Increasing energy efficiency with modular HP three-phase power distribution

technology brief

Abstract

The use of three-phase power distribution allows for simplifying hardware installation, achieving higher efficiency, and reducing energy costs. A comprehensive three-phase power infrastructure involves both rack-level (intra-rack) and row-level (inter-rack) solutions. This paper discusses the latest trends in zoned (end-of-row) power distribution and describes HP solutions that provide customers with a complete and efficient solution for three-phase power distribution.

Introduction

An enterprise data facility contains a large amount of IT equipment with substantial power requirements. Energy usage has increased to the point that it is second only to labor in operating costs for some large facilities. Increased server densities and subsequent rise in power demands on a per-rack basis make it crucial to interface and balance the electrical load properly with facility power to ensure safe and cost-efficient operation.

Power distribution in data centers

The typical data center uses power that originates from the utility power grid and is stepped down to the appropriate range by the building transformer. Power within the data center can be distributed using either a centralized or distributed infrastructure. Centralized systems provide utility or backup power to IT equipment from a single distribution point that includes the alternating current (AC) switchgear, uninterruptible power supplies (UPSs), and power distribution panels. This paper describes a distributed (zoned) system (Figure 1) where utility or generator power from the AC switchgear is distributed among equipment groups or rows. In a zoned system, each IT equipment row includes its own UPS/power distribution infrastructure.

Figure 1. Data center using zoned power distribution

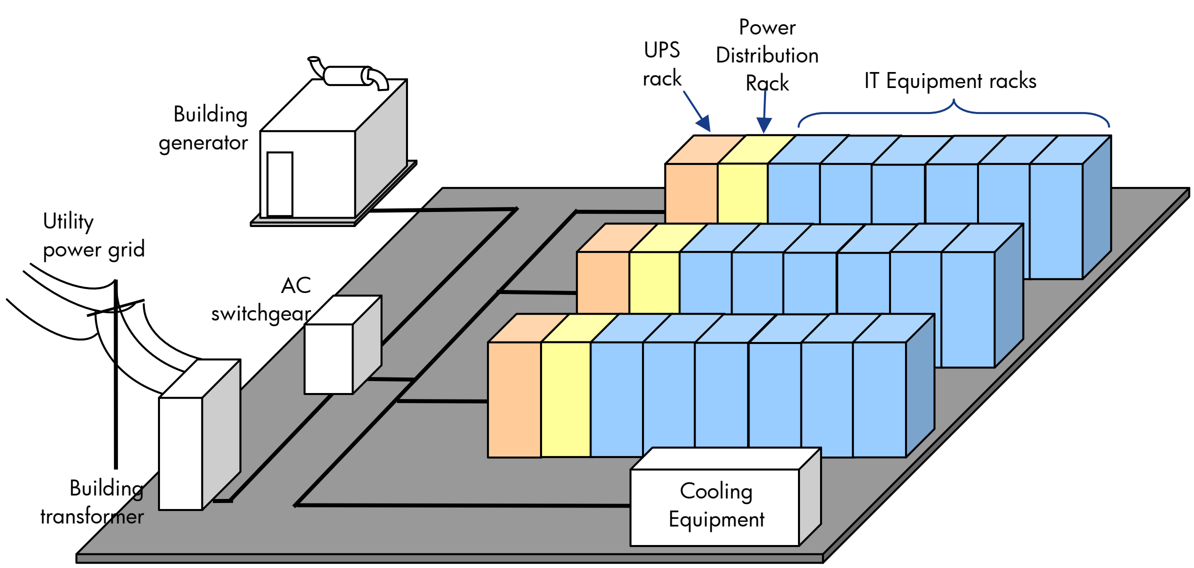
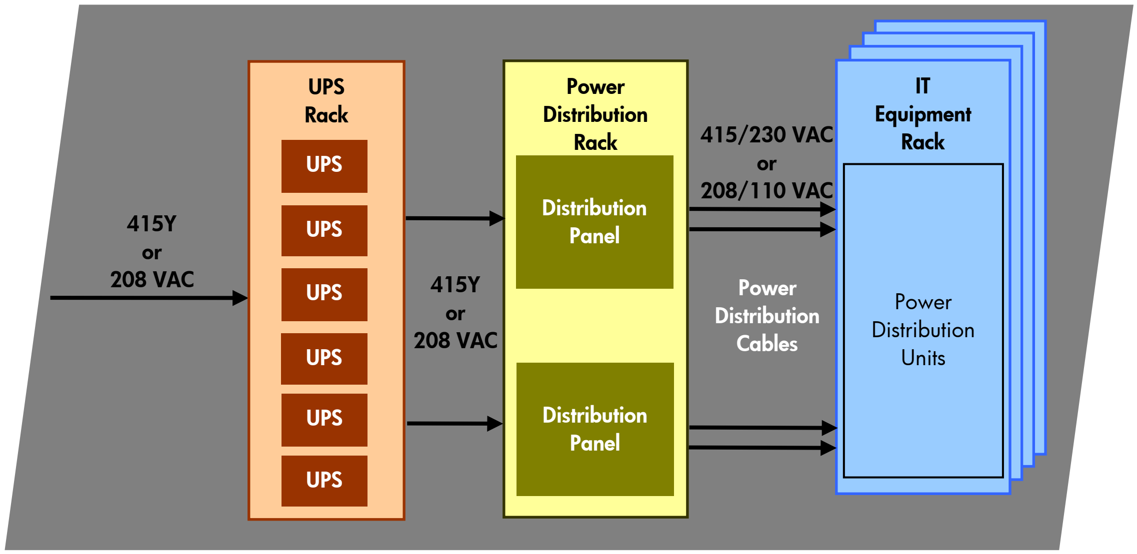


