Power Distribution Architectures

Revision 2
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Part 1 - Summary

Typically, power is distributed to IT loads at 400/230VAC. But in North America, however, power is traditionally distributed at 208/120VAC, which results in deficiencies including greater cost, lower efficiency, and greater space consumed. Using 415/240VAC distribution enables higher density per rack without adding extra circuit breakers as would be the case with 208/120VAC distribution.

Common voltages:
- 400/230VAC
- 415/240VAC
- 480/277VAC
- 208/120VAC

The designation of the two values when written as “208/120” or “415/240” represents the line to line voltage (first number) and line to neutral voltage (second number). In three-phase system with power factor equal to 1, the value of the line to neutral voltage is equal to the line to line voltage divided by the square root of 3 (i.e. 120 = 208 / √3).

Today, virtually all IT equipment is designed for worldwide compatibility and can operate on a voltage range of 100 to 240 volts. This means it can operate on North American voltages of 208 and 120, the Japanese voltages of 200 and 100, and on 230 volts in the rest of the world. Operating IT equipment at its highest possible voltage of 240 volts is most efficient.

Known North American distribution system deficiencies:

- Low distribution voltage (120volts) increases energy cost—it is a law of physics that for the same amount of power, as voltage decreases, current increases. The more current that runs through a wire, the higher the electrical losses and energy cost.

- Low distribution voltage(120volts) that increases copper cost—the lower the voltage, the thicker the wire required to carry the higher current.

- Oversized traditional PDUs that consume floor space and increase floor weight—the increased floor space consumption and floor weight is mainly due to the heavy isolation transformers inside the PDUs and the large cabinets that enclose them.

- Oversized PDU isolation transformers that increase energy costs—The collective PDU capacity in many data centers are 1.5 to 3 times the data center capacity which increases electrical transformer losses and energy costs.

- Multiple branch circuits per rack, with corresponding breakers and cabling - at a lower voltage more branch circuits are required for a given rack density which increases cable clutter, complexity and cost.

The deficiencies explained above increase in magnitude as rack power densities increase. High density server installations where racks can draw from 10 kW to 30 kW per rack place significant strains on the traditional power distribution system.
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*Let's do some math.....*

An increase in circuit voltage while holding current constant increases the capacity of that circuit. The power capacity for a three-phase branch circuit is calculated by using the following formula:

\[ \text{Power} = \text{Volts} \times \text{Amps} \times 3 \]

The “volts” in this formula refers to the line to neutral voltage. Therefore, when comparing the line to neutral voltages of both distribution methods, the comparison should be between 120 V and 240 V and NOT between 208 V and 240 V. For example, assume 20 amp circuits are provided to the load in either case. The power capacity for the 120 V “line to neutral” distribution method is calculated as:

120V branch circuit power capacity = 20 amps x 120 V x 3 = 7.2 kW

However, the capacity for the 240 V “line to neutral” distribution method is calculated as:

240V branch circuit power capacity = 20 amps x 240 V x 3 = 14.4 kW

*Given the same circuit current rating, the 240 V distribution method provides 100% more power than the 120 V distribution method.*

The National Electrical Code® (NEC®), NFPA® 70 and NFPA 70E, as well as local electrical codes, provide minimum standards and requirements in the area of wiring design and protection, wiring methods and materials, as well as equipment for general use with the overall goal of providing safe electrical distribution systems and equipment.

**Part 2 - Types of Power Distribution**

**Panel Board Distribution** - In panel board distribution, the main data center power is distributed to multiple wall-mounted panelboards. Panelboards (typically rated from 1.5 kVA to 75 kVA) may come assembled by the vendor or they may be assembled in the field by the electrical contractor. Individual branch circuits or power cables are cut, terminated, and connected in the field by the contractor. The cables are run either overhead in cable trays (also called ladder trays), or they are run under the raised floor (sometimes in trays under the floor, and sometimes placed directly on the floor) to provide power close to the IT rack enclosures. Wall mount panelboards are a very low cost power distribution strategy,
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made up of parts that an electrician can acquire in days, not weeks, to implement quickly. This approach is very much custom engineered to meet the unique needs of a particular data center.

