ISSUES RELATING TO THE ADOPTION OF HIGHER VOLTAGE DIRECT CURRENT POWER IN THE DATA CENTER

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Executive Summary

Higher voltage direct current (HVdc) power distribution configurations have the potential to reduce energy consumption and increase efficiency in the data center. HVdc systems also typically involve fewer components, which could mean better reliability and total cost of ownership than alternative power systems.

However, if data center operators, equipment manufacturers, and others opt to make HVdc a primary power distribution configuration, some critical issues need to be resolved for maximum cost-effectiveness, ease of adoption, and safety related to HVdc. Although difficult, establishing global HVdc standards will help smooth adoption and avoid some of the expense and inefficiencies that the industry has had to deal with related to variances in AC power systems.

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I. Introduction

Data center managers are typically confronted with three mandates for electrical infrastructure: design for reliability/availability, energy efficiency (lowest operating cost), and space efficiency/utilization. The priority of these three mandates may switch, depending on the situation.

Most data centers today use alternating current (AC) power systems, which distribute electricity somewhere between 100Vac to 600Vac throughout the facilities. However, a growing number of direct current (DC) advocates are promoting the use of DC power in the data center.

For purposes of this paper, the term "higher voltage DC (HVdc)" is used to identify voltages in an information and communications technology equipment (ICTE) space that are higher than 200Vdc and lower than 600Vdc.[1] The HVdc term is used to distinguish voltages in this range from the more common 48Vdc widely used in telecommunications.

The Green Grid—a global consortium of IT companies and professionals—performed qualitative and quantitative comparisons of different power distribution configurations in 2008, using production-grade equipment. There may be advantages in efficiency for HVdc. The Green Grid's quantitative efficiency analysis indicates that power consumption may be lower with HVdc (see Figure 1).

[1] "Low voltage" is defined by the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) as any voltage below 1 kVac or 1.5 kVdc. In the United States, the National Electrical Code® (NEC)® treats anything below 600 Vac as "low voltage."

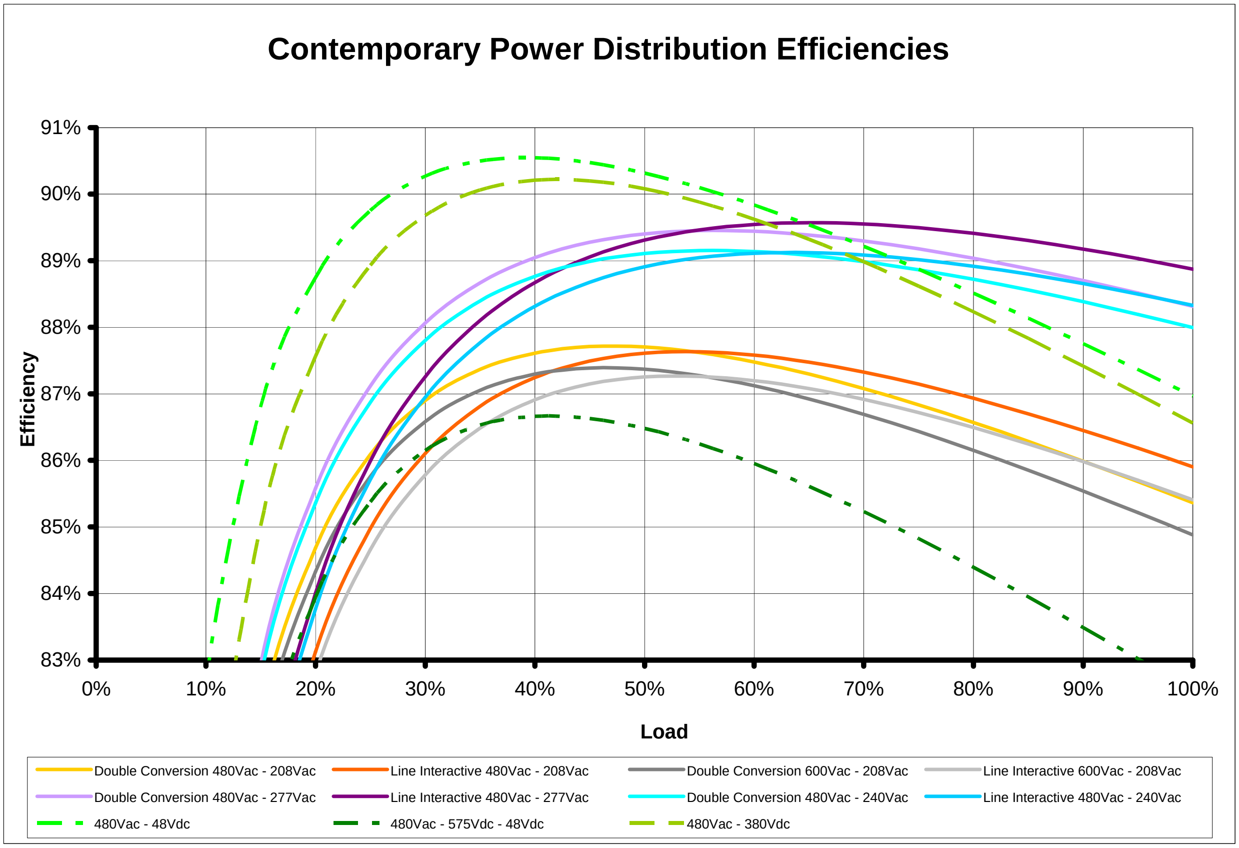

Figure 1. End-to-end efficiency comparison ending at 12Vdc (excluding legacy 480Vac to 208Vac) from The Green Grid's *Quantitative Analysis of Power Distribution Configurations for Data Centers WP#16*[2]

The Green Grid maintains a neutral stance on power distribution configurations; its overarching goal is to promote higher-efficiency data center practices. But if data center operators, equipment vendors, and other proponents around the world decide to make HVdc a primary power distribution configuration, The Green Grid sees a great deal of value in the establishment of global standards to help smooth the transition and avoid some of the expense and inefficiencies that the industry has had to deal with related to variances in AC power systems.

HVdc will have trouble building a groundswell of support as a viable option unless certain key issues are resolved. These issues, which have been debated for the last few years, are not so much technical as they are practical, in that it can be extremely difficult to get multinational, regional, and local organizations to all agree on which standards would be the best.

This white paper identifies some of the areas that need to be addressed for maximum cost-effectiveness, ease of adoption, and safety related to HVdc. Please see the Glossary for a list of acronyms used in this paper.

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[2]The naming convention shown in the chart incorporates the first voltage as the data center input voltage and the second voltage as the power supply unit (PSU) input voltage. Updated efficiency curves for components and topologies are available through the Power Configurations Energy Estimator: http://estimator.thegreengrid.org/pcee and http://estimator.thegreengrid.org/PCEE_FAQ.pdf.

II. Why Consider Higher Voltage DC?

Every time voltage is converted from AC to DC or from one voltage level to another, some of the power is lost in the conversion process. That wasted energy becomes heat, which the data center facility cooling system must remove, thereby contributing to higher facility cooling costs.

