Server Technology,

Efficiency Gains with 480V/277V Power at the Cabinet Level

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Overview

In February 2009, the Data Center Pulse Group, along with the Silicon Valley Leadership Group, began calling for new data center implementations in North America to incorporate support for a 480V/277V power distribution topology.[1] They implored the makers of power supplies and servers to begin extending the operating range of their gear from a high end of 240V to a 277V nominal input. The driving impetus for recommending 277V power to the rack was two-fold – improved efficiencies and lower costs.

This paper explores the merits and drawbacks of 480V/277V power distribution versus the more conventional 208V and 415/240V 3-phase designs in use today. At present there remains a number of challenges associated with implementing 480V/277V at the rack level that will need to be overcome before sales volume of 277V gear is sufficient enough to reach price parity with the acquisition and operating costs of 415V/240V infrastructure and products.

Server Technology's 277/480V
Cabinet Power Distribution Unit (CDU)

[1] http://www.thegreengrid.org/~/media/TechForumPresentations2011/TheDataCenterPulseTopTen.ashx?lang=en

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Baseline

Many major data centers today consume in excess of 87600 MWHr of energy. As such, the power companies and the data centers have found it economical to bring 13kV power lines to the data center building and to use a transformer on site to step down the voltage such that 480VAC enters the building. This helps to reduce the transmission losses along the line from the generation site (or distribution substation) and provides a usable working voltage for the data center. For the purposes of this paper, we will assume that the line voltage entering the data center is 480VAC phase to phase, with 277VAC between phase and neutral as shown below in Figure 1

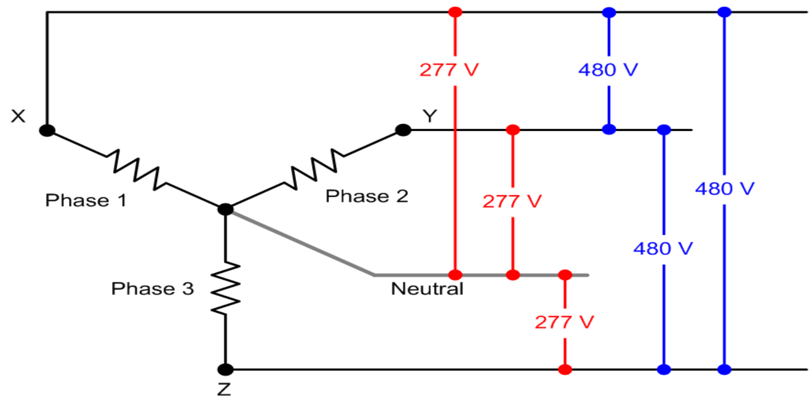

Figure 1. 480VAC 3-phase power at the building entrance

In a typical data center today, once the 480V power is brought inside the data center, the power is frequently converted down to 208V 3-phase power/120V single-phase in either a Wye or Delta configuration. Figure 2 below provides a clear picture of the multi-step conversion process for bringing 208V 3-phase or even 120V single-phase power to the computer cabinet. Figure 3 shows 208VAC 3-phase Wye after the power distribution unit (PDU) transformer, 120 VAC line-to-neutral.

