Overview
Within enterprise data centers, power used for operating the facility, lighting, running IT loads and cooling it is the largest component of operational expense (OPEX) of the facility. Numerous papers and articles have been published by The Green Grid, The Uptime Institute, PG&E, Lawrence Berkeley National Laboratories (LBNL) and others discussing ways to measure, monitor and increase efficiencies. This paper discusses various approaches to reduce power consumption and increase end-to-end efficiency in the data center by bringing 415 VAC power to the IT cabinet/rack level. With power densities continuing to rise, more efficient solutions continue to be explored especially as power cost increases and power availability decreases. The power path from the building entrance to the IT loads contains several power converters and transformers to perform each conversion; there is a loss of power. Reducing the number of transformers and operating at a higher voltage improves efficiency and reduces electrical costs. This paper discusses an alternative approach to power distribution presently being implemented in North American data centers that increase efficiencies and savings by reducing upfront capital costs, power consumption and floor space.
Baseline: Current North American 208 VAC 3-phase Power Distribution

In North America, 277/480 VAC, 3-phase power is delivered to most large commercial buildings and IT facilities. The voltages are measured from line-to-neutral (277 VAC) and line-to-line (480 VAC), as shown below in Figure 1. Automatic switching power supplies inside IT equipment typically operate within a range from 100 VAC to 240 VAC single-phase so the utility power delivered to the facility must be stepped down from 277 VAC through isolation transformers before it may be used, as depicted in Figure 3. This is achieved by routing the facility power through an end of row Power Distribution Unit (PDU) transformer where it is stepped down from 480 VAC 3-phase to 208 VAC 3-phase.

FIGURE 1: 208 VAC 3-phase after the PDU transformer

FIGURE 2: 480 VAC 3-phase power at the building entrance

120 VAC line-to-neutral

FIGURE 3: 480 VAC 3-phase to 208 VAC power path

stay powered. be supported. get ahead.
From the end of row PDU, power is typically distributed in one of three formats by remote power panels (RPP) or rack-level power distribution units (PDUs):

1. 120 VAC single-phase (measured line-to-neutral)
2. 208 VAC single-phase (measured line-to-line)
3. 208 VAC 3-phase (in a Delta or Wye configuration).

Most IT devices have automatic switching power supplies that will accept both low-line voltages of 100-120 VAC and high-line voltages of 200-240 VAC. Running devices at the higher voltage increases efficiencies in the range of 2 to 2.5 percent, so the first step towards optimizing efficiency is for data center managers to ensure that all devices capable of operating at 208 VAC are doing so.

In 208 VAC distribution systems, 208 VAC is implemented with a line-to-line configuration (taking two of 3 lines of 3-phase power) to the rack PDU versus a line-to-neutral configuration for 120 VAC, as seen in Figure 2. The advantage of this 208V system is the capability of delivering 120 VAC for legacy devices; however, as mentioned before, most devices have universal power supplies capable of operating at higher voltages.

Keep in mind that within the IT device’s internal power supply, power goes through one more transformation and conversion in which 120 VAC or 208 VAC is stepped down and then rectified to 12 VDC and other working voltages using DC-DC conversion circuitry. See Figure 4.

New demands for supporting big data, artificial intelligence, and other intense compute loads combined with the quest for improvements in efficiency are causing higher power densities at the cabinet level, leading to new data center designs where 208 VAC 3-phase distribution systems are being replaced with 415 VAC 3-phase systems.
415 VAC 3-phase Power Distribution

Power and cost savings in the data center can be achieved by reducing the number of power transformations and by operating at higher voltages. This can be done by converting the UPS output from 277/480 VAC to 240/415 VAC through an autotransformer and eliminating the PDU transformer. Alternatively, the PDU transformer may be replaced with a PDU autotransformer. In a 415 VAC distribution system, the line-to-neutral voltage is 240 VAC. It is important to note that this is a significant difference from the typical US Baseline System where the line-to-neutral voltage is 120 VAC after the PDU transformer. This approach doubles the voltage being delivered to the devices while increasing efficiencies and reducing installation costs by eliminating components and using smaller diameter cables for distribution.

The 415 VAC power distribution system that is used in much of the world outside of North America is now beginning to gain a foothold within the U.S. and Canada. According to various UPS manufacturers, eliminating the PDU transformer will result in a 2% efficiency gain.

FIGURE 5: Difference between 415 VAC and 208 VAC power distribution systems
Additionally, operating rack-level equipment at 240 VAC vs. 208 VAC will provide an additional 0.2% to 0.3% efficiency gain as shown in Table 1 for the HP ProLiant DL385.