A typical North American AC system[3] (see Figure 2) drops the incoming AC voltage down through a series of conversions to 480Vac. A double conversion uninterruptible power supply (UPS) first converts AC to DC for battery charging, typically resulting in losses of 3% or greater. An inverter converts the voltage back to AC, typically 1% to 3% losses for this second conversion. A power distribution unit (PDU)—which, if it has a transformer, is a third conversion, typically with 1% to 2% losses—distributes AC voltage to power supply units (PSUs) in each of the various ICTE loads. The PSU converts the voltage to 12Vdc, currently with 6% to 10%[4] losses.

A typical HVdc system (see Figure 3) first uses a rectifier to convert the incoming voltage from AC to DC (for example, from 480Vac to 380Vdc) and then a PSU to convert it to 12Vdc. Eliminating the extra conversions means that HVdc power distribution configurations generally need no inverters and fewer step-down converters or intermediate voltages. While it is possible for HVdc power systems to have multiple voltage conversions, that typically would not be the case. This is due to the way that data centers usually design their power systems.

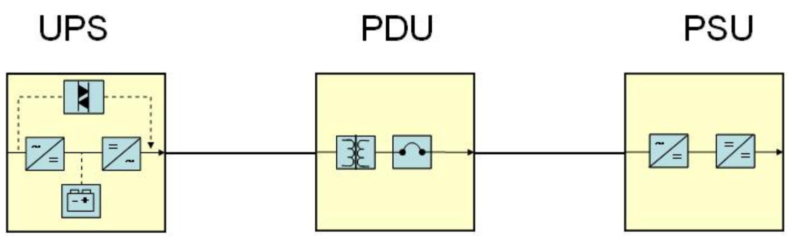

Figure 2. Simplified non-redundant AC system (North America)

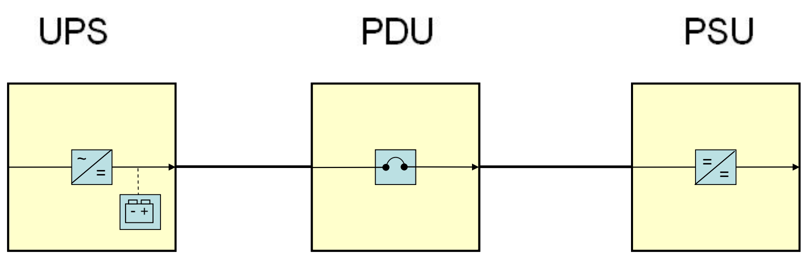

Figure 3. Simplified non-redundant HVdc system

[3] Typical voltages for other jurisdictions include 600 Vac in Canada, 380 Vac to 415 Vac in Europe, and 415 Vac in Japan.
[4] http://www.80plus.org/

With fewer individual parts involved, HVdc systems tend to be less complex and likely to be more reliable than their AC counterparts. In addition to conversion-related hardware, HVdc removes other elements, such as the sensing mechanisms that AC systems must use to ensure that equipment is in synchronization. Paralleling of sources in a DC system is simplified because synchronization is unnecessary. For example, it is easier to add solar, fuel cell, or other alternative energy sources because only a simple converter is needed between the source and the bus.

Synchronization mechanisms and bypass switches are just a couple examples of elements within an AC distribution system that would require a higher level of complexity compared with an HVdc power distribution configuration.

Due to the reduced complexity in HVdc power configurations, they are likely to be more reliable and easier to deploy and configure because phase balancing is not required. The reduction of complexity also saves space. Plus, HVdc systems have the potential to be more cost-effective for several reasons, such as fewer components in the UPS (and possibly in the PSU), reduced cable losses, and a reduced cable cross-sectional area, which requires less copper.

All that said, AC represents far more of a known quantity. HVdc is a relatively new concept and, while well-understood, there are not nearly as many scaled-up, production-level examples of HVdc power distribution configurations in operation. Initial HVdc products will likely vary widely among specific regions and vendors. Despite early efforts to agree on common specifications for HVdc products, the market has tended to reflect the same sorts of incompatible products and goals that have plagued the AC world.

Resolving all the competing goals, methods, and objectives currently at play is no easy task. Industry bodies have been working for several years but have been unable to make much progress toward achieving worldwide conformity and unity. Prompted by concerns about energy savings and environmental issues as well as the desire to promote unification activities, many groups worldwide have launched HVdc demonstration sites. In many cases, technical solutions already exist, but all the divergent criteria must be harmonized to enhance adoption. If HVdc were to be established as a global standard, the following issues need to be addressed:

- Battery attachment method
- Voltage range
- Adaption or creation of PSUs for HVdc
- Availability of full HVdc power chain and components
- Common grounding method
- Existing infrastructure installed in data centers

- Safety issues and regulations
- Qualification criteria

The following sections address each of these issues in detail.

III. Battery Attachment Method

There are two ways of attaching batteries to a system. The first method (see Figure 4) involves a direct connection of the battery to the power distribution bus, providing it with a "wide" voltage range (for example, 260Vdc to 400Vdc). The second method (see Figure 5) includes a DC-to-DC converter between the battery and the bus. This stabilizes the bus voltage, delivering a well-regulated or "narrow" voltage range (for example, about 360Vdc to 400Vdc) to the ICTE PSU.

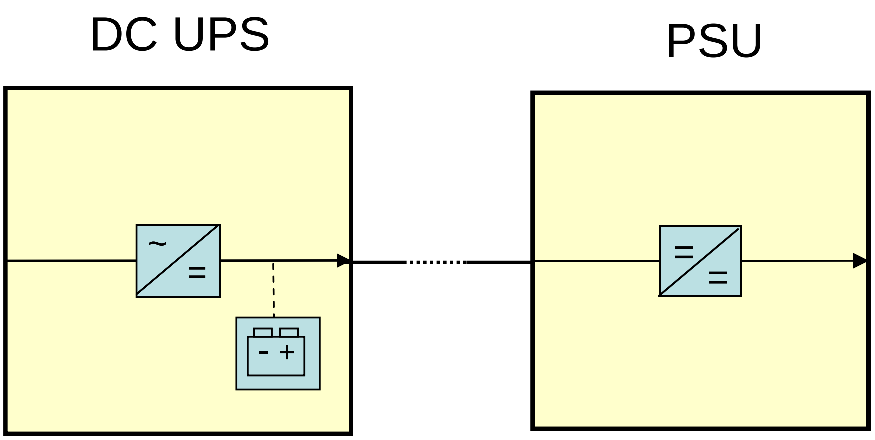

Figure 4. Battery attachment method for HVdc power distribution configurations, wide range

