380 Vdc Architectures for the Modern Data Center

2013

Abstract

The public mandate to develop and operate more efficient, lower cost, more reliable, more sustainable infrastructure clearly includes data center design and operation. Ideally, these concepts are addressed at the concept and design stage and implemented from the foundation to daily operations. Practically, new and different approaches (evolving thinking and technologies) are implemented in all facilities. This paper presents an overview of the case for the application of 380 Vdc as a vehicle for optimization and simplification of the critical electrical system in the modern data center. Specifically, this paper presents currently available architectures consistent with ANSI/BICSI 002-2011 and the EMerge Alliance Data/Telecom Center Standard Version 1.0. Additional EMerge Alliance white papers will explore the specific elements including economics, reliability, safety and efficiency.

The EMerge Alliance is an open industry association leading the rapid adoption of safe dc power distribution in commercial buildings through the development of EMerge Alliance standards. The Alliance has a vision of dc microgrids throughout commercial buildings. This dc platform is an open architecture focused on reducing or eliminating inefficient ac to dc conversions between power sources and digital devices by converting and distributing power in ac form. It is a platform also focused on the potential of allowing for greater integration of renewable and alternative energy sources. We believe that ongoing and increasing demand for improved reliability and energy efficiency across all areas of commercial buildings, data centers and other facility types provide the basis for this broad platform.

The EMerge Alliance has commissioned this series of white papers to introduce current dc technology and topologies for modern data centers. These papers will illustrate currently available technology and topologies, defining the underlying issues and validating the emerging technology.

The EMerge Alliance Data/Telecom Center Standard has been introduced to the industry. This standard defines low voltage dc power distribution system requirements for use in data centers and telecom central offices.

Table of Contents

TABLES

FIGURES

Introduction

The public mandate to develop and operate more efficient, lower cost, more reliable, more sustainable infrastructure clearly includes data center design and operation. Ideally, these concepts are addressed at the concept and design stage and implemented from the foundation to daily operations. Practically, new and different approaches (evolving thinking and technologies) are implemented in all facilities. This paper presents an overview of the case for the application of 380 Vdc as a vehicle for optimization and simplification of the critical electrical system in the modern data center. Specifically, this paper presents currently available architectures consistent with ANSI/BICSI 002-2011 and the EMerge Alliance Data/Telecom Center Standard Version 1.0. This paper begins with architecture and topology – the “foundations” of this approach. Additional EMerge Alliance white papers will explore the specific elements of adopting 380 Vdc including economics, reliability, safety and efficiency.

A need for improved and more efficient power distribution for mission critical applications is a result of continuous increases in global power consumption and a shift in power profile of modern loads. As more and more equipment (already a majority of demand from utilities) is transitioning to electronic loads, which are natively DC, it makes sense to eliminate costly and inefficient ac/dc and dc/ac conversions required to operate electronic equipment. The majority of renewable resource power generation approaches inherently produce dc output. In present ac applications, this requires additional conversion stages to couple with existing electrical distribution.

The adoption of 380 Vdc increases reliability, improves power quality, and eliminates the need for complex synchronization circuits associated with multi-source ac distribution. However, many data centers operators outside of the telecom industry are not quite familiar with dc system architectures and their relationship to established topologies utilizing ac distribution. This paper provides an overview of 380 Vdc power distribution architectures compared to present ac solutions and explores additional novel and modular distribution concepts enabled by the flexibility and simplicity of 380 Vdc based infrastructure.

Transition to dc based distribution systems is not as complex as commonly perceived. Major system elements are already in place and new, optimized devices are under development. Most of the presented distribution architectures concepts presented here have been adopted and verified in data centers and telecom facilities and are ready for practical, immediate implementation.

Core Issues

Historically the primary concern in data center operations is the availability of the critical bus. The industry has addressed this issue in a variety of ways including:

- Enterprise Level
  - Geographical Redundancy
- Facility Level
  - Large scale distribution with centralized redundant UPS
- Equipment "Row Level"
  - UPS installed in row with dedicated equipment racks.
  - One or more redundant PODs allowing sequential facility servicing typically known as "in row distribution"
- Rack Level
  - Dedicated power protection for single equipment racks

These approaches offer varying degrees of redundancy and often result from combining the above methods.

In addition to system availability, ease of maintenance and maintenance practices are vital. This includes both routine maintenance as well as repair time as some users can allow for periodic shutdown while others require that servicing accomplished without affecting system availability. Ultimately, site design criteria reflect user preference and system criticality.

These diversified, present and evolving application requirements, resulted in development and market introduction of a large portfolio of competing topologies and technologies for power protection equipment and systems, (mainly in the form of ac-UPS) as well a proliferation of different application approaches, which are often complex and difficult for data center operators to evaluate.

Still, the drive for reduced power consumption and improved power distribution system efficiency has often resulted in the sacrifice of some operational and maintenance characteristics in the distribution system. These include power quality and reliability (e.g. "eco "mode operation in ac-UPS systems), increased harmonics content, and safety (in cases of higher distribution voltages).

An attractive alternative to meet the objective of improving efficiency and improving (or maintaining) site availability is the application of 380 Vdc distribution rather than ac voltages in data center power distribution or 48 Vdc in telecom facilities.

dc ARCHITECTURE

Presented dc architectures are generally referred to in this paper as 380 Vdc distribution architectures or topologies, representing the normal operating voltage of the described distribution systems with lead acid batteries. 400 Vdc is the upper limit of the allowable voltage in normal operation and is not dependent on battery technology or configuration so it is often used as the generic description. Both 380 Vdc and 400 Vdc are used throughout this paper and should be considered synonymous.

ac vs dc Topologies

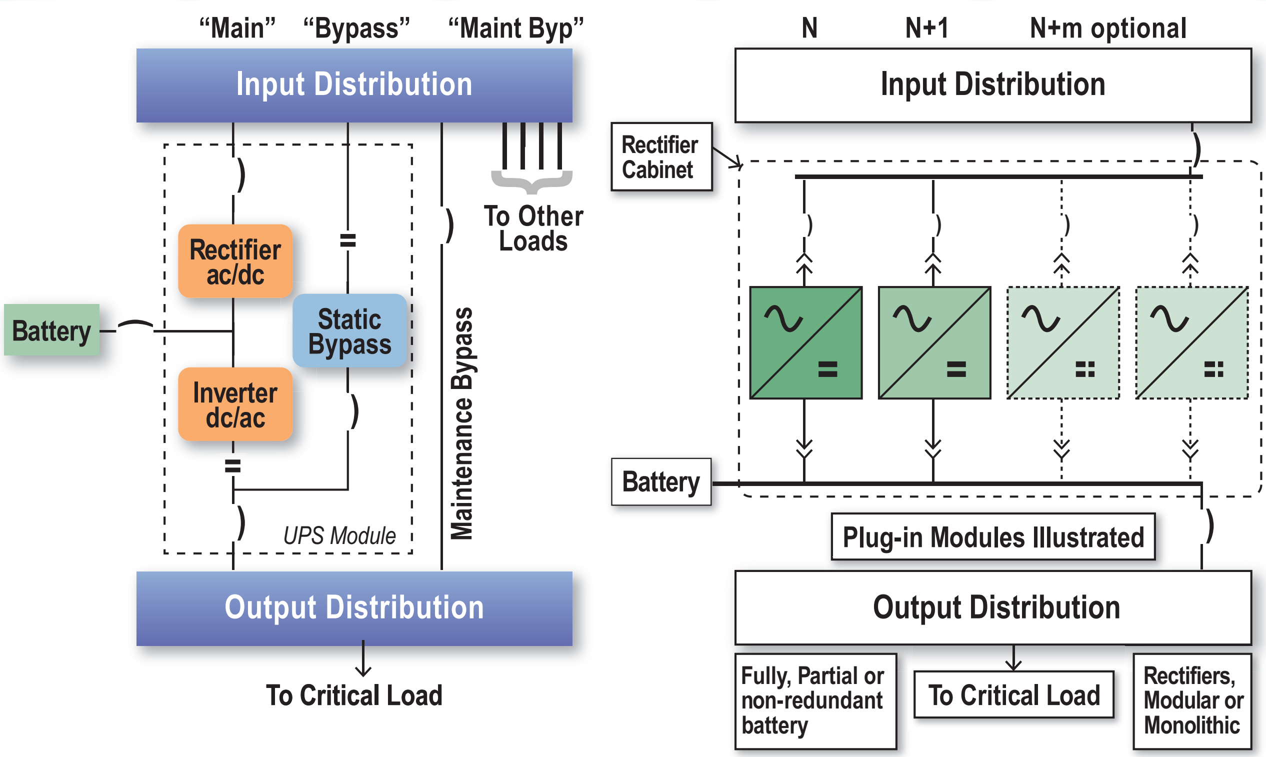
To understand the principles of 380V dc distribution and its application, it is important to first examine the basic differences between ac-UPS and dc-UPS architectures. Presumably the dc input ICT (Information and Communications Technology) equipment power supplies meet the input voltage range of 260-400 Vdc as specified by ETSI EN300-132- 3-1, ITU-T L1200 and the EMerge Alliance Data/Telecom Center Standard Version 1.0, other notable differences include:

