380 Vdc for the Modern Data Center

THE BENEFITS OF dc

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DAVID E. GEARY, P.E.

MEMBER: The EMerge Alliance -IEEE –NFPA –IEC –SCTE –AEE -NSPE

INTRODUCTION

WHY DIRECT CURRENT (dc) POWER IN DATA CENTERS AND WHY NOW?

The Data Center (DC) industry's unprecedented growth is a result of growing Internet traffic because of entertainment, social media, electronic commerce, electronic financial transactions, medical records, trading and the growth of the Internet of Things. Data Center operators, owners, and developers are looking for ways to optimize the design of data centers both from the point of view of IT (servers, storage, switches, etc.) as well as infrastructure (power and cooling). The never-ending quest for more efficient, lower-cost, smaller footprint designs and systems bring to light new technologies and new solutions that can better serve Data Centers.

To add a little insight to digital loads consider these facts: Total datacenter energy consumption by itself is growing at a rate of 12% per year. If the Internet were rated as a country, its total energy consumption would be 5th in the world, AND today the majority of data centers have insufficient power and cooling.

One of the most promising recent trends for today's technology in data center power is moving toward the perspective of the load's need for dc power and away from a focus on how to convert alternating current (ac) power to something usable. This is not ac verses dc, is not analog verses digital, and is not Westinghouse verses Edison. It simply is using the enhanced reliability, lower capital cost & operating expense, dramatic real estate reduction, and more effective integration of alternative energy sources received when focusing on the load's need for dc Power. PLUS, increased efficiency is important and dc does provide, in all cases, an improvement. 380V dc Power Systems are becoming the global standard of choice. While we want to say Edison was right we need to instead recognize that this world has evolved to where the demarcation line between ac and dc has made a shift. The dc load is no longer just a chip, it is now approximately 80% of the building loads enabled by power electronics which justifies the holistic business value of dc.

DIRECT CURRENT (dc) POWER IS MAINSTREAM

When discussing dc and ac power systems our technical emotions take us back to the "Current Wars" fought between Westinghouse and Edison at the dawn of electricity. Ac Power won due to the technology available at the time, but today's technology is driving us back to dc power systems. Engineers have heard over and over that "digital loads should be supported by digital power". Digital power is dc, and unlike in Edison's day, an ac power source is a support characteristic not the focus. While our heart tells us "Edison was right" today's available technologies bring us to a direct collision with the force of 100 years of history and will ultimately push the power industry into a reversed path as it demonstrates that dc power now embodies a future holistic business value that cannot be denied.

THE CASE FOR EDISON – dc POWER AND THE DAWN OF THE 21ST CENTURY: So why DC power today? Just consider the following:

1. Increasingly, equipment operates on dc, requiring conversion from ac sources – **the era of electronics.**

2. Distributed generation and alternative energy systems produce dc power – **the era of the dc micro-grid**

3. Energy storage devices such as batteries, flywheels and capacitors store and deliver dc power – **ease of integration**

4. dc power helps power hybrid (Electric Vehicles (EV)) automobiles, transit buses, and commercial fleets (and visa-versa) **– the era of power electronics in transportation**

5. dc power delivery enhances energy efficiency in data centers, a pressing need – **the era of energy efficient information technology**

6. Improved power electronics allow dc power to be converted easily and efficiently to different voltage levels – **removing the bottlenecks of transformation**

7. The evolution of dc power architectures in computers and other equipment simplifies dc power delivery systems – **standardization of dc voltages**

It is clear that the Data Center as a high density, inherently dc load (IT load) is demanding designs based on this dc load (The CHIP) and not on the source of power (The GRID). Today's power electronics, coupled with the need to expand the use of renewable energy sources, make it apparent that dc power now has a place in national power grids of the world. But before looking at dc power from the load perspective let us revisit "The Case for Edison" as described above.

The data center is one of the fundamental reasons for dc Power to be in today's mainstream besides solar/PV, traction, EV, and wind energy and will be the focus of this paper. Central to this focus are four immutable design facts:

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 chips and integrated circuits (ICs) 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 their core business, i.e. IT operations.** This requires power support systems to have flexible modularity, higher efficiency, more cost effective maintainability, enhanced reliability, and a smaller footprint, while maintaining high security and safety.