Figure 2 shows basic power distribution at the row level of a data center. The primary distribution components are the UPSs, the power distribution rack, and the power distribution cables. While this paper describes the UPSs as being in front of (feeding) the power distribution panels, alternate configurations are possible depending on data center needs.

Figure 2. AC power distribution at the row level



Under normal conditions, the UPSs receive input power from the AC mains in the range of 415Y/230 VAC (international) or 208Y VAC (North America). If the input power rises above or falls below the expected range or if it is interrupted completely, the UPSs go online and apply battery power to the distribution panels. The UPSs will continue to provide battery power until utility power is restored to within the accepted operating range or until the building generator can produce the required power, whichever comes first. Once UPS input power resumes (either because the building generator comes online or because utility power is restored) the UPSs will go back offline and resume their normal mode of operation, which is to charge the batteries while allowing power from the generator to pass through to the power distribution rack. The power distribution rack evenly distributes AC power through the distribution cables to the IT equipment racks.

Concerns and trends in designing power infrastructures

The power distribution system of a data center should provide the following:

- Flexibility—easily adaptable to reconfigurations of the data center
- Scalability—expandable with IT infrastructure growth
- Reliability—providing constant service with no unscheduled downtime
- Efficiency—minimizing the cost of utility power and reducing greenhouse gas emissions

The actual power infrastructure of a data center will depend on several factors:

- Number of racks:
  - Small data center: fewer than 20 racks
  - Medium data center: 20 to 100 racks
  - Large data center: more than100 racks

- Power density per rack:
  - Low density: less than 6 kilowatts per rack
  - Medium density: from 6 to 12 kilowatts per rack
  - High density: more than12 kilowatts per rack
- Data center availability (Uptime Institute Tier Classifications)
  - Tier I: single power path with non-redundant UPS (highest probable downtime)
  - Tier II: single power path with redundant (N+1) UPS
  - Tier III: dual power paths, each with redundant (N+1) UPS, one active and one passive
  - Tier IV: dual power paths each with redundant, active UPSs that allow concurrent maintenance (lowest probable downtime)

Each data center is unique in its requirements based on business needs. The only constant in data centers is change, and the best solution will involve components that allow data centers to change and grow easily. For example, adding one or two racks in today's high-density blade systems can add significantly to the power infrastructure load. Therefore, it is essential that data centers be adaptable to change.

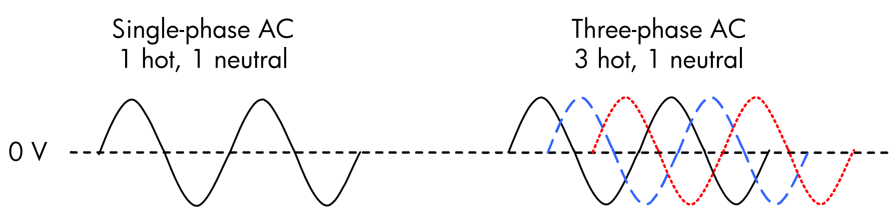
Modular systems allow customers to use a flexible "pay as you grow" strategy and address the issues of adaptability. Three-phase modular systems offer flexibility and cost-effective power distribution.