- In an ac-UPS, the battery is connected between the rectifier and inverter; in the 380 Vdc topology, the battery is connected directly to the critical bus.
- In an ac-UPS, static bypass and maintenance bypass serve the following functions:
  - To allow clearing of major faults (short circuits on the load side). The inverter is a current limiting component and direct utility connection may be required for fault clearing without disruption of critical bus;
  - To maintain critical bus power in the event of UPS failure by switching to utility power;
  - To allow routine maintenance of the UPS;
  - In some recent ac - UPS topologies, bypass is also used as a “preferred or normal” power path for the critical loads in “eco mode” operation

Utilization of bypass circuits require a synchronization circuit to allow acceptable switching between utility and ac-UPS output. Input/output voltages, frequencies and phase angles must be matched, and downstream protection must be sized for both sources. Full isolation of the ac-UPS for servicing without service interruption for maintenance requires a bypass. However, during the maintenance procedures, the critical load is unprotected i.e. connected directly to the utility via the maintenance bypass and exposed to potential abnormalities of the utility supply.

It is not possible to equip dc-UPS's with bypass circuits, therefore the load fault clearing depends on energy stored in the system battery or other energy storage devices that are used within the dc system. In the dc-UPS system, additional redundant rectifiers assure system fault tolerance in the event of individual rectifier failures. Battery charging functions and maintainability is available without any switching and requires simple load sharing circuitry for voltage matching. Systems equipped with modular rectifiers are serviced without load interruption as the rectifiers and other electronic components are hot swappable. This feature allows for a short servicing window and can be performed by trained technicians on site.

These differences result in different considerations for selection of system architecture, protective schemes and coordination. The following diagrams illustrate the dc approach.



Basic Block Diagrams Source TGG 2012

Standards

While there are others, two noteable complementary standards guide the application of 380 Vdc power to the data center. One is available in ANSI/BICSI 002-2011. A second was developed by, and available through, the EMerge Alliance Data/Telecom Center Standard Version 1.0. Summaries of these standards are included as appendices to this paper.

380 Vdc Architectures

This section contains three parts. First, because system availability is a key component in system design, the BICSI “Class” table is included. Second, to ensure clarity, the term “as used in this document” defines several terms. Third, representative diagrams of several topologies are offered to address differing BICSI Classes.

Review of BICSI-002 Equivalent AC Topologies

BICSI-002 standard a data center operators determine suitable power architecture for their facility infrastructure (Topology Class) based on the following site availability criteria:

1. Allowable annual maintenance downtime
2. Impact of downtime event on operations

Tables 1 and 2 summarize the BICSI topology classes and their relationship to the industry performance feature of critical distribution systems:

Topology Class	Key Power Path Feature
Class F0	Single Power Path w/o UPS or Alternate UPS Source
Class F1	Single Power Path with UPS Non Redundant Components
Class F2	Single Power Path with UPS Some Redundant Components
Class F3	Multiple Independent Power Paths, some with UPS Concurrently Maintainable
Class F4	Fault Tolerant

Table 1: ANSI/BICSI 002-2011 Topology Classes (Source BICSI-002-2011, 9.1.6.1)

Performance Feature	Class F0	Class F1	Class F2	Class F3	Class F4
Industry Description	Single Path	Single Path	Single Path + Redundant Components	Dual Path, Concurrently Maintainable	Dual Path, Fault Tolerant
Module Redundancy	None “N”	None “N”	N+1	N+1	2(N+1)
System Redundancy	None “N”	None “N”	Limited N+1	Limited N+1	2(N+1)
Power Paths to Critical Load	One	One	One	Two	Two
UPS Sources to Critical Load	None	One	One	One	Two
Full Maintenance Under Load	No	No	Limited	Yes	Yes
Alternate Long Term Energy (Genset)	No	Yes	Yes	Yes	Yes
Alternate Short Term (Battery)	No	Yes	Yes	Yes	Yes
Fault Tolerance	No	No	Limited	Limited	Yes

Table 2: Industry Description of Data Center System Performance Features Related to BICSI Topology Classes (Source TGG 2012)

Definitions

For the purpose of this paper, the following definitions of dc UPS topologies apply:

1. **Modular Rectifier** – A power conversion component of an ac/dc power system designed for a field replacement by a single technician without power system shutdown i.e. hot swappable. Multiple rectifiers can be paralleled to match the load within the same cabinet. Individual modular rectifiers have smaller ratings than monolithic i.e. more rectifiers in parallel are required for larger deployments; usually of plug–in, hot swappable construction.

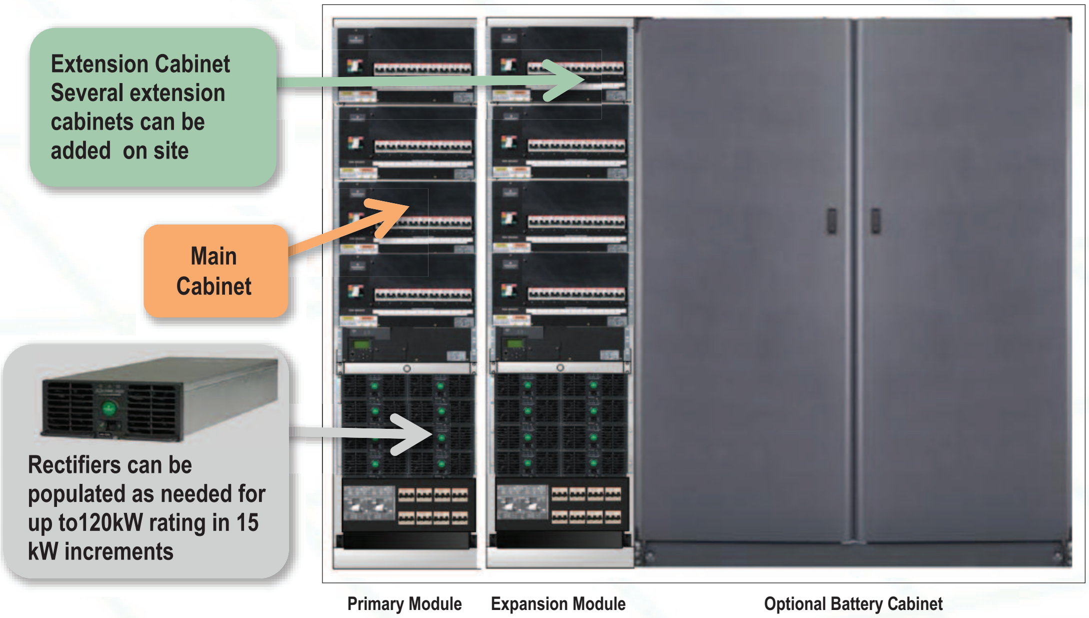


Figure 1: An Example of Modular System Design (Rectifier Weight is ~ 10kG)

2. **Monolithic Rectifier** – A singular power conversion system with fixed power rating requiring partial or complete system shutdown for servicing. Monolithic rectifiers can be designed in large, discrete power ratings and paralleled for increased redundancy and/or capacity.

