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Lenovo Flex System Higher Voltage DC Solutions

Maximize the energy efficiency of your data center by powering with HVDC

Harness HVDC power distribution with Flex System monitoring and management

Manage power consumption of major chassis components

Experience higher RAS in less space with HVDC power distribution

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LENOVO PRESS

Note: Before using this information and the product it supports, read the information in “Notices” on page 77.

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Preface

The need to create and maintain an efficient and reliable data center infrastructure has become more prevalent in recent years. New and different approaches are being sought and adopted in the quest to seize and sustain methods that bring optimization and simplification to data centers.

With the continuous increase in global power consumption and the rise in power load requirements of modern servers, the quest for greater efficiency and reliability of power distribution manifests the need for a more improved and efficient method of distributing power to data centers.

Most electrical infrastructures today use alternating current (AC) to provide power to data centers, which distributes electricity in the range 100 - 600 V AC throughout the facility. However, because of the efficiency and reliability of direct current (DC) power, a growing interest in DC power in data centers is noted. However, as with any new technology that is introduced into a data center, higher voltage direct current (HVDC) power distribution faced the following initial adoption challenges:

- Limited familiarity and understanding of HVDC power
- Limited system-level portfolios of DC specific hardware
- Lack of established practices and general standards
- Limited knowledge of deployment and operating procedures
- Safety obstacles and knowledge

Many of the obstacles were overcome in recent years and the number of HVDC deployments is steadily increasing. This paper describes HVDC and explores specific factors in the adoption of HVDC in data centers, including reliability, safety, and efficiency. We also describe the benefits that can be realized by bringing HVDC power into your data center, and the DC power components that are available in the Lenovo® Flex System™ offering.

Lenovo Flex System servers are based on Intel Xeon processors.

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About dc FUSION: dc FUSION LLC provides independent DC power system consulting services to industries that enable the development, deployment, and proliferation of DC power distribution technologies. Specialized expertise includes in-depth knowledge and experience regarding higher voltage DC topologies that were developed in recent years around the world. Its founders are recognized as leaders of the HVDC initiative though their leadership in the Emerge Alliance, The Green Grid, Society of Cable Telecommunication Engineers (SCTE), and regulatory agencies.

For more information, see this website:

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About Emerson Network Power: Emerson Network Power is a global leader in delivering technology, services, and solutions to enable business critical connectivity. Emerson's expertise includes AC and DC power, renewable energy, infrastructure management, and power switching and controls. Emerson is a pioneer in developing higher voltage DC power systems technology and promoting the standardization and adoption of HVDC.

For more information, see this website:

http://www.EmersonNetworkPower.com/400VDC

About Steel ORCA: Steel ORCA provides data center infrastructure and services that support small, midsize, and enterprise businesses in New York, New Jersey, and Eastern Pennsylvania. In addition to AC-powered services, Steel ORCA has one of the first commercially-available, exclusively HVDC-powered environments in North America. Steel ORCA is committed to providing the required know-how and experience for navigating and managing the change that constantly challenges its clients with the ability to grow, adapt, update, and advance.

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Introduction

The need to create and maintain an efficient and reliable data center infrastructure became more prevalent in recent years. New and different approaches are being sought and adopted in the quest to seize and sustain methods that bring optimization and simplification to data centers.

With the continuous increase in global power consumption and the rise in power load requirements of modern servers, the quest for greater efficiency and reliability of power distribution manifests the need for a more improved and efficient method of distributing power to data centers.

Most electrical infrastructures today use alternating current (AC) to provide power to data centers, which distributes electricity in the range 100 - 600 V AC throughout the facility. However, because of the efficiency and reliability of direct current (DC) power, a growing interest in DC power in data centers was noted. The following factors, though, contribute to the initial adoption challenges of DC power in the data center:

- Limited familiarity and understanding of HVDC power
- Limited system-level portfolios of DC-specific hardware
- Lack of established practices and general standards
- Limited knowledge of deployment and operating procedures
- Safety obstacles and knowledge

This paper describes higher voltage direct current (HVDC) and explores specific factors in the adoption of HVDC in data centers, including reliability, safety, and efficiency. We also describe the benefits that can be realized by bringing HVDC power into your data center, and the DC power components that are available in the Flex System offering from Lenovo.

This chapter includes the following topics:

1.1 What is HVDC

HVDC is the use of DC voltages in the range of 200 - 600 V DC to power components in the data center. The use of HVDC power can result in energy savings and therefore, improved operating expenses.

Clients who benefit most from HVDC power are those clients who operate large data centers or who are looking to maximize energy efficiency on a broad scale. HVDC can be especially attractive to customers who want to expand their current data center footprint or build new (greenfield) data center installations.

The HVDC option for Flex System was introduced to address the growing market demand for HVDC distribution in modern data centers. HVDC distribution has the potential for higher reliability and availability, better efficiency, and less physical space requirements because of fewer components (such as rectifiers) in the data center than do comparable AC distribution systems.

AC is a non-linear sinusoidal waveform in which the electrical current frequently reverses direction. AC electricity is measured in cycles. One cycle is the time that it takes for the waveform to complete 360 degrees with one positive and one negative half cycle. In the United States, there are 60 cycles that are completed per second and the unit of measurement is hertz (Hz). In many other countries, 50 Hz is common.

Unlike AC, DC current is unidirectional, meaning the current only flows in one direction. Common DC power sources are batteries, fuel cells, and solar panels. The distribution of DC is prevalent in the telecommunications industry, where the typical distribution is at -48 V DC. HVDC often is classified as voltages 200 - 600 V DC. The most typical HVDC power distribution in China is 240 V DC. In North America and the rest of the world, it is more common to see 380 V DC deployments.

For AC power deployments today, the most prevalent worldwide distribution is 380 - 600 V AC three-phase. Ultimately, server and IT power subsystems, such as processors, memory, disks and adapters, operate on power inputs between 12 V DC and less than 1 V DC. To provide V DC to the server power subsystem components in an AC data center distribution system, you must go through multiple stages of power conversion, each of which includes associated losses, which lessen the effect of the overall efficiency of your data center.

1.1.1 Conversion steps for AC-sourced power

AC-sourced power can be converted by using the following process:

1. The typical North American AC power distribution brings in 4k V AC - 69k V AC through a transformer to create 480 V AC power for distribution to a double conversion Uninterruptible Power Supply (UPS) unit (which is a rectifier). The UPS unit first converts AC power to DC power for charging the battery stack.
2. An inverter in the UPS converts (for example) 380 V DC back to 480 V AC. Many double conversion UPS units on the market today can have 94% or greater efficiency.
3. The output of the UPS is typically 480 V AC power, which is converted to 208/120 V AC through a transformer with typical losses of 1-2%, and distributed through a Power Distribution Unit (PDU).
4. The IT system power supply converts the AC power input to 12 V DC power for inter-server power distribution. The power supply losses historically range 4 - 10%, depending on such factors as input voltage and server load.

The losses in efficiency throughout the AC power distribution directly affect the data center in the form of heat, for which the data center cooling system must account. These losses drive higher facility energy expenses.

An added complexity in AC distributions is the need for synchronization of the AC waveforms, which are sinusoidal. When paralleling AC power sources, the sinusoidal waveforms between the two sources must be in-phase and have the same amplitude and frequency as each other to ensure that there are no interruptions in power to the IT system.

1.1.2 Conversion steps for HVDC distribution systems

In contrast to the steps that are described in “Conversion steps for AC-sourced power” on page 2, HVDC distribution systems have fewer conversion steps. The power transmission components between AC and DC power distributions are the same up to the front of the UPS. At the UPS is where the process diverges. With DC power distribution, there is no longer a need to invert the DC power that is provided by the UPS batteries back to AC. Instead, a direct connection from the UPS output of 380 V DC power (through a circuit breaker) to the inputs of a DC power supply can be used.

Therefore, the only step in the conversion process is that at the power supply, the 380 V DC is converted to 12 V DC for inter-system power distribution.

This change removes multiple conversion steps from the UPS, PDU or transformer, and IT system power supply front end.

The reduction in conversion steps improves the end-to-end HVDC power distribution efficiency and reduces losses and facility energy consumption. The possible efficiency savings of an HVDC power distribution system over an AC power distribution system can be 5 - 10%, although this savings depends on many factors (such as AC power supply efficiencies and age of the hardware). These improvements directly affect the facility energy costs.

Another advantage of HVDC is reduced complexity of the design, which requires no synchronization between parallel HVDC sources. In general, systems with fewer components offer higher reliability and availability. This factor is one of the main reasons why -48 V DC power is still standard in the telecommunications industry.

With HVDC, it is also easier to add alternative energy sources, such as fuel cells and solar systems to the HVDC bus because these types of energy sources naturally produce DC power.

Other possible cost savings that are associated with HVDC are reduced power supply and UPS costs because of fewer components, and reduced wiring costs because the copper conductors might be smaller gauge (less copper).

The next section describes some of the benefits of HVDC power in the data center.

1.2 Benefits of HVDC

Typically, when the electrical power infrastructure for a data center is designed and implemented, managers face numerous obstacles in ensuring that the infrastructure is optimized for reliability and efficiency.

There are several benefits to having HVDC power in the data center that can bring reliability and efficiency beyond that of an AC power system. HVDC includes the following benefits:

- Reduction in the number of conversions and energy loss before reaching the IT load

  This benefit is one of the clear benefits of using HVDC power. An AC power system requires more transformation to achieve the correct voltage levels (in addition to more rectification steps from AC to DC) than that of a DC power system. This requirement, in turn, causes more power loss in an AC power system.

- Less heat is produced by DC power systems

  When power is lost during the conversion and transformation steps that are required by AC power systems, the power does not disappear. This power loss turns into heat. This heat then dissipates into the data center, which adds to the amount of heat the facilities cooling systems must remove.

- Simplified system architecture

  In the data center, HVDC offers a simpler architecture than do traditional AC power solutions because equipment in the data center, such as servers and storage, require 12 V DC power internally to work. Therefore, by bringing in HVDC power directly to the hardware, the previous steps that were required for converting AC to DC power are eliminated. Fewer operations means less space, material, labor, and cost, and greater simplicity.

- An increase in system reliability by removing conversion equipment

  Because there are less end-to-end individual moving parts that are required to ultimately achieve 12 V DC power in an IT system, the overall architecture is more reliable. This reliability is the result of the need for less equipment that can break down and cause issues.

- High usage of existing floor space

  This benefit of using HVDC comes from requiring less space on expensive raised flooring. By using less transformers, data center rack and floor space is freed up to be used for IT equipment, or you can reduce the data center floor space that you need.

- Better cooling efficiency

  Having a myriad of power cables running to each rack under a raised floor (which is often seen in AC power systems) can largely affect the efficiency of the cooling system by blocking perforated tiles from providing cool air to the cool isles in the data center. The best deployment of DC power system is with the use of busway, which can be located overhead and removes the under floor cabling and clearing the space for cool air to flow freely.

- Easy integration of alternative energy sources

  DC power enables a direct, seamless integration infrastructure for renewable energy sources. For example, sources, such as wind turbine, solar photovoltaic (PV), concentrated solar power (CSP), and batteries, are DC. By removing the AC conversion, there is improved efficiency and return on investment (ROI).

- HVDC power allows the use of DC UPS units

  The use of HVDC power in the data center allows for the use of DC UPS units. This configuration means that less rectification steps are taken from AC to DC back to AC, which means a shorter path with higher efficiency and higher reliability.

- Better IT power supply efficiency

  HVDC directly to the power supply leads to more advances in power supply efficiencies, which eliminate the AC to DC rectification processes that is required when AC input power is used.

- Circuit protection technologies

  HVDC offers opportunities for new circuit protection technologies with the potential of providing for safer systems. As AC data center distribution moves to higher voltages (for example, 400 V AC, 415 V AC, and 480 V AC), system overload, arc flash, and circuit protection at the rack become a bigger safety issue in AC power systems.

- Better power distribution system density

  HVDC power allows for more power delivery than does AC and -48V DC power on the same amount of copper.

- Greater modularity and stability

  Modularity that was not previously available allows for easier design and installation, and enhanced plug-and-play availability.

- No three-phase load balancing to be concerned about

  Load balancing in three-phase AC data centers requires greater attention to detail. For example, a UPS can indicate that a replacement is required if it is near overload because of uneven power draw. This concern does not apply to HVDC because load balancing is not required.

- No single-phase load balancing to be concerned about

  Load balancing within an AC power system in which multiple single-phase loads are used is critical and is typically difficult to achieve. The lack of complete load balancing within an AC power system results in a built-in, ever-changing de-rating effect that must be addressed. This issue is not a concern with HVDC because load balancing is not required.

- Power factor losses not an issue with DC power supplies

  The use of DC power supplies enables more reliability and energy-efficiency because there is no need to account for power factor (PF) in DC power supplies.

- Cooler server temperature

  DC power systems operate inherently cooler than AC power systems because there is less conversion that happening at the power supply.

- Benefits in cooling systems

  Cooling systems can use 380 V brushless DC motors, which provide inherent benefits of the infrastructure to the cooling system.

- No harmonics issue

  Harmonics refers to the distortion of the normal AC waveform that generally is transmitted by non-linear loads. In the data center, power supplies that are used in AC servers represent a non-linear load that can create harmonics. Harmonic currents accumulate in the neutral wire, which causes distribution losses and increased heat generation.

  If the cumulative level of harmonics (known as *total harmonic distortion*) becomes too high, damage to sensitive electronics and reduced efficiency can result and might require equipment de-rating to overcome it. These losses are difficult to predict in complex AC power distribution systems and can be significant. Harmonics are not present in DC power systems because there are no waveforms with which to contend.

- Eliminates the need for paralleling and synchronization

  Combining AC sources requires active paralleling with sophisticated controls and metering. Combining DC sources requires only voltage parity within and between systems.

- Better power quality

  Metering for AC power systems becomes costly when waveform capture and high-speed measurements are required to determine what happened during a power quality event (for example, fault, sag, flicker, high frequency transient, or temporary over-voltage).

  The constant nature of DC voltage and current allows for simpler metering requirements and the ability to decipher a problem and act more quickly when an issue occurs.

- DC distribution features the following future benefits:
  - Solid-state circuit protection
  - Current limits for short circuits
  - Power signatures to allow for active circuit protection and load flow control

All of these benefits contribute to the reliability, availability, and efficiency of the use of HVDC in the data center. In the next section, we describe the efficiency benefits of implementing HVDC.

1.3 Power efficiencies

When talking about efficiency and power, it makes sense to look at the end-to-end topology, or from *grid to chip*, of the infrastructure and how the power is being delivered to a target. It is also important to understand that most internal electrical power that is required in IT systems, such as servers and storage, ultimately requires 12 V of DC power to run.

The use of DC power as the source is more efficient at providing the 12 V DC power to the target than is an AC power source. This efficiency results because the overall delivery of AC power to a target system requires more transforming and rectification (for example, converting AC to DC and back to AC), than what DC power requires to reach and power an IT system.

To quantify AC and DC efficiencies in an example, a typical American data center AC power system might receive a medium voltage from utility; for example, 5 kV, 15 kV or 35 kV. First, this incoming AC voltage must be lowered by transforming and converting it to 480 V AC, for example. In general, these results can have an initial power loss of approximately 0.3%.

This converted voltage can then be distributed through circuit breakers for safety, which typically results in a 0.1% loss. Next, it is sent through a secondary transformer, which typically brings the voltage down to 120/208 V AC.

Further losses are experienced at the UPS with a double conversion (AC-to-DC for battery charging then back to AC), which can typically result in losses of 3% - 10%. Finally, the AC is distributed to the power supply unit (PSU) and requires conversion and stepping down the voltage to provide 12 V DC power to the system. This conversion might account for a 6% - 10% loss of power from grid to chip.

Unlike the AC power system, the HVDC system eliminates the need for extra conversions and rectification steps. For example, the HVDC system requires only a rectifier to convert the incoming voltage from AC to DC (for example, converting from 480 V AC to 380 - 400 V DC). When the power reaches the PSU, it still must be stepped down to 12 V DC. During this step down, there can be loss of approximately 7%.

For more information about power supply functions, see 1.6.2, “AC versus DC power supplies” on page 10.

By eliminating the inherent inefficiencies in AC power infrastructures, including multiple energy-wasting power conversions, transformations, and unnecessary heat-producing components, HVDC systems are much less complex and are likely to be more efficient and reliable.

1.4 Data center HVDC marketplace

The marketplace for HVDC in the data center is evolving and saw major advancements since its early adoption over the past several years.

If we look back 10 years to around 2004, installations were nothing more than Proof of Concepts (PoCs) or Proof of Technology (PoT) from vendors. Vendors who produced PoCs and PoTs to provide DC power to the hardware needed to use modified AC infrastructure components to complete the demonstrations because no infrastructure equipment existed.

The market slowly evolved. Over the next five years, more PoCs and PoTs emerged, which increased interest and encouraged vendors to create and release HVDC portfolios.

Although there is still no standard best practices guide today for governing HVDC in the data center, it is evident that over the past couple of years the use of HVDC in the data center is on the rise. Look at this increase particularly in China (where most of deployment is at 240 V DC), and India (where the integration of renewable energy is driving HVDC development and deployment).

On a global scale, it is more common to see 380 V DC deployments over 240 V DC; however, HVDC is still niche and boarders on a small footprint in the overall deployment of power in the data center. AC power still is the most common method for powering the data center.

1.4.1 HVDC hardware products in the marketplace

Vendors are continuing to develop products, and multiple infrastructure suppliers have increasingly wider portfolios. In turn, it is becoming more common for data center managers to consider HVDC as a viable option for providing power to their data centers.

Current

All necessary technologies exist today to reap the benefits of DC power. However, HVDC in itself is still an emerging technology; for example, among OEMs for servers, storage, and switches. There are still few IT systems in the marketplace today that support HVDC, which makes selection that is limited. However, advances in DC power technologies are driving us to create more DC-driven hardware and DC-powered data centers.

However, because selection is limited today, an end-to-end DC solution is challenging. Aiming for a hybrid DC solution with both AC and DC power available from grid to chip can be the most flexible and efficient method of approaching power for the data center, which allows data center managers to slowly migrate to a full HVDC power system as future HVDC products emerge to the marketplace.

One of the most recent trends for moving today's technology towards HVDC power in the data center comes from looking at the perspective of the IT targets need for DC power, as all server and storage internal operating voltage requirement is DC. This means that the focus is moving away from how to convert AC power to something usable for IT systems, to how to achieve DC power directly to where it is needed.

Future of HVDC

The future for HVDC is promising as it gains a wider acceptance and understanding. However, the current adoption of HVDC still faces challenges and the future widespread adoption depends on the following factors:

- Development of equipment (servers, storage, and switches)

  For the adoption of HVDC to be viable as an end-to-end solution, vendors must offer more HVDC-compatible products at the rack level. A limited offering exists for servers, and in particular, storage, and switches.

  As vendors move towards Common Form Factor (CFF) power supplies across platform offerings, we might see more support for offerings that support HVDC and a wider adoption might occur.

- Safety and understanding

  The uptake and speed of adoption of HVDC to provide power in the data center also rests upon the standards and regulations that are built around this technology. At the time of this writing, there are basic recommendations for standards in place or in the development stages. For more information about standards and safety, see 5.2, “Accomplishments in HVDC safety” on page 66.

There is high activity in HVDC powered data centers. Major progress was made and is still being made on HVDC standards and emerging technologies. The power industry is demonstrating that DC power can embody a holistic business value in the data center.

1.5 HVDC and the adoption of standards

Although HVDC power in the data center is gaining momentum and growing in popularity, the lack of agreement about HVDC standards at the national, regional, and local levels is putting pressure on these groups for faster adoption.