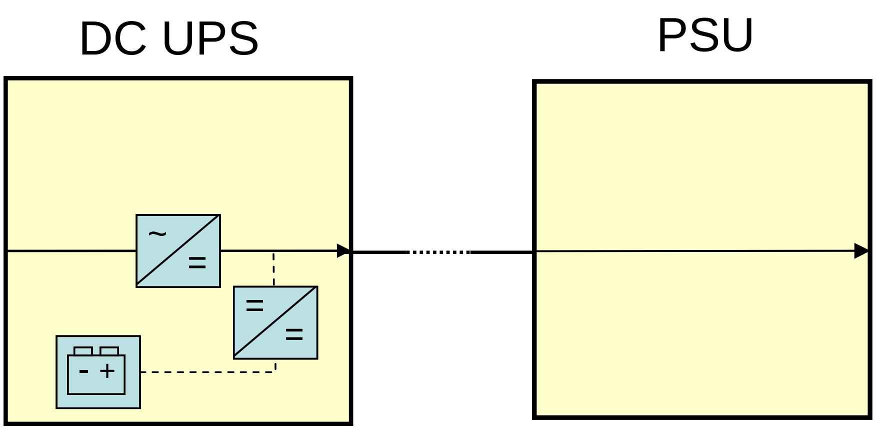

Figure 5. Battery attachment method for HVdc power distribution configurations, narrow range

In the presence of power failure and battery discharge, the battery voltage decreases (see Figure 6). Although a battery may initially supply a certain voltage to a load when mains power is interrupted, battery voltage will almost immediately begin to drop and will continue to decline until the end of the battery discharge. The older the battery, the faster the voltage will drop. As voltage drops, current increases proportionately. The breadth of the voltage range is fundamental to any discussion about standardization of DC voltage. The example in Figure 4 depicts valve-regulated lead-acid (VRLA) batteries, showing one option for float voltage.[5]

[5] Float voltage: a VRLA battery sits for 99% of the time at a float voltage of 2.25 to 2.27 volts per cell (VPC).

Isolating the battery from the output voltage via the DC-to-DC convertor (narrow range) compensates for the declining voltage in the presence of a power failure. Regardless of the current battery voltage, the bus always maintains the specific voltage required by the ICTE PSU. The additional DC-to-DC conversion stage can reduce UPS efficiency by as much as 2% during the converter's operation, although during normal system operation (where the converter is not providing full system load), the losses will be considerably less.

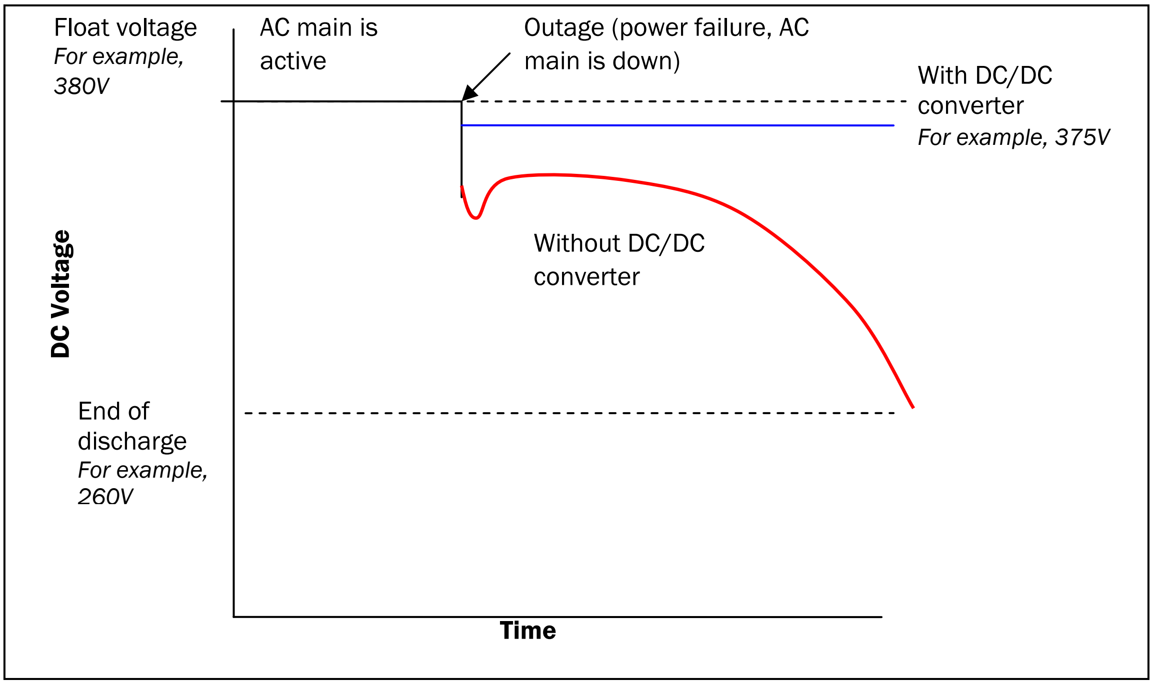

Figure 6. Bus voltage range example

The appropriate input voltage design range for ICTE equipment PSUs will be determined by whichever of the two battery attachment methods is adopted. Advantages and disadvantages of each approach are found in Table 1.

Discharge voltage: In a UPS application, the battery typically discharges to an end-of-discharge voltage of around 1.67 VPC (as shown in Figure 4).
Recharge voltage: During recharge, the DC bus voltage might go up to 2.29 to 2.31 VPC (not shown in Figure 4).

	Narrow-Range		Wide-Range	
	Advantage	Disadvantage	Advantage	Disadvantage
DC UPS and battery	The UPS battery configurations can be more flexible with the converter, ensuring the proper voltage is delivered	A small power loss occurs with the change in voltage; the UPS must be larger and more expensive The additional converter negatively affects reliability (single point of failure during battery discharge)	Minimal losses Smaller, less-expensive UPS More reliable because of fewer components	Some restriction on the UPS battery configurations (defines output voltage range)
PSU in ICTE	ICTE PSUs can be smaller, less expensive, and more efficient when designed for a specific, narrow voltage range	Custom design may be required, which could mean more up-front cost to the vendor and user	A data center can maintain the size, cost, and reliability advantages of the less-complex wide range Chance of parts and design shared with AC PSU	The input voltage range must be wide enough to accept the wide voltage range from the DC UPS and battery
Total System	Cables, breakers, and other parts can be optimized because they must only accommodate the specific, narrow voltage range		No extra conversions take place, so no heat is generated that must be removed/cooled	

Table 1. Advantages and disadvantages of narrow-range and wide-range bus regulation

A decision between narrow-range and wide-range battery attachment needs to be made because the method has an impact on determining voltage range specifications for HVdc. While narrow-range buses make a number of the voltage range issues a lot easier to handle, the wide-range buses appear more likely to be the chosen method because often they are simpler, smaller, and cost less.