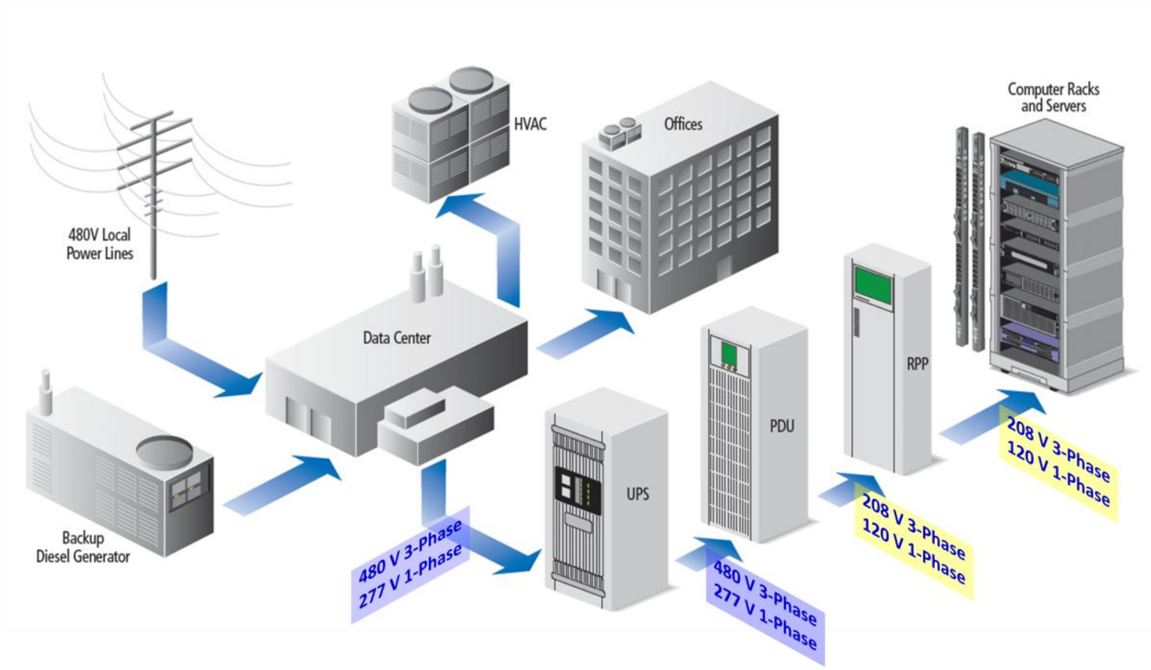

Figure 2.

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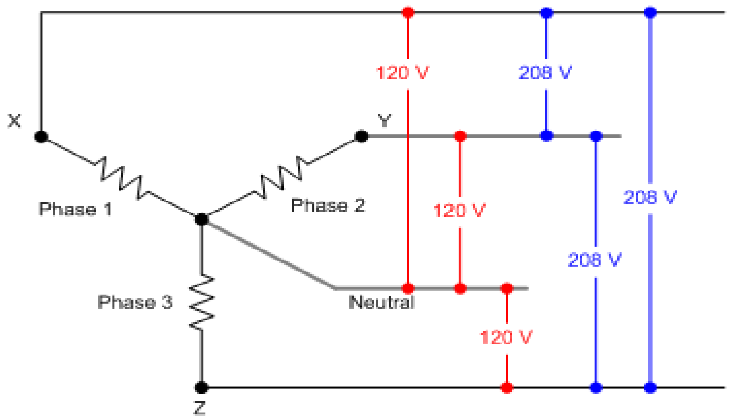

Figure 2. 208VAC 3-phase Wye after the PDU transformer, 120 VAC line-to-neutral

Any time that electrical power is transformed (converted), there will be losses in the form of waste heat associated with the transformation. In the conventional topology depicted in Figure 2, we can see that there is a double-conversion once power enters the data center. The first transformation is at the UPS, and the second is at the end of row PDU. Both of these transformations put heat load inside the data center, requiring additional cooling.

Modern UPS designs typically follow one of two topologies – either a double-conversion type or one with a “line interactive” design.

Looking at Figure 4 of this paper (Figure 28 from Green Grid WP#16)[2], we can see that at the time of writing the Green Grid White Paper, the 480V to 208V conversion end-to-end efficiency peaks at slightly below 88% when measured between 40-60% load, depending on whether it is a double-conversion or line-interactive UPS topology. Since that time there have been incremental improvements in efficiency made by the UPS and end of row PDU/autotransformer manufacturers.