Both ac and dc-UPS systems are available in the above configurations. However, modularity is easier to accomplish with dc power rectifiers than ac-UPSs by requiring fewer plug –in interfaces, smaller physical size and weight for equivalent ratings, simpler paralleling (no need for synchronization circuits) and higher reliability (fewer components). Typical 380 Vdc UPS system configurations are based directly on existing telecom 48 Vdc concepts, which have been applied for decades in highly reliable applications.

Topologies

The following diagrams illustrate how these Topology Classes can be realized with 380 Vdc based power distribution. All illustrations utilize the upstream ac distribution to dc-UPS per BICSI 002-2011 recommendations. They are similar to ac-UPS topologies except for elimination of bypass feeding circuitry that results in simplification of upstream power distribution switchgear and are functionally equivalent in performance to ac-UPS applications.

BICSI Class F1 – Single Power Path with UPS

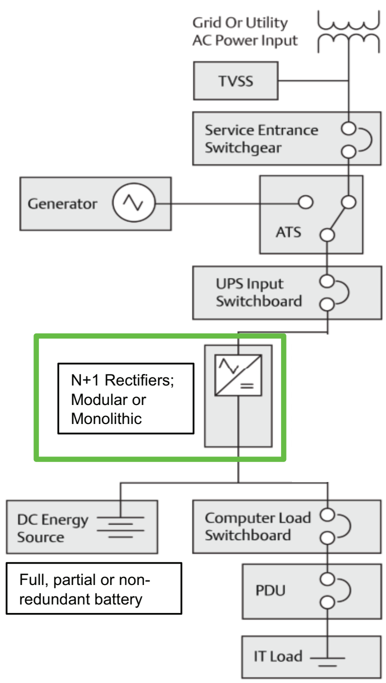


Figure 2: 380 Vdc System Equivalent to BICSI Class F1 (Source TGG 2012)

BICSI Class F2 – Redundant Components

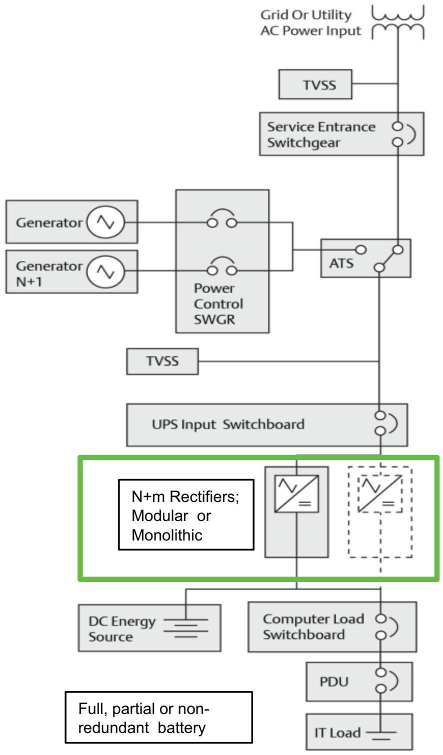


Figure 3: 380 Vdc System Equivalent to BICSI Class F2 (Source TGG 2012)

From the dc-UPS perspective, the only difference between Class F1 and F2 is the number of rectifiers in parallel. In Class F1 the number of rectifiers is N+m. Additional rectifiers provide battery recharge current and redundancy in case of other rectifiers failures (similar in function to the bypass in ac UPS). This arrangement also meets, in principle, Class F2 requirements for a modular dc-UPS construction. With a readily available spare rectifier modular rectifiers are hot swappable. Further availability enhancement can be accomplished by adding additional rectifiers N+m e.g. in the case of a remote, unmanned sites.

BICSI Class F3 – Concurrently Maintainable and Operable

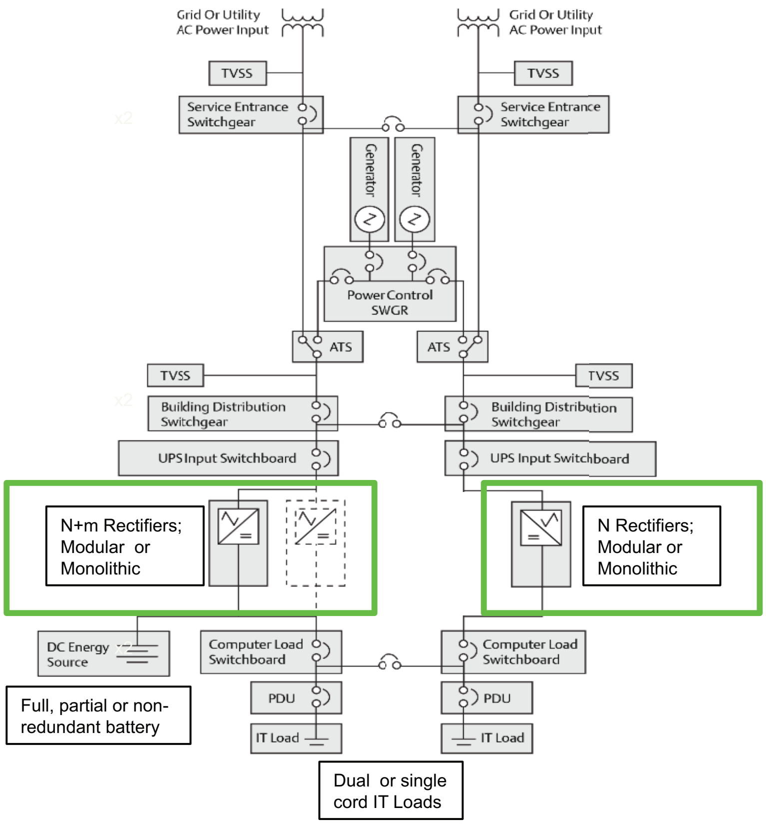


Figure 4: 380 Vdc System Equivalent to BICSI Class F3 (Source TGG)

Class F4 – Dual Path; Fault tolerant

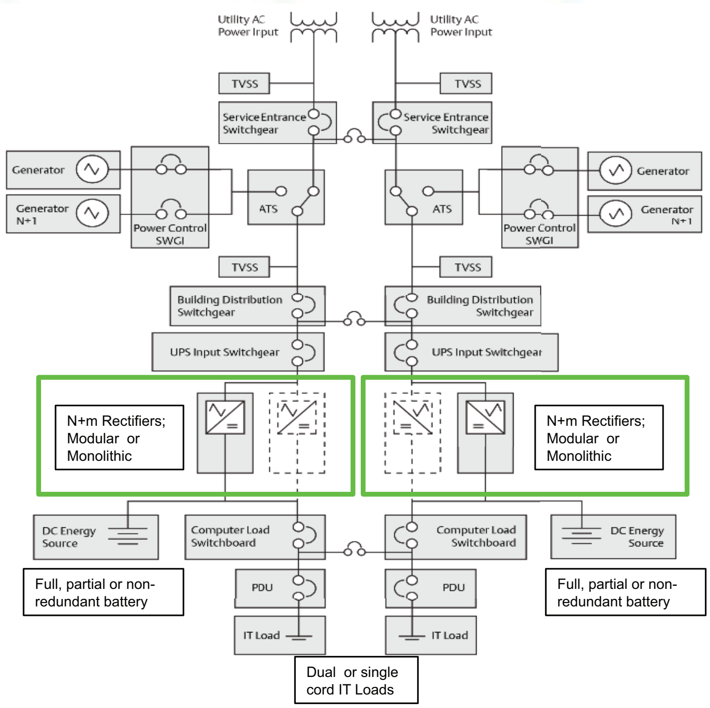


Figure 5: 380 Vdc System Equivalent to BICSI Class F4 (Source TGG)

The only difference between Class F3 and Class F4 application of dc-UPS is the number of rectifiers and batteries in each power path. In Class F3 the left power path (with batteries) is the normal power path to loads. Right power path is an alternative path (equivalent to ac-UPS bypass) for maintenance purposes and does not require the battery back-up. As in the case of Class F1 and F2, the number of redundant rectifiers in each path is dependent on a desired availability level (N+1 to N+m). Class F3 is easily upgraded to Class F4, by adding rectifiers and batteries.