Why three-phase power?

As power requirements for high density compute systems increase, the benefits of distributing three-phase power to individual racks become more significant. Strictly speaking, IT equipment (ITE) does not use three-phase power[1]—the benefits are in its distribution. These benefits include easier load balancing for improved efficiency, cable reduction for simplicity, and larger power rating capability and expandability.

With single-phase power, the voltage across the hot and neutral conductors can be anywhere between its peak (maximum) and zero at any given time, and electrical conductors must be large to meet high amperage requirements. Three-phase power uses four discrete conductors (three hot and one neutral) handling three cycles that are 120 degrees out of phase (Figure 3). The more constant voltage across the three hot conductors results in smoother current flow and allows the use of smaller-gauge conductors to distribute the same amount of AC power.

Figure 3. Comparison of single- and three-phase AC voltage waveforms



The load balancing and increased power handling capabilities of three-phase AC distribution can result in more efficient and economical power distribution. The key components of three-phase power distribution include the UPS, the PDR, and distribution cables.

[1] Some HP BladeSystem blade and power enclosures connect directly to three-phase power and internally distribute split-phase or single-phase power to the power supply units.

Three-phase UPS technology

The main purpose of the UPS is to maximize the availability of IT equipment by providing a constant power source for IT equipment, regardless of the state of the AC power the UPS receives. UPS performance is determined by its design parameters and topology.

UPS load considerations

A UPS should be designed based on two main factors: the AC input feed, and the needs and characteristics of the active output load. In this case, the active output load is comprised of the power supply units (PSUs) of the IT equipment. Table 1 identifies the primary PSU parameters to which a UPS must be designed.

Table 1. Primary parameters of power supply units that affect UPS design

PSU parameter	Parameter description	UPS design criteria
AC input voltage	Typically low-line (100 to 127 VAC) or high-line (200 to 240 VAC) input power. High-density server systems often use power supplies that can operate with either low-line or high-line power, but require high-line power to operate at maximum rated performance and peak efficiency.	UPS must maintain a three-phase output with single-phase and split-phase components that meet the acceptable range of the power supply units.
AC input frequency	Frequency tolerated by most power supply units is typically within the 47 to 64 Hz range to accommodate worldwide applications.	UPS must maintain output frequency within the acceptable range
Power factor correction	Power supply circuitry that compensates for the power loss inherent with reactive components using AC voltage	The cumulative power requirement of all power supply units in a circuit branch should not exceed UPS volt-ampere (VA) and watt (W) ratings
Ride-through capability (holdup time)	Ability of a power supply unit to provide rated output during an AC power interruption, typically 12 to 20 ms.	UPS mode transitions (offline-to-online, online-to-offline) need to occur much faster (5 ms or less) than the power supply unit holdup time to ensure constant operation of power supply unit.
AC line transient handling	Ability of a power supply unit to absorb AC line sags (brownouts) and surges (spikes)	UPS must prevent passing on AC line transients that would adversely affect power supply units.

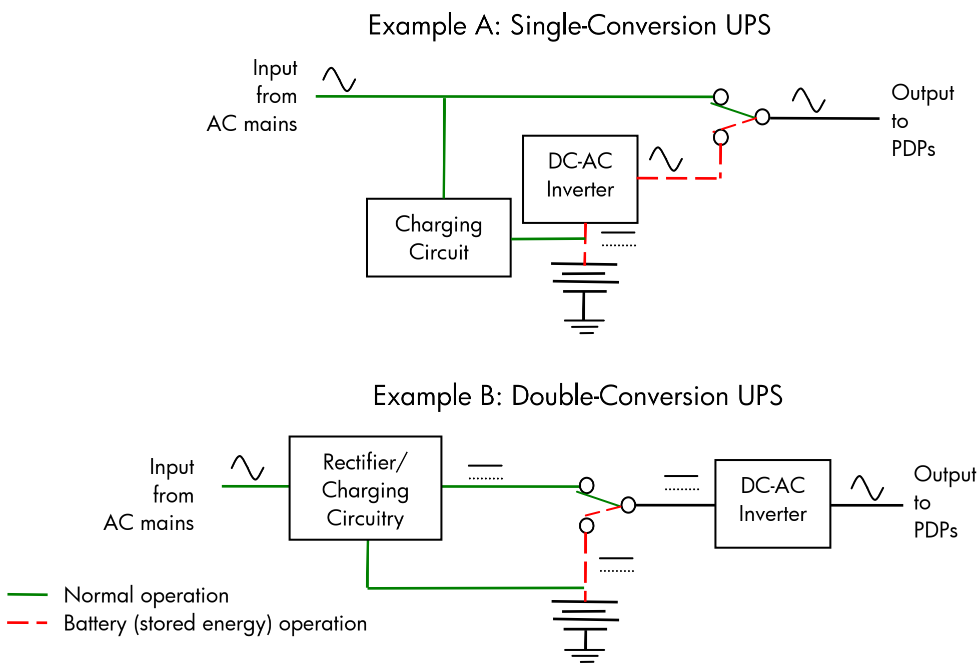
In addition, the UPS must meet the cumulative power consumption of all power supply units included in the output circuit. While UPS specifications generally include both volt-amperes (VA) and watt (W) ratings, the rating in watts provides a truer indication of the loading ability of the UPS. The watts rating will be stated with a time parameter indicating how long the UPS can provide the rated power in the online (battery) mode.