**Advantages**

- Lowest first cost, primarily driven by lower cost components
- Accommodates unusual physical room constraints
- Electrician has more flexibility in breaker and cable combinations, since they are not choosing from pre-configured assemblies
- Parts can be obtained very fast, i.e. from a local electrical supply

**Disadvantages**

- Increased risk of human error since installations are custom engineered and there is greater reliance on the quality of work and skill of the electrician
- If the plenum is used for distributing air, cabling restricts high volume air required by modern IT equipment (over time) which impacts effectiveness of cooling distribution
- Creates an environment that is not readily changeable
- Cable tracing & removing cables can be difficult because of the placement of the power cables under the floor or in trays

**Usually used**

- For smaller capacity installations and when lowest first cost is a top priority
- When IT changes are not likely or frequent
- When density per IT rack is low (if power cables are distributed in air plenum)

**Traditional Field Wired PDU's** - In traditional power distribution systems, the main data center power is distributed to multiple power distribution units (PDUs), typically rated from 50kVA to 500kVA, throughout the IT space. Sometimes, PDUs without transformers are referred to as RPPs (Remote Power Panels). PDUs are fed from centralized sub-feed breakers and are generally placed along the perimeter of the space, throughout the room. Some have an IT rack form factor that line up in a row of racks providing improved aesthetics for the space and bring the distribution closer to the load. Branch circuits are distributed from the PDUs to the IT equipment. Each IT rack enclosure uses one or more branch circuits.
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**Advantages**

- Higher degree of monitoring options than panel board approach
- Low first cost, primarily driven by lower PDU cost than factory-configured or modular PDUs
- Accommodates unusual physical room constraints and allows for more strategic placement of the distribution when compared to wall-mounted panelboards.
- Electrician has more flexibility in breaker and cable combinations, since they are not choosing from pre-configured assemblies

**Disadvantages**

- Increased risk of human error since field-wired designs mean greater reliance on the quality of work and skill of the electrician (i.e. wire terminations done in the field may result in loose connections and other defects)
- Limited warranty of whole power distribution system, since components like breakers and power cables are installed in the field
- If the plenum is used for distributing air, cabling restricts high volume air required by modern IT equipment (over time) which impacts effectiveness of cooling distribution
- Cable tracing & removing cables can be difficult because of the placement of the power cables under the floor or in trays

**Usually used**

- When low first cost is a priority compared to a factory-configured & modular distribution
- When floor space is available but unique room constraints limit the use of factory-configured or modular designs
- When IT changes are not likely or frequent and growth of IT is done at the pod level
- When the IT layout is unknown at the time of the PDU specification, since exact branch breaker ratings and power cable lengths do not get specified until closer to installation

**Traditional Factory-Configured PDU’s** - With factory-configured distribution, much of the field-wiring work that is otherwise done on site is done in a controlled factory. The PDU is configured to the customer’s requirements with factory-assembled branch breakers with power cables pre-cut and terminated to the length and ampcalities required by the IT racks. These cable /breaker assemblies are installed onto the PDU at the factory, so that the only onsite work involves running the conduit from a sub-feed breaker to the PDU input, and then routing the pre-connected cables to the appropriate IT.
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racks. By standardizing the power distribution solution, data center projects can eliminate costly and time-consuming one-time engineering.

**Advantages**

- Pre-fabricated breaker / power cable assemblies improve reliability by minimizing field work
- Integrated design with integrated and pre-configured intelligence for better capacity and change management as load requirements change
- System-level warranty of whole power distribution system, since components are designed, tested, and integrated in a factory
- Accommodates unusual room constraints since PDUs can be rolled into any location on IT floor
- Lower first cost than modular distribution approaches

**Disadvantages**

- The IT room layout must be understood earlier in the planning cycle, since specific breakers and cable lengths are procured with the system; better coordination between IT and facilities is typically necessary
- Higher field cost to install new power cables and breakers as load requirements change compared to modular distribution approaches
- Cable tracing & removing cables can be difficult because of large volumes of cables overlayed in troughs
- Takes up space on the IT room floor
- Heavier shipping weight since it ships with all breakers and cables attached