In conclusion, a single configuration of dc-UPS distribution should be considered as a basic building block for all of BICSI 002-2011 requirements (as shown in Fig 1) with a provision for adding modular rectifiers and batteries. This configuration can be applied in single system topology for Class F1 and F2 and a dual (2N) system for class F3 and F4. The system can be expanded seamlessly (scaled in small increments) for capacity and/or redundancy to match the facility loads at initial capacity while accommodating future expansion and eliminating the "stranded" power syndrome. There is no need for initial deployment of a bypass path and other circuitry sized for ultimate system rating as in the case of ac monolithic UPS systems. With modular dc-UPS systems, battery recharge time is controlled by adding rectifiers as needed rather than overrating the UPS as is the case for monolithic systems.

Alternative DC Topologies

The industry drive for infrastructure cost reduction, elimination of unnecessary redundancies, the desire for selective redundancy capabilities, and the elimination of "stranded" power capacity opens the door for alternative topologies. These alternatives provide sufficient resiliency, but may not strictly comply with the existing ac power based classifications previously discussed.

380 Vdc-UPS System with Dual ac Input and dc Output Configuration

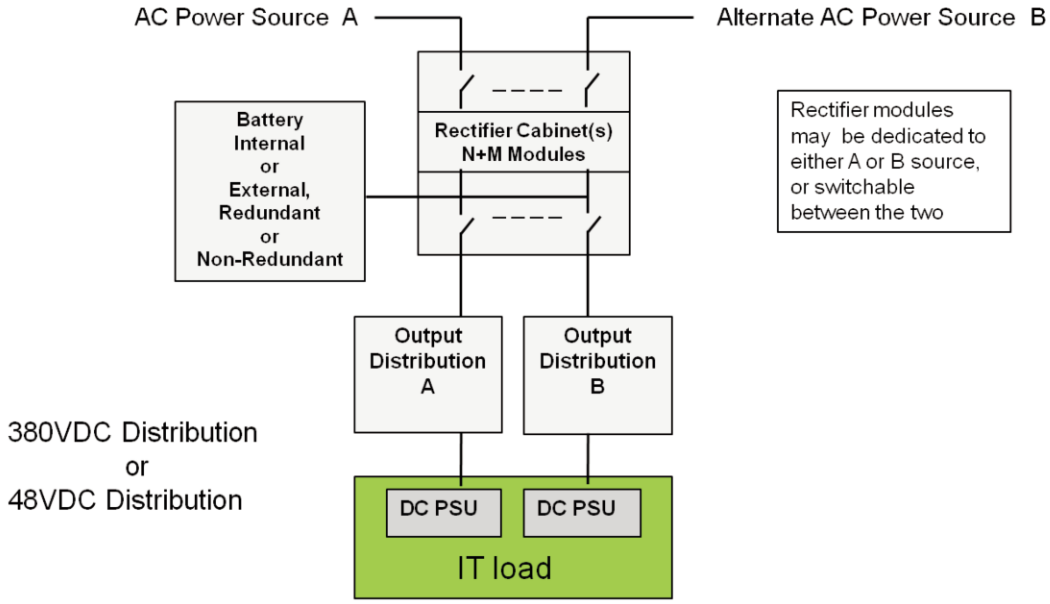


Figure 6: 380 Vdc Configuration Allowing Concurrent Maintenance Upstream and Downstream

The configuration shown in Figure 6 allows servicing of the upstream and downstream distribution equipment without interrupting facility operation by manually switching UPS input and output from one power path to another. This configuration, although not meeting the strict BICSI Class F3 definition, allows for concurrent maintainability and operation and is suitable for facilities utilizing distributed in row distribution. The only common point in the power path is the dc-UPS that is serviceable without system shutdown i.e. live replacement of all major system components due to modularity and resilient design.

Hybrid ac/dc System

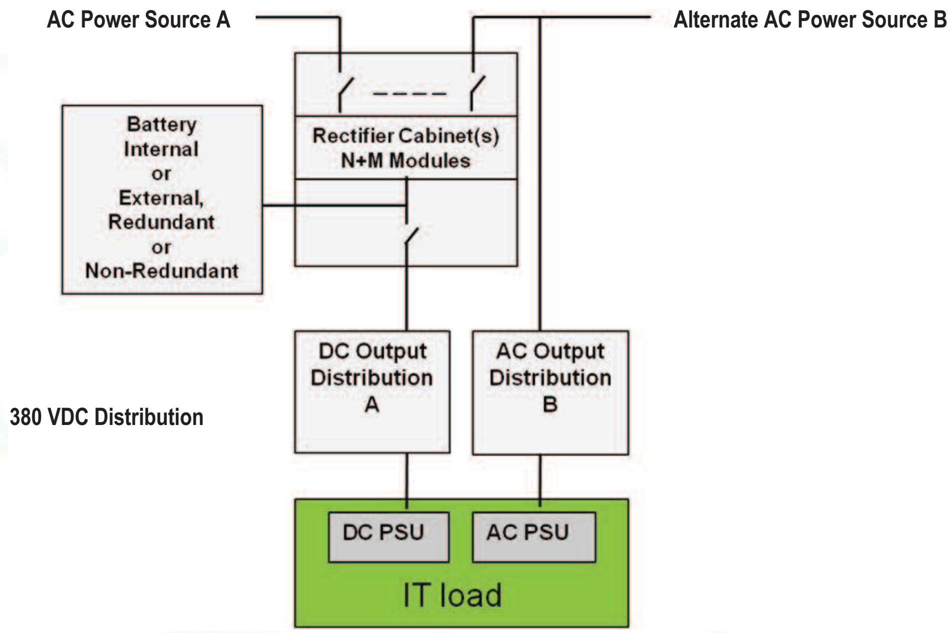


Figure 7: Hybrid ac/dc Configuration

Figure 7 outlines another configuration option that is suitable for dual corded servers equipped with one dc and one ac power supplies or a single dual input (ac and dc) power supply (similar to Facebook approach). The right power path (Source B) can be designated as normal source or perform a function similar to an ac-UPS bypass. The left power (Source A) source provides back up in case of utility failure. The following modes of operation are possible:

1. Both ac and dc PSUs are active and share the load.
2. Power supply B can be designated as a preferred source while power supply A operates in a stand-by mode and is activated only when source B is not available. This mode of operation may provide a slightly higher efficiency under normal conditions. However, it requires a control circuit coordinating the switchover between the two power supplies within acceptable time.
3. Power supply A is designated as a preferred source and power supply B is in a standby mode. Power supply B is activated when distribution A is in the battery back-up mode. In this case switching time between the sources is not critical.

This configuration also allows for concurrent maintenance of all system components without critical bus shutdown.