There are several organizations that have the common objective of implementing standards and safety procedures for HVDC deployments. However, there is no single standards body with global authority, so any competing standards must be resolved to form a common global standard.

Various companies around the world are addressing the following issues:

- Standardizing a common voltage range in all use scenarios
- Developing an official common grounding method for DC-powered IT equipment
- Incorporating methods for attaching batteries
- Further refine safety issues and regulations
- Describing qualification criteria for serviceability

Work continues on a global standard set for implementing and managing HVDC in the data center, which further drives interest, and helps to reduce the complexities that currently revolve around the use of HVDC as mainstream power in the data center.

For more information about what was achieved and the key organizations that are involved in determining global standards and procedures, see 5.2, “Accomplishments in HVDC safety” on page 66.

1.6 Differences between the AC and DC technologies

This section describes the differences between the following power topologies:

1.6.1 Differences between the AC and DC power delivery

Inherently, AC power was the topology of choice for data center power. To understand the principles of HVDC power, it is important to understand the differences between the AC and DC technologies.

Alternating current

AC is an electrical current in which the magnitude and direction vary cyclically, as opposed to DC, in which direction remains constant. The usual waveform of an AC power circuit is a sine wave (although this wave is not the only type of alternating wave in existence). Used generically, AC refers to the form in which electricity is delivered to businesses and residences and delivers power somewhere around 100 V AC - 600 V AC.

An example of an AC sine wave is shown in Figure 1-1. AC is measured according to the cycles of a wave. The frequency of a cycle that a wave completes is (most commonly) measured in hertz (Hz). One complete wave cycle is equivalent to 1 Hz. The number of Hz per second indicates the frequency. For example, 60 cycles per second is equal to 60 Hz. As shown in Figure 1-1, the electrical current reverses direction in a continuous pattern.

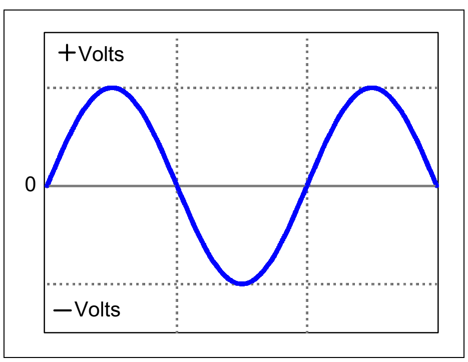

Figure 1-1 AC sine wave, which reverses the electrical current direction in a continuous pattern

It is important to understand that (for example) a 277 V AC power circuit is only the root mean square (RMS) voltage value of the circuit. It can have an oscillating voltage range from a peak of plus 392 V AC to a peak of minus 392 V AC. This range means that insulation and safety equipment must protect against the highest voltage. not the average.

Also included in this consideration is the influence of harmonics and harmonic distortion, which distort this sign wave and can result in higher peak voltage.

Direct current

DC power is the type of power that typically comes from batteries, wall chargers, fuel cells, and solar panels. DC is a constant flow of electric charge and is a linear method of power transmission. DC electric current flows in the same direction, which distinguishes it from AC current. Most electronic circuits require a DC power supply. For IT equipment, 12 V DC is required internally to power servers; therefore, if AC power is supplied, it must be converted to DC at some point.

An example of a DC flow, which travels through a circuit in only one direction, is shown in Figure 1-2.

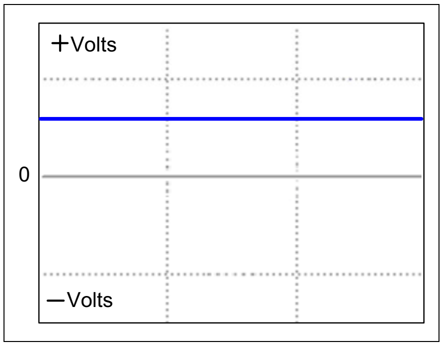

Figure 1-2 DC current, which flows in only one direction

Because AC requires a sine wave and grid synchronization and DC electrical charge flows in a constant direction at a constant rate and does not oscillate, DC power is a more stable approach for power distribution. For instance, a 380 V DC circuit is exactly that, 380 volts, no more, and in normal operation, no less. In addition to making insulation, safety, and circuit protection a straight forward proposition, it makes DC easier to control and simpler to use when multiple sources of power are integrated, such as solar power and batteries.

It is this characteristic that holds great opportunities for new developments in circuit protection, load flow control, short circuit protection, and arc flash exposure protection.

1.6.2 AC versus DC power supplies

The primary load in a server is the processor chip, memory, data storage (disk), and data transmission. All of these loads inherently require a share of 12 V DC power that is fed through an AC or DC power supply. This section describes how the AC and DC power supply operate and ultimately provide 12 V DC power to the servers load.

AC power supply

As seen in Figure 1-3 on page 11, the voltage that is entering the server AC power supply is 208 V AC. The rectification process of turning AC current to DC current is the first step that occurs. (For more information, see 2.1.5, “Rectifier” on page 23.) The bridge rectifier produces an unregulated DC voltage and because of the non-linear load that is performing AC-to-DC conversion, this process can create harmonics and feed back into the AC source. These harmonics must be neutralized by PFC circuit and typically have a poor PF, which means losing about 3% power to heat during the rectification process.

> **Note:** PF is the ratio of the real power that is used to do work and the apparent power that is supplied to the circuit. The PF can be values 0 - 1. The PF is equal to the real or true power in watts (W), divided by the apparent power in volt-ampere (VA).

As an example, a server that uses 70 W of power with a VA of 78 has a PF of 0.9 PF (PF = W/ VA). The PF must be corrected (PFC). This adjustment is done to the electrical circuit so that the PF can be changed to near 1. A PF of near 1 reduces the reactive power in the AC supply circuit and most of the power in the circuit is real power.

The power then passes to a boost converter between the bridge rectifier and the bulk capacitor. It also maintains a constant output voltage while drawing a current that is always in phase and at the same frequency as the line voltage.

It then passes through the filter capacitor and steps the voltage down to 12 V DC, which produces regulated DC voltage for distribution to the internal parts of the server. This process again loses power, which turns into heat and can account for up to 7% power loss, as shown in Figure 1-3.

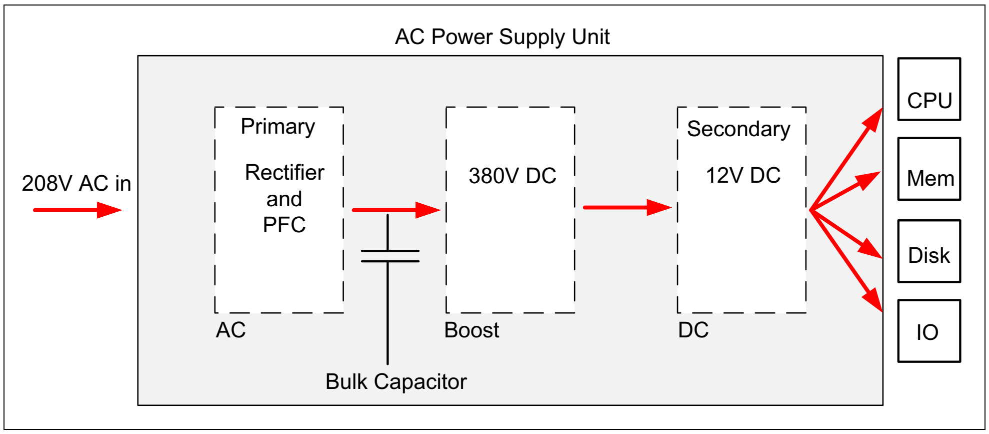

Figure 1-3 AC power supply topology

The AC power supply for the Flex System Enterprise Chassis is shown in Figure 1-4.

Figure 1-4 Flex System Enterprise Chassis AC power supply

DC power supply

The DC power supply is more straightforward and simpler compared to the AC power supply. Because DC power is entering the power supply, there is no need for the rectification process of converting AC to DC. Therefore, there are no harmonics to be concerned about, and no power factor correction is required. For DC circuits, it is as straightforward as P=VI.

In Figure 1-5, we see that 380 V DC power enters the power supply. There is an isolation stage where some supplies isolate the voltage up to 600 V (this step is a protection step from the incoming power lines for sensitive electronic components inside the server). Finally, the voltage is stepped down to a regulated 12 V DC for distribution to the server internal load.

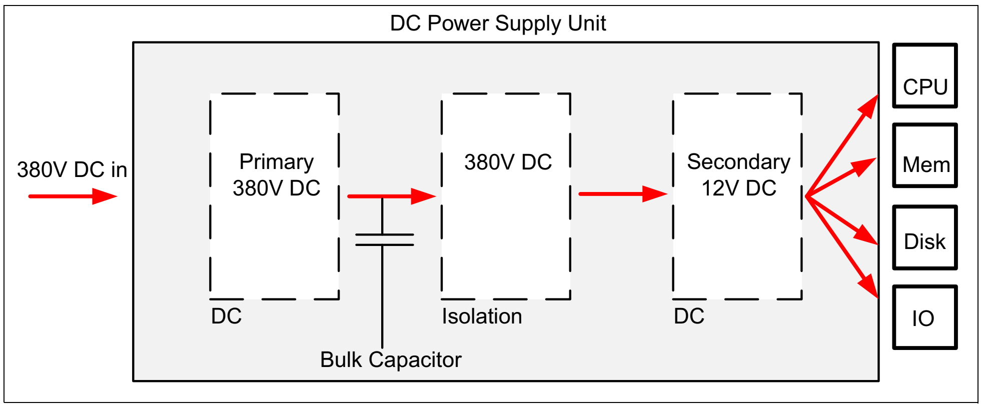

Figure 1-5 DC power supply topology

The Flex System Enterprise Chassis DC power supply is shown in Figure 1-6.

Figure 1-6 Flex System Enterprise Chassis DC power supply

1.6.3 Infrastructure differences

This section describes the differences between AC and DC powered data centers and includes the following sections:

- “AC data center” on page 13
- “DC data center” on page 14

AC data center

The topology of a typical AC data center is shown in Figure 1-7.

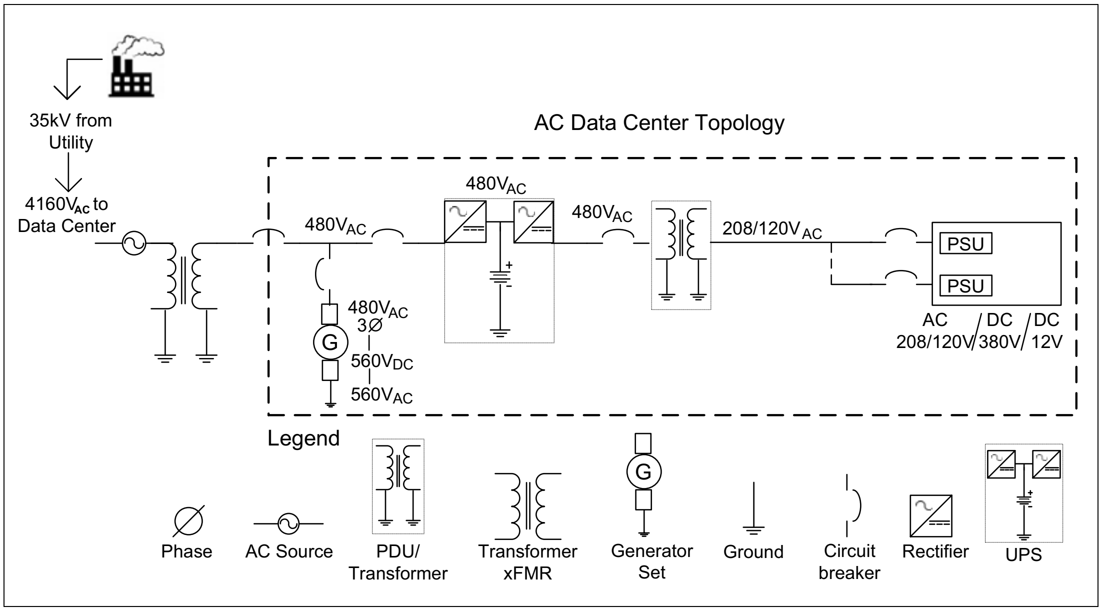

Figure 1-7 AC data center topology example

The following broad process is shown in Figure 1-7:

1. A utility company provides a high-voltage distribution (typical distribution voltages in the US include 5 kV, 15 kV, or 35 kV) to the facility. In this example, 35 kV is brought into the facility to be divided up across the facility.
2. The data center is receiving 4160 V AC of available power from the facility. This power goes through a transformation process by way of a transformer (xFMR) to provide 480 V AC (or for example, 600 V AC) into the data center room.
3. A generator set is attached to this line to ensure that it can synchronize its voltage to the voltage that is running throughout the data center. This step is done to provide backup if there is a power outage.
4. The power can then be attached to an AC UPS. A typical design uses 480 V AC UPS.
5. The power is stepped down by way of another xFMR to (for example, in the US) to 120/208 V AC. Typically, the transformer is in a PDU and it distributes the power to the racks for use by servers and other IT equipment.
6. The power arrives at the server in the form of AC and requires further rectification and voltage step down to provide 12 V DC power to the system load.

Note: Many different data center power distribution topologies are possible. The explanations and diagrams that are shown here are examples of what is commonly used only. Also, these diagrams depict power flow only and do not address redundancy and infrastructure classification.

DC data center

The topology of a DC data center is shown Figure 1-8. A utility company provides a nominal amount of AC power to the facility. Utility companies do not provide DC power to facilities directly. Instead, the data center's incoming line voltage of AC is converted to DC for distribution to the rack, as shown in Figure 1-8.

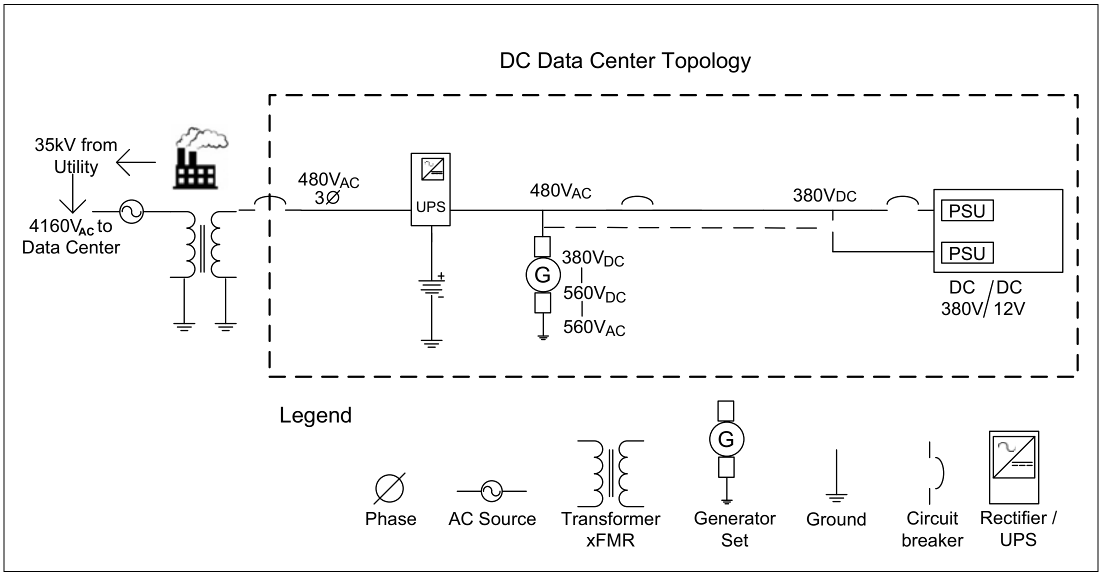

Figure 1-8 DC data center topology example

The following broad process is shown in Figure 1-8:

1. A total of 35 kV is brought into the facility. This 35 kV is sectioned up across the facility.
2. The data center in this example is receiving 4160 V AC of the available power from the facility.
3. The power must be sent through a transformer (xFMR) to provide (in this example) the data center with 480 V AC three-phase power.
4. The generator set can be attached before or after the AC to DC rectification process, depending on whether the generator is an AC or DC generator.
5. The power must be converted from AC to DC. This conversion is done by using a rectifier or DC UPS (a DC UPS is essentially a rectifier with a battery attached). The size of the rectifier that is required depends on the amount of AC power that is converted.
6. The DC power arrives at the server DC power supplies and again, does not require rectification. Isolation of the power occurs inside the power supply. The power is stepped down to 12 V DC for distribution to the system load.

AC versus DC data center power loss

In an AC data center, there can be up to six or more power conversion stages between facility power entry and the point at which power arrives to the chip (or other IT systems; for example, storage and networking).

The power losses because of the use of inefficient power conversion devices from outside and within the equipment result in a large loss of useful electrical power, which directly increases the energy that is required to remove the heat that is produced.

To put this fact into perspective, for every 1 W of power that is used to process data, approximately 0.35 W is required to support power conversion in an AC data center. Therefore, to achieve 1 W at the server, up to 1.35 W is required from the utility company. In addition, about 0.6 to 1 W is required to cool the power conversion equipment.

Unlike a DC power system, for every 1 W of power that is used to process data, approximately 0.15 W is required to support power conversion in the data center. Therefore, to achieve 1 W at the server, it must use approximately only 1.15 W from the utility company.

> **Note:** Power loss values are provided for a typical generic case. These values can differ, depending on the degree of redundancy, level of loading, equipment specs, and so on.

A topology of AC and DC power and where the loss of power can occur from utility to chip is shown in Figure 1-9.