**Usually used**

- When a data center plans to scale their future IT at the pod level
- When a data center requires portable equipment due to likelihood of future move
- When space is not constrained and low first cost is a priority

**Overhead/Underfloor Busway Distribution** - In order to meet the modern IT requirements, alternative power distribution approaches are appearing in data centers. These approaches are more flexible, more manageable, more reliable, and more efficient. Specifically, they include the following attributes:

- **Integrated branch circuit power metering** – Capacity and redundancy are managed on every circuit
- **Flexible changeable power cords with tool-less expansion** – IT zones and associated power distribution can be deployed over time, by anyone
- **Reduced footprint** – Less floor space required than with traditional PDUs
- **High efficiency** – Transformer-less options and minimized copper use
Two modular distribution systems can achieve these desired characteristics:

- **Overhead / underfloor modular distribution** using plug-in units powered by busway overhead or underfloor to feed IT enclosures
- **Floor-mount modular distribution** using branch circuit cables, distributed overhead in cable troughs to the IT enclosures, that are pre-terminated with breaker modules that plug into a finger-safe backplane of a modular PDU. In general, these approaches have a higher first cost per watt than traditional distribution. However, from a lifetime cost perspective, these approaches have lower TCO because of the ability to implement changes faster, avoid stranded capacity (oversizing) with better capacity management, improve efficiency, and reduce maintenance expense.

**Advantages**

- Zero footprint on IT room floor, making more space available for IT equipment
- Improved cable management and tracing, with distribution cable from plug-in unit located directly over or under IT racks
- Inventory of cables can be reduced dramatically with fixed distance from busway to each IT rack
- Tool-less pre-assembled plug in units improves the reliability by eliminating field wire cutting and terminating branch circuits
- System-level warranty of whole power distribution system, since components are designed, tested, and integrated in factory
- Broader range of capacities available in market to address greater capacity needs
- Simpler adds, moves, and changes because cables are not stacked on top of each other

**Disadvantages**

- Ceiling height could constrain overhead implementation of this approach, as space is required above the racks (approximately 25 inches or 0.6 m); raised floor used as air plenum constrains underfloor implementation
- Field installation of multiple bus sections and field-integrated management capabilities requires more time and expense and can create unique problems
- Can interfere with ducts and air containment systems when hung above IT enclosures
- Row placement and length need to be thought through in advance for busway placement since it is intrusive to install or move bus in a live IT environment
- Oversizing of bus is more likely since it is commonly built out on day one

**Usually used**

- When floor space in the IT room is constrained
- In large facilities with an open floor plan with a very well defined IT row layout
- When there is a high degree of confidence in final IT load requirement
- When there is a high frequency of IT equipment turn-over requiring new circuits to be installed (i.e. lab environment)

**Floor-Mount Power Distribution**- Instead of traditional circuit breaker panels with bolted wire terminations, modular PDUs have a backplane into which pre-terminated circuit breaker modules are installed. This arrangement eliminates on-site termination of wires. A new row of 24 IT enclosures, along with all of the associated branch circuit wiring and rack outlet strips, can be installed in an hour, without any wire cutting or terminations. Installation involves installing the sub-feed breakers, placing the distribution units on the floor, running the wire from the sub-feed breakers to the units, inserting the pre-assembled circuits, and routing them to the racks. Power monitoring is included in each branch circuit and automatically configures when plugged in. A large number of data center projects involve the upgrade of an existing data center, with common projects being the addition of capacity or installation of Universal Networking Services
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a high-density zone. The floor-mount modular distribution system is particularly well suited to these types of retrofit projects, because installation is much less disruptive than installing a traditional PDU. As the data center evolves, modular PDUs can operate alongside existing traditional PDUs. In smaller data centers, the modular PDU may be directly integrated with the UPS system into a compact arrangement that can be located in the IT room and integrated into an IT enclosure lineup. In this case, the need for a separate UPS room is eliminated. In some cases there may be one or more zones within a data center where only a small number of branch circuits are needed. This can occur when there is a cluster of very high density racks, or when a small group of racks is isolated by room shape or other constraints. In these cases, there are smaller versions of modular PDUs that directly mount into an IT rack, consuming zero floor footprint