4. **All necessary technologies to reap the benefits of dc Power are available now.**

The electrical engineering characteristics of ac versus dc power needs to be examined in detail before a final conclusion can be made regarding the impetus to change anything. Ac power has been the topology of choice since the beginning of electricity, and there were technical reasons why, some of which are described as follows:

- 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 generation plants and hydro resources) – dc could not easily be stepped up in voltage like ac back then.
- 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 power 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.

So why consider dc power again?

- Loads are becoming more dc and dc compatible
- Better dc to dc converters and dc to ac inverters are becoming available that will allow us to change voltage levels and regulate the system (overcoming a key drawback of dc in the past)
- Use of dc allows for improved power quality and reliability features compared to an ac grid.
- Use of dc allows for the integration of new power electronic technologies to be integrated into circuit protection and controls to allow for safer and more reliable systems.
- Use of dc allows micro-grids to be more viable and there are some interface advantages for Distributed Generation (DG) in dc.

Plus some additional benefits such as:

- **Modern Power Electronics (PE) in dc offer low losses comparable to conventional ac transformer-switch-wire systems, and higher operating voltages**
- Lack of dc transformer is no longer an obstacle; dc/dc converters provide the same or better functionality with comparable efficiency and will ultimately be of a lower cost.
- PEs can provide better control of fault currents (something not easily attainable in conventional ac grids), this control extends to both the ac

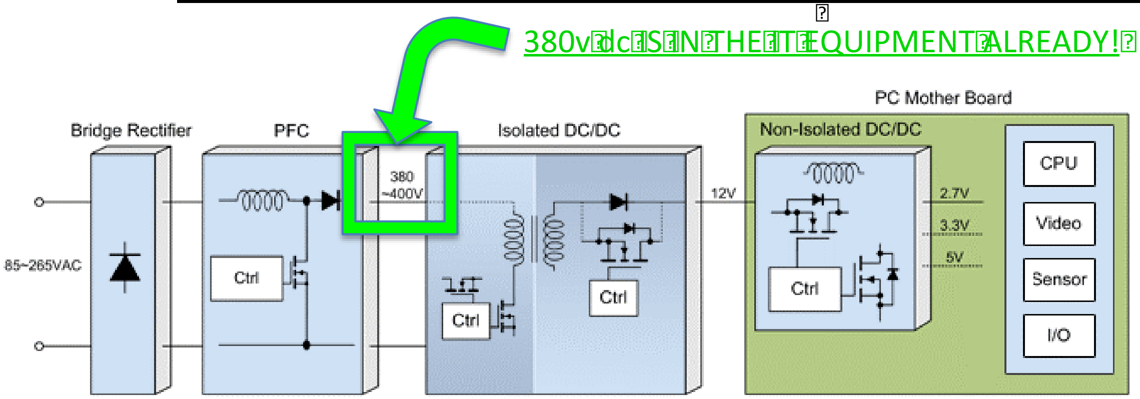
input side (power factor correction, mitigation of transients and harmonics, etc.) as well as outputs (dc, mitigation of fault currents, transients, etc.)

dc Power for dc loads – The Power Supply Story

More and more of our everyday power loads are inherently dc. In data centers that is especially true as data center load growth has resulted in an industry looking different ways of doing things to increase efficiency and reliability. So why don't we start here – the data center. The primary load in the date center is the processor chip, data storage, communication interfaces and data transmission – all inherently dc power loads fed through an ac to dc power supply. So the story begins with the power supply:

WHY 380VDC? THE POWER SUPPLY STORY

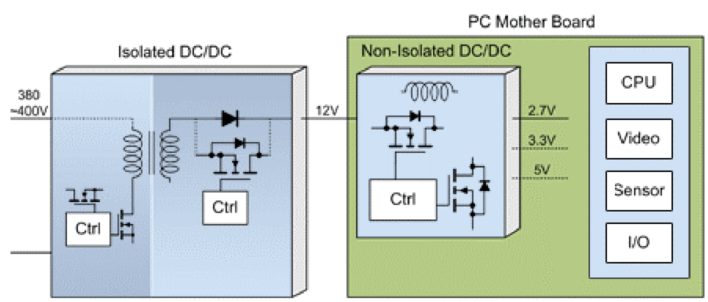
380v dc IS IN THE IT EQUIPMENT ALREADY!



