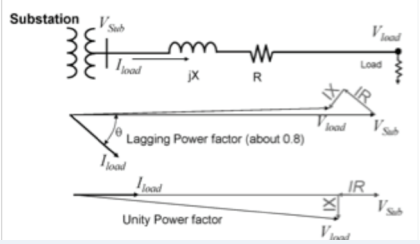
Load Balancing!
Difficult with AC - Inherent with 380V DC



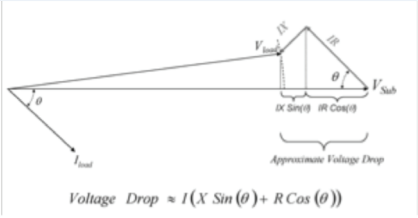
PHASE	A	B	C	SYSTEM DE-RATING
	100%	100%	100%	100%
	100%	95%	95%	96.66%
	100%	95%	90%	95%
	100%	90%	80%	90%

Voltage drop: If everything else is equal, DC has less voltage drop than AC. (When PF is not very close to unity).

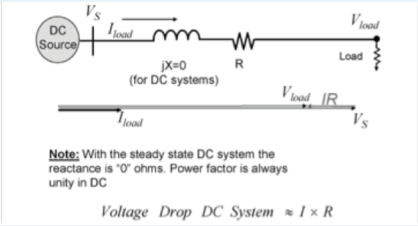
Voltage Drop AC System



Formula for estimating Voltage Drop (AC System)



Voltage Drop AC System



Type of Conductor System	**X/R of Conductor Studied**	**Voltage Drop Conclusion** *(voltage drop % compared for AC and DC at similar RMS values)*
Overhead Systems (0.9 power factor) *(typical crossarm feeder construction techniques)*	2 to 3	The voltage drop is significantly higher for an AC system (50-100% more volts drop per mile)
Overhead Systems (Unity power factor) *(typical crossarm feeder construction techniques)*	2 to 3	The voltage drop is about the same for both AC and DC systems
Underground Cable Systems (0.9 PF)	0.5 to 1	The voltage drop is 10-40% worse per mile for an AC system
Underground Cable Systems (Unity PF)	0.5 to 1	The voltage drop is about the same for both AC and DC systems

Prepared by Nova Energy Specialists, LLC
EPRI DC Power Workshop, Washington DC, June 1-2, 2006

Connectors: Power connectors have been developed and some are UL listed for 380V DC use. Additionally there are new cord/connectors that insure the computer load is turned off prior to physical connections and disconnections.

Additionally there are new solid state technologies that will supplement connectors which will automatically open the DC circuit as connectors are made and un-made.

Wires and cords: According to American manufactures of wire and cable all are inherently rated for both AC and DC. Also, since AC power is rated as an RMS voltage and not a peak-peak voltage, DC wire and cable has a higher voltage rating and thus a higher power rating.

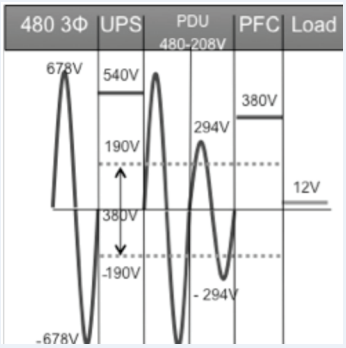
3-Phase, 4-Wire (AC) verses 2-wire (DC): Beside the obvious comparison of 4-wire verses 2-wire and the amount of labor and material when comparing the two, there is another thing to consider. Per NEC requirements adjustment/de-rating factors must be applied to conductors when four or more conductors are installed in a single raceway, (see table below). DC has a distinct advantage when considering this requirement.

TABLE 310.15(B)(3)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable

Number of Conductors[1]	Percent of Values in Table 310.15(B)(16) through Table 310.15(B)(19) as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

[1]Number of conductors is the total number of conductors in the raceway or cable adjusted in accordance with 310.15(B)(5) and (6).

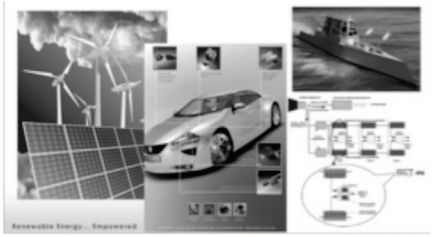
(c) On a 4-wire, 3-phase wye circuit where the major portion of the load consists of nonlinear loads, harmonic currents are present in the neutral conductor; the neutral conductor shall therefore be considered a current-carrying conductor.



Metering/monitoring: Power quality metering for AC systems have become very costly when WAVE FORM CAPTURE and high speed measurements are required to figure out has happened, in hind sight, in a power quality event. The constant nature of DC voltage and current allows for simpler metering requirement and with the ability to decide more quickly when a problem occurs.

Busway distribution: DC is inherently a 2-wire system as proposed with a ground that could be run separately or accommodated by a busway frame. As such, DC presents various options with system distribution configurations that AC power cannot compete.

Cross industry collaboration: "Semi-conductors began to evolve in the 1940s and 1950s and have become the predominant means of using power, and about 80 percent of power used in commercial buildings must go through some form of power electronics so it can be converted to DC," quote from studies conducted by the Center of Power Electronics Systems at Virginia Tech. As the world continues to grow towards a DC load state, and as other industries embrace this topology as well, there is great opportunity to share designs, development and opportunities to invent/develop when cross industry collaboration occurs.



Equipment size, space and cost: DC power is not a new idea, but the way it can now be deployed and the innovation potential that exists in relation, will prove to a positive factor when relating equipment size, space and cost. As industry volume increases volume pricing and system optimization will occur. Recent studies have confirmed a possible cost savings of approximately 15%, and a space savings of approximately 35% when compared to Uptime Institute verified Tier 4 level legacy designs.

Efficiency & Reliability: Less equipment required within a power path/chain that gets usable power to point-A (the load/chip) from point-B (the source/grid) means higher efficiency and more reliability. This really is an engineering fact. Actual numbers will vary based on the many perspectives that are possible but that fact remains.

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