IV. Voltage Range

In the long term, it would clearly be an advantage to have a single data center DC voltage used worldwide. While 380Vdc has been successfully used in multiple demonstration projects, many options exist for HVdc voltage ranges. It's an important specification to agree upon because the range between minimum and maximum voltage affects many different aspects of power standardization across a data center, including:

- System efficiency

- AC PSU redesign
- Cable sizing
- Product cost
- Safety
- Component selection
- Standards

As seen in the previous section, the battery attachment method influences how wide a range of voltage flows from the UPS to the ICTE. Battery configuration also has an impact; the float (charged) and discharge voltages of direct-connect batteries determine the ICTE voltage range.

Figure 7 shows the relationship between power infrastructure and ICTE voltage ranges for the wide range (assuming the widely used 2-volt lead-acid cells). The yellow boxes illustrate typical battery configurations (based on regular practice with 48Vdc systems). The blue boxes represent the most commonly talked-about voltage ranges for ICTE, although some companies have also promoted 575Vdc. The battery voltage range in yellow must be covered by the input voltage range of the ICTE in blue.[6]

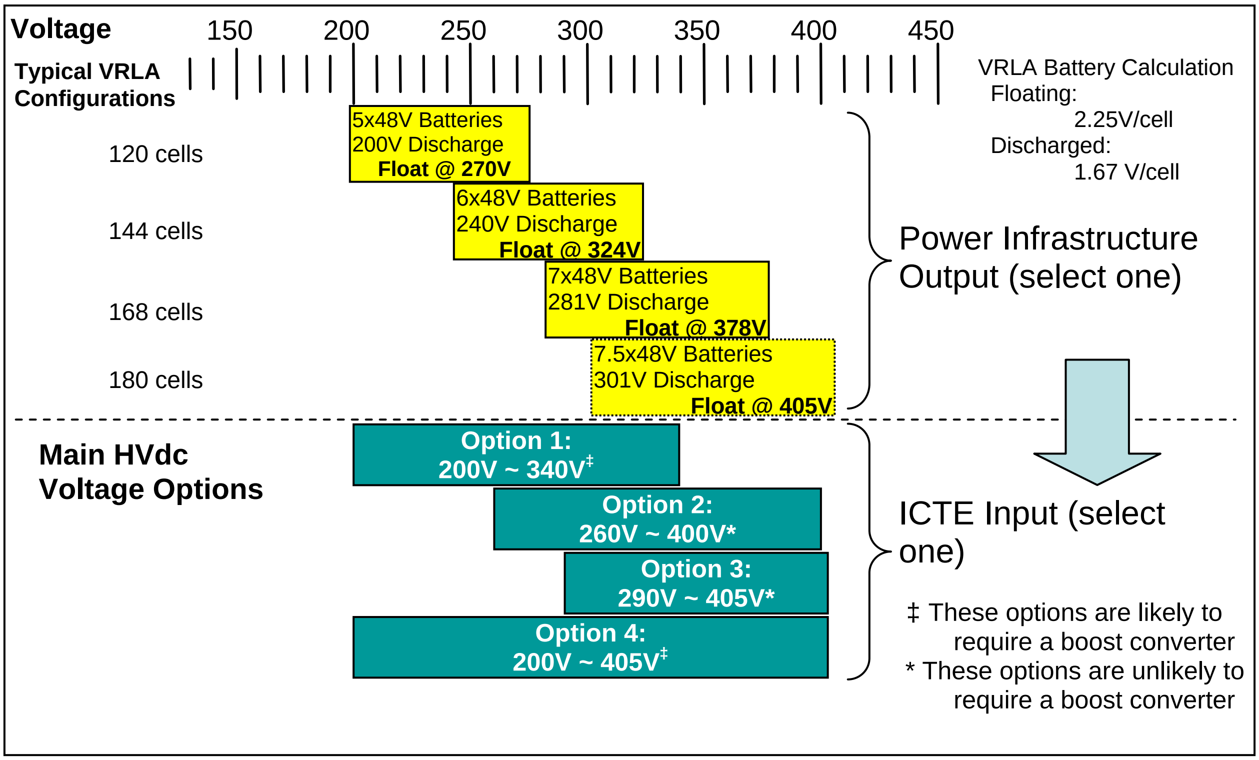

Figure 7. Relationship between power infrastructure and ICTE voltage range

[6] The voltage drop of the wires should also be considered when looking at an end-to-end efficiency review of a whole facility.

Different vendors around the world advocate different HVdc voltage ranges. Many look at the voltage range decision from a cost perspective: How much of their existing power infrastructure could they reuse? How much would need to be replaced to accommodate each of the potential HVdc voltage range specifications?

Some equipment manufacturers may prefer one range over another because of their existing equipment design. Voltage range will have an impact on cost and/or efficiency. Depending on the voltage range chosen, there are differences in the types of capacitors, high-frequency magnetics, and over-current protection devices that can be used. Voltage range also affects separation distances for connectors, conductors, printed wiring boards, and other design aspects.[7]

If the narrow-range battery attachment method were chosen instead of the wide-range, the blue ICTE input voltage range options in Figure 7 would be far narrower: the narrower the range, the more likely the necessity of numerous vendors having to redesign their equipment.[8]

Because the battery attachment method affects possible voltage ranges, a global HVdc voltage range specification will have a considerable impact on both the manufacturers and users of power infrastructure, ICTE, and individual components. This is what makes it such an essential—and difficult—issue to resolve.

The European Telecommunications Standards Institute (ETSI) recently asked for input from a large number of organizations. In February 2010, ETSI selected option 2 (260Vdc to 400Vdc) from Figure 7 above as the supported voltage range in ETSI 300 132-3. The Telecommunication Standardization Sector of the International Telecommunication Union (ITU-T), formerly known as the International Telegraph and Telephone Consultative Committee (CCITT), is discussing the voltage range.

V. Adaptation or Creation of PSUs for HVdc

Of particular concern for vendors and data center customers alike is the degree to which the selected HVdc voltage range will affect the power supply units in ICTE. The components used in HVdc PSUs—whether they are part of a storage device, hard disk array, or individual server—must be able to efficiently handle the voltage

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[7] For example, a global equipment manufacturer might push for a lower voltage range (such as Option 1) because a significant portion of its existing AC designs and the internal DC buses it uses operate with a DC voltage that is about 360 V. If one of the higher voltage ranges were to become the global specification for HVdc, that vendor would need to redesign the majority of its product lines, which may be a costly, time-consuming prospect.

[8] For example, if the power infrastructure delivers between 370 Vdc and 390 Vdc, then ICTE would probably have to handle between 365 Vdc and 395 Vdc to ensure that the ICTE remains operational and the infrastructure provides a voltage range that is at least equal to or slightly narrower than what the PSUs handle. While narrower voltage ranges may be advantageous for certain organizations, they could arguably make it harder to achieve consensus on a standard voltage range specification for HVdc. From the infrastructure point of view, higher voltages can reduce output currents and add design flexibility regarding cable-length and layout. Some equipment manufacturers, data center operators, and research institutes demonstrated 380 Vdc using the internal bus voltage of existing PSUs. In Japan, the U.S., and some European countries, some operators and users have demonstrated 400 Vdc–class data centers to show their effectiveness and stable operation.

range that the data center power system delivers. This means that some HVdc PSUs may require a different design and different components from their AC counterparts.