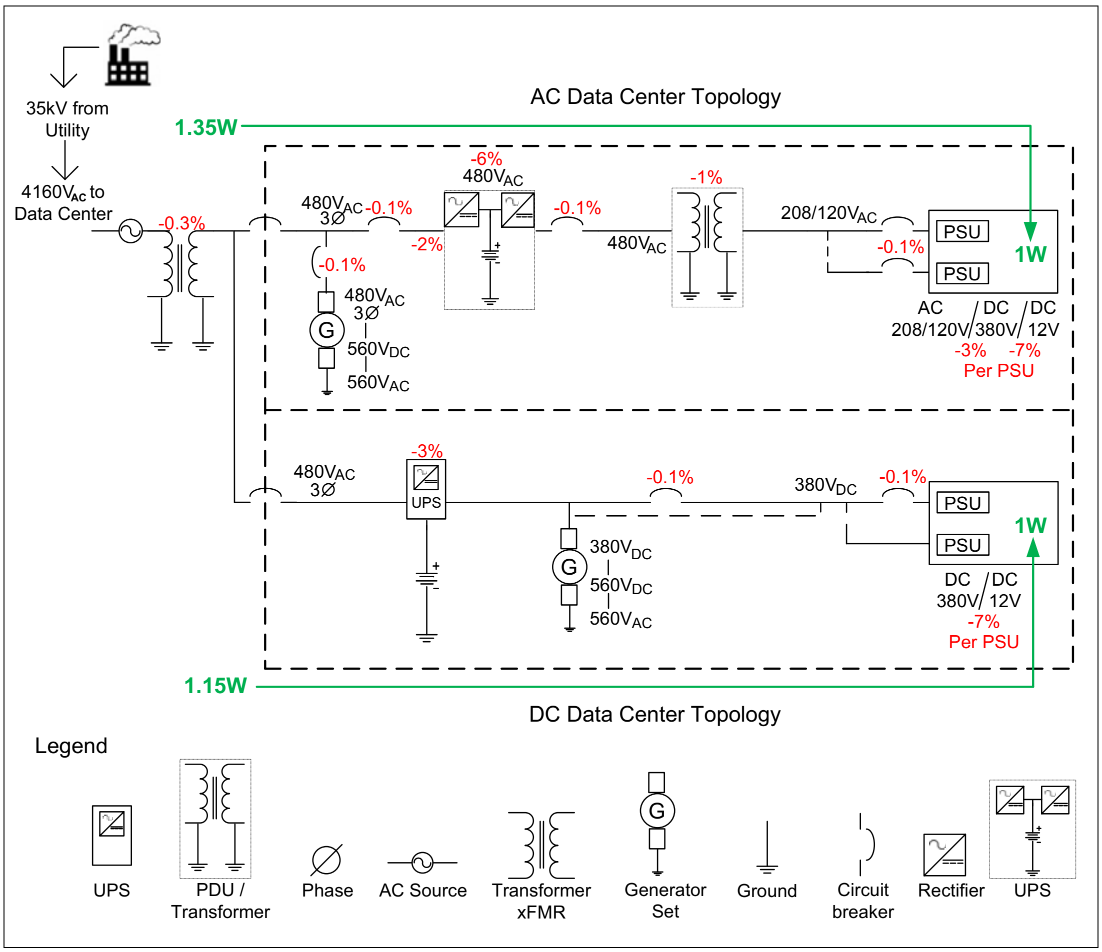

Figure 1-9 AC and DC data center power topology example

Differences between HVDC and Telco -48 V DC

The term HVDC is used to identify voltage in ranges that are higher than 200 V DC and lower than 600 V DC. The term HVDC is used to distinguish voltage in this range from the (today) more commonly and widely used -48 V DC in telecommunications (which is also referred to as *telco* and *telecom*). Consider the following points:

- The cabling infrastructure requirements of -48 V DC are different for HVDC because of the voltage differences between 48 V and (for example) 380 V DC. A -48 V DC infrastructure uses much higher current for the equivalent amount of power. Therefore, a -48 V DC solution requires much more cabling than a 380 V DC solution does to deliver the same amount of power to a rack.
- The lower current in HVDC power means enhanced distribution capabilities, lower equipment cost, and improved sustainability with smaller busway and wire sizes and reduced copper.
- A 48 V DC has its own set of standards and requirements that do not apply to HVDC deployments because HVDC deployments use much higher voltage levels, which call for different standards and safety procedures.
- The use of -48 V DC power was in use in the telecommunications industry since before the inception of the data center industry. As data centers came along and required vast amounts of power, the industry already standardized the use of AC power, which is widely reflected in the industry today.

With advances in DC technology, understanding, and safety, we are starting to see more interest in the benefits that HVDC can bring to the data center over AC power. Because of this fact, we also see more interest in HVDC in the telecommunications industry for its higher current capacity and lower installation costs.

Benefits of HVDC for telecommunications

Deploying HVDC in telecom core sites results in a reduction in cable deployment.

One of the main drivers in deploying HVDC power in telecom sites is the reduction of cable deployment. An HVDC powered site requires up to 85% less current compared to -48 V DC solutions. This reduction is the result of the fact that 400 V is seven times lower than 48 V because of the voltage difference of 380 V - 400 V to 48 V.

Most core telecom sites require a large amount of power. An example is a -48 V DC cable deployment on a large scale (with a requirement of 200 kW of power to travel a distance of 245 feet) that requires 48 x 750 MCM cables. When compared to 380 V DC - 400 V DC, only 4 x 750 MCM cables are needed to carry this amount of power for the same distance.

An example of the cable requirements to transport 200 kW of power for -48 V DC versus HVDC power infrastructure is shown in Figure 1-10.

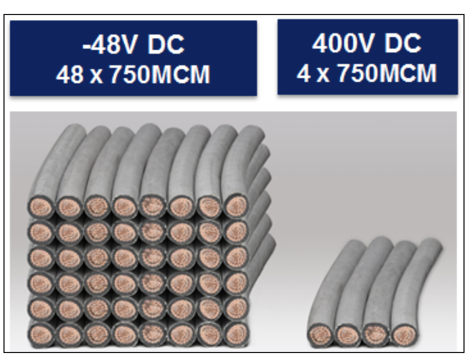

Figure 1-10 Cable requirement to transport 200 kW 245 ft

The amount of cabling that is required for -48 V DC becomes expensive at the capital level (cost of cables, lugs, installation, and so on) and at the operational level (for example, cooling requirements). A lower cable count also results in the following benefits:

- Space savings

  With a reduction in the number of deployed cables, the space savings can be significant.

  In -48 V DC (core) sites, the required space for cables and support infrastructure (and not the density of the equipment) is often the limiting factor for how much equipment physically fits in the racks.

- Heat reduction

  With fewer cables in the infrastructure, there is less power to lose and less heat to dissipate.

- Improved cable management

  Routing and installing fewer cables makes cable management much easier, which also makes it easier to change out cables and perform maintenance.

- Lower cost

  A lower cable count accounts for the following types of cost savings:

  – Capital expense: There is a lower cost of initial cable installation.
  – Operational expense: Ongoing maintenance and heat generation is less, which saves space.

- Used in the future

  HVDC can power -48 V DC loads and new 400 V DC loads. For -48 V DC loads, a second 380 V DC/-48 V DC conversion step is required. This conversion equipment can be placed in equipment rack row or in the equipment rack.

2

HVDC data center infrastructure

In this chapter, we describe the components that are involved in providing power in a High Voltage Direct Current (HVDC) data center.

Figure 2-1 on page 20 shows a grid to chip power component topology and how each component integrates into the overall infrastructure.

This chapter includes the following topics:

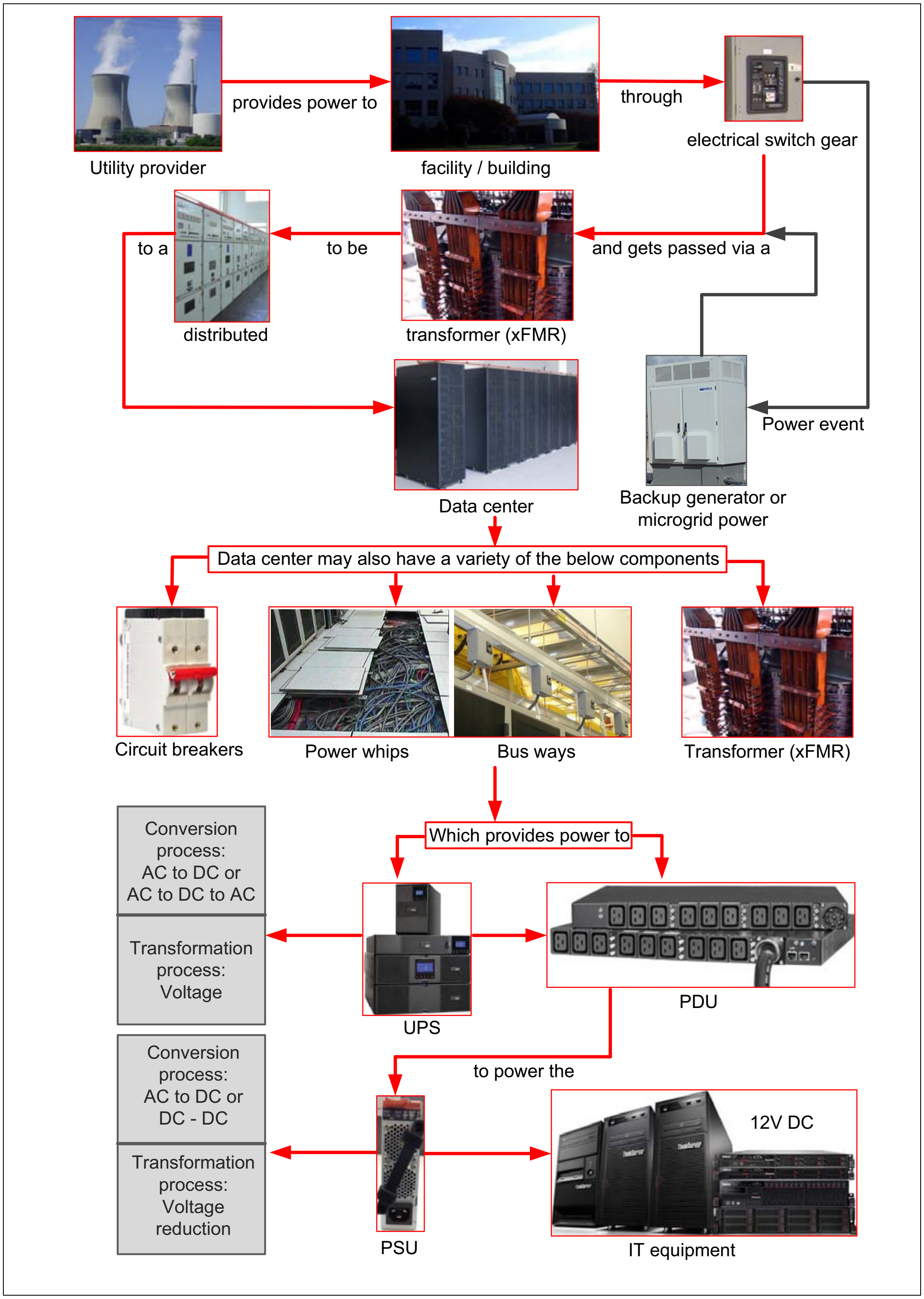

Figure 2-1 Grid-to-chip power component topology

2.1 HVDC data center components

In this section, we describe each component in the data center infrastructure. This section includes the following topics:

2.1.1 Utility provider

A utility provider is an electric power company that is responsible for the generation and distribution of power to a facility, such as offices, residences, and data centers. At the time of this writing, utility companies do not provide direct current (DC) power directly to facilities. The power that is provided by a utility company is in the form of alternating current (AC).

AC power from a utility company enters the facility at medium voltage (MV). In the US, this voltage often is 35 kV, 15 kV, or 5 kV. After the power is at the facility, the voltage is stepped down and distributed to different sections of the facility (such as the data center).

The data center might receive, for example, power at 4160 V AC, which then must be transformed into a usable low voltage (LV) so it can be attached to a distribution panel to be distributed throughout the data center. For more information about power transformation, see 2.1.3, “Transformer (xFMR)” on page 22.

At some point in the data center, the power also must undergo rectification (AC-to-DC) because most data center loads require DC to operate. For more information about the power rectification process, see 2.1.5, “Rectifier” on page 23.

2.1.2 Electrical switch gear

The switch gear provides multiple power and cooling paths, redundancy, and fault tolerance. Switch gear is the combination of electrical disconnect switches, fuses, or circuit breakers and is used to control, protect, and isolate electrical equipment.

There are certain reliability classifications (for example, 1, 2, 3, or 4) of redundancy that can be employed at a data center or building facility that the switch gear manages, as shown in the following examples:

- Reliability classification 1: Consists of a single path for power and cooling distribution without redundant components, which provides 99.671% availability.

- Reliability classification 2: Consists of a single path for power and cooling distribution with redundant components, which provides 99.741% availability.
- Reliability classification 3: Conisists of multiple active power and cooling distribution paths (for instance, from two separate utility company providers, one primary, one backup), but only one path active, has redundant components and is concurrently maintainable, which provides 99.982% availability.
- Reliability classification 4: Consists of multiple active power and cooling distribution paths (for instance, from two separate utility company providers both active), has redundant components and is fault tolerant, which provides 99.995% availability.

As an example, in a reliability classification 3 data center set up, if a power outage occurs at the grid, the electrical switch gear safely switches to the alternative power path that is provided by the backup utility company or backup onsite generator.

Electrical switch gear can also be used to cut the power to equipment to allow work to be done and can be used to clear faults downstream.

2.1.3 Transformer (xFMR)

The purpose of a transformer (xFMR) is to transform (step up or down) AC voltage. A transformer can be external or internal to IT equipment. For example, an external transformer might introduce power to the facility. The power then must be stepped down to 480 V AC, for example. It might need to be stepped down again to 208 V AC.

A converter is an uninterruptible power supply (UPS) or a power supply unit (PSU). In a DC PSU, the 380 - 400 V DC power that is entering the supply must be stepped down to 12 V DC (all IT systems require 12 V DC of internal power; for more information, see 1.1, “What is HVDC” on page 2). The transformer also provides isolation by disconnecting the PSU from the main power line, which makes it responsible for preventing the main line voltage from being delivered to the internal IT power circuit.

2.1.4 Distribution panel

A data center distribution panel receives power from a utility company after it is stepped down by a transformer. It distributes power to the load, which is the rack Power Distribution Unit (PDU) or rack server power supply, by using power whips (cables that run from the power distribution panel under a raised floor or overhead to provide power to racks) or busway systems throughout the data center. For more information about power cable whips and busway systems, see 2.1.9, “Power whips” on page 26 and 2.1.10, “Busway” on page 28.

In a DC data center setting, rectification occurs to provide DC power and is accomplished with a rectifier. The distribution panel can be wall-mounted or free-standing. An example of a wall-mounted electrical distribution panel is shown in Figure 2-2 on page 23.

Figure 2-2 Electrical distribution panel

Distribution panels also contain protective devices for safety, which can include fuse or circuit breakers and current breakers for overcurrent protection.

Note: AC and DC distribution panels are not interchangeable because the protective devices are different.

2.1.5 Rectifier

A utility company supplies data centers with AC power because DC power is not provided directly from electric providers. If the intention is to power hardware with DC power, the AC power that is supplied by the utility company must be converted to DC power at some point. This conversion is done with a rectifier.

A rectifier is an electrical device that converts AC, which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as *rectification*.

AC-to-DC rectification can occur in several locations in a data center's power chain. When AC distribution is used with an AC UPS, rectification occurs within the AC UPS to charge the battery and within the server power supply to provide 12 V DC to the system. When HVDC distribution is used, the AC-to-DC rectification occurs within the DC UPS only.

Note: Rectification in server power supplies and IT equipment requires a steady, constant DC current. Because of the alternating nature of the AC sine wave, the process to rectify to DC produces unidirectional pulses of current. To regulate and smooth the DC output, an electronic filter (capacitor) is used to produce a steady current.

2.1.6 Uninterruptible Power Supply

Availability is crucial in a data center. A UPS that is equipped with batteries or other forms of energy storage systems (such as flywheels) provides a way of ensuring power to systems if there is a power outage from the mains. A battery and flywheel feature the following differences:

- Battery: Batteries store energy and convert it to electrical power through chemical reaction. Traditionally, batteries are the most common form of UPS support in the industry.

- Flywheel: A flywheel mechanically stores and converts kinetic energy by spinning a large, heavy disk. This type of power is not used commonly in today's data centers.

  Flywheel energy storage (FES) works by accelerating a rotor (flywheel) to a high speed and maintaining the energy in the system as rotational energy. When energy is extracted from the system, the rotational speed of the flywheel is reduced as a consequence of the principle of conservation of energy; adding energy to the system results in an increase in the speed of the flywheel.

Depending on the requirements and infrastructure setup, the UPS or energy storage system can have AC or DC output.

A normal AC UPS performs rectification inside the UPS (AC-to-DC for energy storage and then back to AC via an output inverter). Any DC hardware, such as compute loads that are connecting to the AC UPS, also must be rectified from AC to DC.

If a DC UPS is used in an HVDC data center, the DC UPS and the rectifier are one in the same. Unlike an AC UPS, the DC UPS does not have an output inverter and it does provide DC output. For more information about DC UPSs, see in 2.1.7, “HVDC UPS”.

A UPS is typically dimensioned to support an IT load for a certain amount of time (usually 1 minute to a few hours, depending on the size of the UPS batteries and the IT load). The goal is to maintain power to the IT equipment until one of the following events can occur:

- A graceful shut-down of non-critical hardware
- A generator set takes over to provide power to the data center
- Power from the main utility company is restored

An example of a Lenovo 6kVa UPS is shown in Figure 2-3.

Figure 2-3 AC UPS

2.1.7 HVDC UPS

An HVDC UPS takes in AC power from the utility and provides AC-to-DC conversion and backup power via batteries. A typical HVDC UPS contains the following components:

- AC input section
- Rectifier section for AC-to-DC conversion
- HVDC distribution
- System controls
- Connection to batteries

Batteries might be within the HVDC power conversion cabinet, in an adjacent cabinet, or in a separate area of the facility. Figure 2-4 on page 25 shows an example of an HVDC UPS.

Figure 2-4 A 120 kW HVDC UPS

Most HVDC UPSs (for example, the Emerson Network Power's NetSure 9500) are based on a modular architecture with multiple rectifiers that are integrated into the UPS system. Such systems use hot-swappable rectifiers, which can be removed or added to the HVDC UPS system while it is operational with no disruption to the HVDC power distribution. This architecture has many advantages to infrastructure reliability, cost, and footprint. Figure 2-5 shows an example of an HVDC rectifier.

Figure 2-5 Modular 15 kW HVDC rectifier

With modular rectifiers, redundancy can be within the UPS rather than requiring more UPS systems. Because the rectifiers can be replaced with no interruption to the output power, an HVDC UPS system is extremely fault tolerant. This tolerance results in high reliability and significantly reduces the UPS oversizing that is common with AC UPS architectures.

The HVDC UPS capacity also can more closely match the site power requirements. For example, in the case of Emerson's HVDC products, system power capacity can be scaled in increments of 15 kW (the size of a single rectifier). Because rectifiers can be added to an operational HVDC UPS, UPS capacity at a site can be expanded as needed versus oversizing the UPS for potential future growth.

The output of an HVDC UPS is DC voltage (often approximately 380 V DC). The exact output voltage can be adjustable within a range to accommodate different battery configurations that are wanted by the particular site. The output distribution of an HVDC UPS can be connected to a busway (which is connected to an HVDC power distribution rack) or cabled directly to HVDC equipment racks.

2.1.8 Generator set

A generator set (gen set) is an independent source of electrical power that supports the IT equipment load if there is a power utility outage from the main power supply (the power utility company). The gen set is activated when the main power source becomes unavailable.

Most often the generator is connected in parallel with the utility source or connected through a transfer switch and the DC UPS is down stream of both sources.

An example of a generator set external to a building is shown in Figure 2-6.

Figure 2-6 External generator on top of a building

2.1.9 Power whips

Whips are cables that run from the power distribution panel that is under a raised data center floor or over head to provide power to racks. This method traditionally is the most common method for providing power to racks. However, power whips can cause the following issues:

- Difficult to maintain: There often are many whips that are running from a distribution panel under the raised floor distributing power out to PDUs or directly to a server. There can be only one whip that runs from the distribution panel to each PDU or server. This configuration can result in multiple whips that are running to each individual rack, which causes a large mass of cables under the raised floor that makes it maintenance difficult.
- Cooling efficiency: If the cooling from a computer room air conditioning (CRAC) system has a downward flow that provides cool air under the raised floor (which is distributed out by using perforated tiles throughout the data center), a mass of cables can affect the rate and efficiency at which the data center is cooled.
- Hard to change out: A power whip can provide only single-phase or three-phase power to a PDU or rack server directly. If a single-phase circuit must be replaced with a three-phase circuit, the entire whip from the panel to the rack must be run again and replaced.
- Costly to change: Cable whips are expensive. With multiple whips to run per rack, the cost can be high.

Removing an existing whip can also cause other issues. Because the whip runs under the floor alongside many other whips, pulling a whip for removal can cause a snag on another whip, which can cause it to be pulled from a PDU or server. This removal can cause an unexpected outage. Because they are so hard to remove, often they are unplugged and left in place while whips are added, which increases the congestion under the raised floor.

Removing and replacing whips can also be a timely and costly project because you are dealing with a live panel. Therefore, maintenance must be performed by a licensed electrician.