<table>
<thead>
<tr>
<th>Power Supply Specification</th>
<th>HPE 500W Flex Slot Platinum Hot Plug Power Supply Kit</th>
<th>HPE Spare PN 75437</th>
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<tbody>
<tr>
<td>Input Voltage Range (Vrms)</td>
<td></td>
<td>100-240</td>
</tr>
<tr>
<td>Frequency Range (Normal) (Hz)</td>
<td></td>
<td>50-60</td>
</tr>
<tr>
<td>Nominal Input Voltage (Vrms)</td>
<td>100 120 127 200</td>
<td>?</td>
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<tr>
<td>Maximum Rated Output Wattage Rating (Watts)</td>
<td>500 500 500 500</td>
<td>?</td>
</tr>
<tr>
<td>Nominal Input Current (A rms)</td>
<td>5.6 4.6 4.3 2.7</td>
<td>?</td>
</tr>
<tr>
<td>Maximum Rated Input Wattage Rating (Watts)</td>
<td>558 550 543 539</td>
<td>?</td>
</tr>
<tr>
<td>Maximum Rated VA (Volt-Amp)</td>
<td>564 556 549 544</td>
<td>?</td>
</tr>
<tr>
<td>Efficiency (%)</td>
<td>89.6 90.9 92.1 92.8</td>
<td>?</td>
</tr>
<tr>
<td>Power Factor</td>
<td>0.99 0.99 0.99 0.99</td>
<td>?</td>
</tr>
<tr>
<td>Leakage Current (mA)</td>
<td>? ? ? ?</td>
<td>?</td>
</tr>
</tbody>
</table>

**TABLE 1:** HP ProLiant DL385 Gen10 Flex Slot Power Supply

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**FIGURE 6:** Comparison between the baseline power path and the 415 VAC power path with the elimination of the PDU transformer.
To gain a better understanding of the benefits of a 415 VAC system, consider what is necessary to deliver redundant power to a rack of high density blade servers. Using the power configuration calculator from a major blade system manufacturer, the power requirement for four fully populated blade systems is 15.1 kW. Table 2 below shows four different approaches to delivering this amount of power to the rack along with the number of power drops needed to provide redundancy.

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Phase</th>
<th>Current</th>
<th>kW</th>
<th>kW Continuous Rating</th>
<th>Power Drops Required</th>
<th>Total Drops for Redundancy</th>
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<tr>
<td>415</td>
<td>3</td>
<td>30</td>
<td>21.6</td>
<td>17.3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>208</td>
<td>1</td>
<td>30</td>
<td>6.2</td>
<td>5.0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>208</td>
<td>3</td>
<td>30</td>
<td>10.8</td>
<td>8.6</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>208</td>
<td>3</td>
<td>60</td>
<td>21.6</td>
<td>17.3</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>

**TABLE 2: Power Capacity Comparison Voltage**

**415 VAC System**
30 A x 3 x 240 V x 0.80 de-rating = 17.3 kW

**208 VAC 1-Phase, 30 A System**
30A x 208 V x 0.80 de-rating = 5.0 kW

**208 VAC 3-Phase, 30 A System**
30 A x 1.732 x 208 V x 0.80 de-rating = 8.6 kW

**208 VAC 3-Phase, 60 A System**
60 A x 1.732 x 208 V x 0.80 de-rating = 17.3 kW
Efficiency gains by implementing a 415 VAC design are typically 4 to 5%. See Figure 7. Upfront cost savings are also realized by eliminating the PDU transformer, using smaller gauge power cords and less expensive plugs, taking up fewer poles at the breaker panel and requiring fewer power drops to the cabinets. Additional savings come from reductions in cooling costs with the elimination of the PDU transformers and at the cabinet-level by having fewer PDUs and cable drops which can also impede airflow. Additionally, though a 208 V, 60 A system provides the same power as a 415 V, 30 A system, lower current flow allows use of smaller conductors thus lowering the initial costs and reduces line losses due to cable resistance.

**FIGURE 7:** Efficiency gains by eliminating the transformer and running equipment at 240 V rather than 120 V

Table 3 demonstrates the annual cost savings by implementing a more efficient power distribution system based on a $0.10 per kW-hr rate. Since energy rates vary from region to region, higher cost areas will realize greater savings. In general, power distribution equipment is more efficient and runs cooler while operating in the middle of their designed range; therefore additional cost savings can be achieved by understanding the capacity requirements for meeting immediate needs with the ability to expand to accommodate future growth.