UPS topologies: single-conversion versus double-conversion

The basic design of a UPS is referred to as its topology. Two common UPS topologies are single-conversion and double-conversion. A single-conversion UPS (Figure 4A) is a relatively simple design. In normal (offline) operation, a single-conversion UPS routes AC input voltage straight through to the output while charging the internal batteries. When the AC input is out of range or lost, the UPS goes online and uses an inverter to produce the AC output from the battery power. Because of its simple design, the single-conversion UPS is very efficient during normal operation, but it must provide battery operation until utility power is completely restored or until a generator is brought up to a stable condition.

A double-conversion UPS (Figure 4B) includes a rectifier. In normal operation, the rectifier processes the AC input voltage and routes the DC to the inverter that produces the output. In online operation, the batteries provide the input for the inverter as in a single conversion system.

Figure 4. Common UPS topologies



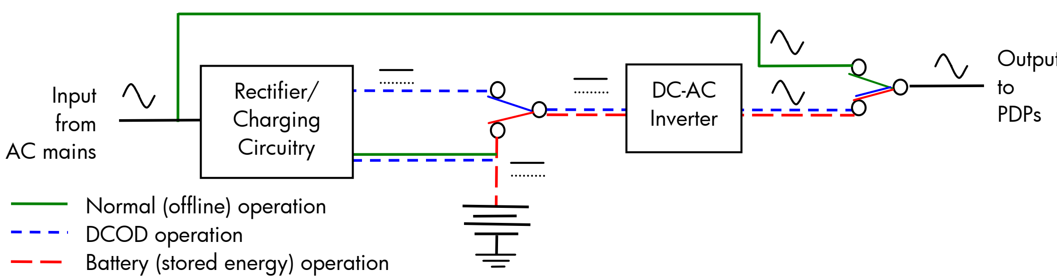
The double-conversion design is more complex and is less efficient, but it can ensure a high-quality output regardless of the condition of the input power. While utility power is absent, the double-conversion UPS can process and use power from a generator that is still stabilizing. Therefore, the double conversion UPS can return to normal operation sooner and reduces the period of time when IT operations are dependent on battery operation.

HP solution: high-efficiency three-phase UPSs

The HP R8000, R12000, and RP12000/3 (the latter shown in Figure 5) are three-phase UPSs that use a hybrid design combining the best features of single-conversion and double-conversion topologies. This double conversion-on-demand (DCOD) topology (Figure 6) offers the efficiency of a single-conversion UPS with the performance of a double-conversion system. Power from the AC mains that meets preset conditions bypasses most of the processing circuitry and is applied to the output for routing to the power distribution panels. During periods when the AC input is irregular or out of tolerance, the rectifier and inverter are switched to DCOD operation to process the AC input and provide a three-phase AC output that meets load requirements. When AC input power is absent, the system goes into battery mode.