A tile that is removed on a raised data center flooring to expose the networking and power cable whips that are stored underneath is shown in Figure 2-7.

Figure 2-7 Raised flooring with networking and power cable whips

A view of the cable whips from under a raised data center flooring is shown in Figure 2-8.

Figure 2-8 Power whips and networking cables under the raised floor in a data center

2.1.10 Busway

A busway is a pre-packaged bus with AC or DC power lines that are running through it. It is another way of providing power to a rack from the distribution panel instead of the use of power whips. In many cases, a busway is the most convenient method for distributing HVDC power to the rack. This method is becoming a popular way to distribute AC and DC power to the rack. Busways can be run under a raised floor as whips can be, or they can be run above the racks.

Unlike cable whips where single-phase or three-phase power is cable whip-dependent (and to change from single to three-phase power, the entire cable whip must be changed out), all busways provide three-phase power.

The busway can also provide single-phase power by using the circuit configuration of a tap-off box that sits above or underneath the rack. Therefore, to change from three-phase to single-phase, there is no more replacement of long cable whips under a raised floor. Instead, it is a matter of configuring the phase by using the plug-in (or slide-in) tap-off box.

On some busways (such as the Starline Busway manufactured by Universal Electric Corp), it is safe to install a tap-off box when it is energized because grounding is established before voltage is applied. The tap-off box is installed at the busway by using a twist locking mechanism that fits inside the access slot of the busway. There is no need to place hands or tools inside the busway. An example of a tap-off box twist locking into a busway is shown in Figure 2-9.

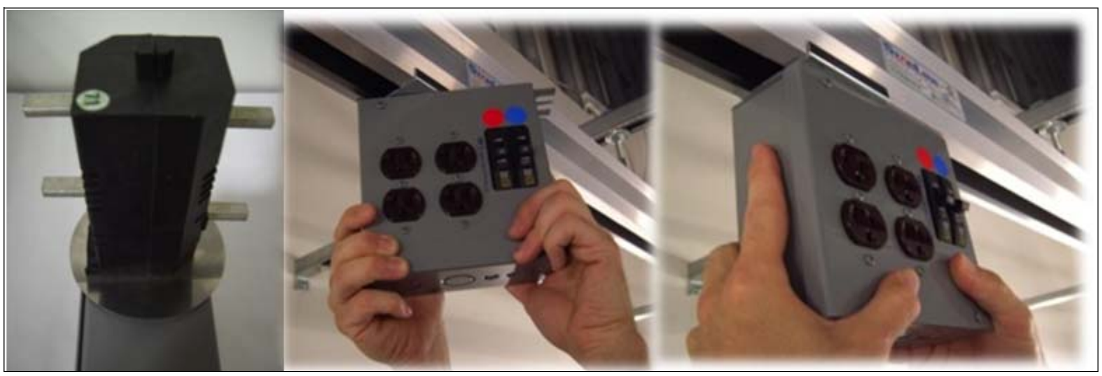

Figure 2-9 Tap-off box twist locking into busway

The power tap-off boxes that connect to the track are available in different configurations and capacities, ranging from 120 V/20 A single-phase up to 208 V/100 A three-phase (or 415/240 V).

The busway also is available in different amperage ratings of 60 - 600 A. Most vendors offer them in four standard ratings of 100 A, 250 A, 400 A, and 800 A.

The tap-off box also contains circuit breakers and connects power in one of two ways: directly into the box or by a cable whip that runs down to the rack.

A tap-off box that connects power cables directly to outlets on the box is shown in Figure 2-10.

Figure 2-10 Tap-off box with power outlets

A tap-off box that connects a main power cable whip to the rack is shown in Figure 2-11.

Figure 2-11 Tap-off box with main power cable whip

Each manufacturer has its own proprietary power tap-off box, which varies in size, shape, capacity, and the number of circuits or receptacles they can support.

A three-phase AC busway contains four fully rated buses and an optional grounding. DC applications require only two buses. Therefore, a busway of the same current rating can carry more power in DC than in AC application or provide two power paths for redundancy. An example of the distribution between a 400 A busway for AC and DC application is shown in Table 2-1.

Table 2-1 Distribution between a 400 A busway and DC applications

Rating	Output
208 V AC @ 400 A	130 kW (.9 PF)
415 V AC @ 400 A	258 kW (.9 PF)
300 V DC @ 400 A	(152 kW x2) 304 kW

The typical track section on a busway is 3.04 m (10 feet) long, although some vendors offer lengths of 0.91 - 3.66 m (3 -12 feet). If the busway needs to be extended, another busway can be connected to a powered down busway by using an end-splice box, T connectors, or right angle connectors.

A busway can carry multiple power lines in the one system to provide multiple tap-off boxes and racks with power. This configuration is achieved by using brackets inside the bus way. Figure 2-12 shows the inside of a bus way and the brackets that are used to keep power cables separated.

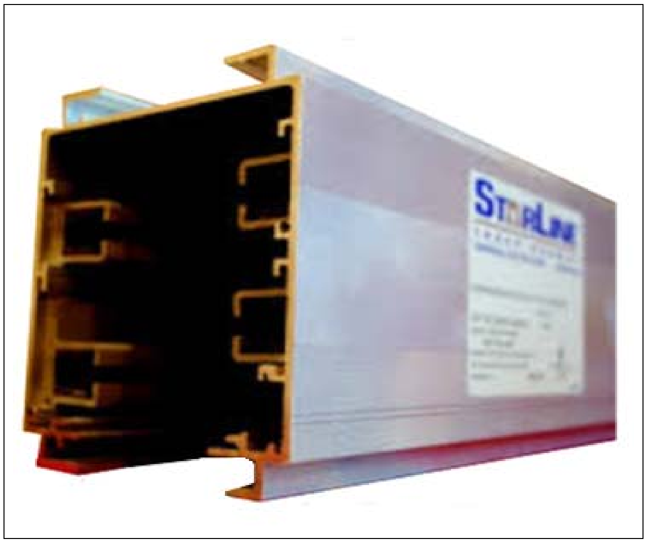

Figure 2-12 Internal view of a busway

The use of a busway over power whips to provide power to the racks features the following advantages:

- Installation is easier: Compared to cable whips that require multiple cables per rack, a power whip solution is cleaner and simpler to deploy.
- Greater flexibility: The flexibility to change from three-phase to single-phase (or vice versa) is more simplified with busways than with power whips.

  For example, changing from three-phase to single-phase power by using a power whip requires the installation of a new cable whip and the existing cable whips might need to be removed.

  Changing from three-phase to single-phase power by using a tap-off box requires configuring the box only, which is easy to access and install.
- Cooling efficiency: Multiple power whips that are running under a raised floor can impede airflow, which makes it less efficient to cool the data center. Moving to an overhead busway eliminates this issue and frees up space under the floor for cool air to flow freely.

  Also, if an overhead busway is used, it acts as a partial barrier that helps to separate the air between the hot and cool isles.
- Lower total cost of ownership: Although a busway can be more costly up front over power whips, the use of multiple long power whips over time can add up, and the hassle of upgrading, installing, and removing cable whips can become more expensive over time.
- Easy to monitor: Busway vendors offer some level of optional systems that can provide energy monitoring and management. In some instances, these features can be integrated within the tap-off box and provide the power input value per tap-off box.

Changes can occur in a data center, so power cable whips can become a problematic and costly issue. The use of a busway can elevate the issues that are associated with power cable whips and provide a more flexible and simpler solution for providing power from the distribution panel.

An example of an overhead busway system in use in a data center is shown in Figure 2-13.

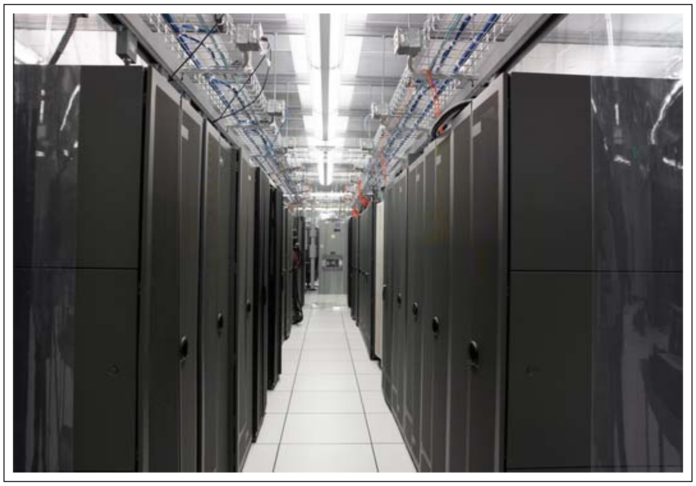

Figure 2-13 Overhead busway that provides power to the racks in a data center

2.1.11 Circuit breaker

For a simple explanation of a circuit breaker, think of a light switch. When a light switch is turned on, a current can pass through the circuit to provide power to a light. When the light switch is turned off, the circuit is broken and current cannot pass through.

A circuit breaker in a data center is an automatically operated electrical switch that protects an electrical circuit from damage. Damage can occur by an overload or a short circuit. If a circuit breaker detects a fault condition, it interrupts the current flow, much like turning a light switch on and off. If a circuit breaker interrupts the current flow of a circuit, it can be reset manually or automatically to resume normal operations.

Circuit breakers are an essential element of the system that provides powers to a data center. They are an important safety mechanism in any facility that receives power, such as buildings and homes. For more information about circuit breakers and HVDC safety, see 5.3.7, “Circuit protection” on page 72.

An example of multiple circuit breaker manufactures for 380v DC is shown in Figure 2-14.

Figure 2-14   Example of a circuit breaker

2.1.12 PDU and server AC and DC line cords

PDU AC and DC line cords connect PDUs to power whips or busways. Depending on the PDU, it can have a detachable line cord or be hardwired (such as an HVDC PDU), as shown in Figure 2-15.

Figure 2-15   AC PDU with a detachable line cord and an HVDC PDU with a hardwired line cord

Server AC and DC line cords connect the power supply of a server to a PDU or directly to a power whip or busway, as shown in Figure 2-16. In this configuration, the PSUs of a server are connecting to a PDU that is installed at the side of the rack.

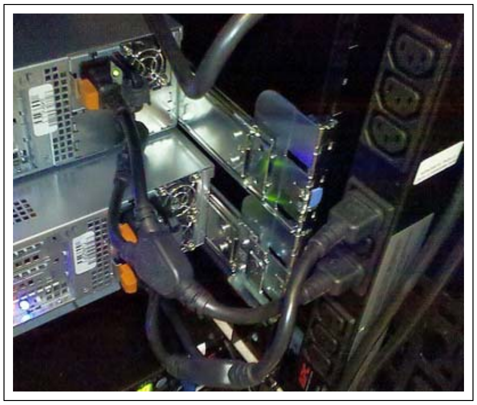

Figure 2-16 Server to PDU line cord connection

There are many types of AC line cords for the many types of PDUs and PSUs. The types vary by current, voltage, and phase.

For HVDC power, fewer line cord options are needed because of the simplicity of DC distribution. Unlike AC power where the line cord can determine single phase or three-phase operation, there are no phase requirements for HVDC, which reduces the number of cable options. For more information about HVDC line cords, see 5.6, “Plug safety certifications” on page 73.

2.1.13 Power Distribution Units

PDUs are needed when power from a distribution panel is required to power multiple pieces of equipment. A PDU has multiple outlets and varies in design by form factor (size), number of outlets, type of outlets, type of inlet, phase, and capacity.

PDUs vary from simple and inexpensive rack-mounted power strips, to larger floor-mounted PDUs with multiple functions that include power filtering to improve power quality, intelligent load balancing, and remote metering and monitoring (by LAN or SNMP). Figure 2-17 shows two AC PDUs, each with nine C19 outlets on the front of the PDU (left) and an HVDC PDU with six Rong-Feng (RF-203P) outlets (right).

Figure 2-17 AC Power Distribution Units (left) and DC Power Distribution Unit (right)

2.1.14 Power Supply Unit

The PSU connects power from the PDU, power cable whip, or busway to the server. Unlike AC PSUs that must rectify AC to DC power (IT equipment ultimately requires 12 V DC to its internal components), a DC power supply receives DC power from the PDU, power cable whip, or busway, and does not need to rectify power. For more information, see 1.1, "What is HVDC" on page 2.

AC and DC power supplies must transform (or step down) the voltage of the power that is received to 12 V DC before it is distributed to the internal components of the IT equipment. For more information about AC and DC power supplies, see 1.6.2, "AC versus DC power supplies" on page 10.

The HVDC PSU for the Flex System Enterprise Chassis is shown in Figure 2-18.

Figure 2-18 HVDC PSU for the Flex System Enterprise Chassis

2.1.15 Computer room air conditioner or computer room air handler

With the amount of IT equipment that is housed in a data center, all of which produce varying amounts of heat, a data center room can become hot. This heat can cause multiple issues in the data center because the equipment can overheat and eventually shut down.

The purpose of a computer room air conditioner (CRAC) and a computer room air handler (CRAH) is to provide cooling to the data center, including keeping the power infrastructure cool (UPSs, PDUs, servers and PSUs, and cabling). Depending on the size of the data center, there might be multiple CRACs or CRAHs that cool the room or a combination of both.

The CRAC and CRAH cool a data center by using the following methods:

- CRAC

  A CRAC unit is like an air conditioner in a residential home. It contains a direct expansion (DX) refrigeration cycle that is built into the unit. Compressors are in the unit to power the refrigeration cycle.

  A CRAC unit works by bringing in air from a rooftop condenser, down through the DX compressor, and then blowing the air over cooling coils that are filled with refrigerant. The cool air is then pushed out by fans that are in the CRAC unit out into the data center.

- CRAH

  A CRAH uses chilled water inside the cooling coils rather than using coils that are filled with refrigerant. Water comes into a building from a chiller plant, passes through a chilled water valve, is pushed down into the coil, and is pushed back out again to the chiller plant to be cycled through again. Air is pushed along the water-filled coil and is then cooled and pushed out by fans that are inside the CRAH into the data center.

The cool air from the CRAC or CRAHs in a data center is commonly pushed out to under a raised floor. The amount and location of cool air that is released into the data center can be controlled by opening and closing perforated tiles that are in the raised flooring around the data center. CRACs and CRAHs can be powered by AC or DC power.

An example of a CRAC that is installed in a data center that uses perforated tiling is shown in Figure 2-19.

Figure 2-19 Computer room air conditioner

2.2 Infrastructure responsibilities

The components that make up the power infrastructure of an HVDC powered data center were described in 2.1, "HVDC data center components" on page 21. The Venn diagram in Figure 2-20 provides a simple topology of the persons who might be responsible for the different components that are found in a data center.

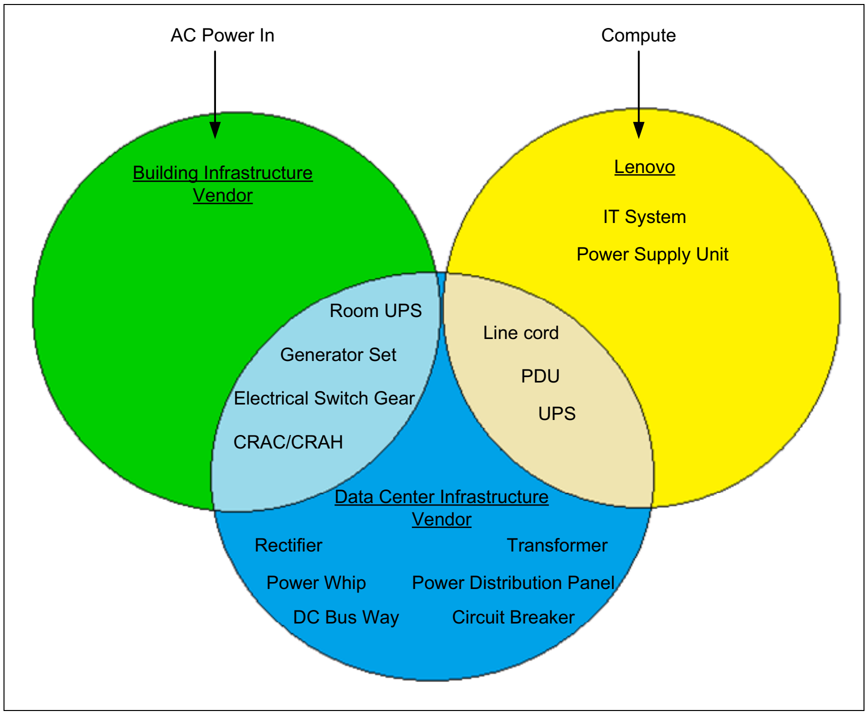

Figure 2-20 Infrastructure responsibility view of the persons who power a data center

The power infrastructure components that make up a data center can be segmented into the following major groups:

- Building infrastructure components
- Data center infrastructure components
- IT hardware components (which is shown as Lenovo in Figure 2-20)

Each group is responsible for the following parts of the overall infrastructure:

- Building infrastructure

  The building infrastructure can hold a large UPS (for example, larger than 15 kVA), a generator set, the network switching gear (also referred to as *electrical switching gear*), and the cooling systems (CRACs or CRAHs).

- Data center infrastructure

  Data center vendors might be responsible for the rectifiers, power whips, busways, transformers (xFMRs), circuit breakers, and power distribution panels. They might also be responsible for the room UPS, gen set, network switch gear, CRAC and CRAHs, line cords, PDUs, and UPSs.

- IT hardware infrastructure

  The IT vendor company (in this case Lenovo) is responsible for the IT equipment, including servers, and might also be responsible for line cords, PDUs, and UPSs.

3

Planning considerations to implement HVDC in data centers

This chapter describes the implementation considerations of HVDC power for the following data center category types:

- Greenfield data center: A new data center build that is designed to use HVDC power.
- Brownfield data center: An AC powered data center that plans to be retrofitted to use HVDC power. Retrofitting occurs through an expansion or redesign of the facility.

It is expensive to completely remove an existing AC infrastructure and replace it with a higher voltage direct current (HVDC) powered infrastructure. Greenfield data centers and expansions to brownfield data centers can present an excellent opportunity for installing and using HVDC power.

This chapter includes the following topics:

3.1 Considerations for implementing HVDC in greenfield data centers

There are many decisions to make when building greenfield data centers. One of the most important aspects is planning which type of power the data center will use. This chapter describes the various aspects to consider when you are planning to use HVDC power for a greenfield data center.

The following methods can be used to incorporate DC power into the new data center:

- Facility level DC configuration: This method delivers HVDC power throughout the facility. This configuration handles the DC conversion and distribution at the building (or data center) level, converting, for example, 480 V AC to 380 V DC, and delivering this power to the DC powered hardware in the rack.
- Row level DC configuration: In this configuration, a DC UPS is in the equipment racks line-up.
- Rack level DC configuration: This configuration accomplishes DC conversion and distribution at the rack level. This conversion is done by using a rectifier unit inside the rack for converting, for example, 208 V AC to 380 V DC at the rack, and delivering this power to the DC-powered hardware in the rack.

Benefits can be realized from the facility-level and rack-level DC configurations, as described in 1.2, “Benefits of HVDC” on page 3. The two key benefits of HVDC power include increases in efficiency and reliability. These benefits are realized by reducing the number of conversions and energy losses before the IT equipment load and by simplifying the architecture.