Advantages

- Pre-fabricated backplane and branch circuit modules ensures a well integrated, reliable system
- Quicker installation time due to roll-in form factor and pre-assembled modules which require minimal field work
- Integrated design with plug and play intelligence for better capacity and change management as load requirements change
- System-level warranty of whole power distribution system, since components are designed, tested, and integrated in factory
- Improved aesthetics, with IT rack form factor for lining up in a row of racks, closer to the load
- Ease of scaling additional PDUs as new IT demand is identified
- Accommodates unusual room constraints since PDUs can be rolled into any location on IT floor

Disadvantages

- Greater number of cables to inventory since distances from PDUs to IT racks vary
- Cable tracing as well as adds and changes can be difficult, especially for high density applications, due to volume and size of cables located in troughs
- Takes up floor space in IT room

Usually used

- When data center has uncertain growth plan and locations are not precisely defined in advance, requiring flexibility to add/move distribution

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- When the room is constrained in shape or ceiling height or has obstructions
- When IT personnel can re-configure the breakers and branch circuits without involvement of third parties
- When speed of deployment is a high priority
- When retrofitting an existing data center with additional capacity or installation of a high-density zone

Part 3 - Relative Cost of different distribution

The final power distribution (i.e. downstream of transformers to the IT racks) accounts for less than 5% of the total capital cost of a data center’s physical infrastructure. Although this represents a small percentage of the total, it’s important to understand the differences in system cost, installation cost, and TCO for the five architectures in order to select the optimal approach for a particular need.

On a per watt basis, there is not a significant difference in the installed cost; however, data centers aren’t typically built upfront for a known final capacity, and when growth plans are factored in, the upfront cost delta among the architectures is greater. Some approaches are highly scalable, which means significant capital expense can be deferred to future years or avoided altogether. Others incur a significant expense on day one, for an uncertain future capacity need. From an operating cost standpoint, cooling inefficiency can result when running power beneath a raised floor that is also being used as an air plenum for distributing cool air to the IT equipment. These under-floor cables, as well as the floor openings for the wire, interfere with the airflow resulting in an inefficient cooling distribution system that must be oversized to adequately cool the load.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Panelboard distribution</th>
<th>Field-wired PDU distribution</th>
<th>Factory-configured PDU distribution</th>
<th>Busway modular distribution</th>
<th>Floor-mount modular distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>Lowest cost approach at $0.15 – $0.30 /watt*</td>
<td>Low cost approach at $0.20 – $0.40 /watt*</td>
<td>Low cost at $0.30 – $0.50 /watt*</td>
<td>$0.40 – $0.60 / watt*</td>
<td>$0.40 – $0.70 / watt*</td>
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<tr>
<td></td>
<td>System is typically installed up front for maximum expected</td>
<td>System is scalable at pod level; Installation labor is greater percent of total cost, which results in greater variation in total first cost.</td>
<td>System is highly scalable so costs can be deferred until capacity need exists; Installation labor is approximately 20% of total cost.</td>
<td>Busway is generally installed up front for maximum expected capacity, resulting in increased first cost; Installation labor is approximately 20% of total cost.</td>
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<td>Operating Cost</td>
<td>Underfloor cabling causes interference with underfloor airflow that reduces cooling efficiency and capacity; changes involve more costly field-work.</td>
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<td>Cabling is generally overhead so no interference with airflow and no leakage from wire openings in floor; changes to breakers / cables involve more costly field-work than modular distribution.</td>
<td>Busway, when run overhead, results in no interference with airflow and no leakage from wire openings in floor; changes to breakers / cables involve less field-work.</td>
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About Universal Networking Services

Universal Networking Services is an industry-leading provider of power and cooling solutions for mission-critical IT infrastructure. From planning to site commissioning, our engineered solutions are reliable, scalable and modular to increase efficiency and lower operational expenses. Our services include: design/build, product acquisition, installation, management and maintenance services.

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