AC POWER SUPPLY SPECIFICATIONS

AC Input Range	110/240V 47-63Hz. Limits: 85 - 264 VRMS (270V Surge), 47 to 63 Hz
DC Input Voltage Range	110 to 373V DC (380V DC surge)

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 (PS) & SPECIFICATIONS WITH LESS PARTS THAN AC PS

Figure 1 – dc power eliminates components within power supplies

Dc power can be provided at a voltage already native to power supplies today and result in new power supply designs that use fewer parts. As we investigate the details of how this is done we can also realize that the legacy ac power environment that power supplies have lived in may have caused many things to be added to these power supplies in order to function in the pre-defined constraints dictated by the

Figure 2 – 380v dc HP Common Slot power supply

typical ac power system operational specifications. If we remove these constraints and offer a very stable, narrow range voltage (such as: 380V dc +/- 5%) then what will that allow the power supply to evolve into? Reduced or elimination of hold-up requirements, simplified filtering required, less transients and surge exposures, other opportunities? So what are the engineering challenges that will allow for optimized power supply design? Power supply designs will improve over time in a dc environment.

THE BENEFITS OF dc

THE BUSINESS CASE TO CHANGE

Expanding on the information provided above, and with the realization that there is an undeniable business case in favor of 380v dc power before wide scale acceptance and deployment can/will begin, the benefits of dc must be presented. The benefits must be so compelling that lack of action to the conversion from ac to dc would be thought of as an unwise business decision as new data center are built or existing data centers are renovated. This is the exact process that was experienced many years ago when ac power finally won as the topology of choice – BUT IN REVERSE!

A data center person can readily and intuitively design, adapt, and optimize power from the perspective of the chip towards the power grid. And yet tradition has been just the opposite. The unique concept of ***Chip2Grid***™ technology captures the power design from the chip's perspective. Looking back from the chip, the internal power supply distribution for computers begins at 380V dc, therefore all IT power supplies can easily migrate to this solution. Since the existing grid is an ac source, the voltage type must be changed to dc only once (half a typical UPS system) rather than multiple conversions back and forth performed by legacy ac UPS and data center power system architectures. Better yet, if the power grid or source is already dc, there is no need to change it back & forth at all. An example would be to power a computer directly from solar or the dc output point of a fuel cell. The power supply for the server would not have to change ac to dc. Power supply providers who manufacture for over 70% of servers globally embrace this technology.

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 focuses on three distinct areas:

1. How to invest more in your core business systems and reduce the non-core (facility) expenditures.
2. The positive realities of components available now in 380V dc.
3. Dc Power Topology of the 380V dc infrastructure. Key issued addressed include: power supply details; connectors; conductors, 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; dc lighting and cross industry collaboration.

Every data center stakeholder, from the operations staff to the Chief Financial Officer, will benefit from a ***Chip2Grid™*** contribution to data center operations and the improved bottom-line it yields. Consider these BENEFITS OF dc:

Effect on Data Center	***Chip2Grid™*** Attribute	Benefit
Data Center Reliability	Higher Reliability	200 to 1000% increase in reliability due to fewer points of failure & flexible energy storage integration.
Funds Reduction #1	Lower capital cost & modularity	Capital costs of electrical facility reduced by 15% or more. First cost can be farther minimized by adding plug-and-play modules as capacity needs increase
Funds Reduction #2	Lower O&M	On average the operation and maintenance costs will be reduced by 33% or more than AC data center power systems.
Funds Reduction #3	Smaller Footprint	With a 35% space savings in the electrical infrastructure, a whole variety of savings are received, could include 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 phased “swap out” at your pace making decision making and planning easier.

Use Renewables	Easier Integration of Renewable Energy	Most renewables are inherently dc -Wind, Solar -Energy Storage -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.