Figure 5. HP RP12000/3 UPS

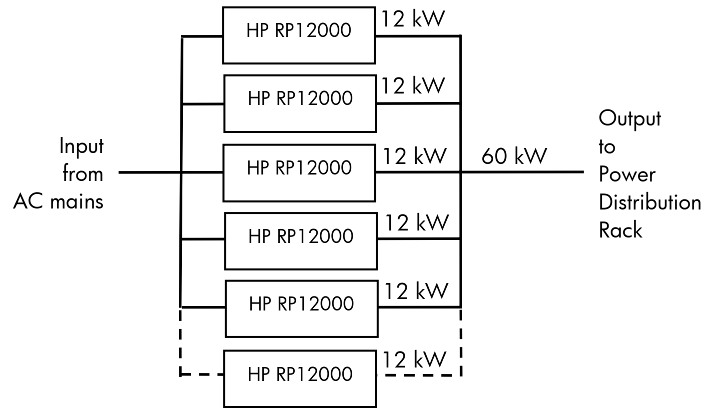
Figure 6. DCOD topology used in HP three-phase UPSs



One characteristic of the DCOD design is the increase of transitions between operational modes. HP three-phase UPSs incorporate minimum-switch technology that reduces the transition time (typically to 2 to 4 ms) between operational modes, preventing IT equipment power supply units from losing input power.

The HP R8000 and R12000 UPSs operate as stand-alone units for a distributed power infrastructure. To meet redundancy or capacity requirements in a zoned power system, the 12-kW HP RP12000/3 UPS uses a patented wireless paralleling architecture to provide up to 60 kW of three-phase AC power and N+1 redundancy (Figure 7).

Figure 7. Paralleling HP UPSs for maximum power and N+1 redundancy



The HP three-phase UPS is contained in a 6U chassis. Six UPSs can be mounted in a standard 19-inch-wide 42U rack and can operate as one using wireless paralleling technology. A display panel on the front of each UPS provides status and control. An optional serial interface allows status and control of the UPS from a remote workstation.

Each UPS includes an automatic maintenance bypass switch that allows replacing the hot-pluggable batteries and electronics module without shutting down the system. The UPS can be configured with one of several input/output receptacle types to match the needs of the facility and equipment load.

HP three-phase UPSs offer more than 97 percent efficiency, even when supplying loads of only 40 percent capacity. Such high efficiency yields significant savings in energy costs compared to legacy UPS systems that operate at only 80 to 85 percent efficiency at the same loading.

Three-phase power distribution technology

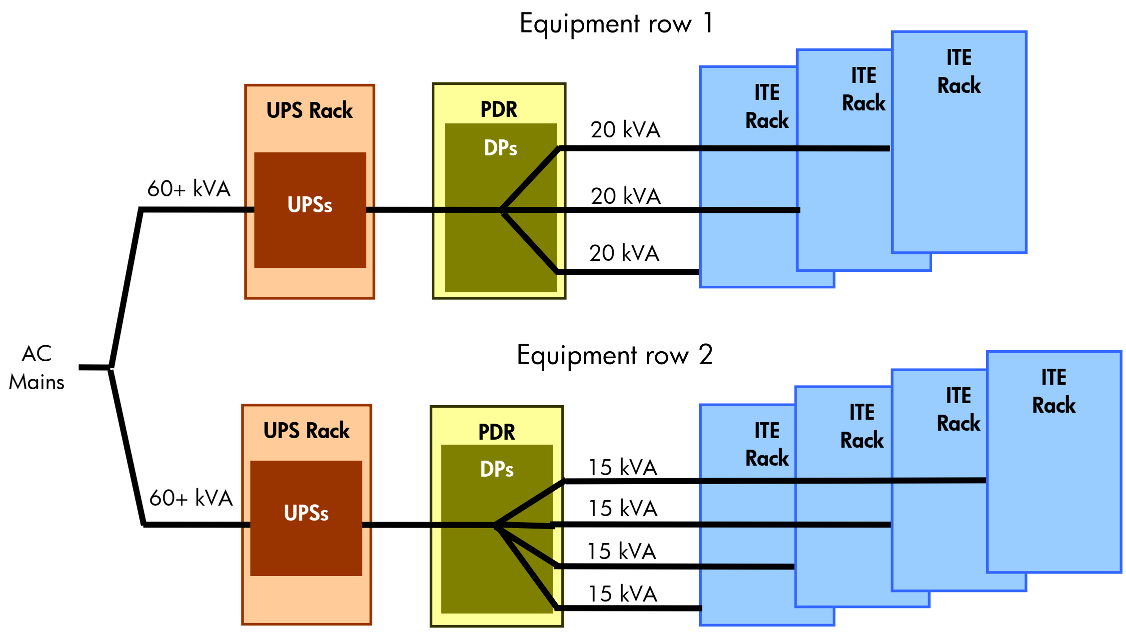
The benefits of distributing three-phase power to individual racks become significant for high-density installations such as blade systems. These benefits include easier load balancing for improved efficiency, cable reduction for simplicity, and larger power rating capability and expandability.