Not all power supplies have the same internal voltages, therefore not all are compatible with all proposed voltage ranges. Once the voltage range is selected, the power supply must be one that is designed (or modified) to operate in that range.

Vendors have two basic approaches to accommodating HVdc: create completely new designs of their AC PSUs or reuse the AC PSUs to the greatest extent possible. Developing an entirely separate, HVdc-optimized power supply product involves a lot of effort, time, and cost on the part of the vendor, but the result should be a product that is more energy efficient.

Conversely, maximum reuse of AC PSUs requires less effort, time, and cost. Vendors can save resources in terms of both design time and materials. Making both AC and HVdc power supply units and parts as close to the same AC design as possible also means that vendors can buy components in volume. However, the end product is slightly less energy efficient. A power supply unit that was originally designed to meet AC requirements cannot be as optimized for HVdc as one that vendors design for HVdc from the start.

Vendors, manufacturers, suppliers, and other similar groups may not be opposed to setting and following global HVdc standards. The difficulty lies in getting everyone to agree on the particular standard. Not surprisingly, companies with expertise within their own regions would prefer standards that make the most of their expertise and result in the least amount of rework.

As challenging as it is to do, establishing battery attachment, voltage range, and other standard specifications for HVdc would promote worldwide interoperability and ultimately benefit customers. Right now, power distribution configuration standards for AC voltages are different in Singapore, England, Japan, the United States, and elsewhere. This makes it difficult or even impossible for a multinational organization to use the same components, designs, etc. in all its geographically dispersed data centers or for a small, 16-server data center to be able to select a best-of-breed product from the worldwide pool of products. Both have to deal with different parts procurement, training, maintenance, spare parts inventory, and so on, depending on their locations' restrictions.

These problems are shared by vendors and suppliers as well. They have to deal with upstream compatibility issues, such as sourcing different sets of plugs for different jurisdictions around the world. They run into the same specialized, geo-specific requirements as their customers. Such difficulties could be reduced for both sides through harmonized standards.

Furthermore, vendors that specialize in products with specific features or add-on functionality are prevented from marketing them globally unless the vendors develop multiple versions that are compatible with the different regional voltage ranges. With agreed-upon global standards, a vendor can pick a certain vertical sector and meet its specialized needs while working within worldwide parameters. For example, HVdc standard specifications would make it possible for a vendor based in one country to cost-effectively develop a hospital-grade UPS for medical centers in other countries or on other continents. Prior to the opportunity for globalization with HVdc, the return on investment might have been too low; vendors did not have a strong business case to create equipment for target markets with completely different voltage ranges. Worldwide HVdc standards can open up a wider, potentially global market for vendors.

Taking steps now to avoid being locked in by regional requirements later will make it easier for data centers, vendors, and related suppliers to take advantage of economies of scale and also to use fewer adaptors and other components because it would no longer be necessary to adjust for multiple regional equipment differences. Fewer parts mean fewer hassles and greener, more reliable data centers.

While power supplies are an important portion of the power distribution configuration, the overall system efficiency is just as important. Each of the elements in the power distribution chain must be designed for efficiency. One inefficient component may be enough to reduce the system's overall end-to-end efficiency by the amount that was gained by changing to HVdc.

VI. Availability of Full HVdc Power Chains/Components

HVdc-related decisions must take the entire power chain into consideration—from UPS to PSU—along with individual components, including input/output connectors, rectifiers, over-current protection, power strips, switching devices, HVdc fault interruption technologies, selective coordination, fault current ratings, packaging, etc. The only way to successfully deploy an HVdc power system is if every part has compatible connectors. If this equipment interoperability aspect is overlooked, the resulting region-specific and vendor-specific variance will lead to the same complexity, purchasing restrictions, and other challenges that the international community faces today with AC power systems. Connectors are reviewed in detail for this paper. However, the same issues apply to all types of components.

While hardwiring a system is always an option, connectors have significant benefits in the data center because of ease of installation and change, safety, and flexibility. In the example given in Figure 8, connectors are needed in locations A, B, C, and D. The Green Grid recommends using similar styles or families of connectors when at all possible to reduce costs and development time. For example, the A-B connector does not need to be the same as the C-D connector, although connectors at both ends of a wire should be of the same style but opposite genders. The most likely A-B connector is the International Electrotechnical Commission (IEC) specification IEC 60309 (formerly IEC 309); the IEC is still developing a standard C-D connector. For more detail on all connectors, please see Appendix A. Connectors.

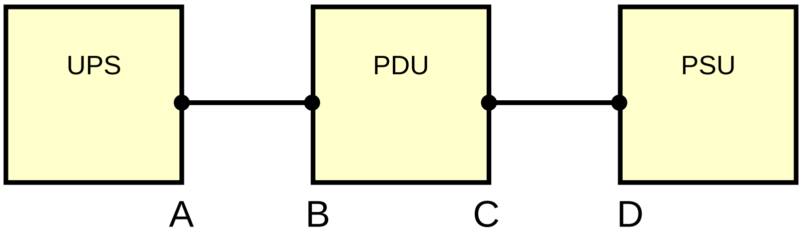


Figure 8. Example connector locations in a simplified Vdc distribution path

For individual loads (connections C and D in Figure 8), there is no accepted standard for Vdc connectors in the overall HVdc voltage range. Multiple, proprietary connectors are available from individual manufacturers, but there is no standard plug and socket. IEC Technical Committee Number 23, Working Group 8, is working on a standard for connectors, with support from the National Electrical Manufacturers Association (NEMA).

For rack-level power feeds, IEC 60309 connectors are the frontrunners, due in large part to their defined keying option for HVdc. The standard already defines connectors for above 250 Vdc operation, but they are uncommon, may not have all the required approvals, and are not currently produced in volume because there is limited historical demand.

At this time, IEC connectors appear likely to be the most widely used because they have the correct form factor and can be made by multiple vendors, but they are not in widespread use.

VII. Existing Data Center Infrastructure

It is important to keep some perspective in the discussion about HVdc power distribution configurations. Total cost of ownership (TCO) plays a crucial role in data centers' decision making. For the many data centers that are already significantly invested in AC and 48Vdc power infrastructures, it would be prohibitively expensive to remove that existing, functioning power infrastructure in favor of an HVdc power system. With a full HVdc power chain solution not yet available, as mentioned in the previous section, data centers could find themselves supporting additional AC power distribution, a move that could add cost and have a negative impact on net efficiency. Essential equipment that is not in the direct critical-power path—such as lighting, air-handling equipment, and various auxiliary equipment—will probably still require AC power inputs for several decades to come. Therefore, dual power distribution systems will likely remain a requirement.

Realistically, an operator of an existing data center today will probably not consider moving over to HVdc until faced with the need for a major data center overhaul or a new wing or greenfield data center. Greenfield facilities and data center expansions present more cost-effective opportunities to switch to new power architectures such as HVdc.