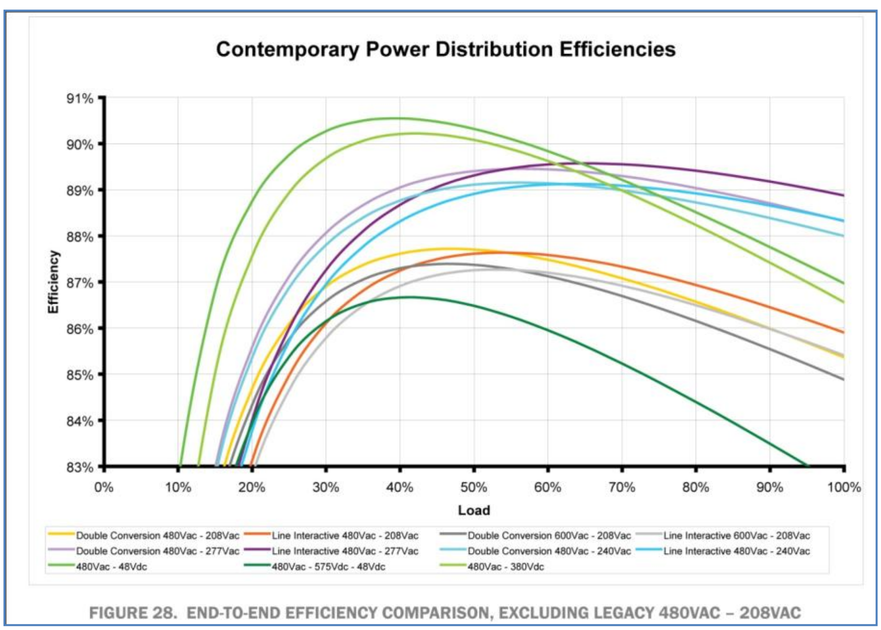

Figure 3 - Green Grid, White Paper (WP#16, p.23)

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[2] http://www.thegreengrid.org/~/media/WhitePapers/White_Paper_16_-_Quantitative_Efficiency_Analysis_30DEC08.ashx

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Historically, the auto-ranging power supplies found within IT equipment in the data center have been able to operate from 100-240VAC. Each of these auto-ranging AC to DC power supplies will transform the input power one more time, turning the available AC power into 12/5/3.3 VDC. Experience has shown that operating the IT load at the higher end of the input voltage range delivers an efficiency benefit of 2-3 percent versus operating at the low end of the acceptable input voltage range.

480VAC 3-Phase Wye Power Distribution Topology

Looking back at Figure 2, removing the PDU or autotransformer (single coil transformer) and its associated transformation losses result in a lower capital expense for the power transmission process from building entrance to the rack, along with reducing the operating expenses associated with the power losses of that transformation. According to various UPS manufacturers, eliminating the PDU transformer will result in a 2% efficiency gain.[3]

Further capital expense can be saved through the reduced amount of copper necessary to transmit an equivalent power at 480VAC versus the 208VAC baseline. Assuming a power density of 10kW to the cabinet (208V 3-phase 60A), the cable size needed at 480V/30A (or even 415V) is less than half of that at 208V. As you can see in Table 1, a circuit delivers the same amount of 415V 3-phase 30A power as a 208V 3-phase 60A circuit at a much lower cable and connector cost.

However, most data centers opt not to go down this path. Instead, they utilize the same size copper, and thus more than double the available power to the cabinet, allowing them to take an immediate jump in compute density for an equivalent square footage. Most data centers are using all of the power coming in and need more.

Circuit Capacity	De-rated Value	208 VAC 3-Phase	415 VAC 3-Phase	480 VAC 3-Phase
20 A	16 A	5.8 kW	11.5 kW	13.3 kW
30 A	24 A	8.6 kW	17.3 kW	19.9 kW
50 A	40 A	14.4 kW	28.8 kW	33.2 kW
60 A	48 A	17.3 kW	34.6 kW	39.9 kW

Table 1. Delivered Capacity

480VAC as a power distribution solution is at present limited to use for North America. For those global companies wanting to take a common approach to data center design no matter where they go in the world, 480V/277V to the rack may not make sense. The international standard remains 400V/230V (415V/240V for North America).

[3] White Paper, STI-100-008 – Power Efficiency Gains by Deploying 415VAC Power Distribution in North American Data Centers, April 20

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Efficiency Gains of 480V/277V vs. 415V/240V and 208V 3-phase

The following graph is taken from a presentation delivered by Paul Marcoux of BB&T and Jerry Sumrell of Syska Hennessy that was presented at 7x24 Exchange in Fall of 2010.[4] It clearly depicts the relative efficiency of HP's power supplies as a function of load and input voltage.