Load balancing and monitoring

Data center power from the AC mains is generally distributed through a hierarchy of branch circuits to ITE PSUs for IT equipment. To maximize efficiency, minimize kVA costs, and reduce the chance of overloading a branch circuit breaker, AC power should be evenly distributed across the three phases of AC power. Equipment loads should be equalized (or as nearly equalized as practical) across the branches at each distribution point (as illustrated in Figure 8).

An IT infrastructure that is well-balanced at initial installation can become unbalanced during system expansion or modification. Each expansion or modification to a branch circuit should be prefaced by pre-measuring or calculating the loading affect of new equipment. Ideally, the load on each branch circuit from the distribution panels (DPs) should be monitored for maintaining overall balance and gauging expansion capability.

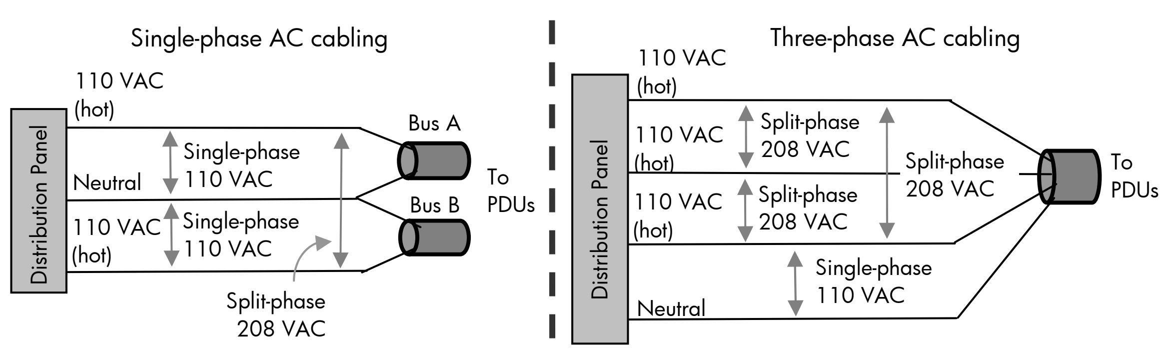
Figure 8. Load balancing at the row level



Cable reduction

Figure 9 shows the differences between single-phase and three-phase AC cabling. With a single-phase distribution system, cables from each side (branch) of the neutral point are routed from distribution panels to equipment groups or racks. Load balancing is more difficult, requiring at least two distribution cables per rack and more careful planning. Racks receiving two AC buses will require power distribution units (PDUs) to be installed in pairs to achieve a balance of equipment loading. With three-phase distribution, each equipment rack requires only one cable providing three hot wires and one neutral conductor. Load balancing is possible with one three-phase PDU, which simplifies the configuration.

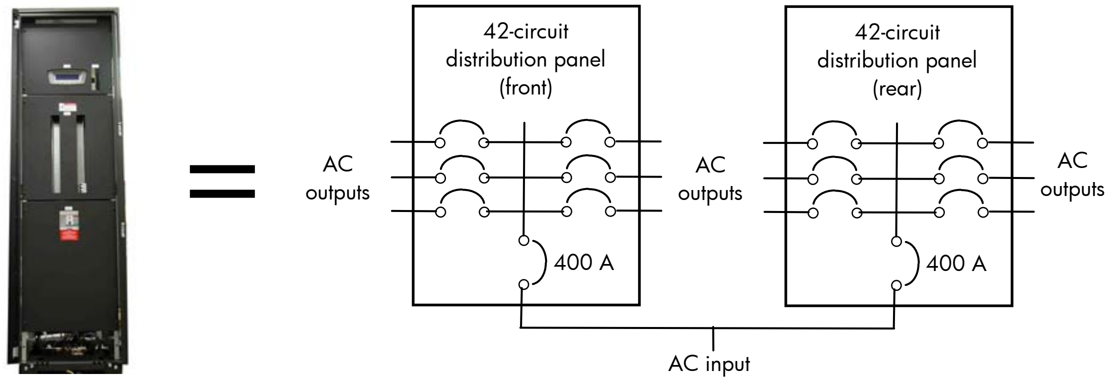
Figure 9. Comparison of single-phase and three-phase AC cabling with North American voltages (ground not shown)



HP solutions: PDR and pre-configured distribution cables

The HP Power Distribution Rack (Figure 10) consists of an HP 10000-series rack configured with two 400-amp, 42-pole distribution panels for a maximum of 84 output circuits. The HP Power Distribution Rack allows either top or bottom entry of AC feed cable and is designed for convection (non-forced) air cooling under full-load operation.