In this section, we describe the following considerations for new greenfield HVDC powered data center deployments:

- 3.1.1, “What hardware is available for HVDC”
- 3.1.2, “Installation, operation, and maintenance of HVDC hardware” on page 39
- 3.1.3, “AHJ approvals for local compliance” on page 39
- 3.1.4, “Grounding methods” on page 39
- 3.1.5, “Using alternative energy sources” on page 40
- 3.1.6, “AC versus DC UPSs” on page 41
- 3.1.7, “Location of power and networking cables” on page 43

3.1.1 What hardware is available for HVDC

When considering HVDC power for the data center, it is important to determine what IT hardware manufacturers, vendors, and suppliers are currently offering, and determine whether this hardware meets the needs of the data centers of today and tomorrow.

At the infrastructure level, the following hardware can require power:

- Computer room air conditioning (CRAC) and Computer room air handling (CRAH)
- Lighting
- Rectifiers
- Transformers
- Generator
- Security System

At the rack level, the following hardware can require power:

- Servers
- External storage
- Rack networking switches
- Top of rack switches (ToR)
- Uninterruptible power supply (UPS)
- Power distribution units (PDU)
- Tape

Designing a DC data center today is easier than in previous years because more of the IT hardware and infrastructure components exist. Although there are more AC-powered systems in use today, the availability of DC systems is likely to increase in the future. This increase is the result of the fact that there is more commonality in the industry among vendors. Also, the industry is seeing a wider adoption of common form factor (CFF) power supplies.

As described in 1.2, “Benefits of HVDC” on page 3, whether the IT equipment has AC powered power supplies or HVDC powered power supplies, both must deliver 12 V DC power internally. Because of this requirement, the availability of the CFF HVDC PSUs makes them interchangeable between certain rack servers and increases the footprint of available HVDC hardware.

> **Note:** CFF power supplies are interchangeable between certain rack servers because of the shape and size of the supply.

3.1.2 Installation, operation, and maintenance of HVDC hardware

Another consideration for HVDC power in greenfield data centers is the installation, operation, and maintenance of high-voltage power. Because HVDC power can produce up to 400 V, the high-voltage levels can be dangerous and touching live wires can be fatal.

It is important to ensure that your staff has the recommended safety certifications and knowledge to operate, service, and handle HVDC power. For more information, see 5.4, “Handling HVDC safely” on page 72.

3.1.3 AHJ approvals for local compliance

When building a greenfield data center, contacting and gaining approval from the local authority having jurisdiction (AHJ) is an important step. The AHJ is an organization that regulates construction sites, overlooks construction processes, and enforces local building codes (such as electrical and fire codes). The AHJ directives ensure that the greenfield data center and the use of HVDC is in compliance with local AHJ regulations.

3.1.4 Grounding methods

Determining how the power is grounded is another important aspect when building greenfield data centers. There are several methods available for grounding power, as described in 5.3.2, “Grounding methods” on page 68. How HVDC power is grounded is of particular importance because of the dangerously high-voltage levels that are used.

Assuming compliance with state and local codes, it is recommended that HVDC power have a high-resistance midpoint grounding (HRMG). For example, the HRMG in 380 V DC environments produces a safe and reliable +/-190 V distribution line regarding earth, as opposed to a dangerously high +/-380 V distribution line that negative and positive grounding produces.

3.1.5 Using alternative energy sources

Another consideration is the option to incorporate an alternative power source, which is referred to as a *micro-grid*. This incorporation can be achieved through the creation of power from renewable energy sources, such as solar power or wind. It can also include power from fuel cells, batteries, or other alternative energy sources. An example of some of the different ways in which a micro-grid an be achieved is shown in Figure 3-1.

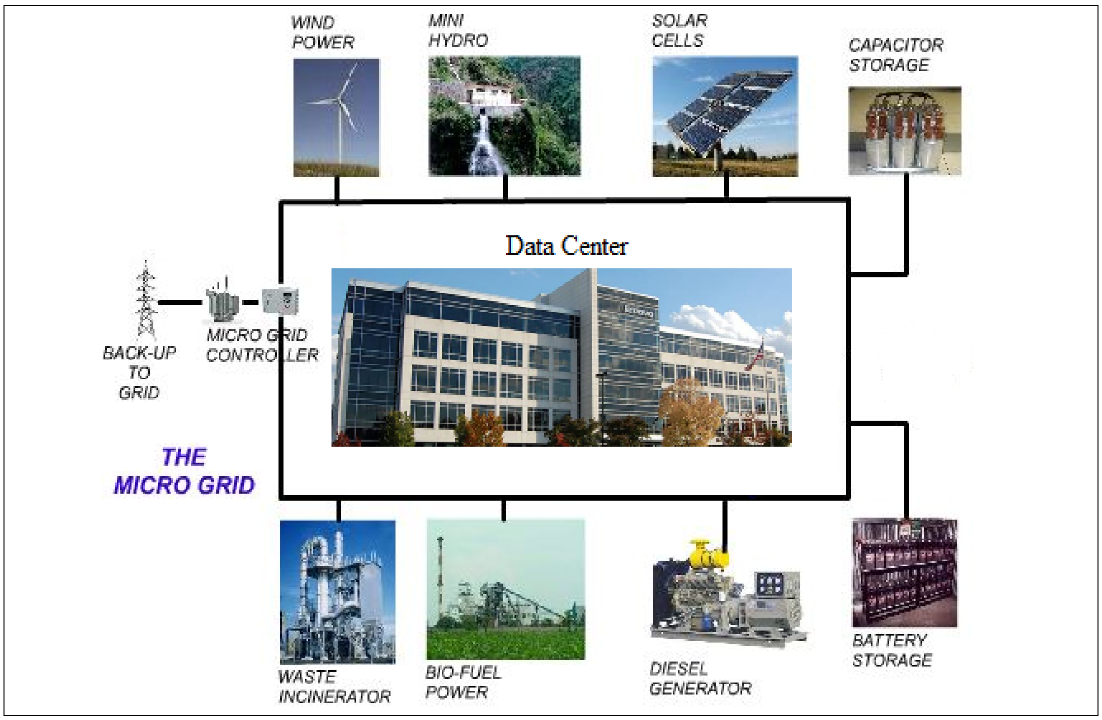

Figure 3-1 Different ways to achieve alternative power

The following more common options are used for renewable and alternative energy sources for data centers:

- Solar

  Solar power is the conversion of sunlight to current electricity directly by using photovoltaics (PV), or indirectly by using concentrated solar power (CSP). Consider the following points:

  – The PV method converts solar energy to electricity by using semi-conducting materials that exhibit a photovoltaic effect. A photovoltaic system uses solar panels that are composed of many solar cells to supply usable solar power.

  – CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam to generate DC power.

- Wind

  Wind power generates electricity from the naturally occurring power of the wind. Wind turbines capture wind energy within the area that is swept by blades and generate DC power.

- Fuel cells

  A fuel cell is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen or another oxidizing agent.

- Biomass

  Biomass-to-energy facilities convert almost any organic material that is made from plants or animals into electricity. Examples include wood and sawdust from forest slash or lumber mills, or agricultural waste from plants or animals.

Micro-grids naturally generate DC power, which is advantageous for DC-powered data centers because it allows for easy integration. Only a simple converter is needed between the renewable energy source and the power bus that provides DC power to the rack.

3.1.6 AC versus DC UPSs

There are two types of UPS: AC UPS and DC UPS. If there is a power outage from the grid, the UPS system isolates IT equipment from interruptions in power and keeps the equipment running until the power is restored from a generator or from the grid.

AC UPS and DC UPS operate differently in that the AC UPS takes AC in and puts out battery-backed AC power. The DC UPS can take in AC, but puts out battery-backed DC power.

Compared to AC UPS, DC UPS can be advantageous for a number of reasons, including it is simpler in its implementation and operation. DC UPSs also feature the following advantages:

- Higher reliability and efficiency

  An AC-powered data center must convert the AC power from the grid into DC power to charge the UPS batteries. The DC power then must be converted back into AC power to enter the rack PDUs or directly to the server. After the power reaches the server, it must be converted back to DC again for internal power to the server. This topology requires more components (which makes it less reliable), and more conversions (which makes it less efficient) than a DC powered UPS.

- Easier to manage

  Unlike an AC UPS in which the voltage, frequency, waveform, and phase balancing and synchronization of circuits requires management, the only aspect of the DC UPS that requires management is the voltage. There is no need for phase balancing and no waveform with which to contend.

- Modularity is easier to accomplish

  There is less hardware inside a DC UPS, so it can be smaller in physical size and lighter in weight for equivalent ratings that are compared to an AC UPS.

- Cost effective to run

  DC UPS systems are less costly to operate than AC UPS systems. DC UPS systems use less power because only one internal power conversion (from AC to DC if AC is the input) is needed, as shown in Figure 3-2.

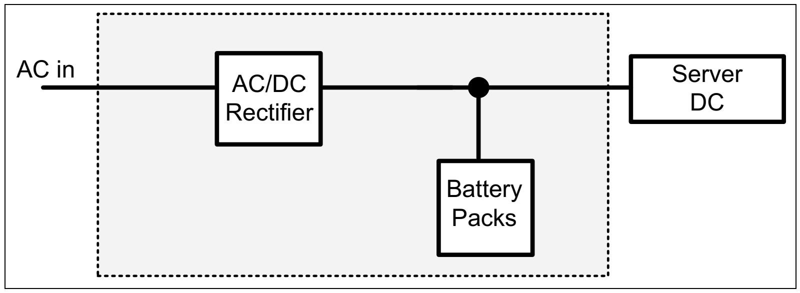

Figure 3-2 DC UPS topology

  AC systems require two internal conversions (AC to DC and back to AC), as shown in Figure 3-3. There is also an internal switch for a maintenance bypass mode (MBP), which is described later in this section.

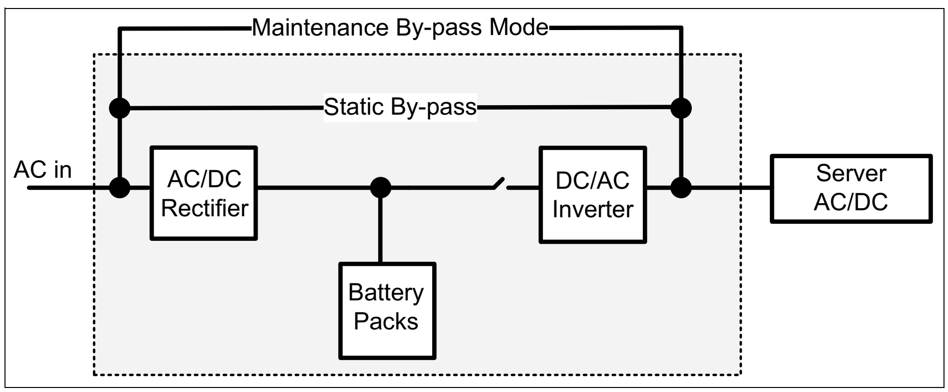

Figure 3-3 AC UPS topology

  As a result of the fewer power conversions that are performed by DC UPS systems, the heat that is dissipated by the system is reduced; therefore, cooling requirements are also reduced.

- Simple architecture

  In an AC UPS, the battery is connected between the rectifier and the inverter. Alternatively, a DC UPS provides a direct connection from the battery to the critical bus (see Figure 3-2 on page 42) and does not require an output inverter. The result is fewer components and a simpler architecture for DC UPS systems.

- Greater run time

  Because there are fewer power conversion steps that are required from a DC UPS, the efficiency and the run time increases.

- Less vulnerability for the supported load

  Most AC UPSs require the use of a static bypass and some UPSs use an external MBP) module, as shown in Figure 3-3 on page 42. These modules in an AC UPS system perform the following tasks:

  – Clear faults from the unit without disruption to the critical bus
  – Maintain critical bus power by using grid power to the bus if there is a UPS failure
  – Allow for routine UPS maintenance

  When an AC UPS uses an MBP for maintenance procedures, the IT equipment is connected directly to the grid by using the MBP and is not protected by UPS batteries in the case of a power outage. This configuration makes the IT equipment vulnerable to outages if a power event occurs from the grid.

  An MBP module cannot be used in a DC UPS system. Load fault clearing depends on energy that is stored in the UPS battery or other energy storage devices. Maintenance is achieved by using redundant rectifiers.

- Less complexity

  Because MBP is not used in a DC UPS system, DC UPS is less complex. The use of an MBP in AC UPS systems requires a synchronization circuit to allow acceptable switching between the utility and the AC UPS output. Input and output voltages, frequencies, and phase angles must be matched, and downstream protection must be sized for both sources.

3.1.7 Location of power and networking cables

In the design stages of planning for a greenfield data center, consideration should be given to the location of the power cable busways and network cabling. They run under a raised floor and connect below the rack or are above the racks and drop down. It can be advantageous to run the cables and busways overhead for the following reasons because under floor solutions can contribute to the data centers inefficiency:

- Blockage of air due to cables and busways

  Under floor cabling often becomes messy and hard to manage over time. As the infrastructure is updated or expands, more cables are added and unused cables are often left behind to avoid the risk of tangling out and pulling a wrong cable, which causes a disruption.

  The result is a mass of cables under the floor that is sitting by the power busways and blocking the flow of cool air, which prevents it from reaching the racks. To manage this issue, the solution often is to turn up the CRAC or CRAH or more units, which makes the data center less efficient and more costly to cool.

- Cool air leakage from raised floor cutouts

  At some point, cables and busways must penetrate the raised floor to connect to the IT equipment and PDUs, which is done by creating cutouts in the raised floor tiles. Typically, the cut outs are only partially filled with cables, which leaves gaps in the raised floor through which cold air can escape into the data center.

  Most data centers are designed as hot aisle and cold aisle configurations with air containment systems. Here, the cutouts in the raised floor make it difficult to prevent cold air from mixing with the hot air. This configuration reduces the capacity of the CRAC and CRAH to remove heat, which, in turn, can create hot spots in the data center. Again, the solution often is to turn up the CRAC or CRAH, or to add units to remove the hot spots, all of which make the data center less efficient and more costly to cool.

Rather than risking disruption to the air flow under a raised floor, placing cable trays and busways overhead reduces clutter, makes cable and busway maintenance and management easier, improves air flow, and reduces the under floor cool air leakage.

3.2 Considerations for retrofitting HVDC in a brownfield data center

There are some key reasons why a data center manager might consider bringing in HVDC power into an existing AC infrastructure, which is also known as a *brownfield data center*. If a brownfield data center is undergoing a major change (for example, a change in infrastructure), this is the time to consider moving to HVDC power.

Before you begin a data center expansion and incorporate HVDC power into a data center, there are several considerations. These considerations determine the readiness of the data center to expand and the feasibility of having HVDC power that is retrofitted into the infrastructure. This section describes some of the design considerations and the following topics:

- 3.2.1, “Hardware availability”
- 3.2.2, “Grounding methods”
- 3.2.3, “Cooling capacity” on page 45
- 3.2.4, “Air flow” on page 45
- 3.2.5, “Current cable footprint and infrastructure” on page 45
- 3.2.6, “Floor space and weight” on page 46
- 3.2.7, “Location of the HVDC hardware in the brownfield data center” on page 47
- 3.2.8, “Circuit breakers” on page 47
- 3.2.9, “Generator set and turbine capacity” on page 48
- 3.2.10, “Trained staff” on page 48

3.2.1 Hardware availability

Similar to the creation of a greenfield data center, retrofitting HVDC power into a brownfield data center requires consideration of HVDC hardware availability, and whether the available hardware meets the requirements of the expansion or retrofit. Consider the following points:

- An initial task is to ensure that the hardware is easy to source for replacement and upgrades, if required.
- The current AC power infrastructure must be evaluated and assessed for how much power capacity is available in the current infrastructure. If certain hardware is not available for use with HVDC power 9for example, storage or switching hardware), can the current AC power infrastructure handle the additional load, if required?
- Ensure that the power supply in the IT system can efficiently handle the voltage level that the installed HVDC power infrastructure provides in the data center. For instance, if the data center has 240 V DC available only and the IT equipment power supplies require 380 V DC, the IT system is not supported.

3.2.2 Grounding methods

Proper grounding of data center equipment protects the equipment and IT staff and improves system reliability. Consider how grounding is achieved in retrofitting HVDC power into a brownfield data center and ensure that it complies with the National Electrical Code (NEC).

As described in 5.3.2, “Grounding methods” on page 68, there are several approaches to grounding power. The recommended grounding approach to use for HVDC power (for example, 380 V DC) is midpoint grounding (see 3.1.4, “Grounding methods” on page 39). This method ensures that if any exposed, live wires are present, they do not carry a dangerous voltage load that is fatal if touched.

3.2.3 Cooling capacity

Expanding a brownfield data center can require adding cooling capacity to the room. This addition can include turning on or installing more CRAC or CRAH. It can also involve opening more perforated tiling in the cold isle (or isles) on a raised floor to release more cold air into the data center if under floor cooling is used.

3.2.4 Air flow

Management of air flow is crucial to efficient data center operation. The expansion of a brownfield data center might require careful assessment of how the extra hardware and cabling might affect the air flow of the data center.

For example, if cold air is delivered under a raised floor for cooling the data center and under floor busways are added to the infrastructure, a buildup of too many cables can cause blockages in air flow and contribute to hot spots in the data center.

In the case of a data center installation of overhead busways that uses in-row, overhead cooling or room air conditioning, you must consider how the placement of overhead busways might affect the airflow in the room.

However, a data center that uses overhead busways with raised floor cooling can benefit from the extra infrastructure, which can help with hot isle and cold isle air containment.

3.2.5 Current cable footprint and infrastructure

The following types of cabling methods are available:

- Under floor cabling, in which networking and power cables are run under a raised floor and enter the racks from the bottom.
- Overhead cabling, in which networking and power cables are run above the racks and enter from the top.

It is not uncommon to see spaghetti-like cabling that becomes entangled in under floor and overhead cabling infrastructures. This tangle can make removing and adding networking and power cables difficult, particularly in AC infrastructures in which multiple power cable whips can be required per rack.

For the environment to be retrofitted with HVDC, assess how moving to a new power infrastructure fits in or around the existing infrastructure. A major issue can be space constraints, as described in “Cabling space constraints” on page 45.

Cabling space constraints

Although AC power infrastructures can use busway to provide power to the rack, it is common to see cable whips used, where multiple individual whips are used per rack. However, HVDC power cables require the use of busway with a tap-off box at the rack, which is more efficient in terms of power transmission.

There are several different types of busway systems available. Review the physical size and installation requirements of the conduit (busway) that you are considering. You also must ensure that the current infrastructure has sufficient space to accommodate them.

For example, some busway systems are designed to hang from the ceiling, and others are supported by brackets that are mounted on top of a rack cabinet. These types of busway installations require sufficient overhead clearance for the busway to run and the tap-off box to be mounted on the busway at the top of the rack.

Other busways are installed under a raised floor; therefore, sufficient space and clearance are needed for the busway to run under the floor to the rack and space for the tap-off box at the rack.

To allow for multiple busways and multiple tap-off boxes for redundant paths, account for power redundancy and the ability to physically accommodate the tap-off points at the busway and rack. Some systems are well-designed and allow the busways to be stacked or staggered, which produces redundant power paths. Other systems have some restrictions or physical limitations.

The busway products that are on the market today are not interchangeable between vendors. Therefore, when you are selecting a busway, ensure that the system is of the appropriate size and can be extended to other racks for future growth and capability (availability of different power size and capacities). This planning avoids making the infrastructure obsolete and having to reinvest in a new infrastructure later on.

Another consideration for retrofitting a data center is the current and projected physical space and weight of the infrastructure, as described next.

3.2.6 Floor space and weight

Raised flooring for a data center is a considerable expense. When expanding a data center, enough contiguous floor space must be available for the new physical hardware. After the floor space is assessed, consider the weight that will be added to the raised floor.