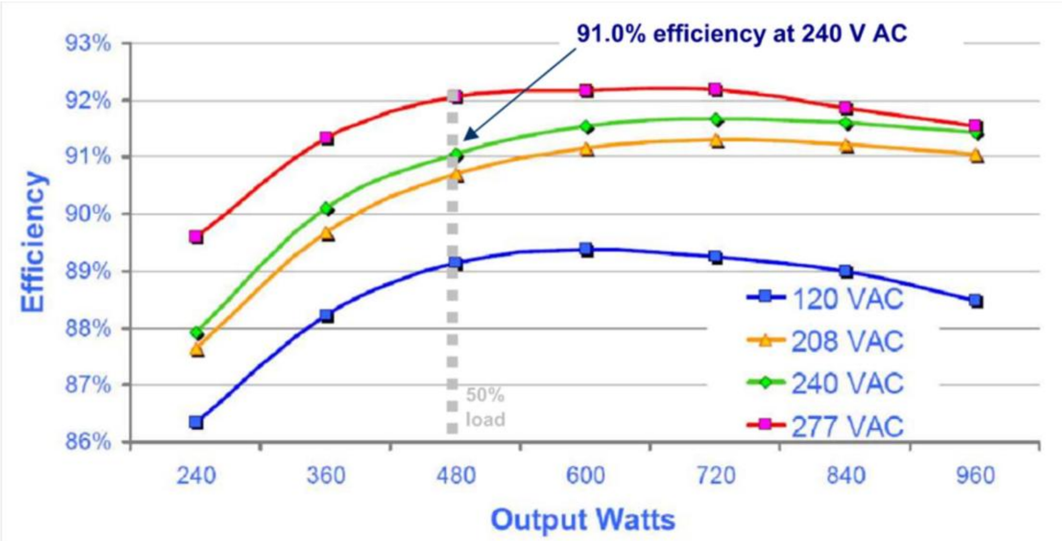

Figure 4. Hewlett-Packard Server Power Supply Efficiency as a function of load

At low loads, the power supply is approximately 2% more efficient than 208V AC, and about 1.7% more efficient than 240V AC.

When the above information is combined with similar data from UPS and other manufacturers for the efficiencies of their gear over a range of voltages, the following table gives a clear picture of the end to end efficiencies of the various power delivery topologies.

	UPS		Distribution		IT Power Supply		Overall Efficiency	
480/277 VAC	96.20	X	99.50	X	92.00	=	88.10%	
400/230 VAC	96.20	X	99.50	X	90.25	=	86.39%	
480 to 208VAC	96.20	X	96.52	X	90.00	=	85.00%	(typical)
48V DC	92.86	X	99.50	X	91.54	=	84.58%	
380V DC	96.00	X	99.50	X	91.75	=	87.64%	
Hybrid 575V DC	95.32	X	92.54	X	91.54	=	80.75%	

Table 2. Distribution Efficiencies

Distributing 480V/277V at the Cabinet Level

[4] p.10 of http://www.7x24carolinas.org/Fall2010Mtg/Syska_BBT_277V_Power_Supplies.pdf

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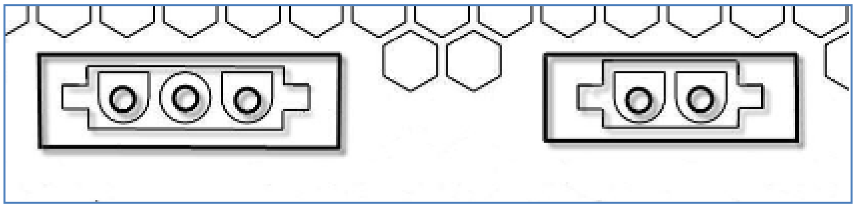
There are a number of cabinet power distribution unit (CDU) vendors in the industry. IBM, HP, Dell, and Oracle all offer either in-house designed or private label units in the lower voltage ranges as well as branded products from APC, Server Technology, and Eaton. However, there are few vendors on the market at the moment with offerings publicly available 480V/277V solution like Server Technology.

At 208VAC to the rack, C13 and C19 outlets are the accepted norm for powering most IT devices. These receptacles do not meet the 277VAC rating required to operate at these higher voltages. At 277VAC to the outlet, there are a number of competing receptacle solutions – but there are a no accepted standards.

Present proposed outlet types for distributing 277V are:

Figure 5, 277V Rated Receptacles
The plug shown is close in form factor to the standard C-13 outlet as seen in Figure 6 above. This configuration allows for rapid incorporation into existing PDU form factors while ensuring that existing 208V-240V power cords are not able to plug in.



277 VAC **-48V DC**

Figure 7. Open Compute Project Power Supply v1.0, p.27

The Open Compute Project Power Supply v1.0[5] uses a Tyco connector as specified in the 450W Power Supply Hardware V1.0 document at http://www.opencompute.org. (See Figure 7.) This looks to be a low cost option but requires unique cabling solution to support it.