Partially Redundant 380 Vdc System

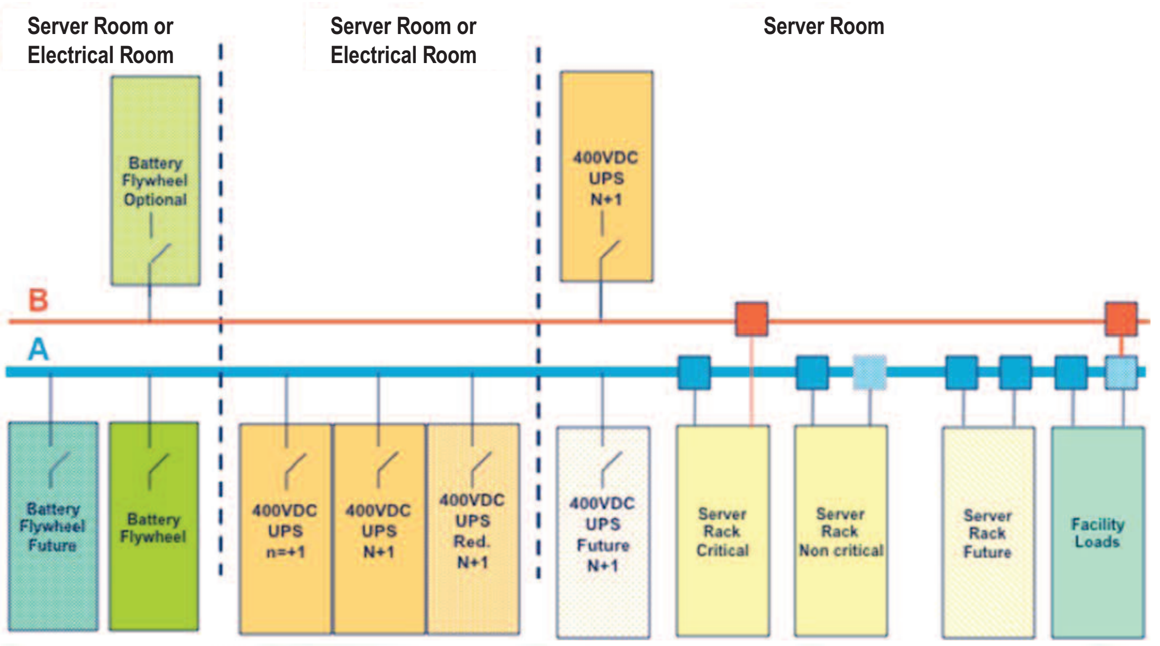


Figure 8: 380 Vdc Distribution Configuration for Sites Requiring Partial Redundancy

Figure 8 shows dc distribution configuration for sites that require partial redundancy only. This example depicts implementation of a dc distribution using a bus-way with circuit drops located on top of server racks. Circuit A is sized for the total load while circuit B is sized to support essential or critical loads only. Energy storage (such as a flywheel or batteries) and DC-UPS can be located remotely to/adjacent to powered ICT equipment in the server room. Adding additional capacity is simplified and equipment location on site is flexible.

Practical Implementation

380 Vdc distribution is as flexible as ac distribution as far as interconnecting methods are concerned. Possible interconnecting methods, shown in Figure 9, can comprise of discrete wiring in conduits, cabling placed on wire-ways, or a busway dependent on customer preference and acceptable methods approved by the local AHJ (authority having jurisdiction). Interconnection cabling sizes are calculated per NEC tables (in the US) just as with ac cabling.

Both circuit breaker and fuse protection components for 380 Vdc are available today. Bus way connections offer greater scalability during equipment relocation and individual cabinet upgrades. Dual bus configuration offers higher reliability. Dual server connection permits system expansion and maintenance without critical bus shutdown.