Figure 10. Functional block diagram of HP Power Distribution Rack



Each 42-pole distribution panel is protected by a 400-amp, three-pole (3P) input circuit breaker. The distribution panels support 1P, 2P, and 3P breakers of a wide range of amperage ratings to allow a variety of three-phase or split-phase distribution configurations.

The power infrastructure administrator can choose among several options that offer different levels of load monitoring:

- **Circuit monitoring panel** provides local display of current loading at the distribution panel level.
- **Enhanced monitoring** provides local display of current demand, voltage levels, AC frequency, total power factor, total/peak kilowatts and kilowatt/hours, and remote access capability with RS-485 Modbus RTU communication port.
- **Branch circuit monitoring system (BCMS)** uses sensors to provide current and alarm conditions for individual branch circuits off the distribution panel, with user-adjustable alarm levels and the capability of remote control and status through an RS-485 Modbus RTU communication port

Monitoring at the distribution panel level allows hundreds of branch circuits feeding tens of enclosures to be monitored remotely through a single IP address.

HP offers a selection of power distribution cables (Figure 11) for connecting the PDR to IT equipment rack PDUs. The power distribution cables are available in various lengths (Table 2) and preconfigured with receptacles for simplified installation and reconfiguration of a row of IT equipment racks.

Figure 11. HP power distribution cable

Table 2. Types of HP Power Distribution Cables

Description	Receptacle type	Conduit length (ft)	Overall wire length (ft)
Metal-clad 3-wire split/single-phase	NEMA L5-30R	5 10 15 20 30	13 18 23 28 38
Metal-clad 3-wire split/single-phase	NEMA L6-20R	Same as above	Same as above
Metal-clad 3-wire split/single-phase	NEMA L6-30R	Same as above	Same as above
Metal-clad 3-wire split/single-phase	CS 8269	Same as above	Same as above
Metal-clad 4-wire three-phase	NEMA L15-30R	Same as above	Same as above
Metal-clad 5-wire three-phase	NEMA L21-30R	Same as above	Same as above
Metal-clad 4-wire three-phase	IEC 460C9	Same as above	Same as above

Configuration examples

This section includes basic configurations for using HP three-phase power components for high-density systems.

High-density system using conventional cooling

Figure 12 shows a UPS rack with parallel HP RP12000/3 UPSs providing 60 kilowatts through a PD rack and power distribution cables to a high-density system of four 15-kW ITE racks. In this example, the ITE racks use conventional air cooling as supplied through plenums in a raised-floor facility. Note that the racks can accommodate cables routed overhead or under the floor.

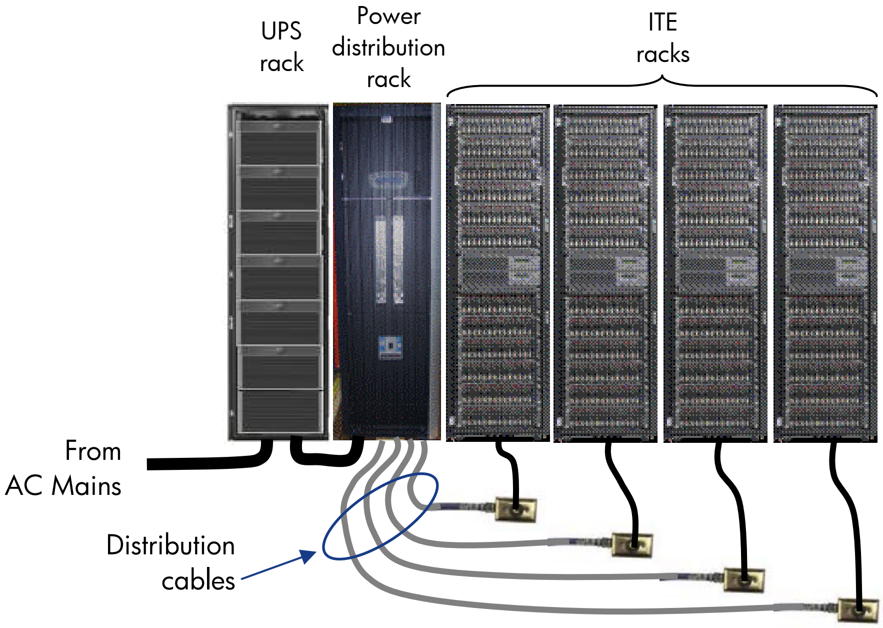
NOTE
Best practices dictate allowing for a certain amount of "headroom" when planning UPS loading. The example in Figure 12 illustrates a maximum loading scenario with no expansion headroom.