What is clear is that resolving HVdc-related issues in the short-term lays the groundwork for making HVdc a viable choice for TCO-conscious data centers in the future.

VIII. Common Grounding Method

As with AC systems, there are many possible choices for grounding DC systems. HVdc systems have several combinations of connecting-point positions for grounding, including positive, negative, and midpoint (see Figure 9). There are also several options for connections to the earth, including floating (no connection), direct (with very low resistance), restrictive, and voltage limit.

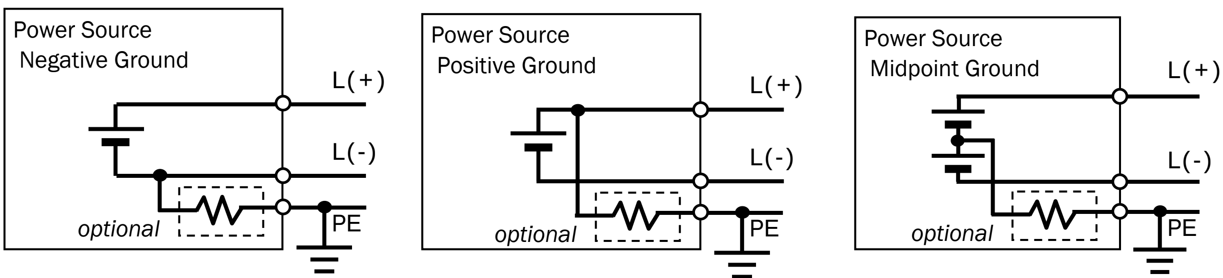


Figure 9. Three HVdc grounding options: negative solid, positive solid, and midpoint high impedance (resistive) grounding

Currently, North America, Canada, and Japan are proposing midpoint grounding to prevent exposure of electric shock at any voltage above 200Vdc (line to ground).

There are many ways to deploy grounding, similar to AC distributions, and they each may have merit for a particular situation. However, The Green Grid would like to see an international body establish a minimal set of deployable, standardized options, instead of the many options that are available today. The Green Grid has safety concerns about mixed grounding systems and believes the most common solution will be the midpoint ground option. An education process needs to occur for DC grounding, as it is different from AC systems. For more details, see Appendix B. Grounding.

IX. Safety Issues and Regulations

HVdc is unlikely to reach widespread adoption unless its safety issues—both real and perceived—are addressed through regulations and education. It is true that AC and HVdc power systems have different characteristics. Arc flash, for example, behaves in a potentially more dangerous manner in an HVdc environment than in an AC one. In both scenarios, a fault can result in a spark of energy released in an arc, possibly causing harm to people or damage to equipment. Because AC is a sine wave that continually alternates between positive and negative voltages, the voltage passes through zero volts twice every cycle (50 to 60 times per second). The zero crossing provides an opportunity to more easily extinguish an arc. HVdc is steady-state current that does not pass through zero volts, so longer duration arcs can occur. This means that new HVdc-specific training is necessary for data center personnel to change their expectations regarding power system behavior.

As of yet, there are no international standards for calculating HVdc arc flash hazard levels; the data provided by the Institute of Electrical and Electronics Engineers (IEEE) in IEEE 1584 only pertains to 3-phase AC arc flash events. Also, the various safety codes and regulations put forth by the IEC and Japan, the United States, the European Union, and other regional bodies currently differ, and none fully covers HVdc.

International HVdc guidelines, reference codes, standards, and data need to be established for data center personnel as well as electricians and inspectors. These may include proper safety attire, maintaining appropriate distances, and the addition of backup staff while working on live components or systems.

Efforts are underway to develop global and regional safety standards for HVdc, such as in National Fire Protection Association (NFPA) 70E for personal protective equipment (PPE). There is a joint NFPA/IEEE effort to enhance the IEEE 1584 standard for DC. Once established, standards can be used to overcome uncertainties, fully train workers, and ensure safety while working with HVdc power systems.

X. Qualification Criteria

Just as safety standards are important for HVdc equipment operation by data center personnel, so, too, are interoperability standards critical for the vendors manufacturing the HVdc equipment. Consistent qualification procedures that need to be established among manufacturers in order to ensure product compatibility should address, among other issues:

- Performance criteria for HVdc equipment
- Handling of transients and dropouts
- Abnormal voltages
- Supply protection
- Bonding requirements
- Electromagnetic interference, immunity, and line disturbances (CISPR 22, CISPR 24, IEC 61000-4)
- Ripple voltage at UPS output

Some of the same bodies that established standards for AC and 48Vdc systems now are working to establish qualification criteria for HVdc, including IEC, ETSI, and several others such as DC Power Partners and the Telecommunication Standardization Sector (ITU-T). Along with developing new qualification criteria, these bodies are reviewing existing standards such as ETS 300 132-3 to see if they can be modified to address HVdc power systems.

XI. Conclusion

It is not yet clear whether data centers will move away from their current mix of AC and 48Vdc power configurations and toward HVdc systems. Adopting HVdc could be a way of reducing energy consumption and increasing data center efficiency. In addition, the reduction in component count of HVdc systems versus AC systems could have a positive impact on reliability and TCO.

The difficulty in establishing a clear path for HVdc is that there are many choices to be made and standards to be written. Numerous organizations, companies, and countries are participating, and many more potentially will be affected. No single standards body has global authority, so the situation has less to do with HVdc per se and more to do with building a worldwide consensus.

Setting global standards for HVdc should help data centers, manufacturers, and others avoid the variances that have complicated AC power equipment and distribution. The most crucial specification that needs to be established is a single voltage range for HVdc. Although clear consensus has yet to be reached on this or many other HVdc specifications, work is well underway with groups such as DC Power Partners, ITU, IEC, and ETSI, and draft standards may be available for public review as early as the end of 2010.

XII. Related Documents and Tools

1. The Green Grid, *Qualitative Analysis of Power Distribution Configurations for Data Centers* (2007) www.thegreengrid.org/en/Global/Content/white-papers/TGG-Quantitative-Analysis.
2. The Green Grid, *Quantitative Analysis of Power Distribution Configurations for Data Centers* (2008) www.thegreengrid.org/en/Global/Content/white-papers/Quantitative-Efficiency-Analysis.
3. The Green Grid, *Power Configuration Energy Estimator*. http://estimator.thegreengrid.org/pcee and the FAQ document, http://estimator.thegreengrid.org/PCEE_FAQ.pdf.
4. The Green Grid, *The Green Grid Peer Review of "DC Power for Improved Data Center Efficiency" by Lawrence Berkeley National Laboratory* (2008) www.thegreengrid.org/~/media/WhitePapers/WhitePaper12LBNLPeerReview050908.ashx?lang=en.
5. Lawrence Berkeley National Laboratory, *DC Power for Data Centers of the Future,* (2008) http://hightech.lbl.gov/dc-powering/.