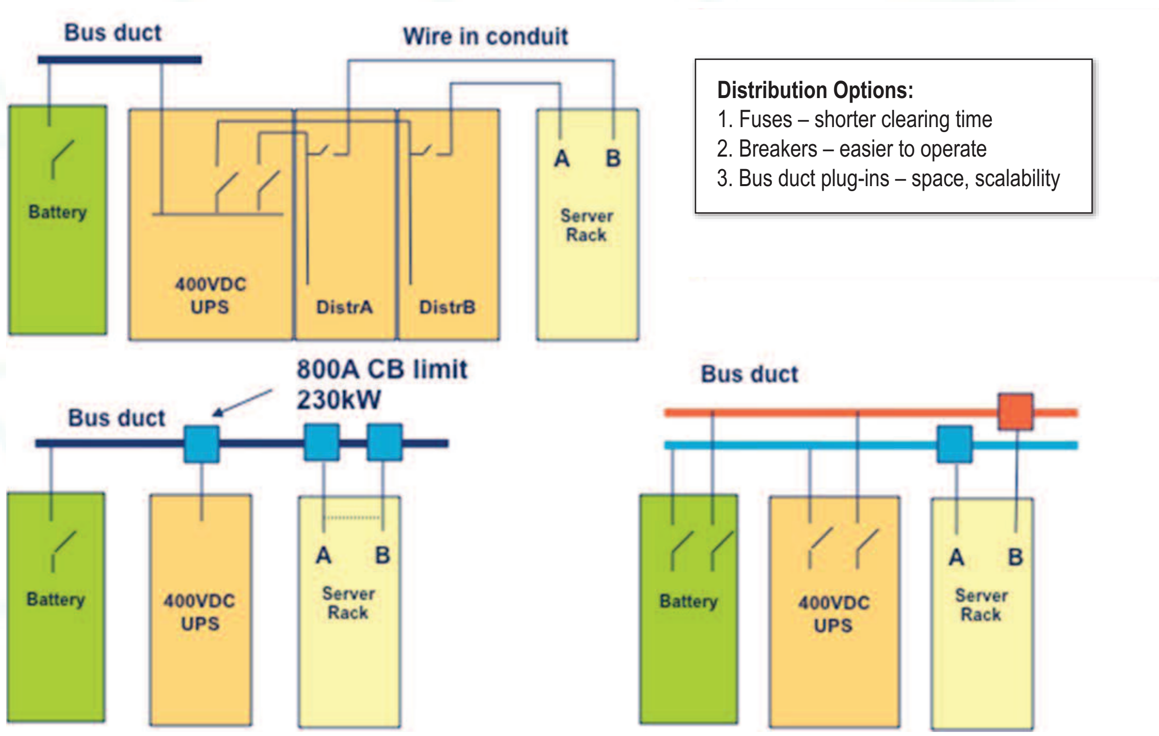


Figure 9: 380 Vdc Distribution Options

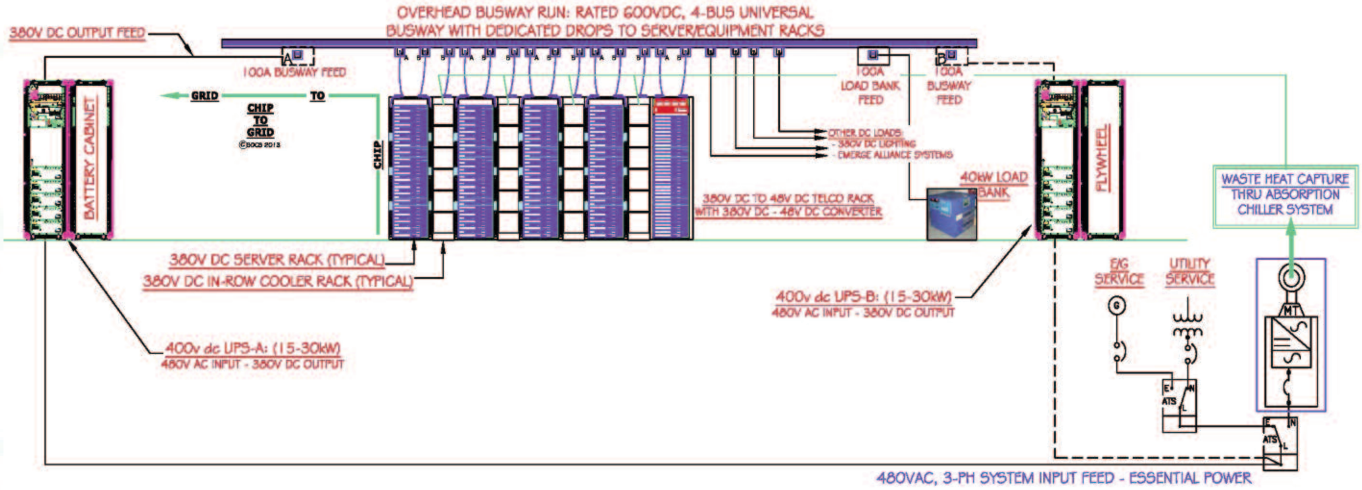
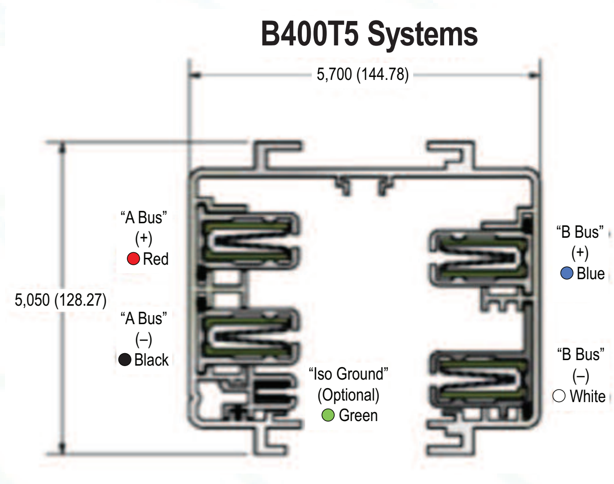


Figure 10: Example of Implementing N+1 and 2N 380 Vdc Distribution Concept for a Small/Medium Site

Figure 10 is an example of a N+1 and 2N, 30 kW deployment. For N+1 configuration dc-UPS "A" is connected to loads via overhead bus-way and pluggable bus-way feeds equipped with a circuit breaker. Power to server racks is delivered via plug-in circuit drops equipped with a circuit breaker and cable drops permitting easy disconnection of any individual rack from the supply. Optionally these feeds can be provided with individual metering and connectors to further enhance the system functionality. A and B distribution from the busway can be deployed if servers are of dual cord design (a reliability enhancement).

For 2N configuration, a second dc-UPS system B is added. There are two options for connecting system B to the load dependent on the busway construction (Figure 11):

1. Use a second, independent busway
2. Utilize internal busway construction to provide both A and B power within the same busway frame as shown below.



400A BUSWAY DISTRIBUTION COMPARISON

208 Vac @ 400A = 144kVA/130kW(0.9pf)

415 Vac @ 400A = 287kVA/258kW(0.9pf)

380 Vdc @ 400A = 152kVA X 2 = 304kVA/kW (1.0pf)

Figure 11: Busway Application for dc Distribution (Source Universal Electric)

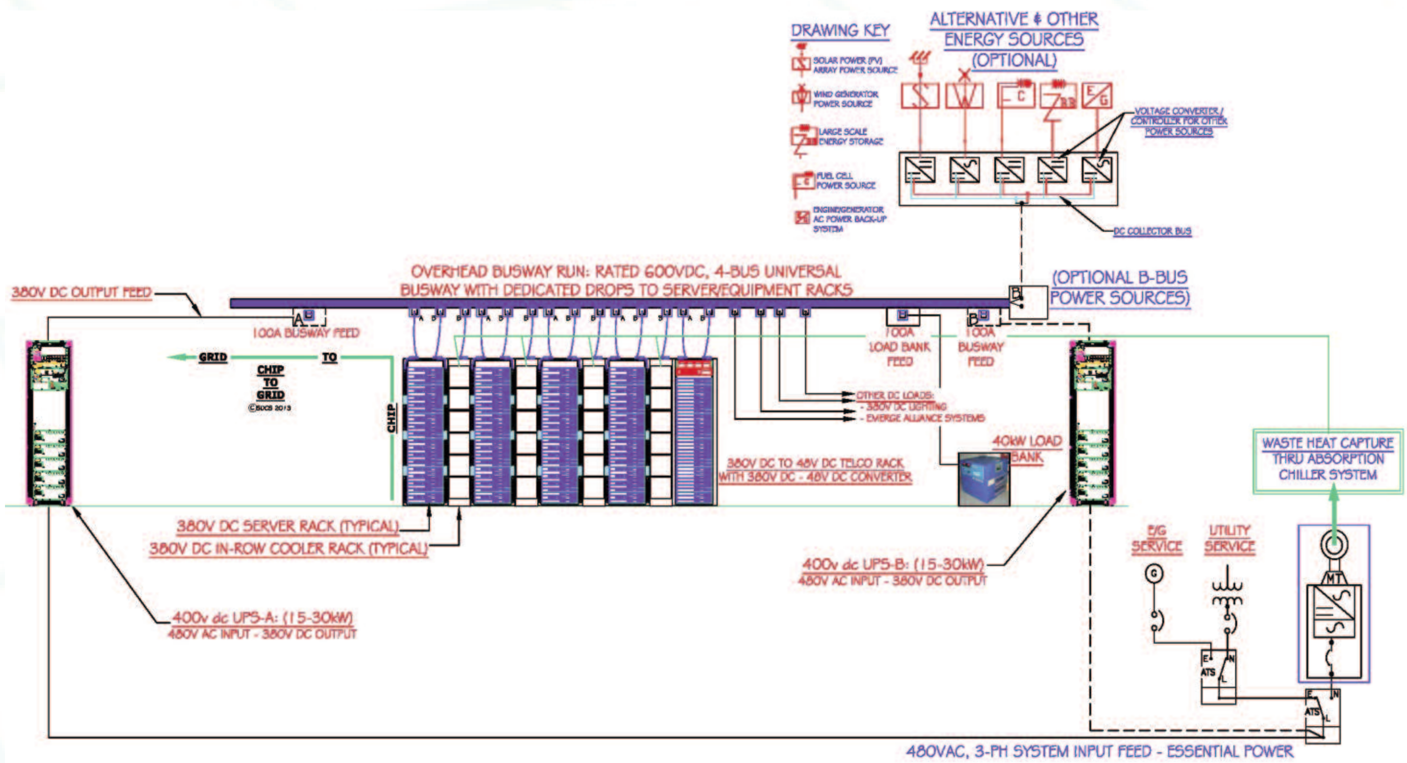


Figure 12: Example of Utilizing Alternative Energy for the "B" Feed

Figure 12 illustrates how site generated energy sources can be coupled to the dc distribution bus by using the B-side of the busway. The connection can be accomplished during initial installation, during expansion, or anytime renewable resources are added without impact on ac distribution infrastructure. The application of 380 Vdc to the modern data center has significant implications that will be developed more fully in additional papers as summarized below:

Implications

The IT Case for 380 Vdc

While this presentation of topologies addresses data center infrastructure essentially looking from the outside in, the ultimate value of the data center is the “chip”. As such, it is valuable to take some time to look from the inside out.

Looking Outward from the Chip

Components inside IT equipment inevitably demand dc power. CPUs, memory, drives and even fans all consume dc power at voltages between 1.35 – 12 Volts. A typical system designed for ac input utilizes ac/dc power supplies (ac PSUs). Enterprise ac PSUs can have single or three-phase ac inputs and convert from the ac input voltage to an output dc voltage for distribution throughout the chassis. A common output voltage for an ac/dc power supply is 12 Vdc. However, the conversion between AC input and 12 Vdc output happens in multiple stages. All current ac/dc power supply designs first rectify and boost the input to approximately 380 Vdc. By choosing a nominal 380 Vdc input, conversion of existing ac designs into dc designs is potentially simplified by leveraging the circuit that already exists in functional ac input power supply designs.