Other companies such as Anderson Power Products also offers a well engineered connector solution for 480V/277V applications. These connectors are UL/CSA rated to 600V. http://www.andersonpower.com/products/powermod-hp-connectors.html

Figure 6. Anderson Power Products

5 http://opencompute.org/specs/Open_Compute_Project_Power_Supply_v1.0.pdf

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Implications of Adopting 480V/277V in the Data Center

As noted in the 2010 7x24 presentation by Syska Hennessy and BB&T[6], the benefits of adopting 480V/277V power (distribution) versus a 480V to 208V infrastructure are :

- Reduced energy losses
- Increased capacity
- Reduced equipment expenses
- Reduced space requirements
- Reduced breakers at the RPP
- Fewer cable runs in the plenum
- Reduced copper
- Operating expense savings due to I^2R losses

While the cost benefits of going forward with 480V/277V power distribution to the rack may be attractive to many, there are a number of other factors to consider before making the decision to implement such a topology.

At present, there remains a cost delta between 240V and 277V power supplies (where available) for the servers in the range of 5-15%. Furthermore, other components of the IT load have yet to adopt 277V power supplies. Load balancers, switches, routers, SANs, NAS, and numerous other data center components remain tied to 240V sources and therefore cannot operate in a 277V environment.
Arc flash represents a potentially lethal hazard for those inexperienced in working with high voltages. Some companies may wish to have electricians perform installations of 277V loads rather than IT personnel until such time as IT personnel can be trained on the proper safety precautions.
As 480V/277V is not an international standard, those companies wanting to deploy a single "global" standard will be better served adopting 415V/240V architecture in North America, which translates directly to the 400V/230V standard found in other countries.

Reasons for Considering 415V/240V

The benefits of adopting a 480V/277V infrastructure in North America are clear. Unfortunately, today there are few customers who have the scale necessary to drive the widespread adoption of this topology. In lieu of adopting 480V/277V, the data center architect may wish to consider 415V/240V as the power infrastructure of his facility for the following reasons:

- 415V/240V delivers double the power of 208V 3-phase for a given amperage, similar to 480V/277V
- it delivers a similar end-to-end efficiency as 480V/277V
- it allows the use of standard C13/C19 outlets
- 415V/240V follows existing wiring standards
- It allows the continued use of existing power supplies/IT loads

[6] http://www.7x24carolinas.org/Fall2010Mtg/Syska_BBT_277V_Power_Supplies.pdf

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480 VAC 3-Phase	415 VAC 3-Phase
Greater efficiency by eliminating transformers and autotransformers	Little or no changes required to UPS and delivery system
Not a common application	Used in the rest of the world outside of US
Additional efficiency gains over 240 VAC by operating at a higher voltage. Unfortunately very few IT devices presently operate at 277 VAC	Efficiency gains operating equipment at 240 VAC (over 120 and 208 VAC)
No standard plugs and outlets exist for this voltage range (no C13 or C19 equivalent)	Existing plugs and connector already exists for equipment
New standards will need to be developed and adopted to cover 277 VAC	US standards already apply to this configuration

Table 3.

Conclusions

The appeal of adopting 480V/277V for the delivery of power to the data center cabinet is evident. The benefits of being able to reduce the number of power transformations taking place before power is finally consumed in performing useful computational work are numerous, being both ecologically sound and fiscally attractive.

Few organizations will operate in the scale needed to be able to adopt this technology. It is the considered opinion of Server Technology that for the near term of the next 24-36 months, the majority of data centers would benefit from leveraging the more widespread availability of the 415V/240V power distribution technologies. This is a power technology in North America with a number of facilities already in operation and is easily accessible to others with current off the shelf devices.

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http://www.eetimes.com/electronics-news/4214876/Facebook-opens-data-center--server-designs

> "Facebook co-designed its 277-volt power supply with Power One and Delta. It developed at least one of its motherboards with Taiwan's Quanta and worked with 10-15 suppliers in all. A team of just three Facebook engineers, lead by Amir Michael, designed the servers, power supply and novel chassis and racks in about 18 months"

p. 14 of http://www.7x24carolinas.org/Fall2010Mtg/Syska_BBT_277V_Power_Supplies.pdf
At higher voltage less current is required to provide the same amount of real power to the server.

- This reduces the losses in the circuits feeding the equipment (I^2R losses).
- Example:
  - 2000 watt load is 100 feet from the RPP.
  - At 208V: I^2R loss is approximately 30 watts.
  - At 277V: I^2R loss is approximately 17 watts
  - Losses are reduced 43%

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