XIII. About The Green Grid™

The Green Grid is a global consortium of companies, government agencies, and educational institutions dedicated to advancing energy efficiency in data centers. The Green Grid does not endorse vendor-specific products or solutions, and instead seeks to provide industry-wide recommendations on best practices, metrics, and technologies that will improve overall data center energy efficiencies. Membership is open to organizations interested in data center operational efficiency at the Contributor, General, or Associate member level. Additional information is available at www.thegreengrid.org.

If you are interested in finding out more on HVdc or contributing to the HVdc effort, join The Green Grid's Power Sub Working Group: power_swg@lists.thegreengrid.org.

XIV. Glossary

The following acronyms are used in this document:

AC	alternating current
CCITT	International Telegraph and Telephone Consultative Committee
CISPR	International Special Committee on Radio Interference (FR)
DC	direct current
EMC	electromagnetic compatibility
ETSI	European Telecommunications Standards Institute
HVdc	higher voltage direct current (200 to 600 volts)
ICTE	information and communications technology equipment
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
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)

XV. Appendix A. Connectors

Section VI, Availability of Full HVdc Power Chains/Components, briefly discusses the current requirements for connectors in a DC configuration. This appendix gives more detail on all the connectors known to The Green Grid at this time.

Potential standard connectors for ICTE power connectors include those based on products from Anderson Power Products and NTT-F/Fujitsu and on IEC standards.

Anderson designed its Saf-D-Grid™ connectors to fit into the same size/form factor that is used for typical AC power connections. These connectors tolerate arc flash inside their housing and are UL certified.

The NTT Facilities (NTT-F)/Fujitsu Components Limited connector incorporates several safety functions, including magnet arc quenching and a casing designed so that the socket and plug cannot be disconnected accidentally.

IEC is scheduled to enact a standard for the 400Vdc plug and socket outlet.

Figure A-1 shows all the possible locations for connectors in a distribution configuration. These are labeled with a letter that corresponds to Table A-1, which shows one or more possible locations for the connectors' use in a DC distribution configuration.

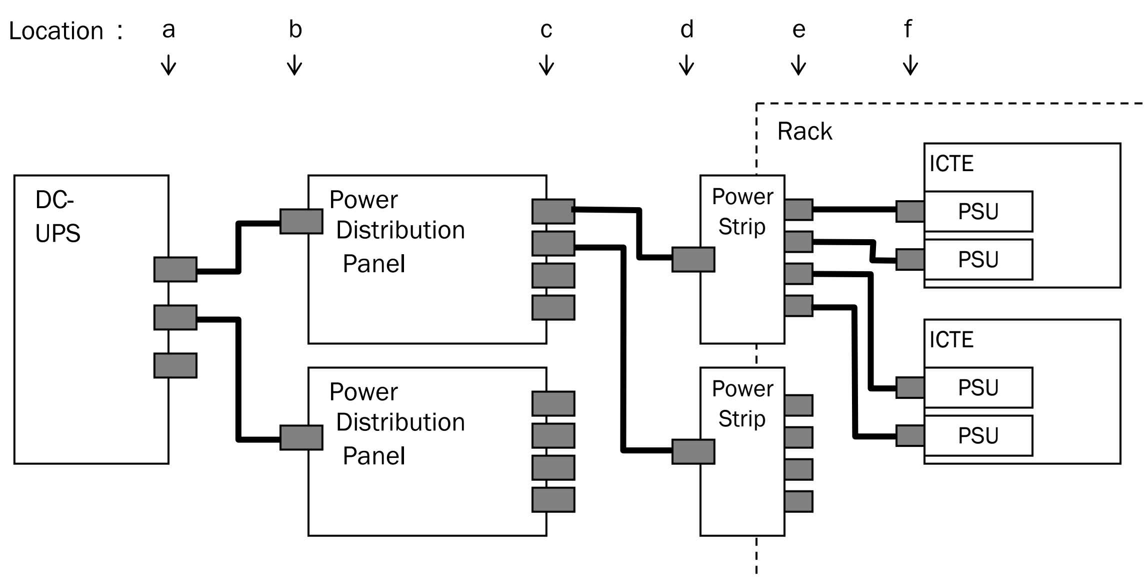


Figure A-1. Basic power distribution configuration path with connector locations

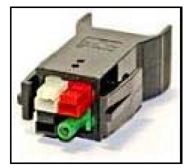
Item No.:	1	2	3	4	5
Applicable Locations	a, b, c, d	e	e, f	e, f	e, f
Model			Saf-D-Grid	PowerPolePak	
Form Factor	-	Custom: ~2.5" (65mm) x 2" (53mm)	C13/C14	C13/C14	IEC PAS 62695
Appearance		 	 		Not Available
Voltage Rating	- 250V 250 – 690V	400V	400V 600V	400V	400V
Standard	IEC60309		-	-	IEC PAS 62695 (Draft)
Development		NTT-F/Fujitsu Components Limited	APP	APP	IEC Draft Publicly Available Standard
Current Rating		10A	20A (UL)	15, 30, 45A (UL)	5A
Arc Extinguish	No	5A: No 10A: Yes, magnet quenching	No	No	No
Mechanical Lock	Screw	5A: No 10A: Yes (double action/interlock)	Yes (latch)	Yes (latch)	No
Safety		-	UL (IEC)	UL, IEC	IEC

Table A-1. Connector examples and their possible locations

XVI. Appendix B. Grounding

Because grounding the positive rail for HVdc is similar to the grounding approach used in a traditional telecommunications environment, it is easy to transition those environments to HVdc. Positive grounding also has a lower chance of producing corrosion in wet environments. However, positive grounding's negative voltages, such as -400Vdc, can be difficult to understand and present a greater safety hazard above 250Vdc. Positive grounding results in negative grounding to earth.

Negative grounding, which produces positive voltages, is a simpler approach that is in line with how most DC voltages operate. But it, too, comes with a safety hazard when above 250Vdc.

Asymmetric voltage involves one hot line, one return line, and protective ground tied to either the positive or negative side.

Midpoint ground, in which a data center is center-earthed, uses two hot lines and protective earth to reduce the shock hazard if someone touches a conductor. So if the HVdc voltage were 400Vdc, choosing the symmetrical ±200Vdc with midpoint ground reduces risk of injury because its line-to-ground provides a safety hazard of less than 250Vdc. If someone touches one conductor, there's only a 200Vdc differential one way or the other. Even if that person were to touch both conductors, the differential is only 400Vdc. (It should be noted that symmetrical voltage retains a line-to-line hazard of greater than 250Vdc.) The industry trend for HVdc is toward using symmetric voltage because of safety considerations.

IEC 60364 describes three families of grounding/earthing arrangements, using the two-letter codes TN, TT, and IT. T represents direct connection of a point with earth (Latin: terra), N represents direct connection to a neutral (or midpoint) conductor, which is connected to the earth, and I represents no connection point with earth (isolation), except perhaps via a high impedance. The first and second letters indicate the connection between earth and the power-supply equipment, and the connection between earth and the electrical device, respectively.