THE BENEFITS OF dc AS RELATED TO COMPONENTS

Components involved and aspects of electrical design engineering with 380V dc technology illustrate some of the positive realities of this approach.

IT power supplies	Power supplies accept 380V dc input and uses what has been shown to be an optimal voltage level. The bus can be center tap high resistance grounded (+/- 190 dc) to further reduce any hazards. 380V dc distribution leads to additional advances in power supply efficiencies.
Universal 380V dc	380V dc is universal. For existing power supplies not currently at 380V dc all that is required is an off-the-shelf receptacle and elimination of ac power conversion components. 380V dc has world-wide/international acceptance and standardization
Safety connectors to the servers	Breaking arc, if present, in the connector is fully extinguished before opening of the connector and passes UL jointed test finger proof tests. Other technologies exist to make sure circuits are not energized when breaking and making connections
Power Distribution System	380V DC allows for more power delivery than ac on the same amount of copper.
Rack mount PDU's	New connector designs offer enhanced reliability. 380V dc offers more power per PDU with less wires and less copper.

Modularity

	Modularity not previously available allows easier design and installation. Enhanced plug-and-play availability.
380V dc UPS	No need to do an ac-dc conversion followed by a dc-ac conversion. Shorter path with higher efficiency and higher reliability.
Load balancing	Load balancing is not required for 380V dc, BUT is 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 for safer systems. As ac data center distribution moves to higher voltages (400V ac, 415V ac, 480V ac) arc flash and circuit protection at the rack becomes a bigger safety issue in ac systems.
Temperature – heat!	Dc systems operate inherently cooler and at the same to hydraulic-magnetic circuit breaker are not subject to de-rating at higher operating temperatures
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 providing inherent benefits of the infrastructure to the cooling system.
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 return on investment.
Dc microgrids	Another advantage of dc power is the potential of creating dc micro-grids. A dc micro-grid is more conducive to the integration of alternative energy sources with traditional energy sources for on-grid and islanding mode operation. Micro grids can support traditional ac loads AND new dc loads at the same time.
Paralleling and Synchronization	Combining ac sources required active paralleling with sophisticated controls and metering – combining dc sources require only voltage parity within and between systems