Issues with ac Power

AC power is characterized by a sinusoidal voltage (60Hz in the US, 50Hz in much of the rest of the world). ac power is provided to a building from the utility in three phases. In three-phase power, each phase has a voltage that is 1/3 out of cycle. Utilities and much of the datacenter equipment (like UPS’s and generators) expect the load on the phases to be nearly balanced. Phase balancing creates a significant challenge for datacenter operations. Many of the devices in the datacenter have single-phase power supplies. To support single-phase power supplies, the three-phase power is split into single phases. It is up to the deployment teams to make sure that power consumption is spread evenly among the different phases. This effort is complicated by the fact that power consumption is highly dependent both on hardware configuration and on workload; as workloads change, a hardware distribution that is balanced today may not be balanced tomorrow.

With 380 Vdc power, the notion of phase goes away completely. ac power factor, phase angle and many other complicating factors are no longer relevant. From an operational standpoint, this relieves the end user burden of balancing the load. In addition dc distribution does not suffer from losses related to skin effect and proximity effect present in ac circuits due to fundamental frequency and harmonics content and eliminates the need for components derating and additional filtering.

Why not use -48 Vdc Power?

Though not always the case, it is typical that most power in the datacenter is consumed by servers versus storage or networking. A dense rack mount server might pack 600 Watts of power consumption into 1 rack-unit of height (1.75"). With 42 rack-units of available space in a standard rack, this means that a fully populated rack might consume more than 25,000 Watts of power. Power is proportional to voltage and current. At -48 Vdc, this would require 520 Amps of current! To put this in perspective, a typical ac facility plug can supply 30 Amps of power, so while -48 Vdc offers many of the benefits of 380 Vdc, larger currents and associated wiring costs make it prohibitive for today's higer powered loads.

Improved Reliability and Resiliency

In any electrical distribution system, both system availability and Total Cost of Ownership (TCO) are driven by a common denominator – simplicity of the distribution topology. Because dc data center infrastructure requires fewer components (especially series connected system elements such as breakers, terminals, connection points), it is less prone to failure and downtime resulting from component malfunction or operator error. In addition, by eliminating the need for load balancing, the predictability of system performance is enhanced and stranded power is eliminated. This results in simplified site evolution planning especially for sites requiring frequent upgrades.

High resiliency of dc distribution is confirmed by many years of successful operation in telecom applications. dc UPS and dc distribution resiliency (tolerance to single and multiple components failures without immediate impact on system availability) comes from several application principles derived from extensive telecom experience in deployment of mission critical systems:

- Modular/redundant conversion stage – (N+m). System continues operation even with multiple rectifier failures over a sufficiently long maintenance window that in most cases no immediate corrective action is necessary. Failed components can be easily replaced on site.

- Independent, distributed controls – main system controller failure does not impact power delivery
- Extended failed components replacement windows
- Fewer distribution breakers connected in series in a distribution system
- No need for complex synchronization circuits
- Simplified maintenance – hot swappable components

Reliability studies and records conducted to date indicate that 380 Vdc systems (much like 48 Vdc systems) exhibit several order higher availability and resiliency than equivalent systems employing ac-UPSs.

Reliability and Efficiency improvements have a direct impact on Total Cost of Ownership. In addition, simplified design directly affects initial design costs and life cycle costs of the center reflected by ease of operation and reduced maintenance.

Total Cost of Ownership

dc power distribution reduces the overall costs of developing and operating a data center. By reducing the investment in infrastructure, maintenance and operating costs, dc power distribution allows a greater percentage of investment to be leveraged more productively.

Safety

All dc topologies presented include the implication that all safety codes and testing/listing agency requirements are met. Follow on studies and new technologies and equipment are being developed with the goal of making dc systems even safer. Clearly, there are characteristics within dc power distribution systems that lend themselves to greater control and response time when undesirable situations arise.

Efficiency

Improved and higher system efficiencies are everyone's goal in these days of higher energy costs, increasing energy demands and volatile state of fossil fuel resource availability and supply. AC power system efficiency has made great strides in recent years. There are greater opportunities for advancement with dc power system deployment as the world looks to alternative energy integration and dc micro-grid deployments.

Looking Forward

While this paper presents some of the most current thinking for the implementation of 380 Vdc to the modern Data Center, this is only the beginning. New applications of existing technology are being presented every day and new technology is being developed.

Versatility, application flexibility and simplicity of dc distribution for mission critical sites allows for addressing any type of critical application and permits achievement of any availability goals required by a user with real potential of infrastructure simplification and cost reduction. As N deployment of N 380 Vdc systems accelerates, so will the pace of innovation in components and architecture optimization.

Acknowledgements

The EMerge Alliance, an open industry association developing standards leading to the rapid adoption of dc power distribution in buildings, relies on its members to contribute white papers such as this. Thank you to BJ Sonnenberg of Emerson Network Power and David E. Geary, PE of Universal Electric's StarLine DC Solutions, for spearheading the creation of this white paper. In addition, thank you to Mietek Glinkowski, PE of ABB, Mark Murrill of Emerson Network Power and Bill Campbell of Emerson Network Power/Liebert for their valuable advice and comments. Many other members contributed from the IT community and regulatory agencies whose companies prohibit them from using their names. Thank you all for taking your time and sharing your knowledge and experience to create this paper.

References

Aldridge, Tomm, Pratt, Annabelle, Kumar, Pavan, Dupy, Dwight, Allee, Guy, Evaluating 400V Direct-Current for Data Centers, Intel Labs White Paper, 2011

ANSI/BICSI 002-2011, Standard, Building Industry Consulting Service International, Rev 2, 2011

Campbell, William., Handlin, H., Murrill, Mark, *AC and DC Power Distribution for Data Centers*, The Green Grid Tech Forum, March 2012

EMerge Alliance Data/Telecom Standard, Emerge Alliance, 2012

ETSI EN300-132-3-1, Standard, European Telecommunications Standards Institute, 2012

Geary, David E., *Phasing Out Alternating Current Directly*, Universal Electric/Starline Solutions White Paper, 2013

Hirose, Keiichi, Tanaka, Toshimitsu, Babasaki, Tadatoshi, Person, Sylvain, Foucault, Oliver, Sonnenberg, BJ, Szpek, *Grounding Concept Considerations and Recommendations for 400 Vdc Distribution System*, IEEE/Intelec 2011

ITU-T 1200, Recommendation Database, International Telecommunications Union, 2012

Pratt, Annabelle, Kumar, Pavan, Aldredge, Tomm V., *Evaluation of 400Vdc Distribution in Telco and Data Centers to Improve Energy Efficiency*, IEEE/Intelec 2007

Salato, Maurizio, Zolj, Adnan, Becker, Dustin, Sonnenberg, BJ, *Power Systems Architectures for 380 Vdc Distribution in Telecom Datacenters*, IEEE/Intelec 2012

Shuguang, Qui, Fuping, Hou, Hui, Jing, *Study and Application on High Voltage DC Power Feeding Systems for Telecommunications in China*, IEEE/Intelec 2012

Talapko, Domagoj, *Telecom Datacenter Power Infrastructure Availability Comaparison of DC and AC UPS*, IEEE/Intelec 2012

Tanaka, Toshimitsu, Asakura, Kaoru, Babasaki, Tadatoshi, *Trends in International Standardization of HVDC Power Feeds*, NTT Technical Review 2013

Tanaka, Toshimitsu, Hirose, Keiichi, Marquet, Didier, Sonnenberg, BJ, Szpek, Marek, *Analysis of the Wiring Design for 380 Vdc Power Distribution System in Telecommunications Site*, IEEE/Intelec 2012

Resources

ANSI/BICSI 002-2011, www.bicsi.org

EMerge Alliance Data/Telecom Center Standard, www.EMergeAlliance.org

ETSI 300 132-3 Standard, European Telecommunication Standard Institute www.etsi.org

IEC, International Electrotechnical Commission, www.iec.ch

ITU, International Telecommunication Union, www.itu.int

NTT, Nippon Telegraph and Telephone, www.ntt.com

TGG, The Green Grid, www.the greengrid.org

Appendix A: BICSI 002-2011

ANSI/BICSI 002-2011,
Data Center Design and Implementation Best Practices

This standard was developed mainly for ac distribution containing ac-UPS systems however, it contains a short reference to dc power systems.