<table>
<thead>
<tr>
<th>IT Load (kW)</th>
<th>1%</th>
<th>2%</th>
<th>3%</th>
<th>4%</th>
<th>5%</th>
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<tbody>
<tr>
<td>250</td>
<td>$2,190</td>
<td>$4,380</td>
<td>$6,570</td>
<td>$8,760</td>
<td>$10,950</td>
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<tr>
<td>500</td>
<td>$4,380</td>
<td>$8,760</td>
<td>$13,140</td>
<td>$17,520</td>
<td>$21,900</td>
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<tr>
<td>750</td>
<td>$6,570</td>
<td>$13,140</td>
<td>$19,710</td>
<td>$26,280</td>
<td>$32,850</td>
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<tr>
<td>1,000</td>
<td>$8,760</td>
<td>$17,520</td>
<td>$26,280</td>
<td>$35,040</td>
<td>$43,800</td>
</tr>
<tr>
<td>1,500</td>
<td>$13,140</td>
<td>$26,280</td>
<td>$39,420</td>
<td>$52,560</td>
<td>$65,700</td>
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<tr>
<td>2,000</td>
<td>$17,520</td>
<td>$35,040</td>
<td>$52,560</td>
<td>$70,080</td>
<td>$87,600</td>
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</table>

**TABLE 3:** Annual energy savings from efficiency gains
Distributing 415 VAC at the Cabinet Level
At the cabinet level, power to the IT loads is distributed through a cabinet Power Distribution Unit (PDU). The PDUs designed for 208 VAC 3-phase systems are not compatible with 415 VAC systems because they are wired line-to-line. In order to deliver 240 VAC single-phase, the outlets must be wired line-to-neutral. Server Technology offers designs that meet these requirements such as the HDOT Pro2 Switched PDU with Alternating Phase outlets below that offers a combination of IEC 60320 C13 and C19 outlets. See Figure 8.

The picture shows an example of a PDU configured for 415 VAC service. This particular PDU has two outlet sections, each with three phases and two circuit breakers per phase, allowing it to deliver 17.2 kW which is the full capacity of the circuit. With this design, if the current in Branch 1 exceeds 20 A, it will trip the breaker and remove power to the branch leaving the rest of the PDU running normally.

Power Monitoring Using Server Technology POPS™ (Per Outlet Power Sensing)
In order to best manage power utilization, the capability to measure and monitor it must be present. As the PDU is the most intelligent device closest to the IT load, it is an ideal point to monitor power consumption. Intelligent PDUs (such as Smart or Switched PDUs) are equipped with local displays that provide useful information at the cabinet when powering up and load testing; however, they provide little accessible information over the course of a day, week or month when placed inside a cabinet that remains closed and is infrequently visited by personnel. Since power draw varies over time, PDUs designed with the ability to be networked and to allow power information to be queried, polled and trended at both a circuit and outlet level provide Data Center and Facilities managers a better understanding of actual equipment power usage and identify underutilized equipment or stranded power capacity.
Information can also be rolled up so power usage can be viewed by device, at an application level, or at a cabinet, row or floor level. Additionally, the accumulated data may be used to calculate the PUE (Power Usage Effectiveness) and other metrics established by The Green Grid and other organizations to gauge and analyze power consumption and efficiency.

**Environmental Monitoring**

Maintaining the proper temperature and humidity range within the cabinet has become critical as densities within the cabinet and higher server utilization due to virtualization/containerization increases. Server Technology PDU’s have the capability to monitor and send alerts from up to four combination temperature and humidity probe inputs per Master + Link PDU in a cabinet. Additionally, when used with a DCIM tool like Sunbird’s PowerIQ, temperature, humidity and power may be logged and trended.

**120 V IT Devices**

Some IT equipment may be supplied with a 120 VAC NEMA power cord that will not be compatible with the PDU in a 415/240 VAC distribution system. Fortunately, most IT equipment manufacturers use power supplies that accept 100 V to 240 V and have standardized on IEC connectors for their products such as the Dell 2161 DS KVM Switch, which is designed with an IEC 60320 C14 inlet. This allows the power cord to be changed out to an IEC type cord. For those devices that do not have universal power supplies that will accept 240 VAC, rack-mounted transformers are available from a number of vendors.

![IEC C14 inlet](image)

**FIGURE 9:** IT Equipment with IEC C14 inlet
Summary
With small data centers operating in the range of tens of kW and large data centers running in tens of MW, incremental increases in efficiencies have the potential to translate into large savings. There are several other proposed power distribution architectures being discussed in the IT industry such as rack-level and facilities-level DC power distribution and 277 VAC distribution that have not yet been widely adopted.

For the time being, most data centers find that distributing 415/240VAC power to the IT rack is the most cost effective and efficient solution available. Server Technology, a brand of Legrand, provides a broad range of PDUs that support 415/240VAC 3-phase power for the most demanding data center requirements.
About Server Technology®

Server Technology, a brand of Legrand, is leading the engineering and manufacturing of customer-driven, innovative and exceptionally reliable power, access and control solutions for monitoring and managing critical IT assets for continual availability.

Server Technology’s power strategy experts are trusted to provide Rack PDU solutions for data centers worldwide ranging from small technology startups to Fortune 100 powerhouses. Because power is all we do, Server Technology can be found in the best cloud and colocation providers, forward thinking labs, and telecommunications operations.

Server Technology customers consistently rank us as providing the highest quality PDUs, the best customer support, and most valuable innovation. We have over 12,000 PDU configurations to fit every data center need and most of our PDUs are shipped within 10 days.

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