The actual number of ITE racks that can be served by a UPS rack depends on the power density of each rack. A 60-kW UPS rack can support:

- 10 low-density racks at 6 kilowatts per rack (larger than 2U servers, storage, networking equipment)
- 5 medium-density racks at 12 kilowatts per rack (1U servers, small blade servers)
- 3 high-density racks at 20 kilowatts per rack (smaller than 2U or densely-packed blade servers)

Online utilities for calculating the power requirements for HP server products are available at the URLs provided in the section titled "For more information" at the end of this paper.

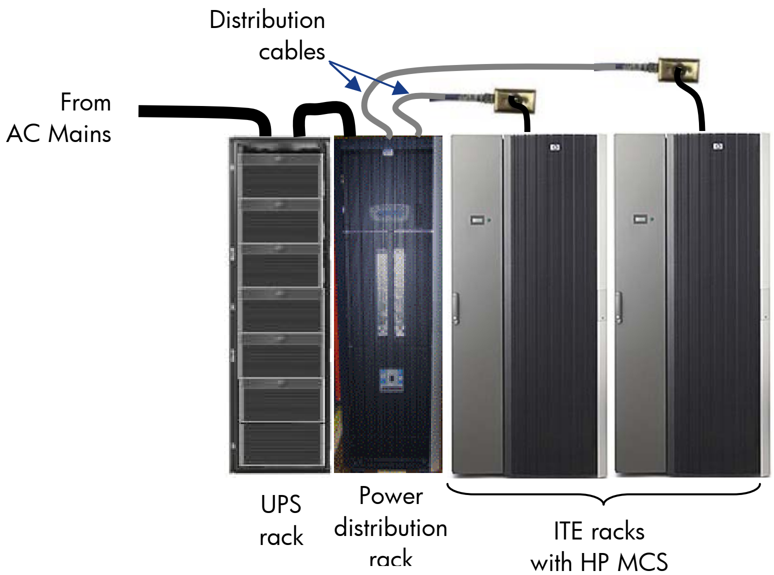
Figure 12. High-density system with conventional cooling



High-density system using chilled-water cooling

Figure 13 shows a high-density system of two 30-kW ITE racks powered from a UPS rack of parallel HP RP12000/3 UPSs to provide 60 kilowatts of power distributed through the HP PDR. In this example, the HP Modular Cooling System (MCS) is used to provide chilled-water, forced-air cooling for the IT equipment. The UPSs and PDR use conventional cooling methods. Cabling is routed overhead in cable trays (not shown) and through the tops of the racks. This configuration is possible in facilities with raised or non-raised floors.

Figure 13. High-density system with the HP MCS



NOTE
Each HP MCS is capable of cooling up to 35 kW of IT equipment. Two or more HP MCS racks with a maximum ITE load will require additional UPS support. Online utilities for calculating the power requirements for HP server products are available at the URLs provided in the section titled "For more information" at the end of this paper.

Conclusion

In the past, data center architects have had to research IT equipment and power distribution products from different sources to build a complete datacenter. There were always concerns of how easily, efficiently, and reliably components from different vendors would interface and work with each other. HP three-phase power solutions are designed to integrate easily with HP IT systems for maximum efficiency.

The HP vision is to provide customers with a turnkey solution for their IT needs. Systems that have been designed and tested to work with each other inherently provide better performance and require less maintenance than a system built from a variety of vendors.

For more information

For additional information, refer to the resources listed below.

Resource	Hyperlink
HP rack and power product information	http://h18004.www1.hp.com/products/servers/platforms/rackandpower.html
HP online Power Calculator for ProLiant servers	http://h30099.www3.hp.com/configurator/powercalcs.asp
HP Power Sizer utility	www.hp.com/go/bladesystem/powercalculator
Additional rack and power white papers	http://h18004.www1.hp.com/products/servers/technology/whitepapers/datacenter.html

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