All floors have a weight limit, so it is important to understand the present and future load on a raised floor to ensure that the floor can hold the added weight. After the expansion is complete and functioning, changing a raised floor is difficult and expensive and runs the risk of downtime.

Consideration should also be given to the structural capacity of the building and how much weight per level it is designed to support. This factor is of particular importance if the data center is on an upper level in the building. The weight-bearing capability on an upper level is normally less than on a ground floor.

3.2.7 Location of the HVDC hardware in the brownfield data center

When planning to bring HVDC power and added IT equipment into a brownfield infrastructure, it is recommended to keep AC-powered and DC-powered components in separate racks and the racks kept in separate spaces. This configuration is significant for the following reasons:

- Multiple cable whips and busways

  AC and HVDC cables cannot be mixed in a single busway, which means having AC and HVDC powered systems in one rack requires multiple cable whips and busways to run to the one rack. In particular, if redundancy for each circuit is required, overhead space or under floor space can be an issue, and the cluttering can make managing and servicing difficult.

  For these reasons, it is also ideal to construct AC and DC isles rather than mixing AC and DC racks in the same isle. Therefore, busways or cable whips can be separated to avoid overlapping, which under-uses the infrastructure.

- Identifying server and PDUs for installation and removal

  Keeping the AC-powered hardware and the HVDC-powered hardware contained to their own racks makes it easier for technicians to identify during hardware installation and removal.

- Convert AC to DC near the rack

  At some point, the AC power must be converted to DC power. If possible, it is best to locate the rack with HVDC hardware as close to the conversion stage (rectifier) as possible. This configuration ensures the maximum efficiency and minimum busway length, which, in turn, minimizes the cost of cabling.

- Access control and safety

  If the staff is not fully trained to work with HVDC hardware and circuits, keeping it contained to its own rack allows controlled access to the hardware for safety. For more information about HVDC and safety, see 5.4, “Handling HVDC safely” on page 72.

- Maintenance safety

  IT staff or qualified electrical technicians might be trained to work on AC hardware and circuits only and not on HVDC hardware and circuits. Keeping the hardware and busways separate allows for clear and easy access between the two types.

- Clearly defined procedures and policies for each type of power

  Procedures and policies differ between AC and HVDC installations. Clearly defined procedures and policies are easier to follow and enforce when they pertain to a specific AC or HVDC space.

3.2.8 Circuit breakers

Circuit breakers and fuse protection components for 380 V DC are available from many vendors. There are different voltage ratings for AC and DC power; therefore, breakers and fuses might not directly translate from AC to DC. A suitable DC circuit breaker must be selected. When you are selecting a DC circuit breaker, ensure the rating suits the environment in which it is installed, that it is listed for DC application, and that it is approved by the NEC, as described in 5.3.7, “Circuit protection” on page 72.

3.2.9 Generator set and turbine capacity

If a standby backup generator is used by the data center for emergency power deployment when grid power is unavailable, ensure that the extra load can be accommodated by the turbine capacity of the generator.

3.2.10 Trained staff

Licensed electricians are commonly part of the team that works with AC-powered systems. However, the requirements for handling DC systems differ and require special training. Ensure that access by trained staff for the installation, maintenance, removal, and disposal of the HVDC system is readily and easily available. For more information about training and special requirements, see in 5.5, “Special access requirements and support staff” on page 72.

3.3 Outsourcing a data center

Designing a greenfield data center or retrofitting a brownfield data center is time-consuming and costly. An alternative to building or retrofitting a data center in-house is to outsource the infrastructure to another company.

Outsourcing data centers is a growing trend, and many US data center hubs are available. There can be many benefits from outsourcing a data center, including financial and operational benefits, flexibility, and greater responsiveness through service level agreements (SLAs).

One of the leading companies in data center collocation, managed hosting, private and public cloud options, and professional services is Steel ORCA. Steel ORCA provides a single-site, long-term, flexible solution in highly efficient facilities. They offer a scalable environment with a pay-as-you-use utility model. Steel ORCA was the first IT outsourcing company to commercially make available 380 V DC power from grid to chip in their data center facility in North America.

For information about Steel ORCA’s DC power facility, see this website:

http://steelorca.com/DC-power-environment

3.3.1 Steel ORCA offerings

The following offerings and services are available from Steel ORCA:

- Collocation

  The Steel ORCA facility has over 300,000 square feet of usable raised floor space and can accommodate racks, cabinets, and private suites.

  This efficiently run facility contains multiple-density environments, metered power, and flexible solutions for tiering power, security, communications, and cabling.

- Managed services

  Steel ORCA maintains your IT operations by using strategic processes for improving efficiency and lowering costs. They provide remote technical assistance, and they operate in accord with SLAs to meet your business requirements.

- DC powered environment

  Steel ORCA has partnered with Universal Electric to implement the first grid to chip 380 V DC solution in North America.

  Steel ORCA also has an interactive showcase so you can visualize how their technologies might improve reliability and reduce total cost of ownership.

- Cloud

  Cloud offerings from Steel ORCA are flexible. You can use the extensible infrastructure for resources, such as storage, email, and print. You pay for only the services that you need.

  Databases and applications are afforded the needed resources and do not impose unnecessary capacity expenses.

  Website resource demands are met by the use of efficient tools for performance and processing scale.

For more information about Steel ORCA, see this website:

http://www.steelorca.com

3.4 Lenovo Data Center Services

The journey to a more efficient and reliable data center by way of retrofitting HVDC power into the environment can be made by making deliberate, incremental steps to slowly or more aggressively incorporate or transform the existing data center into a HVDC powered operation. The Lenovo Data Center Group can assist with this journey through service offerings from the Data Center Services (DCS) team.

The DCS team offers a High Voltage DC Architecture and Planning Workshop to help you in the adoption of a dynamic hybrid approach in powering the infrastructure with AC and HVDC, or assess the requirements for a full transformation to HVDC power. The workshop is designed to assess the current data center infrastructure set up and address the requirements for retrofitting HVDC power into the data center space.

For more information about this offering, contact: power@lenovo.com

4

Flex System offerings

The Flex System platform offers intelligent workload deployment and management for maximum business agility. The Flex System chassis delivers high-speed performance, complete with integrated servers, storage, and networking, for multiple chassis management in data center compute environments. Its flexible design can meet the needs of varying workloads with independently scalable IT resource pools for higher usage and lower cost per workload. Increased security and resiliency protect vital information and promote maximum uptime. The integrated, easy-to-use management system reduces setup time and complexity, which provides a quicker path to return on investment (ROI).

The Flex System offering provides the opportunity to customize solutions with the ability to mix-and-match offerings (such as compute nodes, with a choice of adapters, storage, and the latest Intel Xeon processors), and choice in chassis components (such as network switching, and power supplies). The customized solution can be configured to provide application-appropriate platforms.

This chapter includes the following topics:

4.1 Introduction to the Flex System Enterprise Chassis

The Flex System Enterprise Chassis is a simple, integrated infrastructure platform that supports a mix of compute, storage, and networking resources to meet the demands of applications. The solution is easily scalable with the addition of another chassis with the required nodes.

With Flex System Manager (FSM), multiple chassis' can be monitored from a single window. The 14 node, 10U chassis delivers high-speed performance, complete with integrated servers, storage, and networking. This flexible chassis is designed for simple deployment now and easy scaling to meet future needs.

The 14 bays in the chassis allow the installation of compute or management nodes that use the latest Intel Xeon processors. The chassis also has network switching modules and redundant chassis management modules (CMM) in the rear. A single chassis or a group of chassis' can be fully customized to the specific needs of a computing environment.

The system monitors and manages power usage on all major chassis components, which gives total visibility over power consumption. All of the power supplies that are used in Flex System are hot-swappable and support N+N or N+1 redundant power. There are following power supply options are available to meet the requirements of an environment:

- 2500 W AC power
- 2100 W AC power
- 2500 W HVDC (240 V/380 V) power
- 2500 W -48 V DC power

Note: Mixing different power supplies in the same chassis is not supported.

The AC power supplies that are used in the Flex System Enterprise Chassis operate at high efficiencies and the AC power supplies are certified as 80 PLUS Platinum. The 80 PLUS certification is a performance specification for power supplies that are used within servers and computers. This standard has several ratings, such as Bronze, Silver, Gold, and Platinum. To meet the 80 PLUS Platinum standard, the power supply must have a power factor (PF) of 0.95 or greater at 50% rated load and efficiency equal to or greater than the following values:

- 90% at 20% of rated load
- 94% at 50% of rated load
- 91% at 100% of rated load

The HVDC power supply also operates efficiently, although these power supplies cannot be 80 PLUS certified because there is no PF involved in DC power supplies. The power supply efficiency at various loads is listed in Table 4-3 on page 56.

All power supply modules are combined into a single power domain within the chassis, which distributes power (12.2 V DC) to each of the compute nodes, I/O modules, and ancillary components through the Enterprise Chassis midplane. The midplane is a highly reliable design with no active components. The power bus topology within the chassis is shown in Figure 4-1.

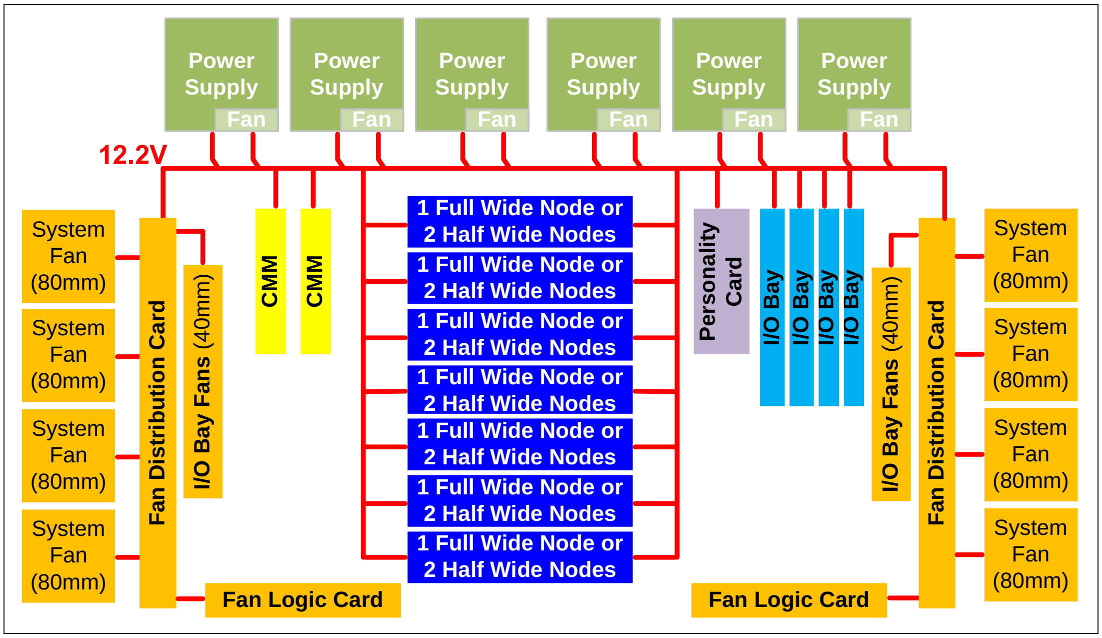

Figure 4-1 Flex System Enterprise Chassis power bus topology

With up to six power supplies that can be installed in the chassis, each power supply provides fault isolation. If there is a power supply failure (even an over voltage fault), the redundant power supplies continue to power the system.

The chassis design also optimizes cooling with cooling zones within the chassis. The system manages the fan modules that are based on node configuration within the chassis. With this management, the system can increase the speed of certain fan modules to cool potential hot spots and use lower speeds for other fan modules where appropriate.

The front of the chassis is shown in Figure 4-2. The nodes are accessed from the front of the chassis and can house up to 14 half-wide nodes or 7 full length nodes.

Figure 4-2 Front of the Flex System Enterprise Chassis

The fans, switch modules, chassis management modules, and power supplies are accessed from the rear of the chassis.

The chassis houses 10 fans (8 x 80 mm fans that are responsible for cooling the nodes, and 2 x 40 mm fan packs, which are responsible for cooling the switch modules and the chassis management module). There are four switch bays, two chassis management module bays, and six power supply bays. The power supplies are cooled by their own internal fans inside the power supply.

The rear of the chassis is shown in Figure 4-3 on page 55.

Figure 4-3 Rear of the Flex System Enterprise Chassis

4.2 HVDC Flex System power supply unit

The HVDC power supply unit (PSU) for the Flex System Enterprise Chassis is a 2500 W PSU and operates at 240 V DC or 380 V DC.

Deploying the HVDC power supply in the Flex System Enterprise Chassis and in the data center can include the following benefits:

- Better energy efficiency (not including the reduced need for cooling in the data center).
- Less space might be required in the data center with the HVDC power infrastructure.

  DC-powered data centers require fewer conversions for incoming electricity and require 25 - 40% less square footage than their AC counterparts.
- Computer equipment can connect directly to back up batteries.

For more information about the benefits of HVDC power, see 1.2, “Benefits of HVDC” on page 3.

4.2.1 HVDC PSU rating and ordering information

Ordering information for the Flex System Enterprise Chassis 2500 W HVDC PSU is listed in Table 4-1.

Table 4-1 Flex System Enterprise Chassis HVDC PSU

Part number	Feature code	Description
00AM765	EPA9	Flex System Enterprise Chassis HVDC 2500 W power module

Ratings for the HVDC PSU are listed in Table 4-2.

Table 4-2 HVDC PSU rating

Description	Rating
PSU DC output wattage	2500 W
PSU nominal input voltage range	240 - 380 V DC (192 V - 400 V input range)
Supports	+380 V, -380 V, or +/- 190 V
Standard - Europe	ETSI EN 30-132-3-1 V2.1.1: 260 – 400 V
Standard - China	CCSA YD/T 2387-2011: 192 – 288 V
PSU max input amps @ 240-380 V	11.5 A
Line cord (SBB part number 00Y9100)	2.5 m DC power cord (ships standard)

The power supply efficiency ratings are listed in Table 4-3. Although still highly efficient across all other loads, the power supplies operate most efficiently when the load is approximately 50%.

Table 4-3 HVDC power supply efficiencies

Load	10% Load		20&% Load		50% Load		100% Load	
Input voltage	240 V DC	380 V DC	240 V DC	380 V DC	240 V DC	380 V DC	240 V DC	380 V DC
Efficiency	92.7%	92.7%	94.1%	94.6%	94.4%	95%	92.1%	93.4%

As described in 1.1.2, "Conversion steps for HVDC distribution systems" on page 3, HVDC power allows for greater efficiency gains at the data center level because it allows for fewer conversion steps in the data center.

4.2.2 PSU installation information

The HVDC power supply is designed for single power operation or parallel operation. However, in the Flex System Enterprise Chassis, a minimum of two power supplies are required for redundancy purposes.

Up to a maximum of six power supplies can be configured in the chassis in an N+N or N+1 power policy.

Note: The total number of power supplies that are required in the chassis depends on the number of nodes that are installed. Use the System x Power Configurator tool for determining the overall power draw from the chassis and the number of PSUs to install.

The System x Power Configurator tool can be downloaded from this website:

http://www.ibm.com/systems/bladecenter/resources/powerconfig.html

The power supplies are labeled from bottom to top, right to left, when viewed from the rear of the chassis. The power supply bays are shown in Figure 4-4.

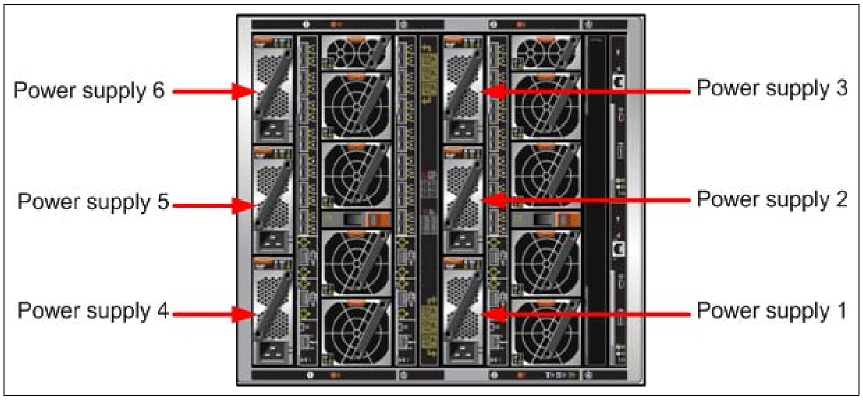

Figure 4-4 Flex System power supply placement

The power supplies must be installed in a certain order. The installation ordering is to populate bays 1 and 4 first, followed by 2, 5, 3, and 6.

4.2.3 HVDC PSU outlet

The outlet on the HVDC PSU for the Flex System Enterprise Chassis is a Rong-Feng (RF-203P) connector. The PSU is shown in Figure 4-5.

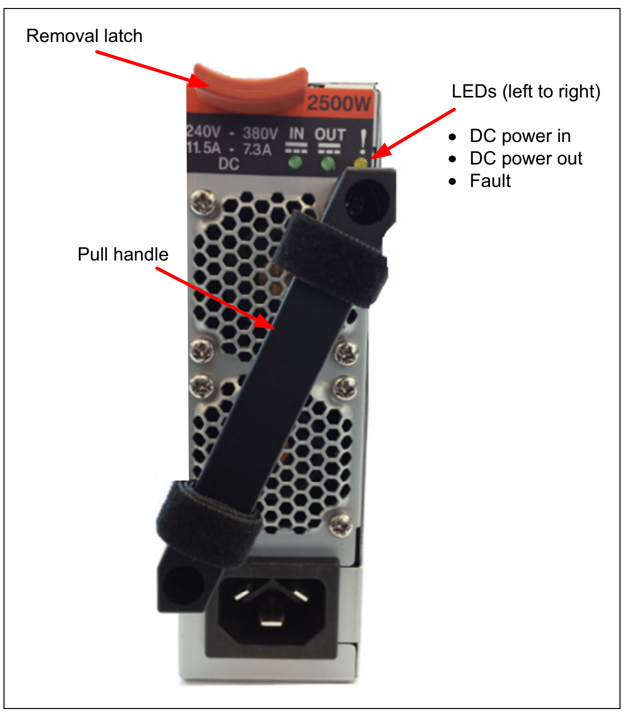

Figure 4-5 HVDC PSU for the Flex System Enterprise Chassis

Each HVDC PSU that is ordered for the Flex System Enterprise Chassis ships standard with a power cable (SBB part number 00Y9100), which is required to connect the PSUs to a supported HVDC power distribution unit (PDU) with Rong-Feng outlets. For more information about the supported HVDC PDU for the Flex System Chassis, see 4.3, “HVDC PDU specifications” on page 59.

For more information about the connection of the PSU to the PDU, see 4.3.1, “Connecting HVDC Flex System to HVDC PDU” on page 62.

Arcing is a concern when HVDC voltages are removed from power supplies. The following approaches can be used to address this concern:

- Shield the arc inside the socket
- Disable input voltage before removing connector
- Eliminate arcing with more signaling

The approach that is chosen by Lenovo is to eliminate the arcing, which is achieved by using the Rong-Feng RF-203 input connector. The RF-203 is a 4-wire connector: +, -, GND, and PS_KILL. The PS_KILL connector is a signal that is connected to GND in the PDU, as shown in Figure 4-6.