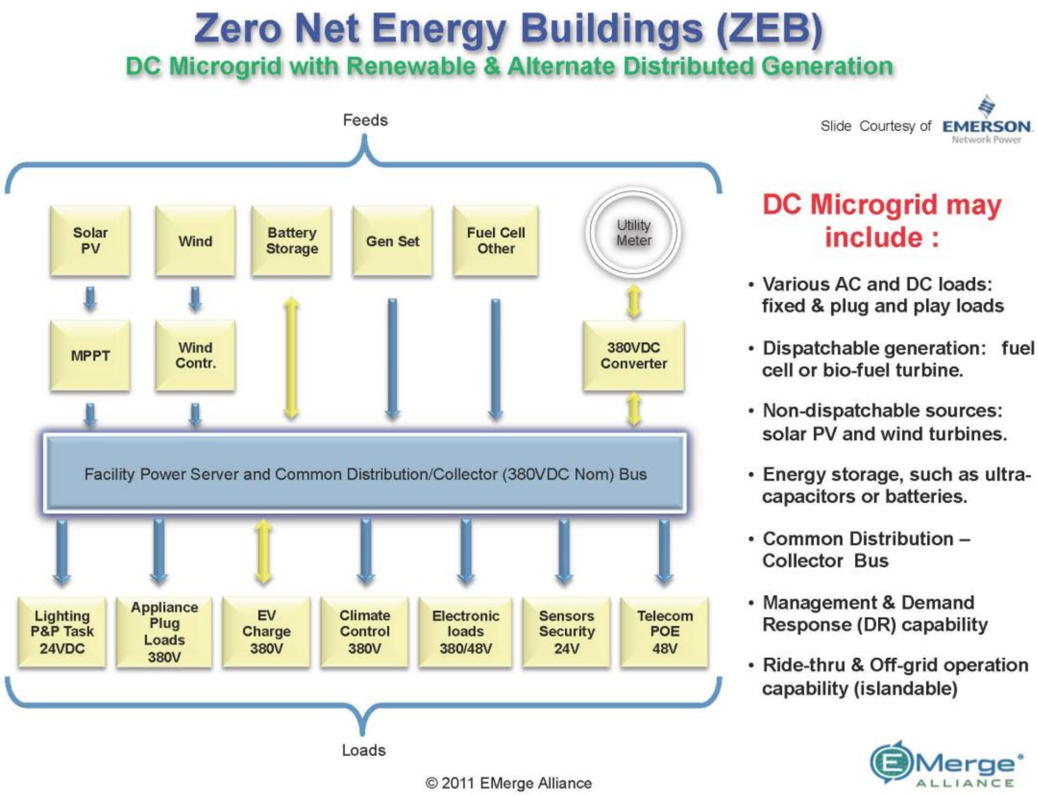


Figure 3: EXAMPLE OF A dc MICRO-GRID CONCEPT

OPERATIONS, MAINTENANCE AND SAFETY OF 380V dc SYSTEMS

Operations and Maintenance:

Data Centers are typically a more complex facility to operate and maintain. Power and cooling systems are required to operate continuously with high reliability and maintainability in order to meet the 7x24 on-line requirements for the computer and communications systems within. As such, most data centers are staffed by a full time, around-the-clock staff to monitor and maintain the building systems. As load densities have increased and as data centers have increased in size the associated power and cooling systems have also become larger and more complex. It is often quoted that human error is the cause of most data center outages and failures. One way to reduce errors is to make the systems simpler and reduce the number of components within these systems. 380V dc power allows just that. Reduced system components mean higher reliability and lower operations and maintenance costs. 380V dc allows for a simpler power system building block topology. Many of the engineering details, which are described earlier, contribute to this fact.

Safety:

High reliability is the number one requirement for Data Center operations. Implicit to this reliability requirement is that electrical systems must also be safe. It is also understood and agreed that electricity, at the voltages and power levels associated with data centers, can be hazardous to individuals exposed to live parts. There are primarily two aspects of electrical safety hazards that one has to keep in mind, arc flash, and electrocution. The first is related to the exposure of a human body to the arc as the source of intense heat causing burns and other severe injury. The second is related to direct contact with the live energize parts causing the electrical current to flow through a human body. As such the following is a list of issues regarding safety of 380V dc versus ac power topologies:

- Both ac and dc systems are engineered safely using properly rated and certified equipment that has been tested for safety.
- Electricity is a hazard. ac and dc systems are designed and rated to eliminate exposure to this hazard. Unsafe operations of ac or dc systems are equally hazardous. Work on the systems is typically allowed only when de-energized.
- UL rated or equivalent dc connectors for hot connect/disconnect of IT equipment exist and new form factors are in development and testing. The Green Grid [7] acknowledges that work around dc powered equipment should not be a problem.
- dc operational experience from other industries is at least as safe as ac operational experience.
- Overcurrent protective devices have an impact on the two most important variables of arc flash hazards:
  - Time (speed of the OCPD)
  - Fault current magnitude (current-limitation may help reduce)
- Fault Current Limitation (FCL) may be able to significantly reduce the energy released during arcing faults. Power and load flow control will be easier and more exact in dc systems primarily due to power electronics.
- As ac voltage levels are increasing in data centers, (400/230VAC, 415/240VAC, 480/277VAC (rms voltages)), so does arc flash exposure to the personnel working with IT racks and servers.
- New technologies are available for dc circuit protection which are faster and more exact than ac circuit protection. Faster and more exact protection will contribute to higher safety.

CONCLUSION AND FUTURE TRENDS

The required DC topology is available now. The financial, reliability, real estate, and adaptability reasons to shift are compelling. For data centers the Chip2Grid™ technology standard is established. It simply is a matter of shifting your attention and money to the output of the data center.

Chip2Grid Technology has powerful benefits using currently available technologies and with great potentials for new technologies to address power consumption, real estate, cost & expense reduction, increased focus on the chip, reduced real estate, and easy green power integration. Plus you get increased efficiency as part of the package.

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