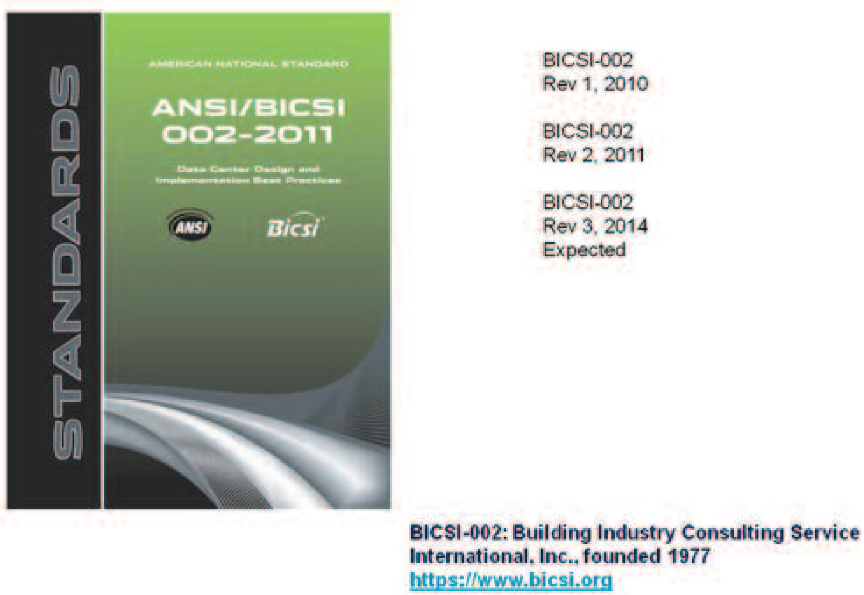


Figure 13: ANSI/BICSI 002-2011

Specifically, BICSI 002-2011 states in §9.3.13.1 that:

> "DC power systems that serve critical loads are common in two forms:
> - the primary power source for access provider and carrier equipment;
> - as an alternative to dc power in computer rooms because of energy efficiency, design simplification, and ease of paralleling alternative energy sources.

The BICSI Standard goes on in §9.3.13.2 to state:

> "Direct current power systems that serve critical loads have the same availability requirements as ac power systems with additional consideration given for personal safety."

380 Vdc distribution topologies fully meet the objective of this standard. This paper describes, in general terms, 380 Vdc architectures that are directly equivalent to those proposed by BICSI 002 for ac solutions. Additionally, possible dc topologies are presented that take advantage of the simplicity and modularity of dc distribution that provides for new, innovative approaches addressing critical site power availability and reduced deployment costs.

Appendix B – The EMerge Alliance Data/Telecom Center Standard

The EMerge Alliance has introduced a standard to guide in the design and implementation of 400 Vdc topologies in the modern data/telecom center.

Rationale

This direct current-power distribution system (DC-PDS), EMerge Alliance Data/Telecom Center Standard [the Standard], is intended to assist in addressing a number of growing challenges in designing, building and operating data and/or telecom centers in commercial buildings. These challenges include:

- The need to improve power consumption efficiency and system reliability;
- The need to adapt to fast-changing device technologies and increasing equipment load densities used in these spaces without incurring large upgrading costs;
- The need to facilitate and integrate renewable energy sources into the power sourcing for a building.

The overall purpose of the Standard is to bridge the gap between commercial building designs meant to accommodate uses that may not change for 30 years or more and ones that need to accommodate dramatic life-cycle changes that occur as often as every one to three years. This is an issue typical of data/telecom centers. The EMerge Alliance Data/Telecom Standard defines a convenient and safe system of voltages and electrical interfaces between the electrical power feed infrastructure specific to the data/telecom center and the load devices that use and control power within that space. Specifically, the Standard defines a nominal 380 Vdc-PDS infrastructure that interconnects sources of power to devices in the data/telecom center that draw the power.

Primary Goals of the Standard:

- Allow faster installation time
- Simplify and allow more flexible reconfiguration capability
- Provide for the use of safe power levels, as defined by the 2011 NFPA® National Electric Code® (see Related Documents Section 2.).
- Allow competitive first-cost in modular / building blocks
- Allow the use of direct current (dc) electric power distribution that facilitates the reduction of energy loss and improves system reliability
- Facilitate the integration of renewable and other dc energy sources such as solar photovoltaic panels, wind, fuel cell, batteries and other native dc power sources including building-wide dc power distribution.

Primary Objectives of the Standard (Limitations of this First Release)

- This first generation Standard for a system platform and its components is designed to support basic data center and/or telecom center equipment and systems. In either case, the intent of the standardized dc-PDS platform is to be highly flexible, allowing for quick and minimally disruptive installation, reconfiguration, relocation, upgrading and/or replacement of system equipment and other components by licensed trade and/or professional data/telecom center maintenance personnel.
- In addition, the rapid development of new dc power electronic systems and devices demands that this document be updated periodically in the areas of circuit protection, power systems control and arc flash protection.

Product Registration and Evaluation:

- EMerge Alliance Registered Products for this standard will be listed on the Alliance's Products registry web page.
- The EMerge Alliance Registered Product program helps specifiers to identify products that are designed to meet requirements of the EMerge Alliance Data/Telecom Center standard.
- New products that are developed and evaluated to the standard will be added to the website on an ongoing basis.

The EMerge Alliance Data/Telecom Center Standard Version 1.0 is a practical guide for the hybrid use of dc power in commercial data centers and telephony central offices and allows the buildings of today to adapt to the needs of tomorrow. Data centers and telephony central offices are huge and growing energy users in nearly every building the energy efficiencies that can come from dc power distribution can be significant. But power efficiency is not the only advantage to a data center operator. Higher reliability, smaller equipment footprints, lower capital outlay and lower operating costs including maintenance can be equally compelling reasons to use dc power distribution. With double digit growth still being projected for data and telephony, the time to consider dc power integration is now.

The Standard offers unprecedented design and space flexibility and provides new opportunities to reduce energy usage while improving reliability, reducing system complexity and cost, and improving sustainability. The Standard calls for the conversion of existing ac power sources to dc power at the distribution level rather than at the rack or within individual servers and other IT devices. This upstream conversion also facilitates optional connections to on-site alternative power generation or storage sources, including solar panels, micro-turbines, fuel cells, and other alternate sources that naturally supply dc power. The option to use native dc power sources for dc loads improves the ROI from on-site renewable investments, reduces energy costs and improves a building's environmental footprint. Having direct access to safe, dc power is the next logical step for commercial buildings. The number of dc powered devices (computers, lights, sensors, etc.) in workplaces of all types is high and is expected to skyrocket with the introduction of new superefficient solid-state lighting and continued growth in information technology applications. By eliminating the inefficiency of numerous ac to dc power conversions, the energy efficiency of building can be improved. Beyond efficiency, the use of dc has the potential to eliminate future landfill waste, and reduce product shipping weights and overall product costs by eliminating unnecessary electronic content used just to accommodate the exclusive use of ac power.

www.EMergeAlliance.org