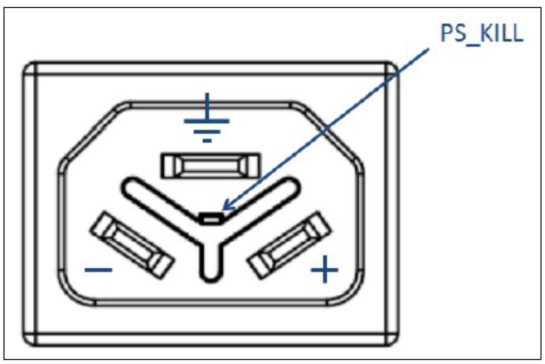

Figure 4-6 Rong-Feng PS_KILL connector

After the jumper cord is unplugged, the power supply is designed to shut down within 2 ms. The speed of this shutdown minimizes the effects of the arcing. The front and back of the plug is shown in Figure 4-7.

Figure 4-7 Rong-Feng (RF-203P) outlet, front and back

More technical specifications for the Rong-Feng RF-203P outlet are listed in Table 4-4.

Table 4-4 Technical specifications for Rong-Feng RF-203P outlet

Specification	Description
Name	Rong-Feng, RF-203
Standard	UL498 and IEC61984
Material	Nylon
Current rating	15A
Voltage rating	435 V DC
Approvals	UL/CUL/TUV/CCC

The dimensions of the Rong-Feng RF-203P outlet are shown in Figure 4-8.

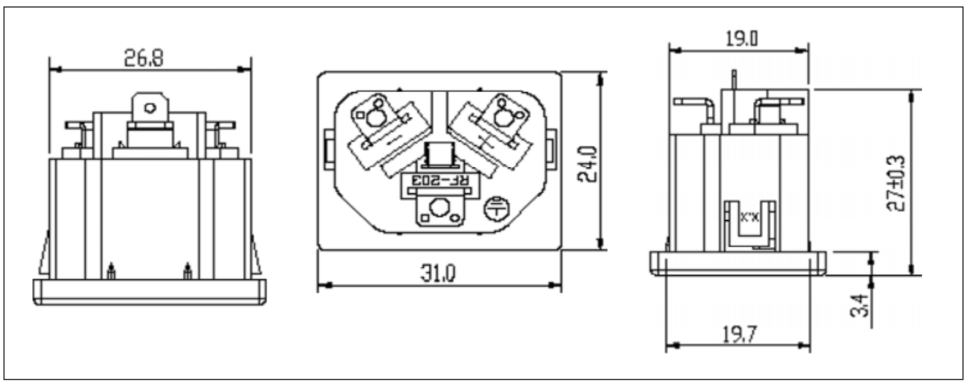

Figure 4-8 Dimensions of the Rong-Feng RF-203P outlet

For more information about the connector, see this website:

http://www.rongfeng.com.tw/highvoltag.htm

The supported HVDC PDU that connects to the HVDC PSU for the Flex System Enterprise Chassis is described in 4.3, “HVDC PDU specifications”.

4.3 HVDC PDU specifications

The compatible PDU that connects to the HVDC PSU for the Flex System Chassis is listed in Table 4-5.

Table 4-5 HVDC PDU ordering information

Part number	Feature code	Description
44T0966	A580	1U Higher voltage DC PDU (240 V/380 V)

This PDU has the following specifications:

- A total of six outlets, Rong-Feng RF-203P connector
- 90A@240-380 V DC
- Amps per outlet: 15 A (10 A derated for US)
- A total of 6 breakers, 15 A each

- Attached unterminated 4.3 m line cord (Pig-tail termination: hardwired, no plug)
- 1U PDU, supporting the side pockets in the 42U 1100 mm Enterprise V2 Dynamic Rack
- Can be mounted in horizontal or vertical locations within the rack
- Basic PDU (no switch or monitor functions)
- One PDU supports one chassis with N+1 redundancy
- Two PDUs support two chassis with N+N redundancy
- This DC power supply is 2500 W

The PDU is shown in Figure 4-9.

Figure 4-9 HVDC PDU front

The outlet is shown in Figure 4-10.

Figure 4-10 HVDC PDU RF-203P outlets

The Rong-Feng plug that is inserted into the PDU for connection to the PSU is shown in Figure 4-11.

Figure 4-11 Line cord for connecting PDU to PSU

There is no inlet plug for providing power to the HVDC PDU; it must be hardwired. The PDU has three standard copper conductors, each with a cross section of 25 sq mm. Figure 4-12 shows the hardwired line cord that is connected to the PDU.

Figure 4-12 HVDC hardwired input line cord

As seen in Figure 4-12, the hardwired cords that connect to the PDU are code colored yellow, blue, and brown. Their functions are listed in Table 4-6.

Table 4-6 HVDC hardwire color codes

Wire color	Function
Yellow	Earth / ground wire
Blue	Negative DC voltage wire
Brown	Positive DC voltage wire

The cord must be connected to an appropriately wired and grounded high-voltage DC power source by a licensed electrician and follow your local electrical codes or requirements.

The HVDC PDU is shipped standard with an accessory kit (part number 46M5293). Table 4-7 on page 62 lists the items that are included in the accessory kit.

Table 4-7 HVDC PDU accessory kit

Part number	Description	Amount shipped
46M5287	Small mounting brackets	2
46M5289	Large mounting bracket	2
12J4072	Long brackets	1
46M5288	Short brackets	4
46M5291	Screw packet 1	14
12J5789	Screw packet 2	8
46M5290	Screw packet 3	4
00N8709	Nut packet 1	6
25R7920	Nut packet 2	6
12J5304	Nut packet 3	8

4.3.1 Connecting HVDC Flex System to HVDC PDU

Examples of connecting the HVDC PSU (part number 00AM765) to the HVDC PDU (part number 44T0966) are described in this section.

The rating per PSU that is installed in the chassis is 11.5A. The capacity of the PDU is 90A, operating at 240 - 380 V DC.

An N+N example of six PSUs that are connected to two HVDC PDUs is shown in Figure 4-13. The remaining amperage on each PDU is 55.5 A with three free outlets remaining.

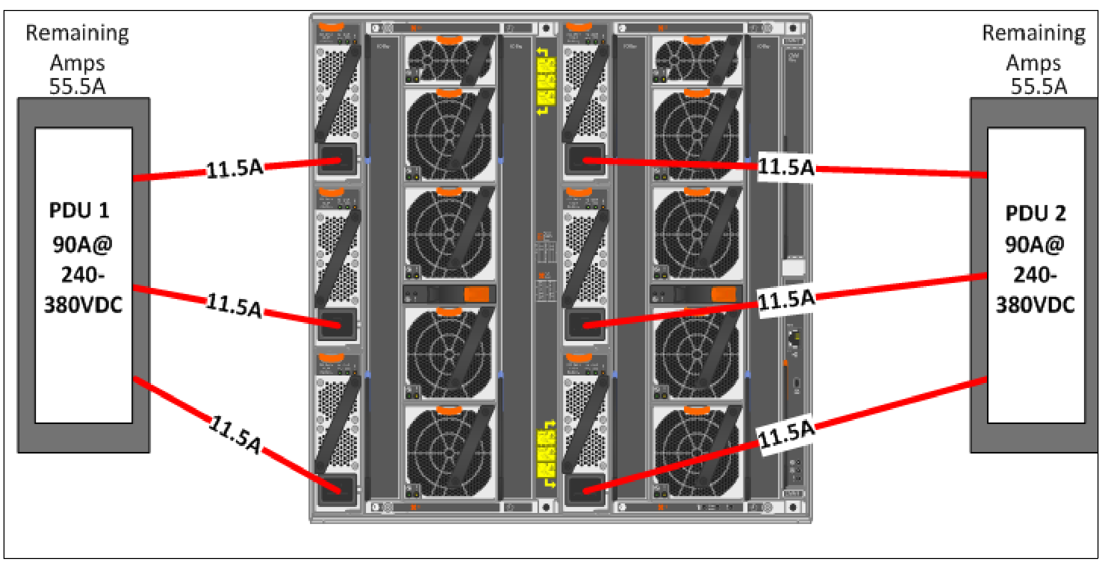

Figure 4-13 N+N connection of the HVDC PSU to the HVDC PDU

An N+1 example of six PSUs that are connected to one HVDC PDU is shown in Figure 4-14. The remaining amperage on the PDU is 21A with no free outlets remaining.

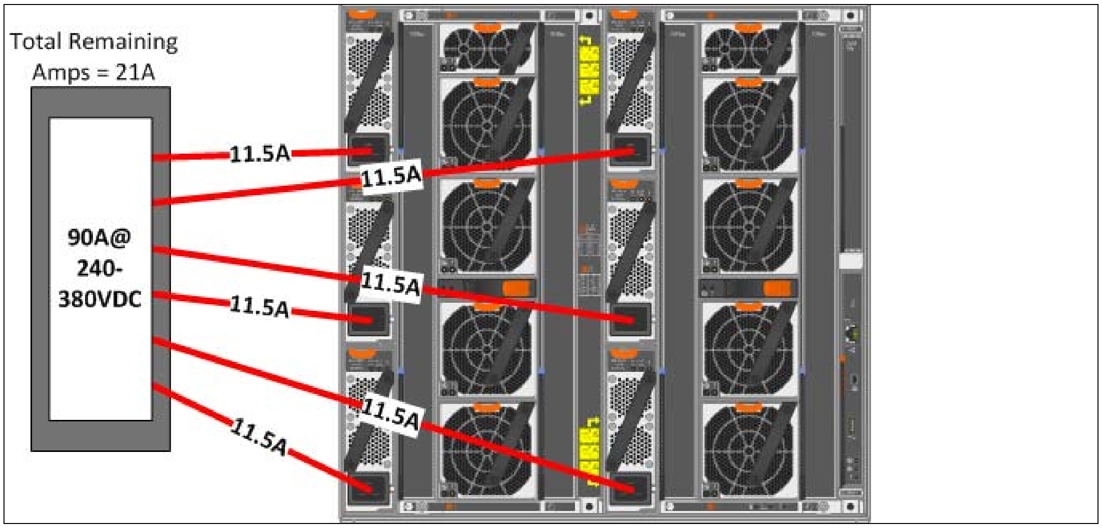

Figure 4-14 N+1 connection of the HVDC PSU to the HVDC PDU

An N+1 example of six PSUs that are connected to one HVDC PDU is shown in Figure 4-15. The remaining amperage on the PDU is 21A with no free outlets remaining.

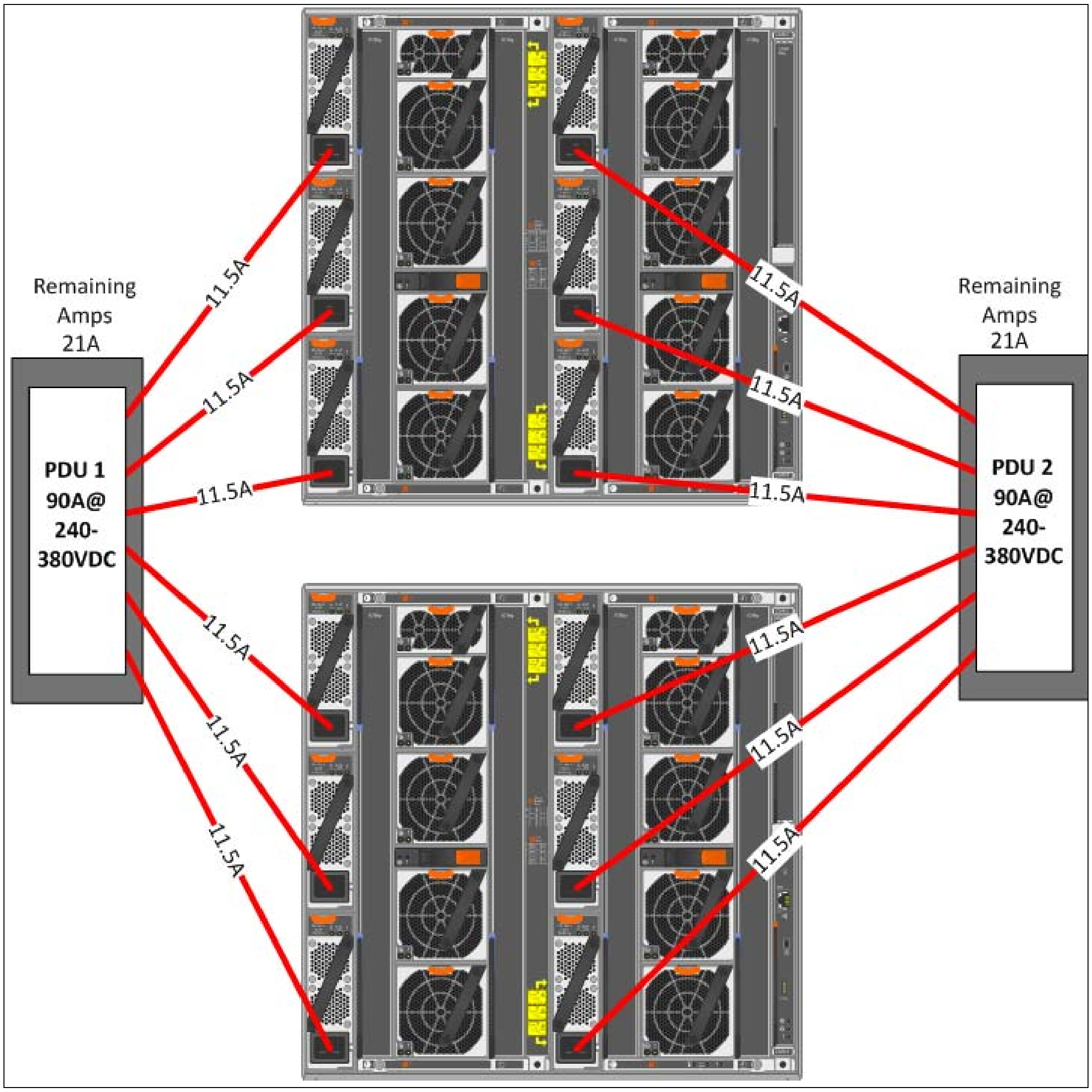

Figure 4-15 N+1 connection of the HVDC PSU to the HVDC PDU, two chassis

For more information about safety considerations when HVDC is implemented in a data center, see Chapter 5, “Safety considerations” on page 65.

5

Safety considerations

When you are deploying and working with HVDC power in the data center, the following safety perceptions must be considered:

- Hazardous voltage
- Arcing
- No current zero crossing: Difficult to break current
- Grounding methods
- Lack of standards

HVDC power, as with AC power, can be dangerous; however, there are ways of handling and working with HVDC power that makes it safer with which to work.

This chapter describes what was done to alleviate some of the concerns about the safe handling of HVDC in the data center and includes the following topics:

5.1 Early adoption issues with HVDC

In early HVDC installations, the equipment was often installed in a confined space and was accessible only by licensed electricians. It was contained in a dedicated area of the room so that IT technicians can access the server room without being exposed to the dangers of the HVDC power that was running to the data center.

In these early days, there were no vendor solutions that were installable without modifications and no solutions that offered HVDC busway systems with tap-off boxes for deploying power to the rack. HVDC power cords were enclosed in make-shift metal conduits and unlike 48 V DC that was used in telecommunication, licensed electricians were required to perform any maintenance or circuit expansion work.

There was also a distinct lack of available hardware from vendors (such as servers, storage, switches, PDUs, and UPSs) to make HVDC power in the data center viable. Early proof of concept (PoC) and proof of technology (PoT) efforts used AC power supplies that were retrofitted to work as DC power supplies by removing the AC to DC rectifier inside the power supplies.

Because there was a lack of infrastructure and only a few deployments, there were a lack of safety protocols and standards. However, there are several mechanisms in place today to make deploying and handling HVDC power in the data center a safe procedure.

5.2 Accomplishments in HVDC safety

Today, there are many established HVDC deployments around the world, including PoC, PoT, and production deployments. These newer HVDC deployments are leading by example and play a key role in the future development of official procedures for safely deploying HVDC power.

There are electrical distribution standards by major standardization organizations that cover low voltage AC and DC. HVDC is a term that is used in this publication; however, it is classified as LVDC by these organizations. The following organizations are guiding the safe and efficient use of DC power:

- National Fire Protection Association (NFPA)
- Underwriters Laboratories (UL)
- International Electrotechnical Commission (IEC)

NFPA and IEC safety standards apply to HVDC regarding safety, circuit protection, and wiring practices. There is ongoing work to improve these standards.

Organizations that are working in the field of standardization also include EMerge Alliance, National Electric Manufacturers Association (NEMA), and IEEE.

The EMerge Alliance is an example of a newly created organization that played a key role in guiding safe distribution of AC and DC since 2008. This organization is based out of California in the US, and includes members from national labs, universities, manufacturers, UL, NEMA, and other industry liaisons. The EMerge Alliance is working to harmonize the multiple 380 V DC specification efforts from institutions, such as the International Electrotechnical Commission (IEC) (SG4) and European Telecommunications Standards Institute (ETSI).

Although the EMerge Alliance is focused on standards in the US and Canada, they do have an international vision for the future, and work closely with other organizations to harmonize and agree on global standards. Through these efforts, the following international standards are current or under development:

- UL: Covers all distribution system components.
- European Telecommunications Standards Institute - (ETSI) EN 300 132 -3-0; European standard: Power supply interface at the input to telecommunications and datacom (ICT) equipment (up to 400V DC) (draft released).
- ETSI - EN 301 605; European standard: Earthing and bonding of 400 VDC data and telecom (ICT) equipment (up to 400V DC) (released).
- International Telecommunication Union (ITU) (ITU-T I.1200): Adopted ETSI voltage levels (released).
- International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) (SG22H): New DC UPS standard (work in progress).
- Alliance for Telecommunications Industry Solutions (ATIS): Voltage levels standard (work in progress).
- Society of Cable Telecommunications Engineers (SCTE): A new committee for technical cable telecommunications professionals.
- National Electrical Code (NEC): The current edition of this code applies to AC and DC wiring, protection, and safety (released).
- EMerge Alliance: Focuses on site and system interfaces (released).
- China Communications Standards Association (YD/T 2378-2011): Standard in China.
- YD/T 2378-2011: 240 V DC Direct Current Power Supply System for Telecommunications (released).
- NEMA and the Electric Power Research Institute (EPRI): A work in the electrical power generation and delivery (work in progress).

Although there is not yet one officially recognized international standard and many different types of deployments exist that work safely and efficiently, some commonality was seen in grounding methods, voltage levels, and the use of busways for safety. For more information, see 5.3, “Safety considerations with HVDC”.

5.3 Safety considerations with HVDC

This section describes some of the safety considerations for the use of HVDC power in the data center. This section includes the following topics:

5.3.1 Voltage range

Many PoCs and PoTs showcased 380 V DC and while it is more common to see 240 V DC deployments within China, 380 V DC is the most commonly deployed voltage level in the industry on a worldwide scale.

Following a common global standard voltage, such as 380 V DC, can be beneficial for the following reasons:

- The knowledge that all PSUs safely plug into the HVDC circuit and work (not all PSUs have the same internal voltage).
- Common cable sizing and plug design can be used.
- Common form factor and interoperability.
- Less vendor effort (power supplies must be designed to operate at certain voltages).

5.3.2 Grounding methods

As with AC power, there are multiple ways in which to ground HVDC power in data centers. The most common grounding methods include negative, positive, and midpoint grounding. Preferable grounding methods for HVDC are described in the ETSI EN 301 605 standard, which includes mid-point and negative grounding. These methods are described next.

High-resistance midpoint grounding

High-resistance midpoint grounding (HRMG) is the safest method of grounding HVDC power. This method of grounding is well-established and is widely used today in 110 and 220 V DC networks in industrial, utility, and railway environments.

HRMG system consists of two symmetrical high ohmic precision resistors that are connected in series between positive (+) and negative (-) conductors that are connected to the same circuit. Midpoint (MP) is connected to MET (main earthing terminal) in the facility, as shown in Figure 5-1.