The first two rows in Figure B-1 below can be married with each smaller box, resulting in 12 possible grounding combinations. For example, there can be positive impedance or midpoint direct grounding. Each of the 12 combinations can be described by one of the families listed in the pink box. For more detailed grounding options, see Figure B-2.

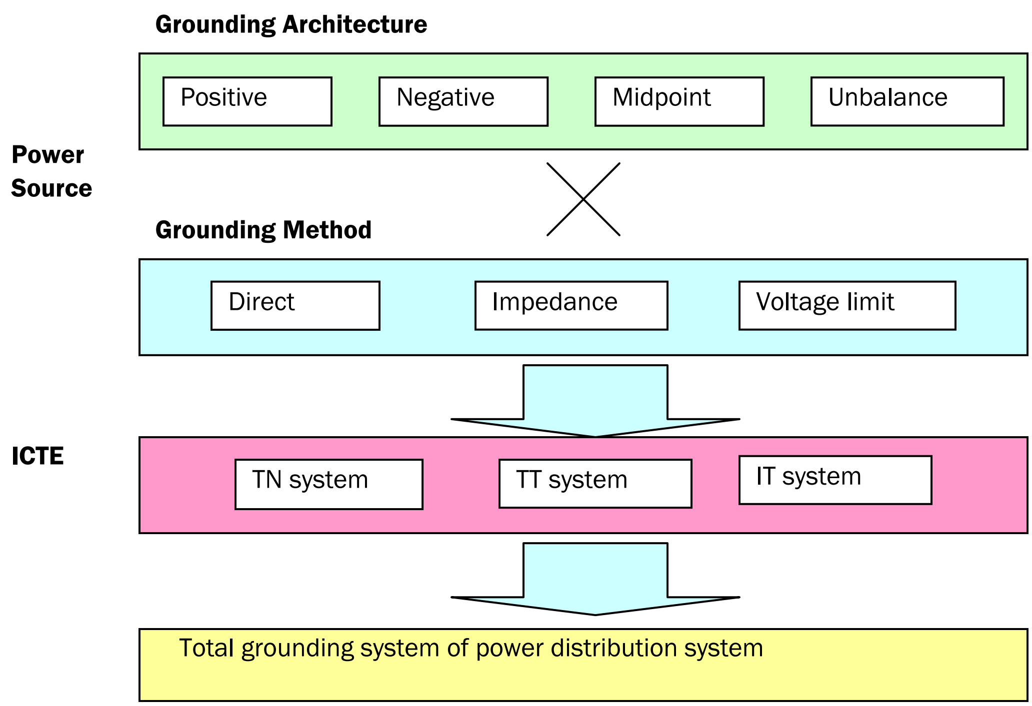
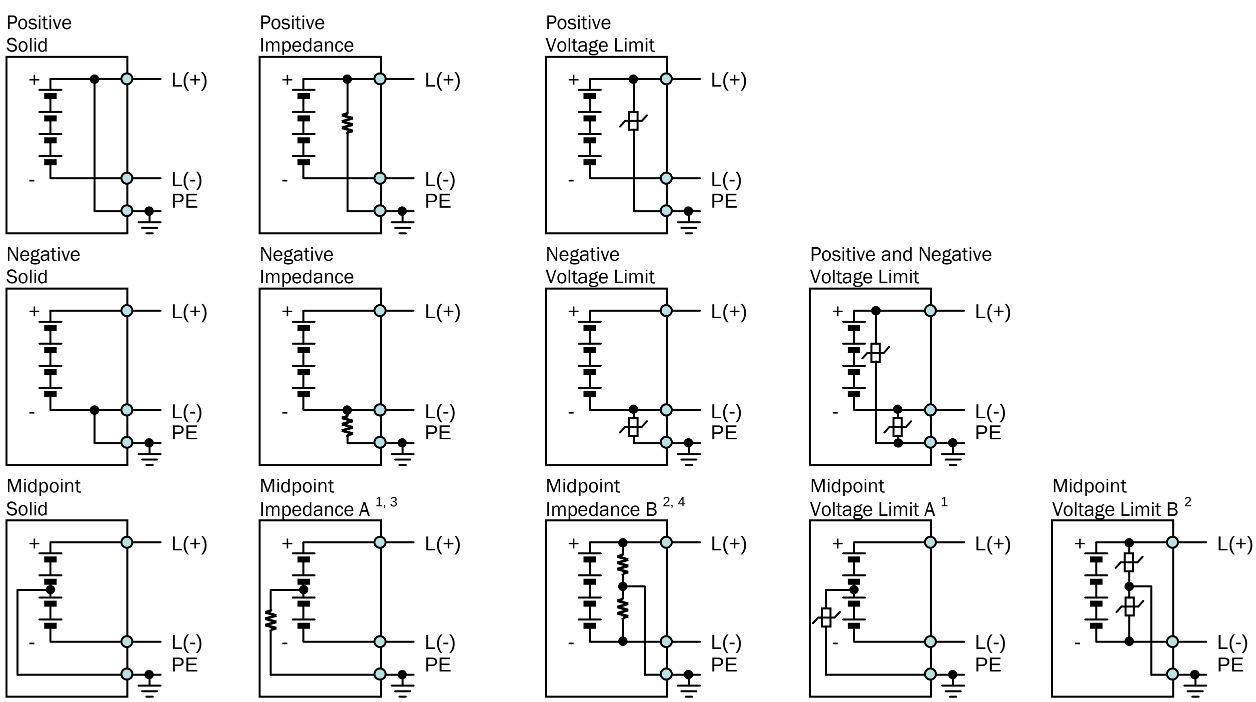


Figure B-1. Grounding options overview



[1] Method available for use when access to tap point within string of battery cells is available.

[2] Method when no access within a string of battery cells is available.

[3] Either high or low impedance may be used, internally or externally to the device.

[4] Only a high impedance may be used.

[5] Example unbalanced tap shown. Other tap points within the battery are possible. Unbalance is defined when the voltage from positive to ground does not equal the voltage from negative to ground.

Figure B-2. Detailed grounding options

Figure B-3 shows a grounding method of the PSU or ICTE. The power lines are isolated from the protective-earthing (PE) line and chassis, and the PE line is connected to the chassis. This method accepts most, if not all, of the grounding methods of the UPS and distribution system in Figure B-2, and it is receiving common acceptance among ICTE and PSU manufacturers.

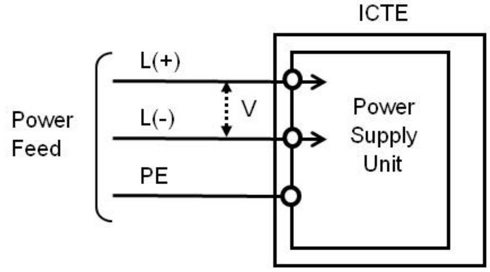


Figure B-3. Grounding method for PSU, ICTE L(+), L(-) isolated from PE, and chassis, where PE is connected to the chassis