This method of grounding makes 380 V DC power as safe as 48 V DC or up to 200 V AC regarding the electrical shock of which it is capable. In this configuration, the voltage between any line to ground (such as equipment housing) is reduced to half of the line to line voltage. As shown in Figure 5-1, the voltage is reduced from 380 V to 190 V.

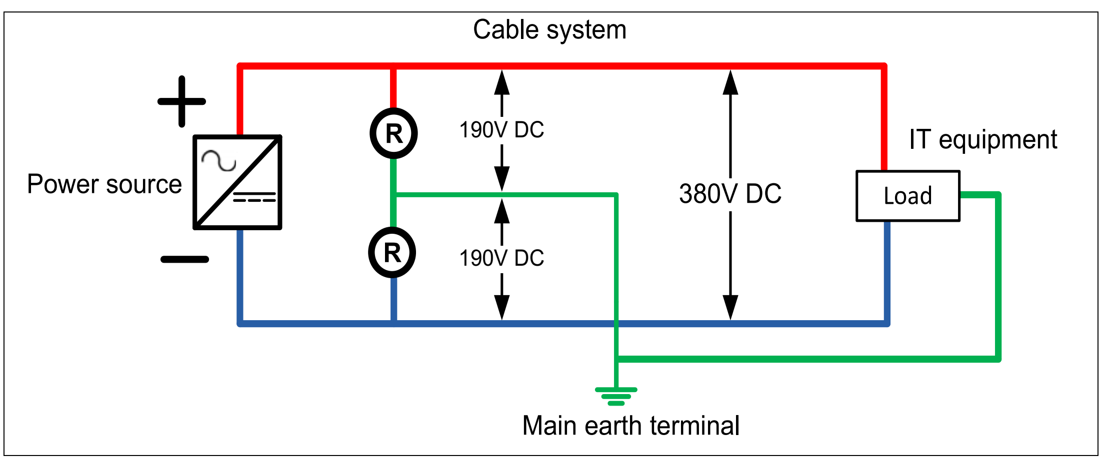

Figure 5-1 Midpoint grounding

Reducing the exposure voltage value by half significantly improves personnel safety. During the exposure, the current that is flowing through the body also is limited by the resistor to a safe value.

The HRMG grounding arrangement also includes the following benefits:

- No arc flash during line-to-ground fault
- Single line-to-ground fault does not affect operational continuity of the DC distribution

HRMG is a preferred grounding method for applications that require continuity of supply (such as data centers and Telco facilities) and provides the highest safety levels. HRMG does require the use of Insulation Monitoring Device (IMS) to detect first line to ground fault because the voltage between the opposite line to ground rises to the full 400 V DC value.

Negative grounding

Negative grounding is not as safe as high resistance mid-point grounding (HRMG), but it is comparable to existing AC systems. However, it does not assure supply continuity during faults. In negative grounded systems, line-to-ground faults open the protective device.

For some applications, users can elect to use negative terminal grounding system (TN-S), especially for large scale, complex distribution to avoid the use of IMS device. An example of negative grounding is shown in Figure 5-2.

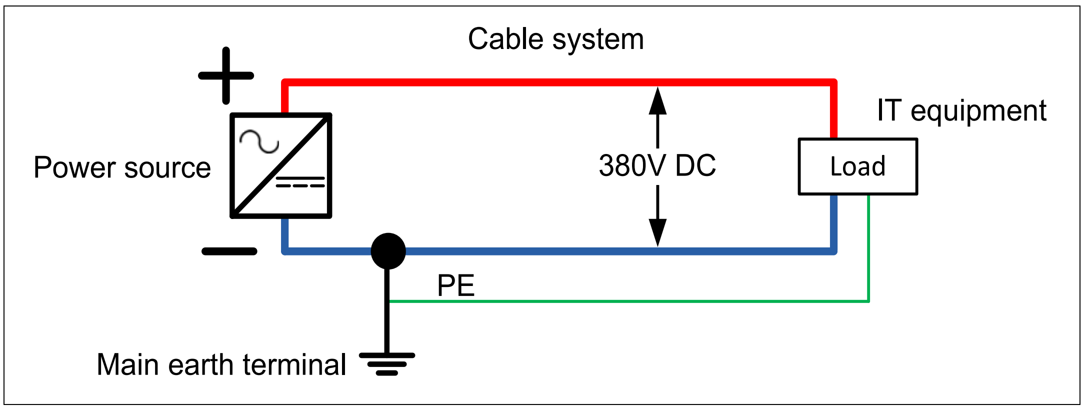

Figure 5-2 Negative grounding

These grounding systems comply with relevant safety requirements, such as IEC 60364-1 or IEC 60364-4-41.

5.3.3 Certified plug types

It is important to use a UL, IEEE, (or within China) the China Compulsory Certificate (CCC) approved plug type for plugging HVDC power into PDUs and PSUs. Certified plugs protect against such situations as arcing, which is described in 5.3.4, “Arcing”.

The physical plug design of certified plugs also prevents users from connecting DC plugs in AC hardware, and vice versa. For more information about certified plug types, see 5.6, “Plug safety certifications” on page 73.

5.3.4 Arcing

Arcing occurs in electrical circuits when the following events occur:

- There is a bad connection in a circuit carrying high current (AC is similar to DC in most cases)
- During disconnection of the components in power distribution (DC is worse than AC)
- Unintentional short circuit of power conductor to earth or between conductors occur (ACis equal to DC)

Electric arcing occurs in normal electrical system operation and at normal load conditions in connectors, switches, and breakers.

Although the mechanism of arcing is the same for AC and DC, the mechanism of arc interruption is different because in DC, there is no natural zero crossing of current. For more information, see 1.6.1, “Differences between the AC and DC power delivery” on page 9.

Effective suppression of arc in DC circuits requires components that are designed for this purpose, including connectors and breakers. The following leading vendors in HVDC plug technology addressed this issue:

- Fujitsu: DC circuit breaker magnetic arc quenching technology
- Delta: The fourth contact pair triggers Hot Swap secondary circuitry of the power supply to avoid breaking the arc
- Anderson Power Products (APP): Connector geometries naturally suppress arcing and contacts have a sacrificial arcing area.

Note: DC and AC plugs and connectors are not interchangeable.

For more information about DC connectors, plug designs, and safety certifications, see 5.6, “Plug safety certifications” on page 73.

5.3.5 Arc flash

Arc flashing can be a concern for AC and DC higher voltage systems because it can present a danger to personnel who are performing maintenance on live electrical equipment. The Occupational Safety and Health Administration describes arc flashing as follows:

> *“...an arc flash is a phenomenon where a flashover of electric current leaves its intended path and travels through the air from one conductor to another, or to ground. The results are often violent and when a human is in close proximity to the arc flash, serious injury and even death can occur...”*[1]

An arc flash can be caused by the following factors:

- Dust
- Dropping tools
- Accidental touching
- Condensation
- Material failure
- Corrosion
- Faulty Installation

[1] *Understanding “Arc Flash”*, from the Workplace Safety Awareness Council, which is available at this website: https://www.osha.gov/dte/grant_materials/fy07/sh-16615-07/arc_flash_handout.pdf

The following circumstances also can cause an arch flash:

- A disconnection of components and equipment in power distribution
- An unintentional short circuit of power conductor to earth or other conductor

The following factors are used to determine the severity of an arc flash injury:

- Proximity of the worker to the hazard
- Temperature (energy that is dissipated during exposure)
- The amount of current available at the point of fault exposure (I_2 t)
- Time for circuit to break

In the US, NFPA 70E standard governs electrical safety in the workplace and outlines specific procedures and practices to be followed for safety when working on live equipment. It covers work practices that are associated with electrical energy during activities, such as installation, inspection, testing, operation, maintenance, and demolition of electrical equipment. The standard contains calculation methods for arc flash in AC and DC circuits, protective clothing requirements, training requirements, and so on.

The following arc flash mitigating methods in DC distribution are available:

- HRMG grounding
- Shielding exposed energized parts
- Plug and play construction (connectorized interfaces)
- Fast acting circuit protection
- Active current limiting fault conditions

Arc flash exposure in DC distribution is typically lower than in AC distribution because of the current limiting characteristics of the DC UPS and isolation from utility. It is also mostly dependent on the size of the energy storage system (such as the battery).

5.3.6 Busways

The busway approach makes HVDC much safer compared to the under-floor cabling. IT equipment can be directly connected into the busway by using plug-in units with breaker boxes (the tap-off box) (see 2.1.10, “Busway” on page 28). The use of a busway minimizes the need to work with live wires, which makes the removal, replacement, or expansion of a circuit much safer. The busway approach also includes the following benefits:

- Removing a circuit

  Removing a busway circuit does not involve tracing and untangling cable whips or causing potential snags and downtime in the process.

- Replacing a circuit

  Removing or changing the power on a circuit (for example, single-phase to three-phase) no longer involves removing a cable whip and replacing it with the correct cabling under or above the floor. The tap-off box that is connected to the busway can be changed to suit the requirements, which eliminates the need to handle cables.

- Expanding a circuit

  Expanding a circuit becomes much less of a hassle and safer. Tool-less, pre-assembled plug-in units eliminate field wire cutting and terminating branch circuits when expanded. It is more of a plug-and-play approach.

5.3.7 Circuit protection

Vendors, including CX-Series, Drive Fuse (DFJ), Emax DC ABB, Tmax, and Cooper Bussmann, all offer HVDC circuit breakers in different shapes, sizes, and capacities (up to 600 - 700 V DC). These breakers feature double insulation for safely installing accessories in the field and modular accessories that work across several circuit sizes.

5.4 Handling HVDC safely

For safety reasons, it is important to handle any power connections properly. The following considerations are important when you are using and handling HVDC power:

- Use proper components with ratings and listings that are selected for safe operation. For example, every vendor has a compatibility matrix for each component in the infrastructure. Ensure that each component that is used is compatible with the vendor listings.
- Use proper grounding methods in distribution. The safest grounding option is midpoint grounding, as described in 5.3, “Safety considerations with HVDC” on page 67.
- Use the plug-in concept where possible because this concept minimizes field installation work. The plug-in concept is used in busway installations, as described in 5.3, “Safety considerations with HVDC” on page 67.
- Adhere to the safety procedures for your local Authority Handling Jurisdiction (AHJ).
- Use certified plugs only. Power connectors were developed (and some are UL/IEEE/CCC listed) for 380 V DC use today. There are also new cord connectors on the market that ensure that the DC load is turned off before physical connections and disconnections. These technologies interrupt the DC load current during the physical disconnection between a plug and receptacle or to ensure that the current is interrupted before the physical separation can occur. Also, there are new protective equipment (PE) and sensing technologies that supplement connectors that automatically open the DC circuit as the connectors mate and separate.

  For more information about certified plugs for HVDC use, see 5.6, “Plug safety certifications” on page 73.

5.5 Special access requirements and support staff

The importance of safety procedures during the installation, operation, and maintenance of HVDC power is clear. However, there is still a need for international HVDC policies and standards to be officially established for data center support staff and for staff members who are installing and inspecting the power infrastructure.

Standards, such as procedures for accessing the distribution board, proper safety attire, certified tools for maintenance, and maintaining an appropriate distance from dangerous circuits or live wires must be officially established.

Because there is no official procedure regulating special access requirements, installation, inspection, operation, maintenance, and demolition of HVDC power in the data center, methods can vary across different countries, regions, buildings, and data centers. Staying current with complex regulatory requirements that can differ in so many ways can be difficult, particularly in-house regulations that are enforced by internal resources only.

However, there are efforts to develop global and regional work place safety standards. This work is being done by the National Fire Protection Association (NFPA). The NFPA has a joint venture with the Institute of Electrical and Electronics Engineers (IEEE). The IEEE is one of the leading standards-making organizations in the world. The NFPA/IEEE initiative was formed at the request of the Occupational Safety and Health Administration (OSHA), which is a federal agency of the US that regulates workplace safety and health. The purpose of the joint venture is to enhance the IEEE 1584 standard for DC. The initiative is referred to as NFPA 70E: Standard for electrical safety in the workplace.

The NFPA 70E regulations help protect staff members by reducing human exposure to major electrical hazards and makes significant changes in the areas of safety, maintenance, and training for support staff. It addresses the following areas:

- Safety-related work practices
- Safety-related maintenance requirements
- Safety requirements for special equipment

The Standard also includes guidance for making hazard identification and risk assessments, selecting appropriate personal protective equipment (PPE, which includes electrical gloves, hot sticks and flash suits), establishing an electrically safe work condition, and employee training not only for staff members who work directly with energized electrical equipment, but for those who work around that equipment.

If the NFPA 70E is recognized as an official standard, it can be used to fully train workers, overcome uncertainties, and ensure safety while working with HVDC powered systems.

5.6 Plug safety certifications

There are a few plug types available for HVDC power. Plugs are in the process of being certified or are certified by UL, IEC and CCC, including the following vendors and plugs:

- Anderson Power Products (APP): Saf-D-Grid (SDG) plugs

  APP’s Safe-D-Grid (SDG) plug is a 400 V DC/20 A plug that includes the following features:

  – Two flat surfaces that have the greatest resistance to arcing.
  – SDG’s flat wiping contacts dampen initiation and the continuation of arcing.
  – The overwipe of connector housings prevents arcing.

  > **Note:** Flat wiping and overwiping allows for minimal contact resistance at high current. When the plug is removed, the wiping action cleans the contact surface during disconnection and prevents arcing.

  – Insulators eliminate the line of sight between contacts upon unmating.
  – Large tracking distances between contacts.
  – Prevents arcing products from developing arcing between lines or ground.
  – Sacrificial contact area that provides an isolation layer in the plug.
  – Prevents dampened arcing damage from affecting electrical performance.

This plug has the following certifications:

– UL 1977 Recognized and UL 817 Listed
– IEC 61984 Certified
– CCC Approved

The Saf-D-Grid plug is shown in Figure 5-3.

Figure 5-3 Saf-D-Grid plug (APP)

- Fujitsu: 400V DC Power Connector

  The Fujitsu connector is a 400 V DC/10 A plug with the following features:

  – Plug and socket with integral miniature DC circuit breaker, with magnetic arc quenching technology.

  – A switch for locking the plug in a Power On or Power Off stage.

  This plug is compatible with specifications in development with IEC. The plug is large and is too large for power supply connections, which makes it incompatible with IEC 320. The socket is specified for fixed installation use only, and no portable multiple outlets or extension cords are permitted to be used with it. The Fujitsu plug is shown in Figure 5-4.

Figure 5-4 Fujitsu plug

- Delta: Rong-Feng/Linetek

  The Delta's Rong-Feng (RF-203P) plug is a 15A plug and has the following features:

  – Plug and Socket with fourth contact pair to trigger switching off power supply (shielding any arc inside the socket).

  – Disable input voltage before removing connectors.

  The Rong-Feng plug type is used by Lenovo for the Flex System Enterprise Chassis HVDC PSU and HVDC PDU.

> **Note:** The PSU, PDU, and cord that is used with the Rong-Feng adapter must be made by the same manufacturer (or reseller, such as Lenovo) to achieve Safety Agency Listings.

This plug has the following certifications:

- UL
- CUL
- TUV
- CCC

Rong Feng is shown in Figure 5-5.

Figure 5-5 Delta Rong-Feng plug

5.7 Reliability, availability, and serviceability

This section describes HVDC power regarding reliability, availability, and serviceability (RAS) in data center deployments.

5.7.1 Reliability and availability

One of the features of the use of HVDC is the high reliability and availability of the DC circuit. Although malfunctions can occur in any hardware, there is less hardware (for example, rectifiers, transformers, and circuit breakers) involved in getting 12 V DC power to the IT equipment compared to AC power and therefore, there is less likelihood that a malfunction can occur.

The use of HVDC also removes other elements, such as sensing mechanisms that AC systems must use to ensure that equipment is in synchronization. DC power is a constant, and the paralleling of sources in a DC system is simplified because synchronization is not required.

Because there is reduced complexity in DC power that is compared to AC power, and less complexity in how HVDC power is physically delivered to an IT system, it is more likely to be reliable and feature increased availability over AC deployments.

5.7.2 Serviceability

Because DC power is simple compared to AC power, faults in a system can be easier to detect, diagnose, and correct, which increases availability.

As with AC power, DC power can be dangerous if not handled by a licensed electrician. The NFPA-70E standard is for electrical safety in the workplace. It outlines the specific procedures and practices to be followed for compliance and safety when working with live wires, installations, inspections, operation, maintenance, and demolition of electrical equipment. The DC requirements were added in 2012 and continue to be defined for safe DC data center deployments.

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Abbreviations and acronyms

AC	alternating current
AHJ	Authority Handling Jurisdiction
APP	Anderson Power Products
ATIS	Alliance for Telecommunications Industry Solutions
CCC	China Compulsory Certificate
CCSA	China Communications Standards Association
CFF	common form factor
CMM	Chassis Management Module
CRAC	computer room air conditioning
CRAH	computer room air handler
CSP	concentrated solar power
CUL	Underwriters' Laboratories of Canada
DC	direct current
DCG	Data Center Group
DCS	Data Center Services
DX	direct expansion
EBG	Enterprise Business Group
EPRI	Electric Power Research Institute
ETSI	European Telecommunications Standard Industry
FES	Flywheel energy storage
FSM	Flex System Manager
GND	ground
HRMG	high resistance midpoint grounding
HVDC	high voltage direct current
I/O	input/output
IBM	International Business Machines
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IT	information technology
ITU	International Telecommunication Union
LAN	local area network
MBA	Masters of Business Administration
MBP	maintenance by-pass
NC	North Carolina
NEC	National Electrical Code
NEMA	National Electric Manufacturers Association
NFPA	National Fire Protection Association
OEM	other equipment manufacturer
OSHA	Occupational Safety and Health Administration
PDU	power distribution unit
PE	protective equipment
PF	power factor
PFC	Power Factor Correction
PPE	personal protective equipment
PSU	power supply unit
PV	photovoltaic
RAS	Reliability, availability, and serviceability
RMS	root mean square
ROI	return on investment
SBB	system building block
SCTE	Society of Cable Telecommunications Engineers
SDG	Saf-D-Grid
SLA	service level agreement
SNMP	Simple Network Management Protocol
TCO	total cost of ownership
TUV	Technischer Überwachungsverein
UL	Underwriters Laboratories
UPS	uninterruptible power supply
VA	volts amperes

Related publications

The publications that are listed in this section are considered particularly suitable for a more detailed discussion of the topics that are covered in this paper.

Lenovo Press publications

The following Lenovo Press publications provide more information about the topic in this document. Some publications that are referenced in this list might be available in softcopy only:

- Lenovo Flex System Enterprise Chassis:

  http://lenovopress.com/tips0863
- Lenovo Flex System Products and Technology:

  http://lenovopress.com/sg248255
- Lenovo Press product guides for Flex System servers and options:

  http://lenovopress.com/flexsystem

Other publications and online resources

For more information, see the following resources:

- Lenovo Flex System home page:

  http://ibm.com/systems/pureflex/flex-converged-infrastructure.html
- System x Power Configurator and Power Guides:

  http://www.ibm.com/systems/bladecenter/resources/powerconfig.html
- dcFUSION:

  http://www.dcFUSION.net
- Steel ORCA - DC Power Environment:

  http://steelorca.com/DC-power-environment
- Rong Feng DC connectors:

  http://www.rongfeng.com.tw/highvoltag.htm
- Workplace Safety Awareness Council paper, *Understanding Arc Flash*:

  https://www.osha.gov/dte/grant_materials/fy07/sh-16615-07/arc_flash_handout.pdf